4-28-2020

Predation Efficiency and Prey Choice of Estuarine Organisms Under Varying Anthropogenic Light Types and Intensities

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Thesis of
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Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Science
M.S. Marine Biology

Nova Southeastern University
Halmos College of Natural Sciences and Oceanography

April 2020

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HALMOS COLLEGE OF NATURAL SCIENCES AND OCEANOGRAPHY

PREDATION EFFICIENCY AND PREY CHOICE OF ESTUARINE ORGANISMS UNDER VARYING ANTHROPOGENIC LIGHT TYPES AND INTENSITIES

By

Carmen Montalvo

Submitted to the Faculty of
Halmos College of Natural Sciences and Oceanography
in partial fulfillment of the requirements for
the degree of Master of Science with a specialty in:

Marine Biology

Nova Southeastern University

May 2020

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Acknowledgements:

David Kerstetter for helping with all the writing and guiding through all the rough patches also for allowing me to use fishing gear and my committee members J. Matt Hoch and Charles Messing for reviewing my thesis so quickly. Abigail Ehlers for helping catch our prey items and taking care of the specimens in times of absence. Jacob Gray for helping to construct the holding tank setup as well as assisting in water quality and feeding. Ed and Cindy Montalvo (parents) for helping to purchase some lab equipment when money was tight. Dad for help setting up the lighting system and blackout curtain. Mom for listening to stress and reading drafts. Matt Stout and Hugh Hare for letting my work schedule be flexible so I could fish and run trials and let me go dive when stressed.

Abstract

The coastlines of Florida are becoming highly urbanized, and the growing human population is affecting many mangrove and estuarine habitats. Exploring the predation efficiency and prey choice of estuarine organisms under varying anthropogenic light types and intensities could help determine anthropogenic effects. Mangrove habitats support both relatively large predators such as Blue Striped Grunt (*Haemulon sciurus*) and Gray Snapper (*Lutjanus griseus*), and a diversity of smaller taxa that occupy lower trophic levels, including Grass Shrimp (*Palaemonetes paludosus*) and Mosquitofish (*Gambusia holbrooki*). Understanding how predation (or predation evasion) efficiencies are affected by different light intensities should offer guidance for managing South Florida coastal ecosystems subject to the effects of increased urbanization.

The goals were to determine if different artificial light intensities and types (1) affect predation efficiency, and (2) alter prey choice, for two mid-level predators found in the south Florida mangrove ecosystem. Under experimental conditions with LED, halogen, and incandescent sources, Mangrove Snappers and Blue Striped Grunts were exposed to combinations of prey. For predation efficiency, LED at its brightest level showed the highest decrease in predation efficiency of both predator species. For prey preference, the Grass Shrimp seemed to be the preferred prey over Mosquitofish under all light conditions for both predator species. Overall, light intensity and light type has some effect on nocturnal predation efficiency and prey choice. Humans influence affects aspects of the near shore ecosystems, and it is important to explore the extent of those effects on behaviors of species in estuarine habitats.

Keywords: fish in mangrove habitat, foraging behavior, artificial light effects, predator-prey relation, coastal development

Introduction

Coastal Ecosystems

Increased anthropogenic development is often associated with increases of artificial light at night, which can modify environmental conditions, alter food webs, and perhaps affect organism survival in these ecosystems. Inshore marine organisms are affected by nocturnal light pollution (Longcore and Rich 2004). Sea turtles and seabirds have been known to become disoriented by light pollution (Longcore and Rich 2013). The mangrove–seagrass ecotone serves as a nocturnal feeding ground for fish especially in the adjacent seagrass beds (Hammerschlag 2009). With increasing light pollution in coastal zones around the world, larger scale changes in intertidal ecosystems could be occurring (Garratt et al. 2019).

Mangrove Ecosystems

Mangroves grow in a relatively narrow fringe between land and sea between latitudes 25˚ N and 30˚ S. Partially submerged red mangrove (*Rhizophora mangle*) prop roots form an important habitat for many ecologically and economically important South Florida fish species and serve as nursery grounds for juveniles prior to their movement to adjacent seagrass beds or reefs (Thayer et al. 1987). These prop roots are aerial roots that drop down from the tree into the water and form an elaborate root system for an array in which animals find shelter, as well as a foraging ground.

Anthropogenic environmental change is exposing animals to a complex array of interacting stressors and is already having important effects on species abundances and distribution (McBryan et al. 2013). Such changes, whether associated with global climate change or local increases in coastal development and other human activities (Wannamaker et al.

2000), may alter the ranges of conditions in mangrove habitats, a major component of tropical coastal ecosystems. Mangroves can be damaged naturally, but the human impact has been the most severe. Worldwide, Valiela et al. (2001) estimated the mangrove area lost between the 1970s and 2000 at 35%, with an annual loss rate of 1-2%.

Florida's important recreational and commercial fisheries would drastically decline without healthy mangrove forests. This habitat supports both relatively large predators such as Blue Striped Grunt (*Haemulon sciurus*) and Gray Snapper (*Lutjanus griseus*), and a diversity of smaller taxa that occupy lower trophic levels, including Grass Shrimp (*Palaemonetes paludosus*) and Mosquitofish (*Gambusia holbrooki*).

Artificial light disrupts interspecific interactions involved in natural patterns of light and dark, which has serious implications for community ecology (Longcore and Rich 2004). The mangrove-seagrass ecotone serves as a hunting corridor for predators targeting juvenile fishes moving along the mangrove roots (Hammerschlag 2009). Understanding how predation (or predation evasion) efficiencies are affected by different light intensities should offer guidance for managing South Florida coastal ecosystems subject to the effects of increased urbanization.

Animals within the Mangrove Ecosystems

The following four organisms were selected to represent their respective trophic levels, because they are abundant in local mangrove systems, represent a variety of different feeding habits, and are easily identified to species (Hammerschlag and Serafy 2010).

Mid-level consumers: Many larger carnivores such as Nurse (*Ginglymostoma cirratum*) and Bonnethead (*Sphyrna tiburo*) sharks are too large to accommodate in the study, so two other mangrove-associated predators – juvenile Blue Striped Grunt and Gray Snapper – were chosen

as representative proxies for the middle trophic level consumers. Mangrove habitats serve as nurseries for juveniles of both species, which typically feed on a variety of small fishes and some crustaceans (Hettler et al. 1989; Faunce and Serafy 2007; 2008). Adult Gray Snappers also occur in the mangroves and have a similar diet (Faunce and Serafy 2007; 2008).

Lower-level consumers: Small prey are similarly transferring energy across trophic levels in estuarine and coastal ecosystems (Taylor et al. 2000). Two common lower trophic level species selected for this study – Grass Shrimp (*Palaemonetes vulgaris*) and Mosquitofish (*Gambusia holbrooki*) – are commonly fed on by many larger organisms in mangrove habitats. Grass Shrimp are generalist feeders; their diets include detritus, small invertebrates, and phytoplankton. Mosquitofish feed on zooplankton, small insects, and detritus. These particular prey species have not been reported in the diet of Gray Snapper and Blue Striped Grunt specifically, but both are similar to caridean shrimp and other small-bodied fishes commonly preyed upon by fishes in mangrove habitats (Hammerschlag et al. 2010).

