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Human Foot Traffic and its Effect on Limpkin (*Aramus guarana*) Foraging, Social Behavior, and
Population Density

Introduction

As the human population grows and previously natural areas become developed, human interactions with wildlife become increasingly common. Businesses and homes are commonly built near wildlife. Despite efforts to minimize effects of construction on native wildlife with methods like creating riparian zones or wildlife corridors, development often negatively impacts ecosystems (Brennen 2008). Studies on human development in natural habitats often focus on natural predators and how their populations will be affected by new infrastructure (Brennan 2008). Less commonly studied is the effect that human foot traffic will have on a species or an ecosystem.

Human-wildlife interactions is also a concern within protected areas, such as parks and nature reserves. In these protected areas people are often encouraged to interact with wildlife through activities like hiking, kayaking, photography, and camping. However, as the recreational activities become more and more common there may be negative effects to the populations in the recreation area such as habituation, increased flight behavior, and lower feeding efficiency (Samia et al. 2015, Arrietta et al. 2015). In common house sparrow (*Passer domesticus*), it was found that increased anthropogenic disturbance led to increased flushing due to lowered ability to detect predators in higher disturbed areas (Meillère et al. 2015). In the nightingales (*Luscinia megarhynchos*), increased background noise causes males to use more energy increasing the amplitude of their song (Brumm 2004). By increasing the time spent

flushing or vocalizing, the amount of time spent foraging or reproducing is reduced and can have negative effects on a population.

Constant recreational activities have dramatic effects on the way many species forage and behave. Coppes et al. (2017) found that red deer (*Cervus elaphus*) avoid areas that are frequented by human foot traffic potentially because they are unable to distinguish between hunters and hikers. Limiting an animal's range through human foot traffic can reduce their ability to find food and forage efficiently. The effect of human presence has also been studied in captive environments including zoos and sanctuaries (Shultz and Young 2018). Coyotes (*Canis latrans*) were found to spend the most time hiding when there were greater amounts of human foot traffic (Shultz and Young 2018). Translated to wild animals, this could mean that increased human foot traffic would result in reduced time spent foraging and lowered foraging efficiency.

It is important to understand the effects of foot traffic and recreation on birds. Birds play a critical role in their ecosystems as they disperse seeds, scavenge dead animals, consume insect pests, and fill many niches as predator and prey (Wiens 1992). Diverse communities of birds create and maintain healthy and attractive natural areas. A better understanding of how we affect bird presence and bird behavior will enable us to better maintain these habitats.

There are a variety of negative effects that human disturbance and recreation can have on bird populations. For example, the green heron (*Butorides virescen*), a wading bird, has reduced foraging efficiency when there is greater recreation traffic (Moore et al. 2016). Green herons spent the most time searching for prey and had the lowest capture success when human interaction was greatest (Moore et al. 2016). Various wading bird species have increased escape and avoidance behaviors in a state park that is frequented by kayakers and paddleboarders

(Arrieta et al. 2014). Given that birds wade in shallow waters to search for food, the authors inferred that this increased avoidance would lead to decreased foraging efficiency (Arrieta et al. 2014). Examples like these are not uncommon and most of the previously published scientific literature (Brumm 2004, Meillère et al. 2015, Coppes et al. 2017) reflects similar results; human disturbance through foot traffic or recreation decreases the health or energy efficiency of a population.

Occasionally, human development may benefit wildlife. For example, some insectivorous birds (Dubay et al. 2017) prefer disrupted areas, likely due to the exposed ground revealing insects. The European robin (*Erithacus rubecula*), an insectivore, follows large mammals, like people, who disturb the soil with their footsteps and expose potential prey (Dubay et al. 2017). Hyraxes (*Heterohyrax brucei* and *Procavia capensis johnstoni*) in Tanzania are also found to benefit from human presence. Increased foot traffic from tourism leads to fewer predators and increased prey availability. This benefit results in larger populations of hyraxes in these areas (Mbise et al. 2017).

Human disturbance has potentially benefited the limpkin (*Aramus guarana*), a wading bird native to Florida and South America, in their ability to find prey (Bravo et al. 2017). Limpkins are secretive birds that live near fresh bodies of water and feed on gastropods (Cottam 1936, Alexander and Hepp 2017). In 2011, the limpkin was listed as a species of concern by the Florida Fish and Wildlife Commission due to habitat loss (Alexander and Hepp 2017). Despite this, sightings of the bird were increasing in Central Florida (Alexander and Hepp 2017, *pers obs.* Alex Stark). It is possible that the development of wetland areas may have indirectly benefit limpkins by increasing prey availability. While untested, it is possible that the recent increase in limpkin sightings could be attributed to the increasing population of their main prey item, the

invasive island apple snail (*Pomacea maculata*). Originally from South America, the island apple snail is a textbook invasive species. They have very few native predators in Florida, they reproduce very quickly, and can survive temperature extremes (Smith et al. 2015). Development of ditches and drainage pipes has allowed the snails to spread quickly and vastly (Smith et al. 2015).

On the other hand, limpkins may have suffered negative consequences of human development and disturbance. The limpkin is commonly called the ‘crying bird’ because of its loud, scream-like vocalization. It is described as a a loud and unmistakable scream that occurs in a series of 4-10 that they emit in territorial displays (Bryan 2002). If human disturbance results in increased background noise, then limpkins may be forced to expend more energy defending their territory.

In Polk County, Florida, lakes are often gathering places for activities like hiking, biking, or water sports that foster interactions between the natural wildlife and recreationists (Polk County Water Atlas). These types of interactions often negatively impact natural feeding, social, and other natural behaviors in birds (Remancha et al 2016, Botsch et al. 2017, Moore et al. 2016). The limpkin’s shore habitat and proximity to recreation activities make it especially vulnerable to human interaction and disturbance.

