Do lights detract freshwater turtles from entering commercial fishing nets?

Manon Veselovsky
Student no. 8259387

BIO 4009 Research Project

Supervisor: Dr. Gabriel Blouin-Demers

April 16th, 2021

Department of Biology
University of Ottawa

Abstract

Bycatch (capture of non-target species) in commercial fishing nets poses a threat to freshwater turtles as turtles entrapped in passively fished submerged nets can drown. Consequently, bycatch reduction devices have been explored to increase the specificity of fishing methods and exclude bycatch species from nets. In this study, I tested the hypothesis that light-emitting diodes attached to nets act as a visual deterrent to freshwater turtles. I predicted fewer turtle captures in nets set with lights than those without lights. Additionally, I predicted that the effect of lights should be greatest for turtle species active at night, when the visual cue of lights should be strongest. Finally, I determined if lights affected captures of target fish. At 10 sites in the Rideau Canal Waterway, Ontario, Canada, I captured 484 turtles of three species and 762 fish of twelve species during 108 capture periods. Lights attached to nets did not significantly reduce the number of captures of particular turtle species, nor did they reduce the overall captures of turtles. Target fish captures were likewise unaffected by lights. My study illustrates the high levels of turtle bycatch in fishing nets and highlights the need for the implementation of effective bycatch reduction devices in the fishing industry, unlike the lights tested here.

Keywords: Bycatch, Turtle, Fisheries, Conservation, Lights

Acknowledgements

I thank Gabriel Blouin-Demers for always finding the time to meet with me to offer thoughts, clarification, and feedback. I thank Audrey Turcotte for her guidance in all aspects of this project and for making herself available far beyond what was required. I thank my family for their endless support throughout this past year. Finally, I thank Parks Canada for helping to fund this project.

Table of Contents

List of Tables

List of Figures

Introduction

Global decline and extinction of species is a major ecological issue (Ceballos et al., 2015). The rate of vertebrate species loss in the last century is estimated to be eight to one hundred times higher than in the previous 10,000 years (Ceballos et al., 2015). This decline in biodiversity is ultimately being driven by human activity (IPBES, 2019). While global targets have been set to reduce the human impact on biodiversity, most of these targets have not been met (IPBES, 2019). With the current trajectory, it is estimated that up to 37% of terrestrial species will face extinction by 2050 (Thomas et al., 2004). Reptiles are one such group whose members are at risk, with 20% of reptile species currently listed as threatened by the International Union for the Conservation of Nature (IUCN) (Bohm et al., 2013).

Among reptiles, turtles are particularly at risk because of population demographics that leave them vulnerable to anthropogenic stressors (Congdon et al., 1993). Turtles naturally experience a high probability of mortality in their early life-stages and have delayed sexual maturity (Brooks et al., 1991). Thus, turtle populations rely on iteroparity and low adult mortality rates for persistence (Brooks et al., 1991; Congdon et al., 1993). This leaves them susceptible to population decline from anthropogenic stressors such as fisheries bycatch (the incidental capture of non-target species) that increase adult mortality (Finkbeiner, 2011). Indeed, it is conservatively estimated that 4600 sea turtles suffer mortality as bycatch each year from fisheries in the United States, contributing to the decline of six sea turtle species (Finkbeiner, 2011). As a result of mortality in fisheries and additional anthropogenic stressors, 61% of all turtle species are listed as threatened or have gone extinct in modern times (Lovich et al., 2018). With fisheries resulting in 96.4 million tonnes of commercial capture and representing a $164.1 billion industry in 2018 (Food and Agriculture Organization, 2020), it is unlikely that this threat will diminish in the near future. Thus, it is more important than ever to employ strategies to mitigate the effects of human stressors on the persistence of turtle species.

Canadian turtle species are also at risk from the persistent threat of fisheries in both freshwater and marine systems (Brazner, 2008; Species at Risk, 2021). In 2018, freshwater and marine fisheries represented a 3-billion-dollar industry in Canada (Fisheries and Oceans Canada, 2019). The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has identified bycatch as a threat to populations of freshwater and sea turtles (Species at Risk, 2021). Indeed, two of four sea turtle species and all ten freshwater species in Canada are listed as at risk in at least one part of the country (Species at Risk, 2021). Unfortunately, the exact impact of freshwater fisheries on turtle populations is unknown as fishers are not required to report turtle bycatch (Species at Risk, 2021).

While the exact impact of commercial freshwater fisheries on turtle populations is unknown, studies suggest that the impact is significant. Larocque et al. (2012b) performed a two-season study that resulted in mortality of 33% of turtles captured in one Ontario lake (a total of 18 individuals). Additionally, a population viability analysis performed by Midwood et al. (2014) indicated that a single mortality of a reproductive female from fishing in an Ontario lake would cause extirpation of three of four turtle species in the lake within 500 years. Mortality of 10 reproductive females from fishing would cause extirpation of the fourth species in the lake within 75 years (Midwood et al., 2014). These results in combination show that the freshwater fishing industry could have drastic effects on the viability of freshwater turtle populations and strategies must be implemented to reduce this impact.

Conservationists have been conducting studies that seek to increase the specificity of fishing methods so that non-target organisms are excluded from fishing nets. In freshwater studies, these efforts have focused on developing devices that exploit differences in the physical characteristics of target species versus turtle species. Such devices include vertical bars placed across the openings of nets that physically prevent turtles from entering and chimney structures on the cod end (capture retaining area) of nets that can allow turtles to escape should they become entrapped (Bury, 2011; Fratto et al., 2008; Larocque, 2012a). Because the physical abilities and average size of co-occurring turtle species can vary widely, the success rate of these devices can vary according to the turtle species' characteristics (Fratto et al., 2008). Furthermore, in some cases the devices can reduce the catch rate of target species (Fratto et al., 2008). Thus, there remains a need for a bycatch mitigation device that acts independently of the physical characteristics of the organism.

One non-physical trait that could be exploited for turtle bycatch reduction is the ability perceive and respond to visual cues. Both freshwater and marine turtles can perceive a wide range of light wavelengths, from the UV spectrum to the red spectrum (Wyneken et al., 2013). Additionally, turtles have the ability to discriminate between different colours of light (Arnold & Neumayer, 1987); this indicates that a range of wavelengths are important visual cues in their lifestyle Young et al., 2012). Indeed, it has been shown that freshwater turtles rely on visual cues for mate selection

(Bulté et al., 2018) and dispersal (Congdon et al., 2011; Pappas et al., 2009; Pappas et al., 2017). Thus, the addition of a visual deterrent to fishing nets could serve as a turtle bycatch reduction device that does not depend on the physical characteristics of the turtle species and may not affect target fish captures.

In marine fisheries, illumination of gillnets with LEDs (light-emitting diodes) significantly reduces the bycatch of sea turtles, small cetaceans, and sea birds with no significant effect on target fish capture rates (Bielli et al., 2020; Ortiz et al., 2016). The purported mechanism behind this reduction is that LEDs on nets serve as a visual deterrent to organisms that rely on visual cues for various behaviours (Bielli et al., 2020), and provides a bycatch reduction method that does not depend on the physical characteristics of the species. No studies to date have tested whether LEDs may be similarly applied to reduce freshwater turtle bycatch.