Natural Light Cycles

During daylight hours, mangrove shorelines can harbor high fish densities with individuals benefitting from the reduced predation risk among the complex prop root habitat. Within mangrove shorelines, fish densities tend to be lower at night as the components of the assemblage disperse into adjacent habitats to forage (Hammerschlag 2009). Many reef fish species migrate for nocturnal foraging to adjacent habitats, such as seagrass and mangroves. Blue Striped Grunts in Belize and the Virgin Islands have been observed leaving the reef to forage in the adjacent seagrass beds after sunset (Burke 1995; McFarland 1979). Juvenile Gray Snapper have also been observed moving out of the mangroves at night to forage in Biscayne

Bay (Hammerschlag 2009). The natural migration and nocturnal foraging of these species could be affected by increased artificial light along the coast.

Anthropogenic Development in Coastal Regions

Urbanization has been identified as a threat to biodiversity (Becker et al. 2013). It is estimated that more than 80% of the worlds' population currently live under light-polluted skies, such that the Milky Way is hidden from one-third of people alive today (Davies and Smyth 2017). More than half of the world's population lives within 100 km of an ocean (Rich and Longcore 2013). Human activities subject many aquatic environments to significant alterations in natural light cycles (Rich and Longcore 2013). Coastlines of Florida are becoming highly urbanized, and the growing human population is affecting many mangrove and estuarine habitats. Florida's current population is estimated to be 21.65 million, and 2 million reside in the Miami-Dade county alone (US Census State and County Population Estimates, 2019). In terms of population density, 2 million residences are spaced at 1,454 residences km^{-2} in Miami-Dade County. Florida has 8,436 miles of coastline and its coastal population is 14,468,197 (NOAA 2019).

Current best estimates indicate that 22% of the worlds' coastal regions are experiencing some degree of artificial illumination, and 20% of marine-protected areas are exposed across their entire range (Davies and Smyth 2017). The human population growth along coastal areas including estuaries will result in an increase of infrastructure such as jetties, wharfs, and marinas, as well as directly adjacent housing. This infrastructure is often associated with artificial night lighting. However, the implications of these unnatural lighting regimes for fish faunas in coastal areas are largely unknown (Becker et al. 2013).

Anthropogenic Light Sources

Artificial light is often associated with man-made structures. With the urbanization and development of the coastlines, much of the new infrastructure could be influencing the ecological structure of surrounding coastal habitats. Ecological light pollution includes chronic or periodic increased illumination as well as unexpected changes in illumination and direct glare (Longcore and Rich 2004). A brief search through common dock lighting and floodlighting available on popular marine supply sites such as West Marine and Overton's found that LED lighting was the most common, followed by halogen and incandescent for floodlights. However, many of the common LED lighting available was offered in white or multiple colors, which disrupt marine life more than red or orange hues. While LEDs are often advocated for their potential to reduce global CO_2 emissions and the ability to tailor their spectra to avoid unwanted environmental impacts, environmental scientists and human health experts have raised concerns about the broad-spectrum light and prominent short wavelength peak (Davies and Smyth 2017).

Widespread lighting associated with development along the coast could influence animal behavior. Urban lighting associated with artificial structures is increasing, which results in altering the natural light regime of the surrounding aquatic environments. A range of intra- and interspecific interactions could be affected including foraging, predation, sexual communication (ability to locate, identify and assess the fitness of conspecifics through visual displays) and camouflage (Davies and Smyth 2017). Unlike daylight, nighttime artificial light creates considerable unnatural contrasting light conditions between the man-made structures and the surrounding ambient light conditions (Becker et al. 2013).

Review of Ecosystem Problems with Anthropogenic Light Source

Artificial light has only recently been recognized as a cause for environmental concern (Davies et al. 2014). This light disrupts interspecific interactions that evolved under natural conditions and patterns of light and dark, with serious implications for community ecology (Longcore and Rich 2004). Garratt et al. (2019) reported that 47% of non-rare taxa along a United Kingdom shoreline were individually found to either increase or decrease in abundance (or the probability of occurrence) with increasing illumination, accounting for shore height and sediment characteristics. However, little information is available on how light pollution affects those species, behaviors, and interactions that are affected by the intensity, spectra, and periodicity of natural nighttime light in marine ecosystems (Davies et al. 2014). Many organisms are extremely sensitive to natural light and use light cues as dim as the moon and the Milky Way to orient themselves, navigate landscapes, and identify conspecifics and resources at night (Davies and Smyth 2017). Organisms could experience disorientation from the additional light, which could cause attraction or repulsion from glare, either of which could affect foraging, reproduction, communication, and other critical behaviors (Longcore and Rich 2004).

With respect to predation in particular, the artificial light in urban estuarine and coastal waters could create an unnatural top-down regulation of affected fish populations. Interactions between light and behavior in highly altered coastal ecosystems could have a strong effect on the fundamental ecological processes that regulate biological communities (Becker et al. 2013). Garratt et al. (2019) mapped the exposure of intertidal organisms in a sandy shore ecosystem in the United Kingdom to artificial light from High Pressure Sodium promenade lighting and demonstrated for the first time its consequences for intertidal macroinvertebrate community composition and structure. Increased light at night may benefit diurnal species, permitting them

to forage for longer periods of time, but any gains due to increased activity time could be offset by increased predation risk (Longcore and Rich 2004).

Specific Review of Fish Problems with Anthropogenic Light Sources

The effects of food availability and predation risk on fish foraging behavior has been investigated both in laboratory and field experiments, mostly in temperate freshwater systems during daylight hours (Hammerschlag 2009). However, little attention has been paid towards nocturnal fish foraging decisions along subtropical shorelines when most species emerge. Artificial lighting could be changing foraging and nocturnal migrations of many fish taxa. Juvenile grunts (Family Haemulidae) are abundant predators that remain on coral reefs during the day and leave the reef after sunset (Burke 1995). Species interactions across trophic levels are also guided by light availability, which determines the timing and success of predatory activity and the ability of prey to avoid predation (Garratt et al. 2019). The conditions created by artificial lighting might benefit them by increasing prey concentrations and enhancing their foraging opportunities (Becker et al. 2013).

The scattered growth of artificial lighting around the world is a significant barrier to predicting where organisms will be able to seek out suitably dark habitats in the future and identifying where to allocate dark corridors that enable such migrations to happen (Davies and Smyth 2017). Artificial lighting and its contrast on ambient conditions could also affect nocturnal interactions among animals. Artificial light at night can trigger ecological effects spanning trophic levels, and the nature of such impacts depends on the wavelengths emitted by the lighting technology employed (Bennie et al. 2018). Urban lighting could create conditions in

surrounding water that specifically benefits certain fish guilds such as piscivorous predators (Becker et al. 2013).