Research on limpkins has been very limited and most studies have not examined the details of their behavior. Furthermore, it remains unknown what effect foot traffic has on the limpkin’s population densities and their foraging and social behavior. I aimed to examine the details of limpkin behavior in relation to human disturbance. I specifically examined the potential impact of human foot traffic on the population densities, foraging efficiency and social behavior of the limpkin at various lake sites in Polk County, FL. I hypothesized that 1) limpkin

densities would be higher at lake sites with higher amounts of foot traffic 2) food capture rates would be higher in lakes with higher foot traffic or greater development and 3) more time will be spent foraging and vocalizing at lake sites with a higher amounts of human foot traffic.

Methods

Field Sites

I chose ten field sites with watersheds from within Polk County, which varied in their level of human disturbance from foot traffic. I obtained permissions for each site through Florida Fish and Wildlife and Circle B Bar Reserve. Lakes predicted from previous observation to have high foot traffic (more than 1 person within 25m of the bird on average) include: Lake Morton, Lake Hollingsworth, Lake Mirror, Circle B Bar Reserve Heron Hide-Out and the park at Lake Parker. Lakes with low foot traffic (less than 1 person within 25m of the bird on average) include: Circle B Bar Reserve Alligator Alley, Lake Hunter, Lake Somerset, and lakeside at Lake Parker, Lake Wire. Each site was a diverse wetland or lake that was either accessible around the entire perimeter or had 1km of uninterrupted area that could be used as an alternative for transects and observation.

Estimating Human Disturbance

During each behavioral observation, at each 20-second interval, the number of people that passed within 25 meters of the focal bird was recorded. These data were averaged for the total behavioral observation time. Low disturbance lakes were classified as on average having less than 1 person within 25m of the focal bird, and high disturbance lakes are classified as having more than 1 person within 25m of the focal bird. The total number of humans observed

was divided by the number of 20 second intervals in the behavioral observation to determine the average number of human beings per observation (total # of humans/ # of intervals). Each site had 6-10 behavioral observations; the mean of human foot traffic for the whole field site was calculated using the human foot traffic averages for each behavioral observation.

Limpkin Population Survey

Limpkin (*Aramus guarana*) population estimates were completed at each of the field sites between April 2018 and February 2019. Transect lines were placed around the perimeter of the lakes, as limpkin are typically found foraging in the shallow waters along the edges of these areas. Ideally, the entire perimeter of the site was used for transect lines and the starting position was randomly generated. However, often times, the sites had residential areas that reached the edge of the water or the vegetation itself restricted the observer view and therefore these areas could not be used for surveying. In this case, 1km transects were used instead, in the available areas. Six transect walks were completed at each field site. For each limpkin encountered, the distance from the transect to the bird was measured using a Forest Pro rangefinder. The angle that the bird was from the transect were found using a compass and recorded. The GPS coordinates were also recorded for each siting of a limpkin. This data was used to create an ArcGIS map that depicts the density variance across the study area.

Behavioral Observations

Observations on limpkin foraging and social behaviors were conducted using 20-minute observation periods with 20-second intervals. Observations took place from September 2018 to February 2019. Each observation was completed between 8AM and 12PM as this time had the

most favorable weather for bird sightings (pers. obs. Alex Stark 2018). I created an ethogram (Table 1) that was used to define behaviors at each interval. At each interval, I recorded the state behavior of the limpkin (Table 1). All occurrences of event behaviors were recorded during the observation period. After observations, the proportion of time that was spent foraging and performing social interactions was calculated and compared between the lakes and human foot traffic data. Ten observations were completed at Lake Mirror, Lake Morton, Lake Hollingsworth, and the park at Lake Parker. Each of the other parks had between six and nine observations that will be used to complete behavioral data for that site.

The proportion of time spent performing each activity was calculated for each state behavior ($\# \text{ of occurrences} / \# \text{ of intervals}$). The average proportion of time spent in each behavior in each observation was used to determine the average proportion of time spent performing each behavior at each site (Table 4). For event behaviors, the average number of times per observation period that an event behavior occurred at each site was calculated ($\# \text{ of occurrences} / \# \text{ of 20 second intervals}$) (Table 5). The proportions of time were multiplied by 3 to indicate proportion of time per hour and the number of occurrences per observation was multiplied by 3 to indicate the average number of occurrences per hour.

Statistical Analysis

Population density data were analyzed using DISTANCE software to generate a population estimate of the limpkins (D) for each field site. Density of each population were compared to human foot traffic, using a Spearman's Rank Correlation. Proportions of time spent performing each state behavior were compared to human foot traffic at each site using a Spearman's Rank Correlation. Frequency of each event behavior was compared to the human foot traffic at each site using a Spearman's Rank Correlation. Frequency of prey capture and the proportion of time spent handling were also compared using a Spearman's Rank Correlation to analyze whether the data was providing logical results.

Table 1: Ethogram of limpkin states and events

| Category | State or Event | Action | Abb. | Description |
|---------------|----------------|--|------|---|
| Movement | State | Wading | WA | Walking through water with top of head pointed straight up and neck connection is between 0-90 degrees |
| | State | Active State | AS | Walking through water with head directed towards water, between 90-180 degrees on neck connection, with eyes directed towards the water |
| | State | Walking | WAL | Subject makes forward progress with feet in contact with ground, not carrying anything, not touching water |
| | State | Stationary | ST | body and head completely still for at least 5 seconds |
| Flying | State | Flying | FL | Flying, wings are moving, and entire bird is suspended in air |
| | Event | Flying with Shell | FWS | Takes flight with shell in beak |
| | Event | Flying without Shell | FWS | Takes flight with no shell in beak |
| Foraging | State | Handling | HA | Manipulation of prey item through physical contact with feet of beak |
| | Event | Searching | SE | Stabbing of beak into sediment one or more times in rapid succession |
| | Event | Walks with Shell | WWS | Moves more than 5m with prey in mouth and feet in contact with ground |
| | Event | Spearing | SP | Use of beak to spear through operculum or shell or through prey item |
| | Event | Catches Prey | CP | Bird removes prey item from water using beak |
| Social | Events | Social Young | | Within 1ft of immature limpkin |
| | Events | Social Adult | INA | Within 3ft of another adult limpkin |
| | Event | Feeds Young | FY | food is transferred from beak of adult limpkin to the mouth of an immature limpkin |
| Vocalization | Event | "Scream" Vocalization (Cornell Lab of Ornithology) | SV | makes scream-like vocalization with beak open more than one inch |
| | Event | Quiet Vocalization | QV | makes low-intensity vocalization with beak open less than an inch |
| Self-Directed | State | Preening | PR | Moves beak repeatedly through feathers for more than 3 seconds |
| | Event | Touches Feathers | TF | Briefly touches feathers for less than 3 seconds with beak or feet |
| | State | Not Visible | NV | Subject moves out of sight of observer |
| Other | State | Other | OT | Bird is engaged in activity not described in this ethogram |