Therefore, I conducted a study to evaluate whether the vision of freshwater turtles and addition of lights to fishing nets could be used in freshwater turtle bycatch reduction. The main objectives of my research are to (1) test the hypothesis that lights deter freshwater turtles from entering fishing nets and (2) test the effect of lights on target fish captures. More specifically, I predicted that LED lights should reduce freshwater turtle bycatch. I predicted that this effect should be strongest for the eastern musk turtle (*Sternotherus odoratus*) and common snapping turtle (*Chelydra serpentina*) as these species are active at night (Ernst, 1986; Rowe et al., 2020) when the visual cue of lights should be strongest. Finally, I predicted that target freshwater fish should not be affected by the presence of lights as their spectral coverage is narrow (Hawryshyn et al., 1988). Target fish species in this system are sunfish (*Lepomis* spp.), rock bass (*Ameirus* spp.), yellow perch (*Perca flavescens*), bullheads (*Ameiurus* spp.) and black crappie (*Pomoxis nigromaculatus*) (Fisheries and Oceans Canada, 2020).

Methods

Study area

I deployed commercial hoop nets at 10 sites along the Rideau Canal system (Figure 1) between June 16th and August 21st, 2020. These sites had habitat suitable for both turtles and fish, with spots that would allow turtles to bask (rocks, logs) and open water areas suited to fish. Nets were placed at locations close to potential turtle basking spots within the site to maximize potential for turtle and fish landings. Nets were deployed in shallow water (37 to 99 cm in depth) allowing the leads to intercept the entire water column.

Nets and lights

Five hoop nets of similar construction were used over the course of this study. Each net had two trapping structures composed of hoops, chokes, and two side wings set at a forty-five-degree angle from the net opening (Figure 2). Trapping structures were paired to form a single net by connecting their primary hoops via a central lead 24 to 25 m in length and 1.3 to 1.9 m in height. Nets were identified and remained paired for the duration of the study. The total net length (four side leads and central lead) of the nets ranged from 39.3 m to 42.4 m. Treatment nets were set with Centrofishing CM-1 green LEDs (Figure 3) attached every 4-4.1 m on the central lead and wings. Control nets did not have lights attached. Floats were placed within the trapping structures to ensure air access for any air-breathing species captured.

Net deployment

Nets were deployed using a tandem design to limit confounding variables and experimentally account for temporal effects. A treatment and control net were set at the beginning of the week to capture turtles and fish, temporally paired to account for daily variation in capture conditions. From June 16th to July 15th, 2020 both of these nets alternated between two locations each capture period to allow the replenishment of the capture area. Thus, four locations within each site were used. A single net ID was used at each location in the site, and both treatments were applied at least once at each location. After July 15th, this method was modified; rather than moving the nets each day, they remained in a single location for the week. This allowed additional nets to be deployed to increase sampling effort. Depending on the capture rate of the first two nets, one to two additional nets would be set that week. With this method, all nets alternated between one day with lights and one day without lights, and a treatment and control net were always maintained within each day. Because of this change in method, the number of days a net had been at a single location within a site was recorded to be controlled for in the statistical analysis. Both the original and revised method served to experimentally account for potential confounds such as net, location quality, and environmental variation.

Data and measurements

To determine the effect of LEDs on the capture rates of turtles and target fish, I visited nets daily to record information on the species captured and measure environmental variables. Upon arrival at each net, I recorded the duration of the capture period (soak time), tallied the number of individuals captured by species, and recorded any holes found in the nets. The soak time was recorded to allow the standardization of the number of individuals captured by the time effort of each capture period in the statistical analysis. Additionally, because temperature and season can cause variation in turtle activity (Ernst, 1986; Lovich et al., 1988), I recorded the Julian day and the start and end water temperature for each capture period. The start time of the subsequent capture period was recorded once manipulations around the net were complete.

Statistical Analyses

Turtle and Fish Capture Rates – To analyze the effect of lights on the capture rate of turtle species and target fish species, I constructed two generalized linear mixed effect models for turtles and fish, each with the count of individuals captured in a net as the response variable, standardized by the soak time of the given net. This modeling the counts as the rate of capture. To detect multicollinearity between model parameters, the general variance inflation factor (GVIF) of each variable was calculated. GVIFs allow detection of multicollinearity for both categorical and continuous data, with the squared $GVIF^{(1/(2*Df))}$ being equivalent to the variance inflation factor (VIF) of a continuous variable (Fox & Monette, 1992). Any $GVIF^{(1/(2*Df))}$ greater than 2, equivalent to a VIF of 4, was excluded from the model. Julian day was consequently eliminated from these models as its value was above threshold, showing multicollinearity with it and the site. This is not of concern for the purposes of this analysis as the presence/absence of lights is the sole effect of interest and did not exhibit collinearity with the removed term. Thus, the models for the target and turtle counts included water temperature, number of holes, presence/absence of lights, and days placed as fixed model parameters. Net and Site ID were incorporated as random effects to account for potential non-independence of data within these groups, giving a total of six predictors with the sample size being the number of capture periods (n = 108). I used a negative binomial distribution suited to over-dispersed count data (Payne et al., 2015) as the deviance of the full model was greater than the degrees of freedom. This and all subsequent statistical analyses were conducted using the lmerTest package (Kuznetsova et al. 2017) in R statistical software (v. 4.0.3, 2020).

Species-specific effects – To evaluate species-specific effects of lights, I built a generalized linear mixed effects model with frequency as the dependent variable. The fixed independent variables of this model were species, lights, and the two-way interaction of these terms. Site was again included as a random variable to account for potential non-independence of species counts arising from this factor. Therefore, this model included a total of three independent terms with the sample size being the number of turtles (n = 454) and tested the internal null hypothesis that the frequency of turtles captured by species does not depend on the presence or absence of lights. The results of all analyses are presented with the mean ± two standard errors.

Results

In 2486 fishing hours and 108 capture periods (52 treatment, 56 control), I caught 762 fish of twelve species and 484 turtles of three species. The nets in the 56 control periods had a mean soak time of 23.1 ± 0.5 hours and captured 367 fish of target species, 60 fish of bycatch species, and 268 turtles. The nets in the 52 treatment periods had a mean soak time of 22.9 ± 0.5 hours and captured 300 fish of target species, 35 fish of bycatch species, and 216 turtles. Treatment nets captured 0.18 ± 0.05 turtles per hour while control nets captured 0.21 ± 0.08 turtles per hour. Fish were caught in 92% (99/108) of capture periods, and turtles in 88% (95/108) of capture periods. Of the 484 turtles captured, there were 241 painted turtles (*Chrysemys picta*), 177 eastern musk turtles (*Sternotherus odoratus*), and 66 common snapping turtles (*Chelydra serpentina*).