Predator Efficiency Experimentation Methods

Predation affects prey populations and communities, but such effects can be attenuated when abiotic conditions interfere with foraging activities (Lunt and Smee 2015). Previous studies have observed predation efficiency under a variety of conditions. Marti et al. (2006) compared the predation efficiency of indigenous larvivorous fish species on larvae in drainage ditches. Conducted in Argentina, this study had both field and laboratory components, in which small freshwater fish species (*Cnesterodon decemmaculatus* and *Jenynsia multidentata*) consumed mosquito larvae (*Culex pipiens*). In the laboratory experiment, the feeding tests were conducted at 25˚C in individual aquariums with a 7-day fast-acclimation period to laboratory conditions and with a 1-hour wait period before counting the surviving larvae (Marti et al. 2006). Mattila (1992) found that a slight increase in aquarium habitat complexity significantly increased the survival of two prey species—an amphipod (*Corophium volutator*) and an isopod (*Asellus aquaticus*)—and correspondingly decreased predation efficiency of a freshwater European Perch (*Perca fluviatilis*) and Ruffe (*Gymnocephalus cernuus*), respectively. The predators were starved for 24 hours prior to each trial to ensure they fed actively, and remaining prey was counted after the experimental period.

Previous studies observed predation efficiency with factors that include turbidity and habitat complexity, although direct studies using light as a factor are limited. Benefield and Minella (1996) examined the effects on predation by Killifish on Grass Shrimp with variations in turbidity and light intensity. Light intensity only affected the reactive distance as the illumination

increased from near darkness to very low levels (Benefield and Minello 1996). Light, turbidity, habitat complexity, human presence, and prey availability are some of the direct and indirect effects that could affect predation efficiency. Information and studies on the direct and indirect effects on predation efficiency and prey selection of estuarine organisms is important for understanding the full impact of human presence along coastlines on coastal ecosystems.

Nocturnal light pollution has been a concern due its probable ecological consequences. As most fish are visual foragers, visual conditions in the water may alter the strength of their regulation via predation on lower trophic levels (Jonsson et al. 2013). However, an understanding of the effects of artificial light on coastal aquatic environments is limited. Interactions between behavior and light can also influence the outcomes of predator–prey encounters that may have consequences throughout the local ecosystem (Becker et al. 2013). The goals of this project are to determine if different artificial light intensities and types for two mid-level predators in the South Florida mangrove ecosystem (1) affect predation efficiency at night, and (2) alter prey choice.

Methods and Materials

Species Choice and Specimen Collection

Two species from the middle trophic level—juvenile Gray Snapper and Blue Striped Grunt, both medium-sized carnivores —and two from the lower trophic level—Grass Shrimp and Mosquitofish, both omnivores— were used in order to provide a range and variety of feeding habits and diets. These fishes and invertebrates were selected because they are abundant, easily identified to species level, represent a variety at each trophic level, and have different feeding habits (Hammerschlag and Serafy 2009). Appropriate collection permits were obtained from the

Florida Fish and Wildlife Conservation Commission (FWC; details on permit) and the NSU Institutional Animal Care and Use Committee (IACUC; protocol 2018.06.DK8 to D. Kerstetter).

Gray Snappers and Blue Striped Grunts were caught and collected by hook-and-line gear from the shoreline along the Intercoastal Waterway (ICW) in Dania Beach, Florida. Each fish was measured with a ruler before being placed in divider aquariums, one fish per section of the aquarium. Mean total lengths were 14.5 cm (n=14, range: 11.6-15.8 cm) for Gray Snappers and 9.8 cm (n=10, range: 8.8-13.6 cm) for Blue Striped Grunts.

Grass shrimp and Mosquitofish were collected by seine net the shallows of mangroves during low tide in Whiskey Creek near the Diana Beach Pier (Dania Beach, FL, USA). Collected individuals were placed in aerated containers for transport to holding aquariums similar to those used for the predator species. Lengths ranges were 0.07-1.7 cm for Grass Shrimp and 1.2-2.5 cm for Mosquitofish.

Individual fish were kept in holding tanks for two to three weeks to ensure each individual was exposed to each experimental condition. The holding tanks for predator and prey species were kept at 25˚C, 29 ppt, and covered with mesh to prevent escapes. Water temperature was maintained with Aqueon Submersible Aquarium Heaters set to constant values. The temperature was a mean value for the area, per the National Ocean and Atmospheric Association (NOAA) database (seatemperature.org). The salinity was chosen based on a mean value of salinity data collected around Port Everglades from 1997 to 2007 measured 2 to 4 times annually (USACOE, 2015).

Predator Efficiency and Prey Preference Experimentation

Four light intensities and three types of light were used in experiments: *no light*, *low*, *intermediate*, and *high*, under LED, halogen, and incandescent sources. Bulb details are as follows: LED—refresh daylight, EQ A15, 60 watt, dimmable 500 lumen brightness; halogen—crystal clear, 60 watt, dimmable 750 lumen clear light, and incandescent—soft white, 75 watt, dimmable 890 lumen. All bulbs were standard general use, energy-efficient, and manufactured by General Electric. Light types were chosen due to their common occurrence in households, docks, and other human structures found along waterways and coastlines. Briefly searching popular marine supply companies (West Marine and Overton's) for dock lighting helped determine the light types chosen here. Light-Emitting Diodes (LEDs) have grown from a 9% share of the lighting market in 2011 to 45% in 2014 (Davies and Smyth 2017). LEDs have also been used in other studies observing effects of artificial light at night on various marine animals. Artificial nighttime lighting, specifically LED, influences the behavior of intertidal and invertebrate organisms, and triggers ecological effects spanning trophic levels (Bernies et al. 2018, Underwood et al. 2017, & Davies and Smyth 2017).

The light intensities were measured with an LED Light Meter (model LT40, resolution 0-400,00 lux, resolution 01 lux, error +/-3%; Extech Instruments). Light level measurements under *No light* for all light types were at 0.5 Lux. *Low* intensity was 6.6 Lux for LED, 93.7 Lux for halogen, and 91.5 Lux for incandescent. *Medium* intensity was 447.3 Lux for LED, 472.3 Lux for halogen, 493.8 Lux for incandescent. Finally, *high* intensity for LED was 1281 Lux, 1358 Lux for halogen, and 1921 Lux for incandescent. A Lutron Credenza slide dimmer connected all bulbs and was dimmed simultaneously and consistently through each trial. The slider on the dimmer had markings for the set intensities for each level used in the experimental trials for all

light types. *No light* was represented with the slider in the off position. One click above off represented *low*, 2 clicks above off *medium*, and all the way up on the dimmer *high*. Levels were based on the dimmer markings and not measurement of lux for each light type.

Each predator and prey specimen was exposed to all three light intensities from each type of light bulb. Experimental aquariums were kept at the same parameters as the holding aquariums, apart from light exposure during nighttime predation trials. Blackout fabric surrounded the experimental aquariums to prevent excess light and avoid outside disturbances during trials (Figure 1).

Prior to each trial, predators were fasted for 48 hours to ensure an empty digestive tract (Mattila 1992, Benefield and Minello 1996, Marti et al. 2006). Each predator was assigned a numbered tank to avoid repeat use of the same individual when switching between trials and introducing new predators to experimental conditions. Each predator that completed a trial was removed and placed in corresponding holding tank, while a new predator was introduced to trial conditions, so more than one experiment could be run at a time. Individuals experienced LED, halogen, and incandescent bulbs with the four light levels while given an opportunity to feed on either Grass Shrimp, Mosquitofish, or a combination of the two.