Results

I completed a total of 60 transect walks, six walks at each of the field sites, in order to complete density estimates. I also completed at least six observations of limpkin behavior at each site (mean = 8.5 observations; range = 6 – 10 observations) for a total of 84 observation periods (28 total hours of observations).

Human Disturbance

People were within 25 m of the limpkins almost once per observation period (mean = 0.846 people/observation period \pm 0.59). The total number of people present per observations period was highly variable. The lake with the greatest amount of human foot traffic is Lake Hollingsworth (mean = 1.750 \pm .57 people / observation period), and the lake with the least amount of human foot traffic is Lake Somerset (mean = 0.073 people / observation period \pm .119). During five of the six observation periods at Lake Somerset, there was no foot traffic recorded.

Table 2. The average human disturbance for each lake site.

| Lake | Mean Number of People /Observation Period |
|-----------------|---|
| Alligator Alley | 1.293 |
| Heron hideout | 1.312 |
| Hollingsworth | 1.750 |
| Hunter | 0.153 |
| Mirror | 1.401 |
| Morton | 0.702 |
| Parker Park | 0.721 |
| Parker Road | 0.167 |
| Somerset | 0.073 |
| Wire | 0.805 |

Density Estimates

The mean density estimate for limpkins in several lake sites within Polk County is 0.316 birds/ha. The output suggest that we should be 95% confident that the true density of limpkins is between 0.1784 and 0.8746 birds/ha. The density of limpkins at Lake Morton ($D = 1.07$ limpkins/ha) was more than twice that of any of the other lakes surveyed (Table 3). Heron Hideout ($D = 0.483$ limpkins/ha), Lake Hollingsworth, ($D = 0.422$ limpkins/ha), Parker Park ($D = 0.426$ limpkins/ha), and Hunter ($D = 0.356$) also had higher than average density estimates. Lake Somerset had the lowest density of limpkins ($D = 0.033$ limpkins/ha). Alligator Alley ($D = 0.225$ limpkins/ha), Parker Road ($D = 0.132$ limpkin/ha), Lake Wire ($D = 0.182$), and Lake Mirror ($D = 0.282$) each had lower than average densities of limpkins. Due to the relatively few limpkins that were spotted during my transect walks, all of the lakes except for Lake Morton and Lake Parker were deemed to be data deficient by the DISTANCE software. Therefore, these estimates of density must be considered cautiously.

Table 3. The densities and the lower and upper 95% confidence intervals for each lake site.

| Lake | D (Density Estimate) | Lower Confidence | Upper Confidence |
|--------------------|-------------------------------------|-----------------------------|-----------------------------|
| Alligator Alley | 0.225 | 0.046 | 1.091 |
| Heron Hideout | 0.483 | 0.201 | 1.161 |
| Hollingsworth | 0.422 | 0.174 | 1.022 |
| Hunter | 0.356 | 0.088 | 1.435 |
| Mirror | 0.285 | 0.175 | 0.463 |
| Morton | 1.07 | 0.748 | 1.533 |
| Parker Park | 0.426 | 0.253 | 0.718 |
| Parker Road | 0.132 | 0.027 | 0.634 |
| Somerset | 0.033 | 0.006 | 0.19 |
| Wire | 0.182 | 0.066 | 0.499 |

While the recorded GPS coordinates did not generate the true density at each specific site, it demonstrates the dramatic difference in the number of sightings at each location. The lake with the highest abundance of sightings was Lake Morton (n = 41 limpkin sightings). Lakes with relatively few sightings of limpkins included Lake Parker and Lake Somerset (n = 2 limpkin sightings).

