Illuminated gillnets reduce elasmobranch bycatch across multiple wavelengths and taxonomic groups

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Introduction: Globally, the incidental capture of non-target species (bycatch) in fisheries has been linked to declines of several protected marine species, including elasmobranchs (i.e., sharks and rays), necessitating the development of bycatch reduction strategies to mitigate bycatch impacts while ensuring fisher livelihoods (Oliver et al., 2015). Net illumination is an emerging bycatch reduction technology that has successfully reduced sea turtle and other marine megafauna bycatch while maintaining aggregate target catch across multiple coastal gillnet fisheries (Lucas & Berggren, 2022). However, little research has been conducted to understand how elasmobranchs and bony fish respond to net illumination, especially across multiple taxonomic groups and within different taxonomic levels. Furthermore, most studies have used green LED lights, limiting our understanding of how net illumination performs across different wavelengths and illumination methods. Here, we conducted controlled fishery experiments in Mexico's Gulf of California using four different light types to examine the effects of artificial gillnet illumination on a diverse array of elasmobranch and bony fish species.

Methods: Paired net illumination trials were conducted in a bottom-set gillnet fishery in the Gulf of California near Bahía de los Ángeles, Baja California, Mexico, from 2008 to 2014 during June and July. A total of 106 paired trials were completed with four types of artificial illumination: green light-emitting diodes (LEDs) (n = 23), chemiluminescent green glowsticks (n = 18), orange LEDs (n = 29), and ultraviolet (UV) LEDs (n = 36). Paired nets were set 200 meters apart in locations with similar bottom topography around sunset and left to soak overnight. LED lights were placed 10 meters apart on the float line, while glowsticks were placed every 5 meters to account for their lower light intensity. Lights were placed on both control and illuminated nets, with control lights deactivated. At the end of each soak, fish were counted and classified by species.

To assess how bony fish and elasmobranchs respond to four types of artificial illumination, we fitted two Generalized Linear Mixed-Effects Models (GLMMs), one for each taxon. Our dependent variable, the number of fish caught per set, was modeled using a negative binomial distribution to account for overdispersion. The predictor variables of interest, net treatment and light type, were connected by an interaction term. The natural logarithm of unit effort (log[(net length [m]/100)*(soak time [hr]/12)]) was included as an offset term to account for differences in fishing effort between sets. Fisher, net orientation, date, location, depth, and experiment ID were also considered as possible predictors to account for variation between trials. Akaike's information criterion (AIC) was used to select the combination of variables that led to the best-fit models.

To elucidate the fine-scale taxonomic effects of net illumination on a variety of bony fish and elasmobranch groups, we also performed paired t-tests to determine whether each order's catch per unit effort (CPUE = number of fish/([net length/100 m] × [net soak time/12 h])) was significantly different in illuminated versus control nets.

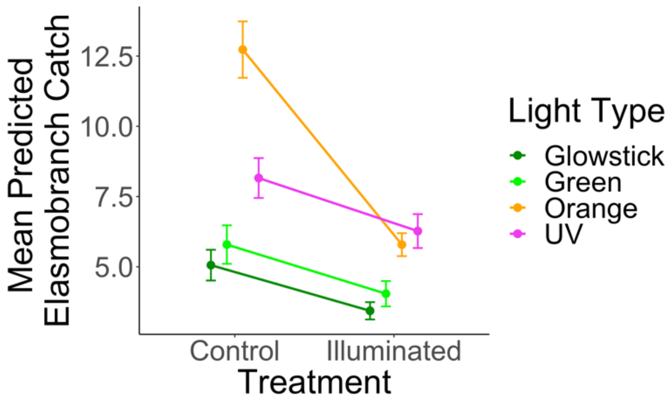

Figure 1. Mean predicted catch for elasmobranchs for each net treatment and light type. Error bars represent standard error.

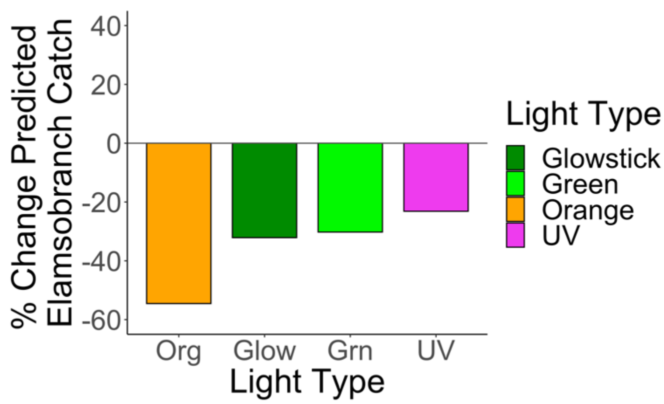

Figure 2. Percentage decrease for mean predicted elasmobranch catch in illuminated nets.