A plastic mesh divider was placed inside the aquarium to separate predator from prey until the proper amount of prey items and light intensity was achieved (Figures 3). For each trial, 20 prey items were accessible to the predator under various light conditions in the following combinations: a) 20 Grass Shrimp; b) 20 Mosquitofish; and c) a combination of 10 Grass Shrimp and 10 Mosquitofish. The prey items were available to the predator for a 1-hour period and at the conclusion of the trial, the predator was removed, and remaining prey counted (Mattila 1992,

Benefield and Minello 1996). Predation efficiency was determined by the number of prey items remaining divided by the total number of prey items available.

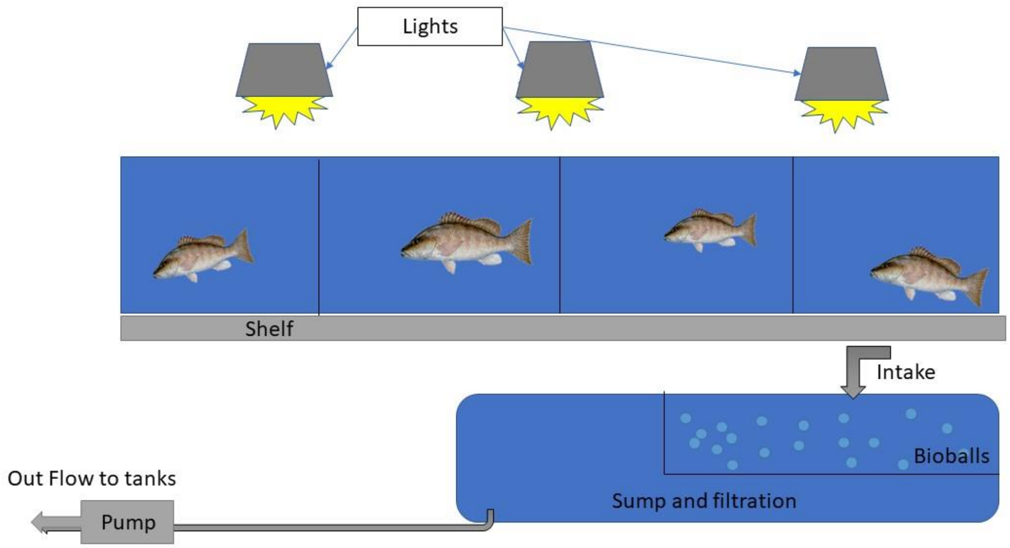

Figure 1: Experimental setup with lights, filtration system, mesh net covering, and blackout fabric surrounding the tanks. Each light was mounted with a clamp and had no cover, just the bare bulb. Lights were placed and directed to ensure evenly light exposure. Diagram not to scale.

Experimental trials

After predators were collected and allowed to acclimate, an individual would be exposed to the experimental light levels and prey choices. When not undergoing predation trials, individuals experienced a normal light cycle via uncovered windows in the holding room.

Trials were run approximately between 8:00 pm and 9:00 pm. The light type and intensity were set, a fine mesh partition was placed in each tank, and the prey counted out and placed into the side of the divider separate from the predator. Prey was acclimated; then the partition was removed and tanks covered. During trials, blackout cloth was placed around the tanks to limit external disturbances. Predators were allowed an hour to consume prey, and tanks were periodically checked to ensure prey had not escaped (i.e., jumped out). After the allotted time for predation, the cover was removed, and any remaining prey counted. After the predation trial was recorded, the lights were turned off to allow the predators to return to a natural light cycle.

Eight individuals were exposed to each light level from each light type three separate times to give the predators the various prey options of shrimp, fish, or combination. Eight Mangrove Snappers and eight Blue Striped Grunts were used for these trials; the same eight individuals of each species were used for every condition to limit variation. A total of 216 trials were run and recorded.

Statistical Methods

Rstudio (R version 3.5.1, 2018-07-02) was used for statistical analyses. The Shaprio-Wilks and Bartlett tests were used to evaluate normality and homogeneity of data. If needed, data were log-transformed using logarithmic function in attempt to pass normality and

homogeneity assumptions. However, even log-transformations were insufficient, and the Kruskal-Wallis test was used for assessing results (the non-parametric equivalent to the parametric two-way ANOVA test for fixed factor model). This nonparametric test is used to determine statistically significant differences between two or more groups of an independent variable on a continuous or ordinal dependent variable. For significant results, a post-hoc multiple comparison test after Kruskal-Wallis was run to determine significant factors and/or interactions for predation efficiency. Kruskalmc (Multiple Comparison Test after Kruskal Wallis) was the analysis code used to run the non-parametric multiple comparisons test for significance. When the obtained value of a Kruskal-Wallis test is significant, it indicates that at least one of the groups is different from at least one of the others. This test helps to determine which groups are different with pairwise comparisons adjusted appropriately. Those pairs of groups which have observed differences higher than a critical value are considered statistically different at the given probability (p value). Three type of multiple comparisons were implemented: comparisons between treatments, 'one-tailed' and 'two-tailed' comparison treatments versus control (Giraudoux 2010). Significance was assessed for all testing at a = 0.05 and is shown in the figures by asterisks for significant interactions and factors.

Post-hoc power analysis was performed to assess the statistical power of the results using GPower (Version 3.1.9.4; Faul et al. 2007). A higher statistical power indicates a decreasing probability of a Type II (false negative) error. Set values for alpha, sample size, and effect size were used to determine the power analysis. Alpha was set at 0.05 to coincide with the p-value range used in Rstudio, sample size was total number of individuals for both species, and the effect size was estimated at 1.52. Effect size was calculated within GPower using the direct partial N^2 value (Faul et al. 2007).

Results:

Statistical analyses

Two-way ANOVAs for a fixed factor model were carried out in Rstudio to identify significant interactions in the data. However, the data did not pass Shapiro-Wilks normality and Bartlett Homogeneity tests (p values <0.05), even after transformation. The non-parametric Kruskal-Wallis test resulted in a significant p value (X^2=355.68, df=35, p= 2.2e-16).

Further analysis with the non-parametric post-hoc multiple comparison helped determine the significant conditions for predation efficiency. The post-hoc test showed a significant difference between predation efficiency under *high* halogen light with a combination of Grass shrimp and Mosquito fish for both predator species. *No light* also showed significance under all light types with shrimp as the prey item. *High* incandescent light conditions with shrimp, fish, and combination were significant relative other interactions and factors according to the post-hoc test. LED lighting conditions with all prey combinations were significantly different for both species. Combination of prey under *low* light conditions showed significance in predation efficiency across all light types. Fish prey items under *high* light conditions had a significance in predation efficiency for both predator species. Predation efficiency was significantly lower at the high setting for intensity of all light types (Figure 4). A combination of prey types and *no light* permitted a higher predation efficiency rate (Figure 4).

No light across prey and light types had a higher predation efficiency than other combined factors (Table 1). Blue Striped grunts have a higher overall predation efficiency than Mangrove Snappers under all of the lighting conditions and prey options (Table 1). Blue Striped Grunts, however, showed the highest efficiency with shrimp as the only prey item with *no light*

across all light types (Table 1). LED light seemed to permit the highest average predation efficiency among the Blue Striped Grunts (Table 1). Predation efficiency for both Mangrove Snappers and Blue Striped Grunts was also higher with shrimp as the prey choice under LED lighting (Figure 2).