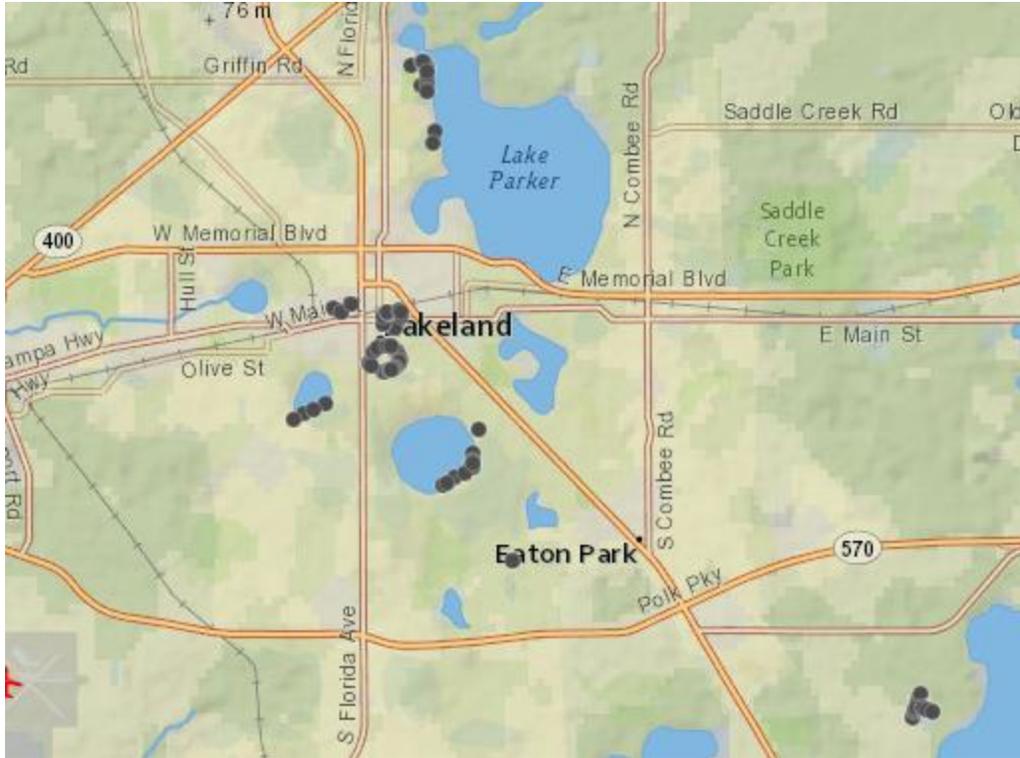


Figure 1: Map of entire research field, each black circle indicates the location of a limpkin sighting.

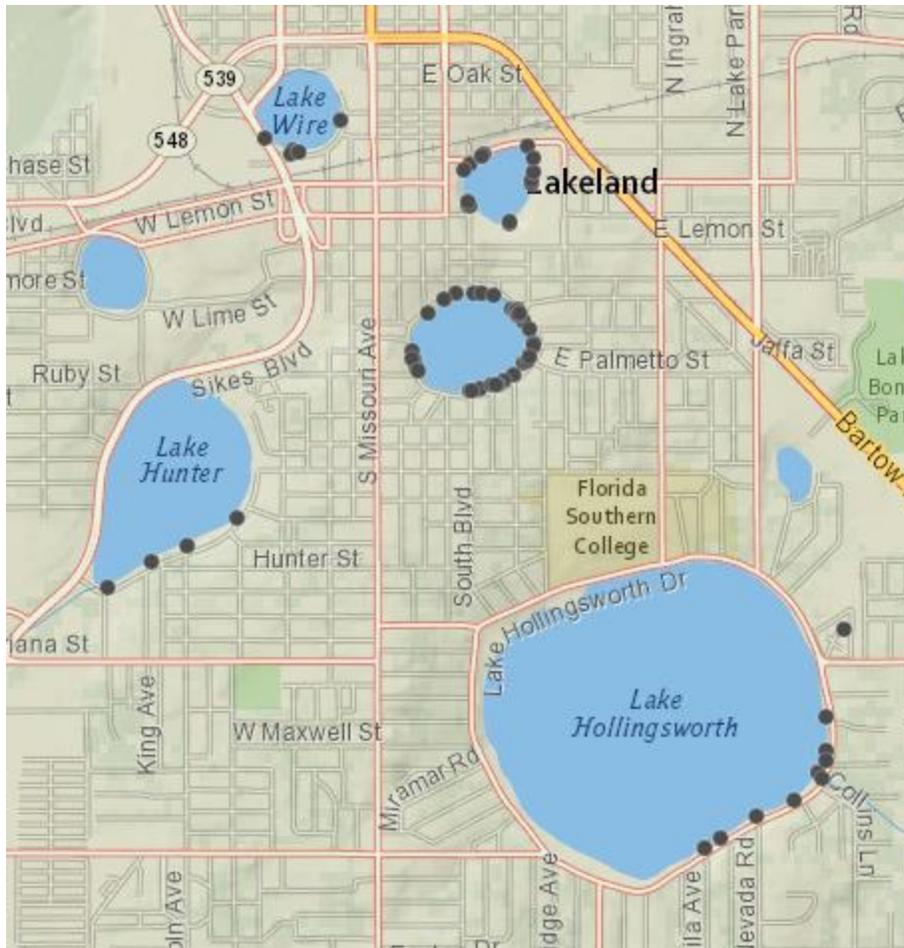


Figure 2: Map of field sites in downtown and suburban Lakeland, FL. From left to right: Lake Hunter, Lake Wire, Lake Morton, Lake Mirror, Lake Hollingsworth.



Figure 3: Map of field sites at Lake Parker. Northern sightings are in Lake Parker Park field site, two southern sightings were along the transect on Lake Parker road.

Limpkin Behavior

Activity Budget

The limpkins spent the majority of their time either in a stationary position (mean = 34.9 ± 12.2% of time) or in an active state searching for prey (mean = 30.0 ± 12.8% of time) (Table 4). When I observed feeding behavior, I only saw the limpkins handling the invasive island apple snail (*Pomacea maculata*). When limpkins were found stationary at the beginning of the observation period, they tended to stay in stationary positions for a majority of an observation period. It also was common to see a focal bird in an alert state for most of or an entire observation period. Active states included wading through the water with the head and eyes pointed downwards as well as repeated stabbing of the sediment to locate prey. This behavior is typically only interrupted as prey capture (handling) or relocation to another foraging site (flying or walking). Limpkins spent 6.0% of their time handling food (usually the invasive island apple snail) (mean = 6.1 ± 4.0% of time). After capturing a prey item, a limpkin would most often carry the prey to a hard surface, the bank, or an accumulation of sediment and begin to break open the shell with its beak. To do so they spear the shell with their beak until the operculum breaks open and they can extract the meat inside the shell. If they cannot break open the operculum, occasionally, they will just break through the shell with their beak instead. Flying was uncommon (mean = 1.4 ± 1.9% of time), but tended to occur when other birds entered the searching area or if particularly loud groups of humans walked near the focal bird.