When controlling for environmental and experimental effects, lights did not significantly affect capture rates of the groups of interest. For turtles, the rate of capture was 15% lower in nets set with lights, but this difference was not significant ($p = 0.36$; Table 2; Figure 4), and the 95% confidence interval ranged from a 39% reduction to a 20% increase in turtle bycatch. Additionally, there was no significant interaction between the presence of lights and species to indicate that the effect of lights depended on the species of turtle (all p values > 0.05; Table 4, Figure 6). The sole significant predictor of turtle captures was the number of days a net was deployed at a given location ($p = 0.03$; Table 2), with daily turtle capture rates decreasing the longer a net was deployed. Similar to turtles, target fish capture rates were reduced in nets with lights by 18%, but this difference was also not significant ($p = 0.25$; Table 3, Figure 5). Again, the 95% confidence interval was wide, ranging from a 42% decrease to a 15% increase in target fish capture rate. The number of days a net was deployed at a given location was also the most important predictor of this group ($p < 0.001$; Table 3), with target capture rates decreasing the longer a net was deployed. Target fish captures also significantly increased with water temperature ($p = 0.04$; Table 3). Finally, lights did not affect specific turtle species, as there was no change in the frequency of specific turtle species in nets with lights compared to nets without lights ($p = 0.96$; Table 3, Figure 6).

Discussion

Effect of lights

The goal of my study was to test the hypothesis that lights act as a visual deterrent to turtles and to assess their effect on target fish captures. Overall, the findings of my study do not support my hypothesis nor any species-specific predictions. The rate of turtle captures was slightly lower in nets set with lights, but this difference was not statistically significant. This remained true when analyzing the effects of lights on specific species of turtles, with turtles active at night showing no difference in their response to lights. Target captures were slightly decreased in nets set with lights, but this difference was not statistically significant.

The properties of freshwater may significantly reduce the luminance of green lights, reducing the overall illumination of freshwater fishing nets with lights. It has been shown that blue and green light are the dominant wavelengths illuminating ocean water, while freshwater illumination is dominated by longer wavelengths as that are not scattered by high turbidity (Scherbakov et al., 2013). Thus, it is possible that net illumination with green lights is diminished in freshwater when compared to ocean water. This effect may also be exacerbated in my study, as I set nets in vegetated shallows with low water clarity. Future studies evaluating the effect of lights on species in freshwater systems should focus on longer wavelengths that are less attenuated in freshwater.

Turtle captures

In my study, freshwater turtle species were not affected by green lights attached to fishing nets. It should be noted that the wavelength properties of the lights used in my study could affect freshwater turtle perception. Specifically, it is possible that freshwater turtle species do not see green light in the same way as their marine counterparts. It has been found that freshwater turtle vision has shifted to perceive longer wavelengths (Dvorak & Granda, 77; Emerling, 2016; Hall et al, 2018). This indicates that spectral ranges with high colour discrimination may also have shifted in freshwater turtle species compared to marine turtle species. A study by Arnold & Neumayer (1987) showed that the red-eared slider (*Pseudemys scripta elegans)*, a freshwater turtle species, has poor colour discrimination in the blue-green to green wavelength range. This suggests that the illumination of objects with green lights may not serve as a strong visual cue to this species of freshwater turtle as contrast of objects illuminated with green light could be low (Arnold & Neumayer, 1987). Unfortunately, I could not find additional literature on the colour discrimination abilities of other freshwater turtle species. If Arnold & Nemayer's finding is true for freshwater turtle species in general, then illuminating nets with green lights would not be expected to serve as a strong visual cue to this group.

It is also possible that green wavelengths do not elicit a strong detraction response in freshwater turtles. Studies on sea turtles have shown that hatchlings are attracted and detracted by lights of specific spectral ranges, while other colours within their visible spectrum elicit no response (Hall et al., 2018; Witherington & Bjorndal, 1991). Thus, if the visual cue deterring marine turtles from entering nets is the light itself, the aversion response to lights should be spectrum dependent. Unfortunately, while responses to varying wavelengths have been studied in marine turtle hatchlings, there is limited literature on behavioural responses in freshwater turtle species to varying wavelengths of light. It has been shown that hatchling freshwater turtles are attracted to open horizon lines when dispersing from nests (Congdon et al., 2011), but the mechanism underlying this attraction has not been determined and it could be a simple function of overall light intensity. Understanding how freshwater turtles respond to specific wavelengths of light would help determine whether lights can act as visual bycatch reduction devices.

Fish captures

My study found that target fish captures were lower in nets set with lights. This finding suggests that fish species are possibly deterred by green lights and this is an important consideration for future studies. However, the behavioural responses of fish species to lights have shown wide variation. While illumination of marine net studies with green lights have shown no reduction in target fish capture rates (Bielli et al., 2020; Ortiz et al., 2016), other marine studies have shown target fish to have general attraction to lights (Afonso et al., 2020), general avoidance of lights (Bui et al., 2012), or species-specific attraction and avoidance of lights (Marchesan et al., 2004). Reactions to lights within freshwater systems are also variable, with strobe lights detracting common carp and brown bullhead (Kim & Mandrak, 2016), and green light attracting sturgeon (Ford et al., 2018) while detracting walleye (Ford et al., 2019). Thus, the effect that lights attached to nets may have on target fish captures is likely species-dependent and should be evaluated in the specific scenarios that lights may be applied.

Freshwater turtle bycatch and implications for conservation

Turtles were consistently captured as bycatch within my study, illustrating the need for proper management of freshwater fisheries. While the locations of my nets were chosen in shallows to target both turtle and fish species, other studies have shown similar evidence of high turtle bycatch rates in Ontario waters (Barko et al., 2004; Larocque et al., 2012b). As mentioned previously, Midwood et al. (2014) found that mortality of a small number of reproductive females would cause extirpation of turtle populations in lakes. Previous studies have shown mortality rates to be at unsustainable levels despite taking measures to mitigate risk: a study by Larocque (2012b) resulted in 33% mortality in nets that were set for two and six days with air provision in one lake and a study by Barko et al. (2004) resulted in 10.3% mortality in nets visited every 24-48 hours without the provision of air. In my study, I provided air space and visited nets daily, resulting in a 0.4% mortality rate. Thus, it is likely that both daily net visits and provision of air are important to effectively reduce mortality of turtles in fishing nets should they become entrapped.

Conclusion

Commercial fisheries are a persistent threat to freshwater turtle species captured as bycatch and strategies to reduce this threat must be explored. My study found that green lights attached to commercial fishing nets are not an effective device to reduce the capture rate of turtles in freshwater fisheries. Capture rates of turtles did not significantly differ in nets set with and without lights; additionally, there were no species-specific effects of lights on turtle captures. Finally, capture rates of target species were lower in nets set with lights, but this difference was not significant.

While my study excludes green lights as a viable option in the reduction of freshwater turtle bycatch, it is possible that lights of a different colour could yield different results. Further research is needed to determine the perception and behavioural responses of freshwater turtles to varying wavelengths of lights. Future studies should focus on longer light wavelengths that are not scattered in freshwater. Studies should also evaluate the behavioural responses of target fish species to specific wavelengths, as fish species can vary widely in their response to lights.