A post-hoc power analysis was performed and resulted in a beta value of 81.3%, which indicated fairly high statistical power for these sample sizes and a minimization of the likelihood of a false negative.

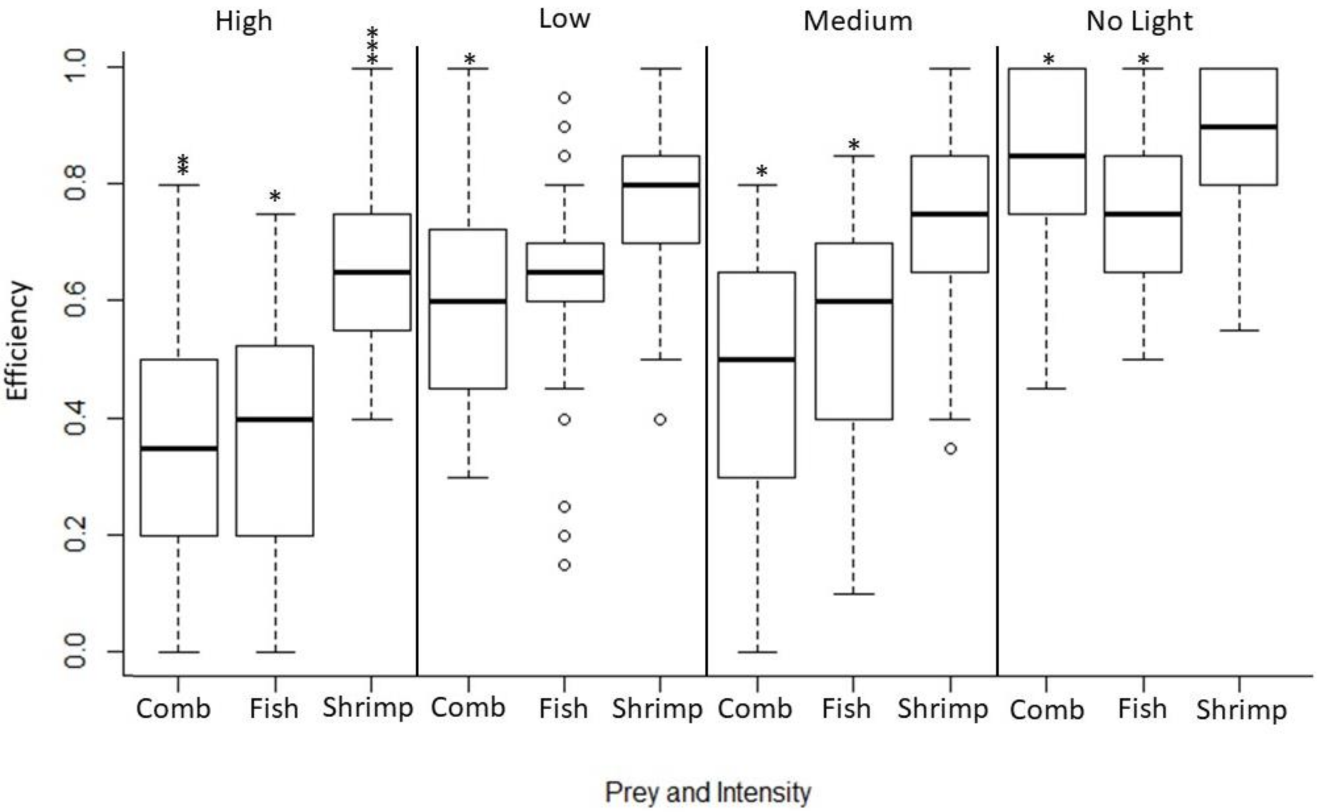

Figure 2: Predation efficiency effects by light intensity and prey choice for both Mangrove Snapper and Blue Striped Grunt combined. Graph comparing the efficiency with different light intensities and prey choices. Upper and lower bars designate the maximum and minimum of the data set, and circles above and below some boxplots are outliers within the dataset. Each tick mark on the x- axis is the prey type. First is combination (Comb) of fish and shrimp, followed by fish, and finally shrimp, then repeated across different experimental light types. Asterisks indicate significance between interactions and conditions.

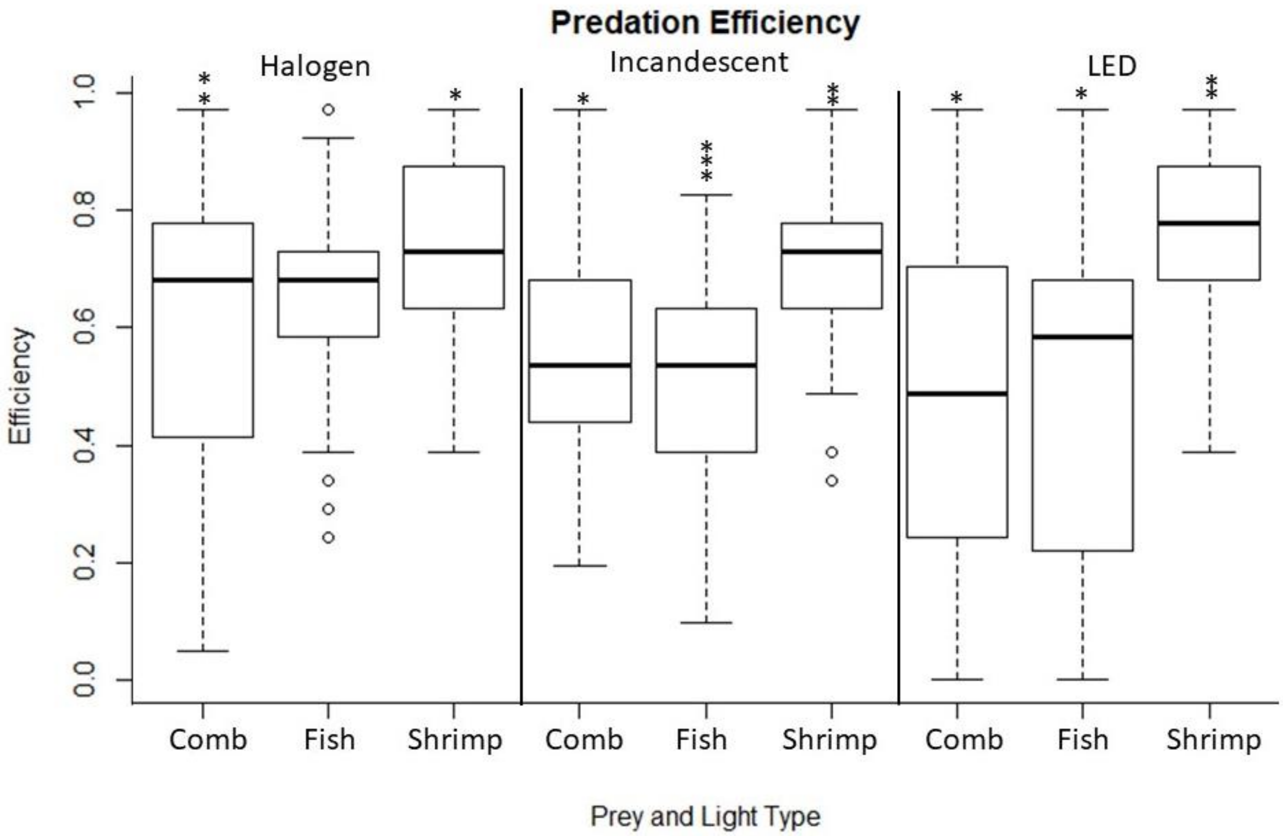

Figure 3: Predation efficiency effects by prey and light type for both species Mangrove Snapper and Blue Striped Grunt combined data. The comparison of predation efficiency with light type and prey choice are shown above with outliers represented by circles above and below boxplots. Each tick mark on the x- axis is the prey. First is combination (Comb), followed by fish, and shrimp, and repeated with different intensities. Asterisks indicate significance between interactions and conditions.