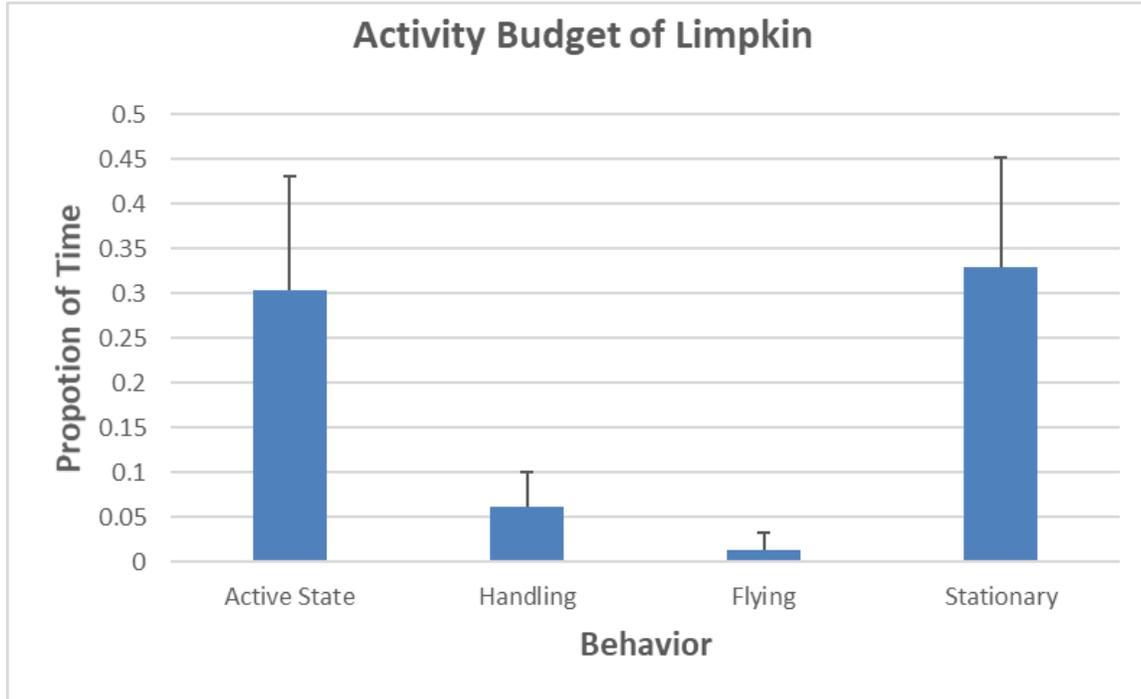


Figure 4. Activity budgets of limpkins at various lake sites in Polk County, FL. State behaviors walking, preening, wading, and other are not included.

Event Behaviors

Searching behavior, the stabbing of the beak repeatedly into the sediment, was extremely common at each of the sites (mean = 48.63 ± 23.67 / hr). It often occurred while the limpkin was active; the behavior would be repeated every few seconds. Spearing behavior only occurred after the capture of large apple snails (*Pomacea maculata*) (mean = 3.33 ± 3.48 / hr). The limpkins would carry the snail to a hard surface and repeatedly stab the operculum with its beak until the shell broke open. Then, limpkins would typically take the exposed body of the snail and shake the shell until the meat comes loose for ingestion. If the prey item was small, such as

a juvenile snail, the bird simply crushed the item in its beak without stabbing it first. On average, limpkins captured several prey items per hour (mean = 2.80 ± 2.44 captures / hr).

Vocalization behavior was highly variable. I was able to distinguish two general types of vocalizations, quiet vocalizations and loud, scream-like vocalizations. The quiet vocalizations were often emitted when other limpkins were nearby (< 5 m of the focal bird). These vocalizations consisted of low intensity calls that were short in duration ((mean = 3.4 ± 3.09 / hr). The quiet vocalizations were emitted every several seconds for the entire observation period.

The scream vocalization, a distinctive intense cry-like call of the limpkin was most often emitted when limpkins were alone (mean = 2.62 ± 2.69 /hr). Sometimes this scream occurred shortly after I heard a scream call in the distance. During multiple observations, the scream vocalization preceded a flight response. The vocalization was also heard when a limpkin entered an area already occupied by another limpkin. Both the 'resident' and 'incoming' limpkin were noted to emit these scream calls. After these vocal interactions, one of the two limpkins usually flew or walked away.

Table 4. Limpkin foraging behavior and vocal communication at each lake site.

| | <i>Rates of Behavior (per hour)</i> | | | | |
|-----------------|-------------------------------------|-----------------|---------------------|----------------------------|-----------------------------|
| Lake | Searching | Spearing | Prey Capture | Quiet Vocalizations | Scream Vocalizations |
| Alligator Alley | 19.71 | 0.000 | 0.43 | 1.71 | 5.57 |
| Heron hideout | 90.00 | 4.33 | 4.67 | 1.67 | 1.67 |
| Parker road | 39.43 | 1.29 | 0.86 | 7.29 | 6.43 |
| Parker park | 77.70 | 4.50 | 5.10 | 1.20 | 1.80 |
| Somerset | 52.50 | 0.75 | 1.13 | 0.75 | 0.75 |
| Hunter | 53.00 | 10.00 | 2.00 | 1.50 | 0.50 |
| Wire | 44.14 | 1.29 | 8.14 | 4.29 | 0.43 |
| Hollingsworth | 62.70 | 8.40 | 2.10 | 3.60 | 5.40 |
| Mirror | 28.80 | 2.40 | 2.40 | 10.20 | 1.20 |
| Morton | 18.30 | 0.30 | 1.20 | 1.80 | 2.40 |
| Overall Mean | 48.63 | 3.33 | 2.80 | 3.40 | 2.62 |

Impacts of Human Disturbance

There is no relationship between human foot traffic and the density of limpkins across the various lake sites ($n = 10$, $r_s = .382$, $p > 0.05$). There were also no significant relationship between the amount of human foot traffic and the amount of prey captured, or time spent searching, or time spent vocalizing. There is a significant positive relationship between the amount of human foot traffic and the time limpkins spent handling food ($n = 10$ lakes, $r_s = 0.648$, $p = 0.043$). Often, after a limpkin captures a prey item, it carries the food item to a nearby river bank. These areas usually contain a walking path with regular human foot traffic. Handling time appeared to increase when limpkins that carried food items changed directions and ultimately moved away from river banks occupied by people.