References

Afonso, A., Mourato, B., Hazin, H., & Hazin, F. (2021). The effect of light attractor color in pelagic longline fisheries. *Fisheries Research*, *235*. https://doi.org/10.1016/j.fishres.2020.105822

Arnold, K., & Neumeyer, C. (1987). Wavelength discrimination in the turtle Pseudemys scripta elegans. *Vision Research (Oxford)*, *27*(9), 1501–1511. https://doi.org/10.1016/0042-6989(87)90159-3

Barko, V.A., Briggler, J.T., & Ostendorf, D.E. (2004). passive fishing techniques: a cause of turtle mortality in the mississippi river. the journal of wildlife management, 68(4), 1145–1150. https://doi.org/10.2193/0022-541x(2004)068[1145:pftaco]2.0.co;2

Bui, S., Oppedal, F., Korsøen, Ø., Sonny, D., & Dempster, T. (2013). Group behavioural responses of Atlantic salmon (Salmo salar L.) to light, infrasound and sound stimuli. *PloS One*, *8*(5). https://doi.org/10.1371/journal.pone.0063696

Brazner, J., & McMillan, J. (2008). Loggerhead turtle (Caretta caretta) bycatch in Canadian pelagic longline fisheries: Relative importance in the western North Atlantic and opportunities for mitigation. *Fisheries Research*, *91*(2), 310–324. https://doi.org/10.1016/j.fishres.2007.12.023

Bulté, G., Chlebak, R., Dawson, J., & Blouin-Demers, G. (2018). Studying mate choice in the wild using 3D printed decoys and action cameras: a case of study of male choice in the northern map turtle. *Animal Behaviour*, *138*, 141–143. https://doi.org/10.1016/j.anbehav.2018.02.018

Bielli, A., Alfaro-Shigueto, J., Doherty, P., Godley, B., Ortiz, C., Pasara, A., … Mangel, J. (2020). An illuminating idea to reduce bycatch in the Peruvian small-scale gillnet fishery. *Biological Conservation*, *241*, 108277. https://doi.org/10.1016/j.biocon.2019.108277

Bohm, M., B. Collen, J. E. M. Baillie, P. Bowles, J. Chanson, N. Cox, G. Hammerson, M. Hoffmann, S. R. Livingstone, M. Ram, A. G. J. Rhodin, S. N. Stuart, P. P. van Dijk, B. E. Young, L. E. Afuang, A. Aghasyan, A. Garcia, C. Aguilar, R. Ajtic, … & Zug, G. (2013). The conservation status of the world’s reptiles. *Biological Conservation 157*:372‑385.

Brooks, R., Brown, G., & Galbraith, D. (1991). Effects of a sudden increase in natural mortality of adults on a population of the common snapping turtle (Chelydra serpentina). *Canadian Journal of Zoology*, *69*(5), 1314–1320. https://doi.org/10.1139/z91-185

Bury, R. B. (2011). Modifications of traps to reduce bycatch of freshwater turtles. *The Journal of Wildlife Management*, *75*(1), 3–5. https://doi.org/10.1002/jwmg.31

Ceballos, G., Ehrlich, P. R., Barnosky, A. D., García, A., Pringle, R. M., & Palmer, T. M. (2015). Accelerated modern human–induced species losses: Entering the sixth mass extinction. *Science Advances*, *1*(5), 1. https://doi.org/10.1126/sciadv.1400253

Congdon, J.D., Dunham, A.E., & Van Loben Sels, R.C. (1993). Delayed Sexual Maturity and Demographics of Blanding’s Turtles (*Emydoidea blandingii*): Implications for Conservation and Management of Long-Lived Organisms. *Conservation Biology*, *7*(4), 826–833. https://doi.org/10.1046/j.1523-1739.1993.740826.x

Congdon, J.D., Pappas, M., Brecke, B., & Capps, J. (2011). Conservation Implications of Initial Orientation of Naïve Hatchling Snapping Turtles (Chelydra serpentina) and Painted Turtles (Chrysemys picta belli) Dispersing From Experimental Nests. *Chelonian Conservation and Biology*, *10*(1), 42–53. https://doi.org/10.2744/CCB-0849.1

Diaz, S., J. Settele, E. S. Brondizio, H. T. Ngo, M. Gueze, J. Agard, A. Arneth, P., Balvanera, K. A. Brauman, S. H. M. Butchart, K. M. A. Chan, L. A. Garibaldi, K.Ichii, J. Liu, S. M. Subramanian, G. F. Midgley, P. Miloslavich, Z. Molnar, D. Obura, A. Pfaff, S. Polasky, A. Purvis, J. Razzaque, B. Reyers, R. Roy Chowdhury, Y. J., Shin, I. J. Visseren-Hamakers, K. J. Willis, & C. N. Zayas (eds.). (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES secretariat, Bonn, Germany.

Dvorak, C., & Granda, A. (1990). Wavelength-dependent temporal properties of retinal horizontal cells in turtles. *Visual Neuroscience*, *4*(5), 427–435. https://doi.org/10.1017/S0952523800005186

Carl H. Ernst. (1986). Ecology of the Turtle, Sternotherus odoratus, in Southeastern Pennsylvania. *Journal of Herpetology*, *20*(3), 341–352. https://doi.org/10.2307/1564501

Emerling, C. (2017). Archelosaurian Color Vision, Parietal Eye Loss, and the Crocodylian Nocturnal Bottleneck. *Molecular Biology and Evolution*, *34*(3), 666–676. https://doi.org/10.1093/molbev/msw265

Finkbeiner, E., Wallace, B., Moore, J., Lewison, R., Crowder, L., & Read, A. (2011). Cumulative estimates of sea turtle bycatch and mortality in USA fisheries between 1990 and 2007. *Biological Conservation*, *144*(11), 2719–2727. https://doi.org/10.1016/j.biocon.2011.07.033

Fisheries and Oceans Canada. (2020). *2019 Freshwater landings*. https://www.dfo-mpo.gc.ca/stats/commercial/land-debarq/freshwater-eaudouce/2019-eng.htm

Food and Agriculture Organization of the United Nations. (2020). *The State of the World Fisheries and Aquaculture.* http://www.fao.org/3/ca9229en/ca9229en.pdf

Fox, J., & Monette, G. (1992). Generalized Collinearity Diagnostics. *Journal of the American Statistical Association*, *87*(417), 178–183. https://doi.org/10.1080/01621459.1992.10475190

Ford, M., Elvidge, C., Baker, D., Pratt, T., Smokorowski, K., Sills, M., Patrick, P., & Cooke, S. (2018). Preferences of age-0 white sturgeon for different colours and strobe rates of LED lights may inform behavioural guidance strategies. *Environmental Biology of Fishes*, *101*(4), 667–674. https://doi.org/10.1007/s10641-018-0727-1

Ford, M., Elvidge, C., Patrick, P., Sills, M., & Cooke, S. (2019). Coloured LED light as a potential behavioural guidance tool for age 0 and 2 year walleye Sander vitreus. *Journal of Fish Biology*, *95*(5), 1249–1256. https://doi.org/10.1111/jfb.14124

Fratto, Z., Barko, V., Pitts, P., Sheriff, S., Briggler, J., Sullivan, K., McKeage, B., & Johnson, T.. (2008). Evaluation of Turtle Exclusion and Escapement Devices for Hoop-Nets. *The Journal of Wildlife Management*, *72*(7), 1628–1633. https://doi.org/10.2193/2007-216