__Results:__ Aggregate elasmobranch catch is significantly reduced in illuminated nets when using each of the four light types (p = < 0.001; Figure 1). A significant interaction between treatment and light type (p = 0.021) indicates that the light types have varied effects on elasmobranch catch. Orange LEDs appear to be most effective for reducing elasmobranch catch (-54.5% CPUE), followed by green glowsticks (-32.1% CPUE), green LEDs (-30.2% CPUE), and UV LEDs (-23.1% CPUE; Figure 2).

Of the five elasmobranch orders caught with sufficient sample size for analysis, we found four elasmobranch orders with significantly lower CPUE in illuminated nets: Carcharhiniformes (ground sharks; p < 0.001), Myliobatiformes (stingrays, manta rays, and eagle rays; p = 0.018), Rhinopristiformes (guitarfish/shovelnose rays; p < 0.001), and Torpediniformes (electric rays; p = 0.032; Figure 3).

Aggregate bony fish catch is not significantly affected by net illumination of any kind (p = 0.756). Furthermore, there is no significant interaction between treatment and light type (p = 0.231), indicating that the effects of each light type on aggregate bony fish catch are statistically similar. Siluriformes (catfish) was the only bony fish order with significantly lower CPUE in illuminated nets (p = 0.001, Figure 3).

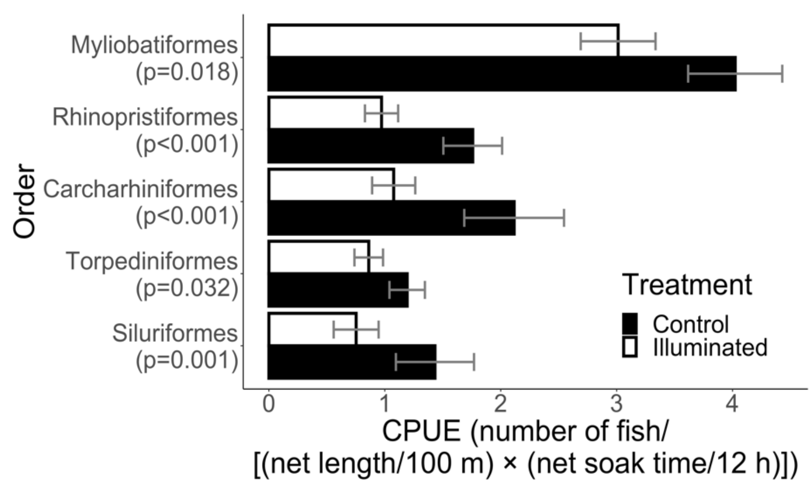

Figure 3. Mean catch per unit effort (CPUE) in control and illuminated nets for orders significantly affected by net illumination when all light types are combined for analysis. Error bars represent standard error.

Discussion: This is the first study to elucidate taxa-specific effects of gillnet illumination using multiple light types on elasmobranchs and bony fish, filling a critical knowledge gap in bycatch reduction research. We found that net illumination significantly reduced elasmobranch catch across multiple light types and orders, with orange LEDs being the most effective. Several elasmobranch species are threatened by overfishing and bycatch (Dulvy et al., 2014; Pacoureau et al., 2021), necessitating mitigation solutions. Of the 14 elasmobranch species captured belonging to the orders with significantly lower catch in illuminated nets, 11 are globally listed as Vulnerable or greater in the IUCN. Therefore, net illumination appears to be effective for many elasmobranchs of conservation concern and should be explored as a bycatch reduction solution in fisheries with high elasmobranch bycatch.

Additionally, we found no significant effects of net illumination on aggregate bony fish catch, confirming the results of previous net illumination studies that found no effect on bony fish target catch using either UV or green LEDs (e.g., Allman et al., 2020; Snape et al., 2024). These results suggest that multiple wavelengths and light types can maintain fishing production across fisheries where bony fish are the primary target catch.

While we found no change in aggregate bony fish catch, illuminated nets significantly decreased Siluriformes (i.e., catfish) catch. While it is unclear why some fish species have varied responses to net illumination, responses may be affected by differences in 1) physiology, 2) behavioral responses to the light itself, and 3) behavioral responses to environmental changes created by the light (e.g., attracting prey). Overall, our results demonstrate that net illumination can reduce the bycatch of a diverse array of elasmobranchs while maintaining most bony fish catch, highlighting the importance of a species-specific approach to bycatch reduction research.

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