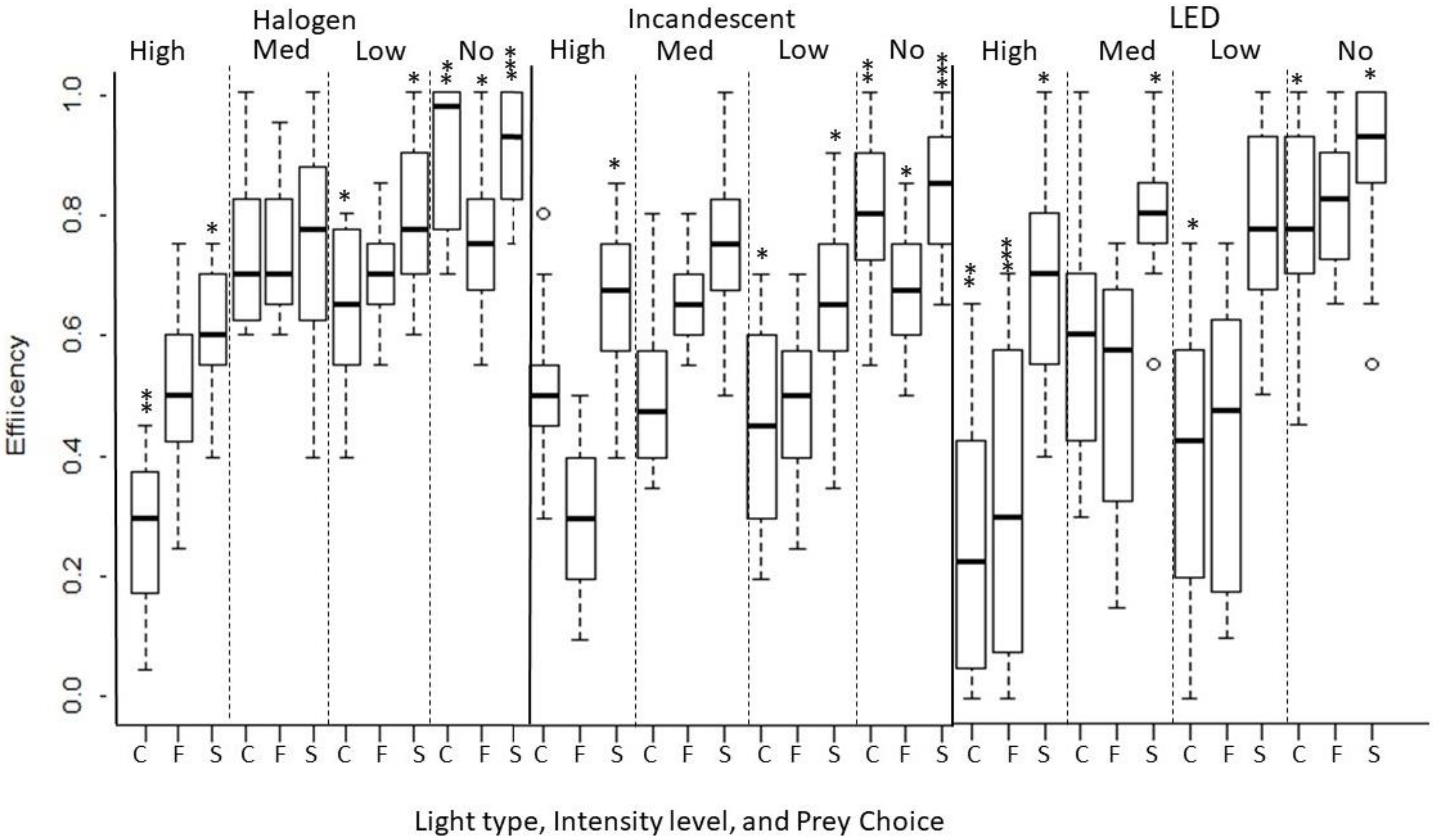

Figure 4: Predation efficiency effects by prey choice, light type, and intensity. From left to right: Prey under Halogen starting with combination and high intensity. Graph is categorized by prey items and light intensity on the x- axis with each split a light type. X-axis abbreviations: combination (C), fish (F), and shrimp (S). Each group of three tic marks is repeated for the different light intensities. Asterisks indicate significance between interactions and conditions.

LED Conditions (Blue Striped Grunt)

Predation efficiency was highest under *no light* conditions across all prey combinations and light types (Table 1). Mean predation efficiencies were as follows: *No light*: 96% (SD = 0.05) for shrimp, 84% (SD =0.06) for fish, and 81% (SD = 0.13) for a combination; *low* light: 86% (SD = 0.07) for shrimp, 68% (SD =0.05) for fish, and 74% (SD = 0.13) for a combination; *intermediate light*: 92% (SD = 0.07) for shrimp, 64% (SD =0.06) for fish, and 58% (SD = 0.11) for a combination and *high light*: 82% (SD = 0.09) for shrimp, 57% (SD =0.09) for fish, and 42% (SD = 0.13) for a combination. Overall mean predation efficiency of Blue Striped Grunt for LED under *high light* conditions was 60%.

Halogen Conditions (Blue Striped Grunt)

Mean predation efficiencies were as follows: *no light* 94% (SD = 0.05) for shrimp, 67% (SD =0.07) for fish, and 93% (SD = 0.10) for a combination; *low light*: 73% (SD = 0.19) for shrimp, 65% (SD =0.04) for fish, and 72% (SD = 0.10) for a combination; *intermediate light*: 85% (SD = 0.10) for shrimp, 66% (SD =0.08) for fish, and 66% (SD = 0.15) for a combination and *high light*: 61% (SD = 0.11) for shrimp, 41% (SD =0.10) for fish, and 35% (SD = 0.09) for a combination. Overall mean predation efficiency for Blue Striped Grunts under Halogen at *high light* conditions was 38%.