Granda A., Dvorak C. (1977) Vision in Turtles. In: Crescitelli F. (eds) The Visual System in Vertebrates. Handbook of Sensory Physiology, vol 7 / 5. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-66468-7_8

Hall, M., Alverson, D., & Metuzals, K. (2000). By-Catch: Problems and Solutions. *Marine Pollution Bulletin*, *41(1)*, 204–219. https://doi.org/10.1016/S0025-326X(00)00111-9

Hall, R., Robson, S., & Ariel, E. (2018). Colour vision of green turtle (Chelonia mydas) hatchlings: do they still prefer blue under water? *PeerJ (San Francisco, CA)*, *6*, e5572–e5572. https://doi.org/10.7717/peerj.5572

Hawryshyn, C., Arnold, M., McFarland, W., & Loew, E. (1988). Aspects of color vision in bluegill sunfish (Lepomis macrochirus): ecological and evolutionary relevance. *Journal of Comparative Physiology. A, Sensory, Neural, and Behavioral Physiology*, *164*(1), 107–116. https://doi.org/10.1007/BF00612724

Kim, J., & Mandrak, N. (2017). Effects of strobe lights on the behaviour of freshwater fishes. *Environmental Biology of Fishes*, *100*(11), 1427–1434. https://doi.org/10.1007/s10641-017-0653-7

Kuznetsova, A., P. Brockhoff, and R. Christensen. 2017. lmerTest Package: Tests in Linear Mixed Effects Models. Journal of Statistical Software 82:1‑26.

Larocque, S., Cooke, S., & Blouin-Demers, G. (2012a). Mitigating bycatch of freshwater turtles in passively fished fyke nets through the use of exclusion and escape modifications. *Fisheries Research*, *125-126*, 149–155. https://doi.org/10.1016/j.fishres.2012.02.018

Larocque, S., Colotelo, A., Cooke, S., Blouin-Demers, G., Haxton, T., Smokorowski, K., Gompper, M., & Branch, T. (2012b). Seasonal patterns in bycatch composition and mortality associated with a freshwater hoop net fishery. *Animal Conservation*, *15*(1), 53–60. https://doi.org/10.1111/j.1469-1795.2011.00487.x

Jeffrey E. Lovich. (1988). Geographic Variation in the Seasonal Activity Cycle of Spotted Turtles, Clemmys guttata. *Journal of Herpetology*, *22*(4), 482–485. https://doi.org/10.2307/1564346

Lovich, J., Ennen, J., Agha, M., & Gibbons, J. (2018). Where Have All the Turtles Gone, and Why Does It Matter? *Bioscience*, *68*(10), 771–781. https://doi.org/10.1093/biosci/biy095

Marchesan, M., Spoto, M., Verginella, L., & Ferrero, E. (2005). Behavioural effects of artificial light on fish species of commercial interest. *Fisheries Research*, *73*(1), 171–185. https://doi.org/10.1016/j.fishres.2004.12.009

Midwood, J., Cairns, N., Stoot, L., Cooke, S., & Blouin-Demers, G. (2015). Bycatch mortality can cause extirpation in four freshwater turtle species. *Aquatic Conservation*, *25*(1), 71–80. https://doi.org/10.1002/aqc.2475

Oakleaf, J., Kennedy, C., Baruch-Mordo, S., West, P., Gerber, J., Jarvis, L., & Kiesecker, J. (2015). A World at Risk: Aggregating Development Trends to Forecast Global Habitat Conversion. *PloS One*, *10*(10), https://doi.org/10.1371/journal.pone.0138334

Ortiz, N., Mangel, J. C., Wang, J., Alfaro-Shigueto, J., Pingo, S., Jimenez, A., Suarez, T., Swimmer, Y., Carvalho, F., & Godley, B. J. (2016). Reducing green turtle bycatch in small-scale fisheries using illuminated gillnets: the cost of saving a sea turtle. *Marine Ecology Progress Series*, *545*, 251–259. https://doi.org/10.3354/meps11610

Pappas, M., Congdon, J., Brecke, B., & Capps, J. (2009). Orientation and dispersal of hatchling Blandings turtles (Emydoidea blandingii) from experimental nests. *Canadian Journal of Zoology*, *87*(9), 755–766. https://doi.org/10.1139/Z09-065

Pappas, M., Congdon, J., & Brecke, B. (2017). Orientation in Five Species of Hatchling River Turtles Dispersing from Experimental Nests. *Chelonian Conservation and Biology*, *16*(1), 3–11. https://doi.org/10.2744/CCB-1234.1

Payne, E., Gebregziabher, M., Hardin, J., Ramakrishnan, V., & Egede, L. (2018). An empirical approach to determine a threshold for assessing overdispersion in Poisson and negative binomial models for count data. *Communications in Statistics. Simulation and Computation*, *47*(6), 1722–1738. https://doi.org/10.1080/03610918.2017.1323223

Rhodin, A., Stanford, C., Dijk, P., Eisemberg, C., Luiselli, L., Mittermeier, R., Hudson, R., Horne, B., Goode, E., Kuchling, G., Walde, A., Baard, E., Berry, K., Bertolero, A., Blanck, T., Bour, R., Buhlmann, K., Cayot, L., Collett, S., … Ennen, J. (2018). Global Conservation Status of Turtles and Tortoises (Order Testudines). *Chelonian Conservation and Biology*, *17*(2), 135–. https://doi.org/10.2744/CCB-1348.1

Rowe, J., Mulligan, W., Martin, C., Goerge, T., & Bunce, M. (2020). Spatial and Thermal Ecology of Snapping Turtles (Chelydra serpentina) in a Small, Dystrophic Lake in Central Michigan. *Chelonian Conservation and Biology*, *19*(1), 22. https://doi.org/10.2744/CCB-1358.1

Shcherbakov, D., Knörzer, A., Espenhahn, S., Hilbig, R., Haas, U., & Blum, M. (2013). Sensitivity differences in fish offer near-infrared vision as an adaptable evolutionary trait. *PloS One*, *8*(5), e64429–e64429. https://doi.org/10.1371/journal.pone.0064429

Species At Risk Public Registry. (2021). Retrieved from https://species-registry.canada.ca/index-en.html

Thomas, D., Cameron, A., Green, R., Bakkenes, M., Beaumont, L., Collingham, Y., Erasmus, B., Ferreira de Siqueira, M., Grainger, A., Hannah, L., Hughes, Huntley, B., van Jaarsveld, A., Midgley, G., Miles, L., Ortega-Huerta, M., Peterson, T., Philips, O., & Williams, S. (2004). Extinction risk from climate change. *Nature*, *427*(6970), 145–148. https://doi.org/10.1038/nature02121

Wang, J., Barkan, J., Fisler, S., Godinez-Reyes, C., & Swimmer, Y. (2013). Developing ultraviolet illumination of gillnets as a method to reduce sea turtle bycatch. *Biology Letters (2005)*, *9*(5), 20130383–20130383. https://doi.org/10.1098/rsbl.2013.0383

Witherington, B. & Bjorndal, K. (1991). Influences of Wavelength and Intensity on Hatchling Sea Turtle Phototaxis: Implications for Sea-Finding Behavior. *Copeia*, *1991*(4), 1060–1069. https://doi.org/10.2307/1446101