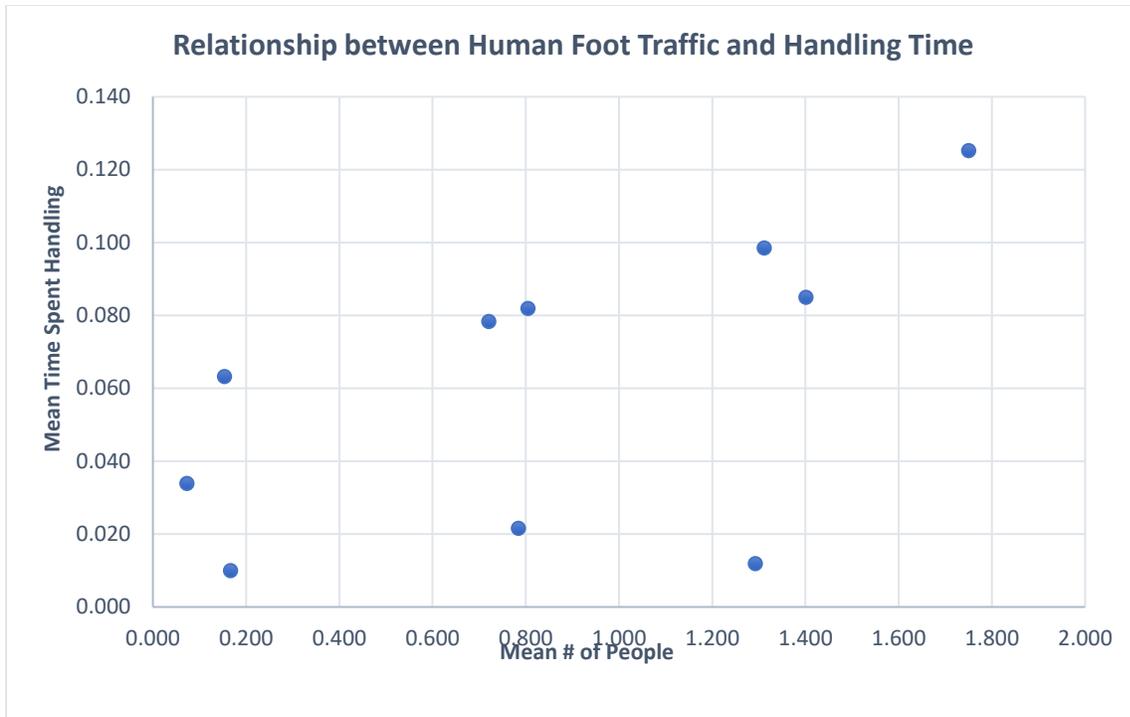


Figure 5. Relationship between human foot traffic (mean number of people present during each sampling point) and the mean proportion of time limpkins spent handling prey at each site.

As expected, the capture rate was also related to handling time ($n = 10$, $r = 0.758$, $p = 0.011$). In other words, limpkins spend more time handling food at lake sites in which they captured the most food.

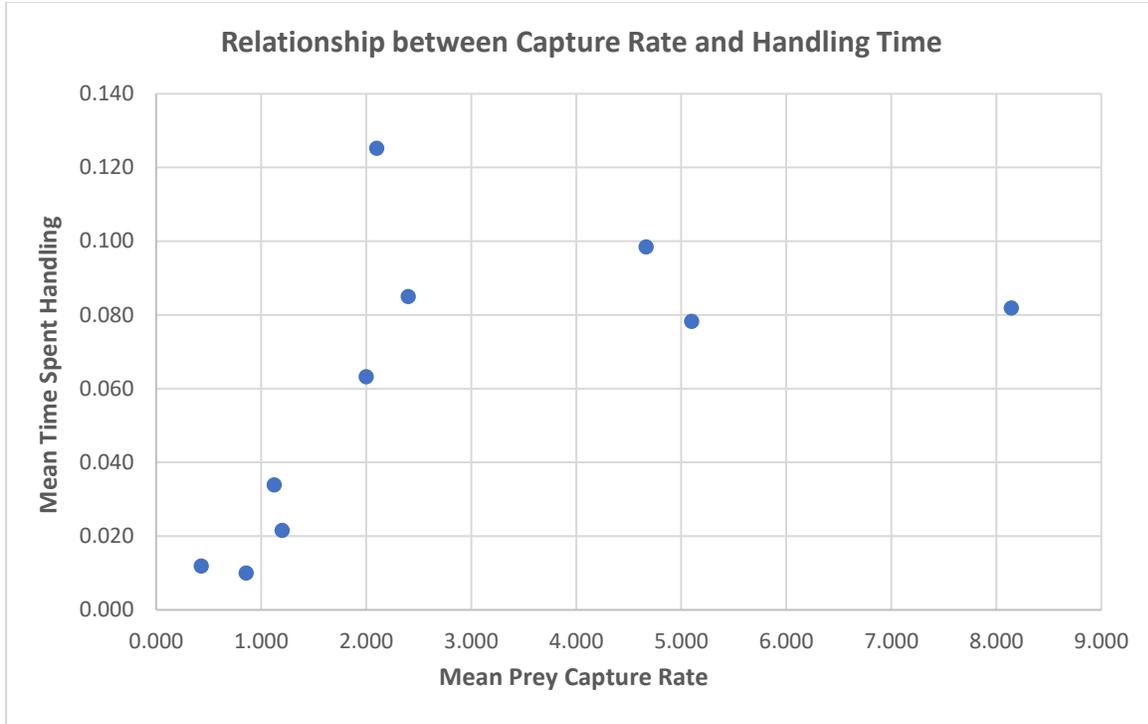


Figure 6. Relationship between prey capture rate (mean number of prey captured at each site) and the mean proportion of time s=limpkins spent handling prey at each site.