Incandescent Conditions (Blue Striped Grunts)

Mean predation efficiency for shrimp under incandescent *no light* conditions was 84% (SD = 0.12), 61% (SD =0.08) for fish, and 74% (SD = 0.12) for a combination. Incandescent light *low* conditions mean predation efficiency was 76% (SD = 0.08) for shrimp, 68% (SD

=0.08) for fish, and 53% (SD = 0.14) for a combination. Under incandescent *intermediate* light conditions, mean predation efficiency was 72% (SD = 0.09) for shrimp, 55% (SD =0.11) for fish, and 57% (SD = 0.10) for a combination. Finally, for incandescent *high* light conditions, mean predation efficiency was 70% (SD = 0.10) for shrimp, 33% (SD =0.10) for fish, and 59% (SD = 0.11) for a combination. Blue Striped Grunts had mean predation efficiency at 49% under *high* incandescent lighting overall.

LED Conditions (Mangrove Snapper)

Mangrove Snappers had the lowest mean predation efficiency under *high* light intensity, LED, and the combination of prey items (Table 1). Shrimp as the prey option seemed to be the preferred across the experimental conditions (Table 1). LED and incandescent light looks to have the most effect on the predation efficiency. The lowest mean predation efficiency was the combination of fish and shrimp under *high* LED lighting (Table1). *No light* conditions mean predation efficiency was 84% (SD = 0.15) for shrimp, 81% (SD =0.14) for fish, and 79% (SD = 0.18) for a combination. LED light *low* conditions mean predation efficiency was 78% (SD = 0.12) for shrimp, 34% (SD =0.14) for fish, and 44% (SD = 0.10) for a combination. Under LED *intermediate* light conditions, mean predation efficiency was 66% (SD = 0.09) for shrimp, 19% (SD =0.09) for fish, and 19% (SD = 0.12) for a combination. Finally, for LED *high* light conditions, mean predation efficiency was 53% (SD = 0.11) for shrimp, 9% (SD =0.09) for fish, and 8% (SD = 0.07) for a combination. The overall mean predation efficiency for Mangrove Snappers under *high* LED light was 20%.

Halogen Conditions (Mangrove Snapper)

No light conditions mean predation efficiency was 87% (SD = 0.11) for shrimp, 83% (SD =0.09) for fish, and 88% (SD = 0.12) for a combination. Under halogen *low* light conditions, mean predation efficiency for was 77% (SD = 0.16) for shrimp, 81% (SD =0.10) for fish, and 74% (SD = 0.13) for a combination. Under halogen *intermediate* light conditions, mean predation efficiency was 73% (SD = 0.09) for shrimp, 75% (SD =0.06) for fish, and 74% (SD = 0.13) for a combination. Finally, for halogen *high* light conditions, mean predation efficiency was 59% (SD = 0.09) for shrimp, 60% (SD =0.09) for fish, and 21% (SD = 0.09) for a combination. The overall mean predation efficiency for Mangrove Snappers under halogen light was at 38%.

Incandescent Conditions (Mangrove Snapper)

No light conditions, predation efficiency was 84% (SD = 0.08) for shrimp, 73% (SD =0.08) for fish, and 86% (SD = 0.11) for a combination. Incandescent light *low* conditions mean predation efficiency was 73% (SD = 0.16) for shrimp, 63% (SD =0.07) for fish, and 46% (SD = 0.06) for a combination. Under incandescent *intermediate* light conditions, mean predation efficiency was 66% (SD = 0.09) for shrimp, 44% (SD =0.10) for fish, and 29% (SD = 0.07) for a combination. Finally, for incandescent *high* light conditions, mean predation efficiency was 62% (SD = 0.13) for shrimp, 26% (SD =0.13) for fish, and 46% (SD = 0.09) for a combination. The overall mean predation efficiency for Mangrove Snappers under *high* incandescent light conditions was at 38%.

Table 1: Mangrove Snapper (MS) and Blue Striped Grunt (BSG) mean predation efficiency and standard deviation separated into prey, intensity, and light type by species. Light levels: *No Light (NL), low*, *medium*, and *high*. Light types: *LED*, *halogen (halo.),* and *incandescent (Incand.).* Prey types: *shrimp*, *fish,* and *combination (comb.).*

Species	*NL/ Shrimp/ LED*	*Low/Shrimp/LED*	*Medium/Shrimp/LED*	*High/Shrimp/LED*
MS	84% (SD=.15)	78% (SD=.12)	66% (SD= .09)	53% (SD= .11)
BSG	96% (SD= .05)	86% (SD= .07)	92% (SD=.07)	82% (SD= .09)
	NL/Fish/ LED	*Low/Fish/ LED*	*Medium/Fish/ LED*	*High/Fish/ LED*
MS	81% (SD=.14)	34% (SD=.14)	19% (SD= .09)	9% (SD= .09)
BSG	84% (SD= .06)	68% (SD= .05)	64% (SD=.06)	57% (SD= .09)
	NL/Comb./ LED	*Low/Comb./ LED*	*Medium/Comb./ LED*	*High/Comb./ LED*
MS	79% (SD=.18)	44% (SD= .10)	19% (SD=.12)	8% (SD= .07)
BSG	81% (SD= .13)	74% (SD=.13)	58% (SD=.11)	42% (SD=.13)
	NL/Shrimp/ Halo.	*Low/Shrimp/ Halo.*	*Medium/Shrimp/ Halo.*	*High/Shrimp/ Halo.*
MS	87% (SD= .11)	77% (SD=.16)	73% (SD=.09)	59% (SD= .09)
BSG	94% (SD= .05)	73% (SD=.19)	85% (SD=.10)	61% (SD= .11)
	NL/Fish/ Halo.	*Low/Fish/ Halo.*	*Medium/Fish/ Halo.*	*High/Fish/ Halo.*
MS	83% (SD= .09)	81% (SD= .10)	75% (SD= .06)	60% (SD= .09)
BSG	67% (SD= .07)	65% (SD=.04)	66% (SD=.08)	41% (SD=.10)
	NL/Comb./ Halo.	*Low/Comb./ Halo.*	*Medium/Comb./ Halo.*	*High/Comb./ Halo.*
MS	88% (SD= .12)	74% (SD= .13)	64% (SD= .13)	21% (SD= .09)
BSG	93% (SD= .10)	72% (SD=.10)	66% (SD=.15)	35% (SD= .09)
	NL/Shrimp/ Incand.	*Low/Shrimp/ Incand.*	*Medium/Shrimp/ Incand.*	*High/Shrimp/ Incand.*
MS	84% (SD= .08)	73% (SD= .16)	58% (SD= .09)	62% (SD= .13)
BSG	84% (SD= .12)	76% (SD=.08)	72% (SD=.09)	70% (SD=.10)
	NL/Fish/ Incand.	*Low/Fish/ Incand.*	*Medium/Fish/ Incand.*	*High/Fish/ Incand.*
MS	73% (SD= .08)	63% (SD= .07)	44% (SD= .10)	26% (SD=.13)
BSG	61% (SD= .08)	68% (SD=.08)	55% (SD=.11)	33% (SD=.10)
	NL/Comb./Incand.	*Low/Comb./Incand.*	*Medium/Comb./Incand.*	*High/Comb./Incand.*
MS	86% (SD= .11)	46% (SD=.06)	29% (SD= .07)	46% (SD=.09)
BSG	74% (SD=.12)	53% (SD=.14)	57% (SD=.10)	59% (SD=.11)

Discussion:

Both the Mangrove Snappers and Blue Striped Grunts seemed to prefer the Grass Shrimp over the Mosquitofish when offered the choice. Blue Striped Grunts showed the lowest predation efficiency when incandescent light was set at the highest intensity with only fish as prey choice. Lower predation efficiency with Mosquitofish under a high intensity could be due to the predator's inability to camouflage itself from the prey or from other larger predators. Overall, both predators exhibited lower predation efficiency with Mosquitofish as prey. The Mosquitofish may have presented more laborious for survival, especially when the easier caught prey, Grass Shrimp, were present. Grass Shrimp seemed to be the preferred prey item among both species regardless of lighting conditions.