Wyneken, J., Lohmann, K., & Musick, J. (2013). *The biology of sea turtles. Volume III*. CRC Press. https://doi.org/10.1201/b13895

Young, M., Salmon, M., & Forward, R. (2012). Visual Wavelength Discrimination by the Loggerhead Turtle, Caretta caretta. *The Biological Bulletin (Lancaster)*, *222*(1), 46–55. https://doi.org/10.1086/BBLv222n1p46

Table 1: Generalized linear mixed effects model evaluating the effect of lights on turtle capture rates in commercial fishing nets set with (Y) and without lights in the Rideau Canal Waterway, Ontario, Canada (n =108). Incidence rate ratios (IRRs) show the proportional change in the rate of turtle captures with the associated variable. An IRR < 1 indicates a decrease in turtle capture rate associated with that variable, while IRR > 1 indicates an increase in turtle capture rate. Additional fixed model parameters were the number of days a net remained at a given location, average water temperature, number of holes in the net. Random effects were the net ID and site.

Predictors	*Incidence Rate Ratios*	*CI*	*Statistic*	*p*
(Intercept)	1.35	0.09 – 21.06	0.21	0.830
Lights [Y]	0.85	0.61 – 1.20	-0.92	0.359
Water temperature	1.01	0.91 – 1.12	0.20	0.841
Days at location	0.80	0.65 – 0.98	-2.17	**0.030**
Holes	0.83	0.68 – 1.03	-1.70	0.088
Observations	108			
Marginal R^2 / Conditional R^2	0.072 / 0.331			

Table 2: Generalized linear mixed effects model evaluating the effect of lights on fish capture rates in commercial fishing nets set with lights (Y) and without lights in the Rideau Canal Waterway, Ontario, Canada (n =108). Incidence rate ratios (IRRs) give the proportional change in capture rate of each variable. An IRR < 1 indicates a decrease in turtle capture with the associated variable, while IRR > 1 indicates an increase in turtle capture rate with the associated variable. Additional fixed model parameters were the number of days a net remained at a given location, average water temperature, number of holes in the net. Random effects were the net ID and site.

Predictors	*Incidence Rate Ratios*	*CI*	*Statistic*	*p*
(Intercept)	0.29	0.03 – 3.01	-1.04	0.299
Lights [Y]	0.82	0.58 – 1.15	-1.15	0.248
Water temperature	1.10	1.00 – 1.20	2.07	**0.038**
Days at location	0.65	0.53 – 0.80	-4.14	**<0.001**
Holes	0.92	0.75 – 1.13	-0.78	0.435
Observations	108			
Marginal R^2 / Conditional R^2	0.195 / 0.393			

Table 3: Generalized linear mixed effects model of the effect of lights on turtle capture frequency in nets deployed in the Rideau Canal Waterway, Ontario, Canada. The interaction term tests for differences in the proportions of species captured in nets with lights and nets without lights to determine if the effect of lights on turtles is species-specific.

Variables	**Chi-square**	**Df**	**p value**
Species	29.1452	2	< 0.001
Lights	0.4705	1	0.49
Species:Lights	0.0837	2	0.96

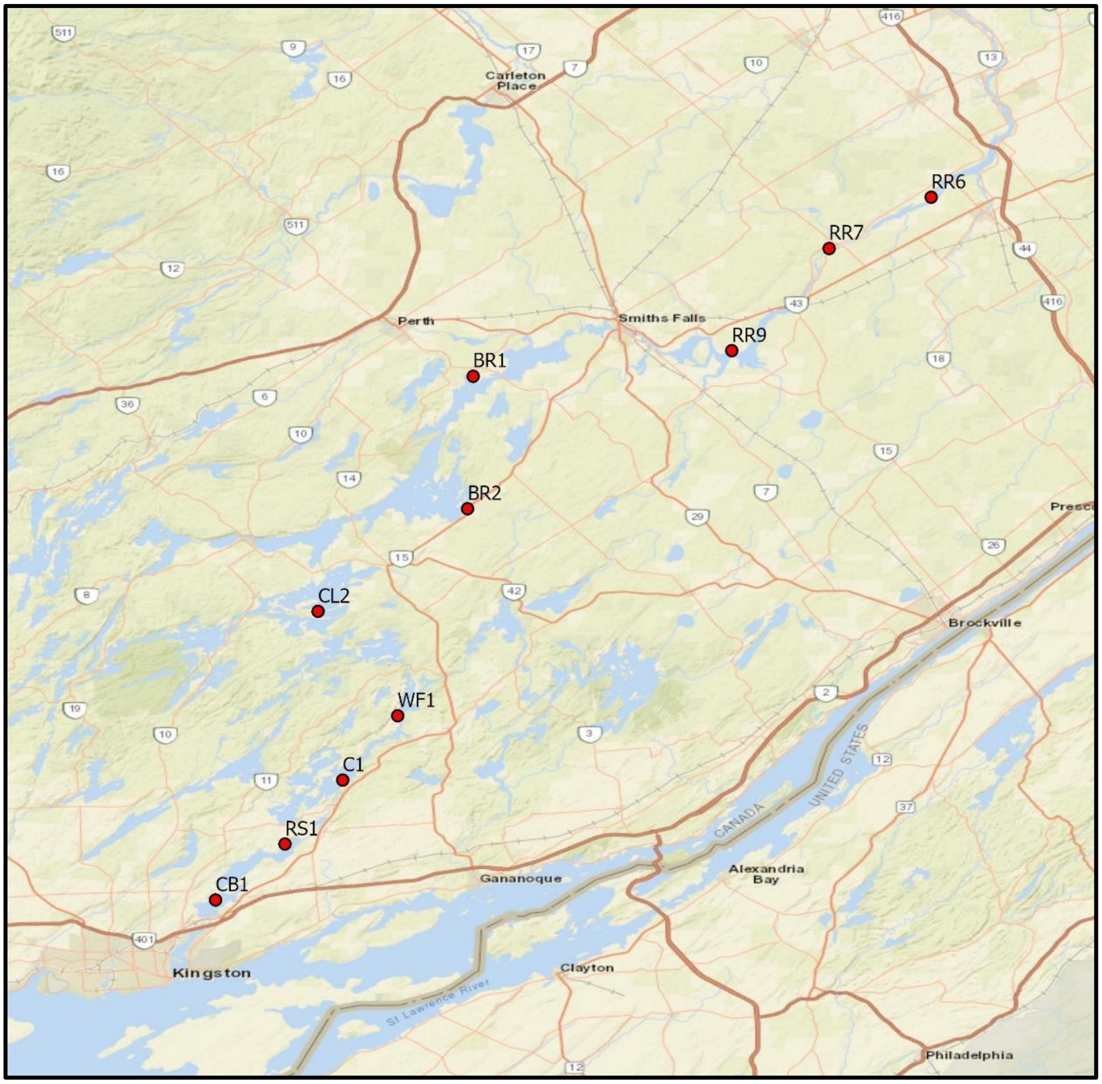

Figure 1. Locations of sites in the Rideau Canal Waterway, Ontario, Canada where I tested the effect of lights attached to commercial fishing nets on the capture rates of turtles and target fish. Sites were visited between June 16th and August 21st, 2020.