Discussion

Human foot traffic as well as limpkins (*Aramus guarana*) behavior and density were variable at each of the 10 surveyed sites. Lake Hollingworth, a popular lake for recreation, had the highest foot traffic ($x = 1.750$ people/ observation period) while other lakes with less opportunity for recreation, such as Lake Somerset, had lower human foot traffic ($x = .073$ people/ observation period). Limpkins were observed at each site; Lake Morton has the highest density ($D = 1.07$ limpkins/ha) and Lake Somerset had the lowest density ($D = .033$ limpkins/ha). Behavior was also variable at each of the sites; no limpkin behavioral observation was the same. The most common behaviors observed were continuous stabbing of the bill into the sediment in search of food (searching) or no motion at all. However, it was not uncommon to observe a limpkin feeding or vocalizing during an observation as well.

Effect of Human Disturbance on Behavior

Human disturbance negatively affects the ability of animals to forage successfully. When disturbed, animals increase the amount of time they spend being vigilant (Li et al. 2015, Moore et al. 2016). In this study, there was no relationship found between the amount of human foot traffic and the time limpkins spent actively searching for food, wading through the water with the head pointed downward, or repeatedly stabbing the sediment. On the other hand, there was a significant positive relationship found between the amount of human foot traffic and the time that limpkins spent handling or manipulating prey items.

After a limpkin captured a prey item (typically an island apple snail), it would carry that item to the nearest solid surface to break open the shell. This surface normally was the trail where pedestrians walk. When limpkins initially attempted to carry snails to the trail when

pedestrians were present, they would change directions and move away from the area. This movement and hesitation to approach an area increases the amount of time that the limpkin is handling prey. The longer that prey are handled, the greater the risk of dropping them or having them stolen through aggressive interaction (Johnson et al. 2001); ultimately, foraging efficiency is decreased.

Green herons (*Butorides virescens*) are also wading birds that forage in shallow fresh water environments. Green herons have higher levels of foraging efficiency (number of captures/number of strikes) in areas with lower levels of human foot and recreation traffic eg. kayaking, boating, and swimming (Moore et al. 2016). Wintering hooded cranes spent more time being vigilant in highly disturbed rice patty fields compared to natural wetland areas (Li et al. 2015). This increased amount of vigilance behavior reduced their foraging efficiency by increasing the amount of interruptions during foraging and reducing the time spent searching for food.

Similar to these examples, disturbance from human foot traffic has a negative effect on the foraging efficiency of the limpkin due to distracted and extra-vigilant foraging behaviors and should be considered when managing wetland habitats.

Limpkin Behaviors

Details of limpkin behavior has largely remained undescribed. The little that has been reported, emphasized prey choice, brief descriptions of foraging behaviors, and response to vocalizations (Cottam 1936, Marion et al. 1981, Bennets and Drietz 1997), but did not examine specifically how the limpkin forages or its vocalizations in terms of natural behavior. This study observes specific behaviors of the limpkin: searching for prey, spearing shells, prey capture, prey

handling, scream vocalizations, and quiet vocalizations. Describing the basic foraging and vocalization behaviors will be important in understanding their population and how to effectively manage it.

Foraging

Previous descriptions of limpkin foraging behavior mention the repeated stabbing on the long, curved beak into the sediment, often with their full head being submerged in deeper water (Bennetts and Drietz 1997, pers. obs. Alex Stark 2018). This activity takes up a large portion of the limpkins time, 30% on average. They also describe the spearing behavior used to break open the operculum of a snail shell (Collett 1977, Bennetts and Drietz 1997). This behavior is often preceded by manipulation and movement of the prey item using their beak (pers. obs. Alex Stark 2018). They will carry their prey to a hard surface to allow for effective spearing behavior and will typically move away from any other conspecifics (pers. obs. Alex Stark 2018). Movement away from conspecifics will occur as walking or as flying/flushing behavior (pers. obs. Alex Stark 2018).

A large portion of the limpkins time is spent searching for prey and this behavior may be affected by human disturbance and development. While, it was not found in this study that time spent actively searching for prey was related to the amount of human foot traffic at each site, time spent searching is likely related to the amount of prey that is available. . In Florida and Georgia habitats, limpkins are often found in locations with easier access to their main prey source for the area, the invasive island apple snail, *Pomacea maculata* (Marzolf et al. 2019, pers. obs Alexandra Stark 2018). *Pomacea maculata*, the main prey item of the limpkin, are often more populous in lakes and

streams with high development or connectivity (Smith et al. 2015). In highly developed areas, such as Lake Mirror, Lake Parker Park, Lake Wire, and Heron Hideout there is a higher than the average prey capture recorded. In the downtown Lakeland area, Lake Mirror is surrounded by concrete with pink island apple snail eggs lining the edges of the water. In suburban areas, Lake Wire and Lake Parker have concrete structures connecting them to other lakes and habitats, potentially providing invasive snails an entry point (Smith et al. 2015). These drain pipes and the plant life in the water have pink island apple snail eggs, indicating a high availability of prey for the limpkin (Marzolf 2019). Heron Hideout and Alligator Alley are located on the same body of water, but Heron Hideout has multiple drainage systems while Alligator Alley has no visible drainage areas. Heron Hideout had the largest amount of prey capture, potentially due to the proximity to drainage areas.

Other factors, like human provisioning, may also be impacting the rate of prey capture in limpkins. Suburban lakes, Morton and Hollingsworth, are also in developed areas but have below average capture rates. As a result of human provisioning, these lakes have very large bird populations. The limpkins may have increased competition for territory in these lakes due to increased populations of other bird species (Orians and Willson 1964). Unnatural feeding of birds increases intraspecific aggression and increases population size (Orams 2002). Although limpkins were not observed feeding on bird seed or bread, they may have allocated more energy toward territoriality if there is a large amount of heterospecific competition for space (Orians and Willson 1964). I did observe limpkins become startled after interactions with nearby birds. This behavior included the lifting of wings, quick jumping, and often relocation of the focal limpkin.