Blue Striped Grunts seemed to be the least affected in lighting conditions and had a higher predation efficiency over the Mangrove Snappers overall. Results from these experiments show that juvenile Mangrove Snappers could be more susceptible to artificial light intrusion into the mangroves and estuaries, which may change their natural foraging behavior.

Understanding natural nocturnal habits of estuarine organisms is important to determine the extent of the effects artificial lighting on those organisms. Mangrove Snappers seem to be affected to some degree under most light types and under any intensities. Light types seem to have less effect on Blue Striped Grunts predation efficiency. McFarland et al. (1979) observed that Blue Striped Grunts' eyes adapt to lighting changes during twilight and dawn periods for optimum timing to migrate to and from mangrove habitats and sea grass beds. This study could support why Blue Striped Grunts were more successful than Mangrove Snappers, so further analysis and observation is needed. Predation can significantly affect prey populations and

communities, but predator effects can be attenuated when abiotic conditions interfere with foraging activities (Lunt and Smee 2015).

Lighting lux measurements were not uniform across all light types, which could be due to differences in lumens among each type. The lower luminosities might not have covered the same area at the same intensities when measured in lux. However, even with the minor variations in lux readings, the three light levels across each light type were generally equivalent, and each light was set to the same mark for each light level for each trial. In future studies, lux and lumens across all light types and levels could be more uniform to reduce any possible variation.

This study found that artificial light has some effect on organisms within the mangrove and estuarine habitats. Light brightness during the predation events seems to have had the greatest effect on predation. Perhaps the experimental fish predators were more hesitant in pursuing prey due to their own exposure under light to potential larger predators. More in-depth study with a larger sample size and more species could help determine the extent of these effects. Studying similar conditions on larger estuarine organisms, such as adult fishes and sharks, could also give insight into artificial light effects on nocturnal foraging and feeding habits of estuarine organisms and how elaborate its effects are on the surrounding ecosystem.

Future Studies

Effects on predators can cascade through communities by causing changes in behavior, density, and distributions at multiple trophic levels (Lunt and Smee 2015). Future studies could vary the color and wavelengths of light to investigate possible effects on marine organisms. A follow-up investigation focused on the most common waterway dock and restaurant lighting

could reveal specific effects on nocturnal estuarian predator behavior and hunting strategies in greater detail. Moonlight (moon phases) and starlight (overcast skies) could also be the subject of a future study in investigating natural ecological light effects on nocturnal feeding behaviors. As most fish are visual foragers, visual conditions in the water may alter the strength of their regulation via predation on lower trophic levels (Jonsson et al. 2013). Additionally, study of the biology of fish eyes could improve understanding of the adaptions of species for foraging diurnally versus nocturnally. Studying adult versus juvenile predatory behaviors under different light conditions could also provide insights into how such environmental variations affect different life cycle stages of economically important species.

Conclusions

Some of the catastrophic consequences of light for certain taxonomic groups are well known, such as the deaths of migratory birds around tall lighted structures, and those of hatchling sea turtles disoriented by lights on their natal beaches (Longcore et al. 2004). More subtle influences of artificial night lighting on the behavior and community ecology of species are less well recognized. *No light,* in the experimental conditions, had the least negative effect on predation efficiency across all prey items for both Mangrove Snappers and Blue Striped Grunts. *No light* conditions may reflect foraging behavior under natural nocturnal lighting. LEDs illuminate a broad range of wavelengths; they have the potential to affect a greater variety of biological responses that are sensitive to specific wavelengths (Davies and Smyth 2017). This could contribute to the predation efficiency of Mangrove Snapper being most affected by LED lighting overall. Nocturnal species may find themselves competing for resources with diurnal species where such interactions had previously not existed, and differences in the sensitivity of

animal visual systems to white LED light spectra could change the balance of species interactions (Davies and Smyth 2017). Blue Striped Grunts had a higher predation efficiency over Mangrove Snappers under all experimental conditions.

However, shrimp under LED light conditions seem to have been preyed upon most efficiently across all light intensities, which could show Grass Shrimp are preferred prey when these predators are given a choice. Becker et al. (2013) suggested that artificial light often associated with man-made structures has the potential to alter fish communities within urban estuarine ecosystems by creating optimal conditions for predators. Both Mangrove Snappers and Blue Striped Grunts seemed to prefer shrimp under most light conditions in the current study. Blue Striped Grunts have been observed foraging within sea grass beds after dusk, where Grass Shrimp are found (Burke 1995; Rooker et al. 1991; Hammerschlag 2009). Both seemed to hesitate in predation under higher levels of light intensities when offered any prey item in this experiment. The hesitation could be due to the costs of survival outweighing the energy gained (Fraser et al. 1997).

Knowledge of the ecological and economic values of estuarine and coastal ecosystems is essential, because many of these ecosystems are declining globally (Barbour and Adams 2015). Although studies have researched the effects of other anthropogenic aspects, investigations of how light affects the estuarine environment and its organisms is not as extensive. Garratt et al.'s (2019) study in the United Kingdom found that changes in the community composition, species richness and cumulative biomass of macroinvertebrates were related to the level of exposure to artificial light pollution from adjacent High Pressure Sodium promenade lighting with illuminances equivalent to residential side streets. In Florida, 80% of all commercially or recreationally targeted marine species depend on the mangrove environment during some stage

of their life cycle (Lewis et al. 1985). Mangroves and its inhabitants are very important for the health and growth of other marine habitats. Keeping the mangrove nurseries and habitats as natural as possible would benefit fisheries and other human-associated activities.

Many fishes shelter in the mangrove habitats by day and mostly forage in sea grass beds by night (Hammerschlag 2009; Rooker et al. 1991). Future coastal developments should consider the ecological impacts of lighting on adjacent aquatic environments. Becker et al. (2013) suggested minimizing lighting around coastal infrastructure and using red lights, which have limited penetration through water. Lighting regulations similar to sea turtle lighting restrictions from the Florida Fish and Wildlife Conservation Commission could be implemented. Shielded lights narrow the area affected, and using the lowest wattage and lumens needed for the application will also reduce potential negative effects. The current study showed that higher intensity lighting affects the behavior of marine species. Longer wavelength lights (red, orange, or amber) are also less disruptive to marine animals. As shown in this study, white lighting affects estuarian organisms' foraging behaviors. Predator and prey relationships are ecologically important. Human impacts reach into the night with artificial light along coastlines, which likely affect near-shore mangrove habitats and its organisms. With these experimental trials, artificial light was found to have effects on predation behaviors in these two estuarine fishes.

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