Figure 2. Illustration of a net deployed in Rideau Canal Waterway to assess the effects of lights on capture rates of target fish and turtles between June 16th and August 21st, 2020. Floats were placed inside the capture structures (hoops) and lead wings placed at an approximately 45° from the capture structure opening. Two capture structures were paired and connected via a centre lead approximately 24 m in length to form a single net. Each pair was given an ID and were deployed as paired for the duration of the study.

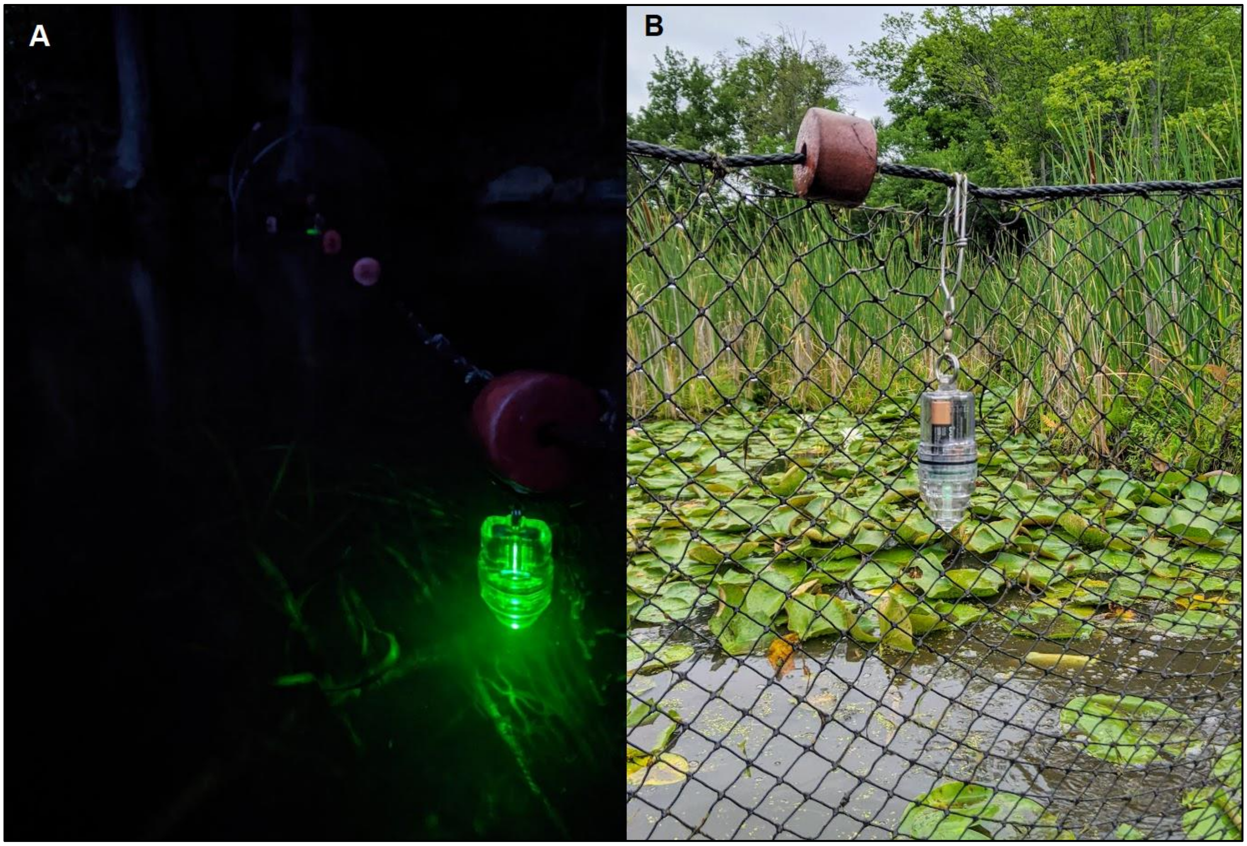

Figure 3. Examples of lights that were attached to commercial fishing nets in the Rideau Canal Waterway between June 16th and August 21st, 2020. These lights were used to evaluate their effect on turtle and target fish capture rates. (A) A submerged, powered light attached to a net lead and viewed after sunset. (B) A powered light attached to a net lead lifted out of the water and viewed during the day.