Future studies should examine the effects of this interspecific competition on limpkin foraging behavior.

Vocalization

The limpkin is often referred to as ‘the crying bird’ due to its loud, scream like vocalization (Cornell Lab of Ornithology). This vocalization often occurs after hearing a conspecific call in the distance. Researchers have used this response to obtain recordings of the call and to estimate densities (Marion et al. 1981). This attraction to the call may mean that this is a familial vocalization used to maintain a connection with family members (Marion et al. 1981). However, this vocalization is also observed in this study when a limpkin enters another limpkin’s territory.

Limpkins also produces a low intensity call that is short in duration (*pers. obs* Alex Stark 2018). This call was typically emitted while other limpkins (often dependent young) were within 5 meters of the focal bird (*pers. obs.* Alex Stark). To my knowledge, this call has not been previously described in a peer-reviewed scientific publication. It is possible that this vocalization is used as a contact call during parent-offspring interactions, as it was observed being emitted from an adult with several juveniles nearby. Juvenile limpkins also emitted this call while in close association with a parent. This low intensity vocalization was also emitted by a solitary limpkin who used the call for the entire observation period, suggesting that the call may either be directly related to arousal. This call may have been a distress call, however, the bird did not appear injured.

Limpkin Density

Previous studies have struggled to estimate the density of the limpkin due to its secretive and solitary nature (Alexander and Hepp 2014). Densities have been estimated using playback vocalizations as well as point locations (Marion et al 1981, Alexander and Hepp 2014). Playback vocalizations successfully brought limpkins to the sound of the calls. However, it can only be used to generate density estimates when able to record the distance the limpkin came from when responding to the call (Marion et al. 1981). This would have been difficult to do in the chosen field sites due to thick tree coverage. Point locations were able to generate successful density estimates however in this study transects were chosen to allow more coverage and varied views of the vegetation where limpkins often reside (Alexander and Hepp 2014). Previous studies have found limpkin densities to be correlated with moderate vegetation cover, likely because this is the preferred habitat of the apple snail, their main food source (Alexander and Hepp 2014).

The estimates of density – seasonal influences

Transects were completed at various times of the year, taking place in the summer, fall, and winter and this change in season may have affected the accuracy of the density estimates. This was done to obtain data that was spread throughout the year, not just their most popular season. However, transects at Lake Parker Road, Alligator Alley, and Heron Hideout were completed in late winter/ early spring and Lake Morton and Lake Hollingsworth were completed almost entirely in late summer. These seasonal changes may have influenced the density of birds at the sites. Late summer in Florida is much warmer than spring, fall and winter; this often causes birds to stay in their nests to avoid the extreme heat (Robbins 1984). The temperature also varied greatly throughout the day, so the timing of the transect walks was planned to be

balanced across mornings and afternoons. However, many transects during the summer took place between 10 AM- 3 PM due to the availability of the observer. In Florida, this is the hottest part of the day and the extreme temperature may have affected the activity of the birds and their visibility to the observer (Robbins 1984). During summer months, limpkins were more abundant during the cooler hours, normally before 8 AM, before the sun has risen, and after 6 PM, when the sun starts to set (pers. Observation Alex Stark). By completing transects mainly during the heat of the day, the density estimates may be slightly lower than the true density.

DISTANCE Software

The secretive and solitary nature of the limpkin also led to a low amount of limpkin sightings at each sight. The birds hide in the vegetation and are difficult to spot during observations despite observational practice (Alexander and Hepp 2014). The DISTANCE software used to generate the estimates is typically used to generate density estimates for organisms with more frequent sightings. Because the limpkins sightings were lower than the software recommended, this likely impacted the accuracy of the density estimates. A study estimating gopher tortoise densities had a similar issue; they would often have too few sightings to accurately estimate population density (Stober et al. 2017). They recommend counting other indicators of the gopher tortoise's presence, like burrows (Stober et al. 2017). This suggestion could be applied to limpkins as well. It may be beneficial in the future to count shells that indicate limpkin presence or nests in locations with known limpkin populations.

Conclusion

The limpkin vocal repertoire and its behaviors have only been vaguely described. While this study described the limpkins vocalizations and situations they occurred in, future research should examine in greater detail the limpkin vocalizations to better understand the purpose of the different calls. This study also includes detailed descriptions of limpkin foraging behavior. I found that there was no relationship between human foot traffic and density, active searching behavior, spearing behavior, prey capture, or vocalizations. As it was not analyzed in this study, it would be beneficial to look further into the effects of seasonality and time of day on limpkin behavior and density as this variable was not addressed in this study.

The effects of development and disturbance on limpkin behavior has not been well documented in previous literature. Through direct observations and quantitative analyses, this study has demonstrated that human disturbance negatively affects the foraging efficiency of the limpkin by increasing the amount of time that limpkin spend handling their food. By spending more time manipulating their food the limpkin increases their chance of dropping their prey or losing it to aggressive interactions. I recommend that this impact should be considered when managing wetland habitats and the limpkin population.

Management of trails or walking paths can reduce the interaction between wildlife and human disturbance (Coppes and Braunisch 2013). In locations with narrow trails, widening the berm area on the left and right of the walking trail can increase the distance from a human to a limpkin. By increasing this distance, the limpkin has more space to approach the hard surface of the berm for extraction of food from a snail shell. To prevent human foot traffic in the berm area, use of non-invasive barriers (ropes or signs) may be successful in preventing interaction between humans and wildlife. Overall, efforts should be made reduce the interaction between

humans and the limpkin to reduce the effect human disturbance has on the foraging efficiency of the limpkin.

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