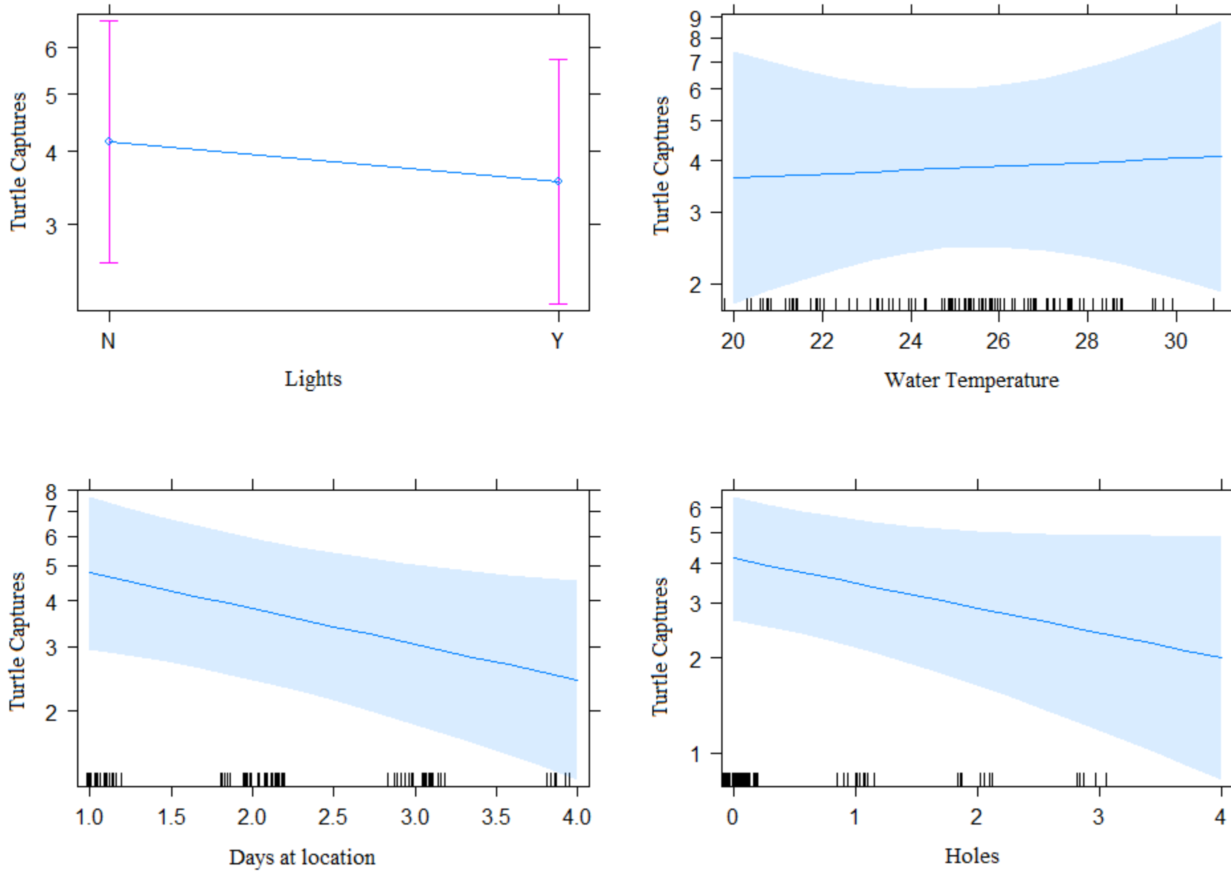

Figure 4: The predicted number of turtles captured by each of the fixed effects evaluated. Predictions are made with the mean capture period duration of nets set in the Rideau Canal Waterway. Error bars are the 95% confidence interval. Each individual plot shows the expected number of turtles captured when all other variables are held at their mean. Fixed model parameters were the number of days a net remained at a given location, average water temperature, number of holes in the net. Random effects were the net ID and site.

.

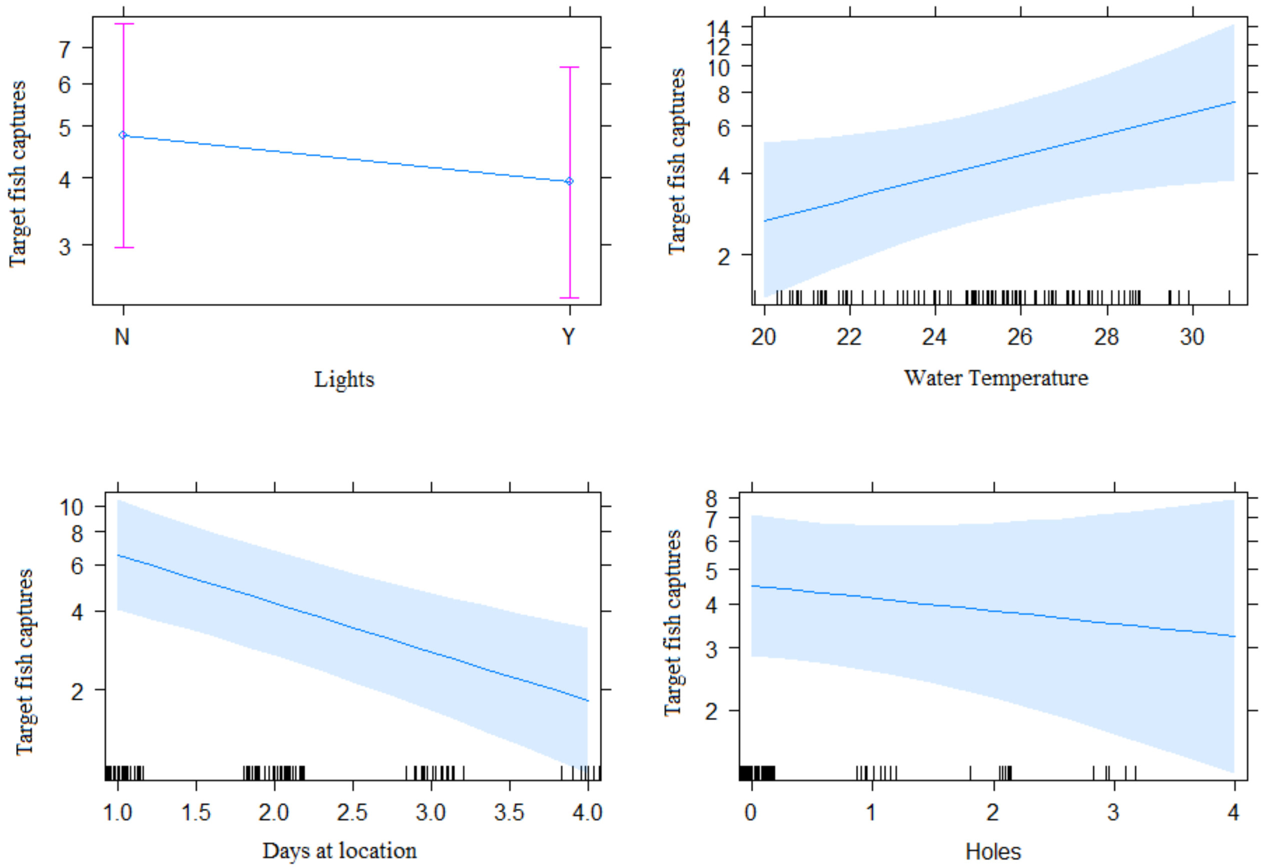

Figure 5: The number of fish captured as predicted by each of the fixed effects evaluated. Predictions are made with the mean capture period duration of nets set in the Rideau Canal Waterway. Error bars are the 95% confidence interval. Each individual plot shows the expected number of turtles captured when all other variables are held at their mean. Fixed model parameters were the number of days a net remained at a given location, average water temperature, number of holes in the net. Random effects were the net ID and site.

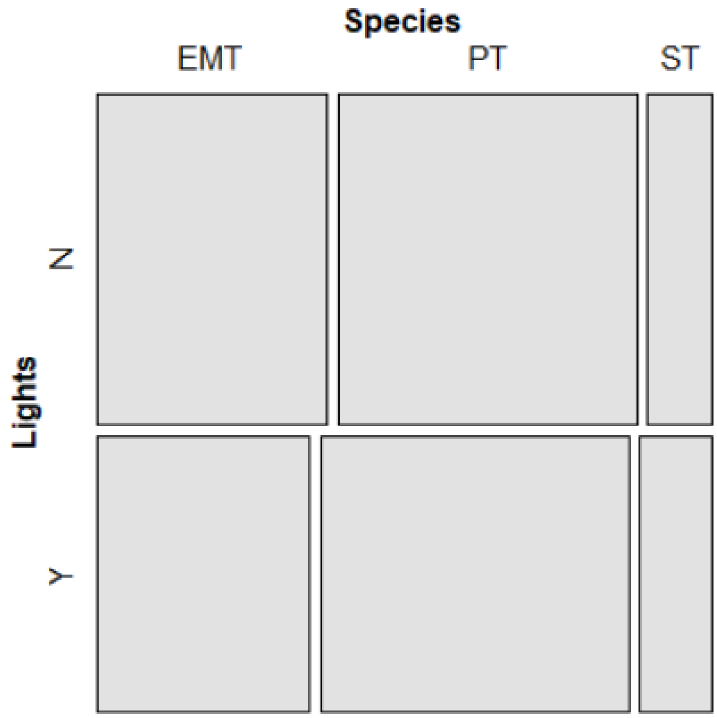

Figure 6: Mosaic plot showing the difference in species composition in nets deployed with lights (Y) and without lights (N) in the Rideau Canal Waterway, Ontario, Canada. Box width indicates the frequency of captures of a specific species. The top row shows the proportions of species captures in nets without lights and the bottom row shows the proportions of species captures in nets with lights. PT = painted turtle; EMT = eastern musk turtle; ST = snapping turtle.