Using Camera Trapping to Evaluate the Diel and Seasonal Activity Patterns of the Critically Endangered Saint Lucia Whiptail (Cnemidophorus vanzoi)

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Using Camera Trapping to Evaluate the Diel and Seasonal Activity Patterns of the Critically Endangered Saint Lucia Whiptail (*Cnemidophorus vanzoi*)

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Abstract

Insular endemic reptiles are disproportionately represented on lists of threatened and endangered species and are, therefore, of great conservation interest and concern. Conservationists are constantly seeking strategies and technologies to maximize the impacts of their efforts. Camera overhead augmented temperature (COAT) camera trapping has recently emerged as a means by which to monitor reptiles. I deployed 12 COAT camera trap stations on Maria Major, Saint Lucia, West Indies to determine their efficacy in monitoring the Critically Endangered Saint Lucia whiptail (*Cnemidophorus vanzoi*) and the Critically Endangered Saint Lucia racer (*Erythrolamprus ornatus*), and to evaluate their diel and seasonal activity patterns. The camera station design successfully captured many images of the whiptail but failed to detect the racer.

Analysis of the activity patterns of the Saint Lucia whiptail revealed a unimodal diel activity pattern with a peak in activity occurring in late morning. This pattern was found to be weaker in the rainy season than the dry season when the peak activity period lasted for three hours rather than one. Diel activity in the rainy season also shifted one hour later in the day. The Saint Lucia whiptail exhibited increased activity in the rainy season as opposed to the dry season. Interestingly, adult male whiptails were found to be equally active between seasons (0.23 detections/camera-day) while the combined grouping of female and juvenile whiptails exhibited a 150% increase in activity in the rainy season (dry season detection rate: 0.06 detections/camera-day; rainy season: 0.15 detections/camera-day). This may possibly be explained by estivation or reproductive

strategy, but further research is required to determine the causality of the seasonal variance in female and juvenile activity.

Various multiple linear regression analyses were performed to evaluate the effect of environmental variables on whiptail activity. In general, abiotic factors that have an immediate cooling effect, including precipitation, cloud cover, and wind speed, were shown to have a significant negative effect on whiptail activity while abiotic factors that have a warming effect, including high temperature and soil temperature, were shown to have a significant positive effect on whiptail activity. As an ectotherm, the Saint Lucia whiptail requires external sources of heat to regulate its body temperature, so these relationships make intuitive sense; however, the global model only accounted for 21% of the variance in whiptail activity. An interesting nuance to the hydroregulatory effects of moisture on whiptail activity is that precipitation was negatively correlated with activity while volumetric soil water was positively correlated with activity, so, while the short-term effect of rainfall reduced activity, the medium-term effect of rainfall increased activity. Future research is required to further explain how environmental variables influence whiptail activity. One key metric to be included in future research is insect abundance.

This camera trapping methodology proved to be successful at capturing data on the Saint Lucia whiptail and could be used by conservationists to monitor the population trend of the species in subsequent years. Alternative camera trapping methods should be tested to find a more suitable methodology to monitor the Saint Lucia racer.

Dedication

To my mother, whose unwavering support has been the cornerstone of my academic journey. From the early days of volunteering in my classrooms and helping with my homework to the past several months where you have welcomed me home to write this thesis, you have always been there for me. Thank you for letting me turn the kitchen table into my office during the holidays, refilling my coffee cup whenever it ran dry, and making sure there was always a fresh loaf of banana bread or batch of gumdrop cookies to pick me up throughout the day.

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Secondly, I would like to thank all the amazing Saint Lucians who made this research possible. Pius Haynes, thank you for securing the research permit despite the challenging timeline. I would not have made it out of the airport without you. Saphira Hunt, your guidance, coordination, and reliability were invaluable to this effort. Your keen eye, light feet, and quick hands when you jumped into action to catch a racer during camera station installation was a sight to behold. Not even in my wildest dreams did I expect to see a racer in person. Thank you. To the Muscle Team: Melvin Eugene and Benjamine Sealys, by no right should we have been able to install all 12 camera stations in just four days in the field. The equipment was heavy, the holes and trenches were deep, and the soil was root and rock. I raise a Piton to you. Cheers. To the Technology Team: Jeanette Victor, Aloysius Charles, Stephen Lesmond, Bertrand Eliza, Saphira, Melvin, and Benjamine, this research would not have been possible without your hard work. Thank you for noticing the small things, like wisping strands of silt fence plastic or fast-growing vines, and preventing them from becoming bigger problems. Your perception and initiative made this endeavor a success.

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Chapter I

Introduction

Insular endemic reptiles are disproportionately represented on lists of threatened and endangered species and are therefore of great conservation interest and concern (Powell & Henderson, 2005). Many endemic reptiles of the Lesser Antilles have restricted ranges rendering them highly susceptible to island extirpations and extinctions. The distributions of these species tend to be well known, but population statuses and ecologies are often less well documented (Williams et al., 2016). These more detailed evaluations tend to require intensive effort and force practitioners to make difficult decisions about how to prioritize their efforts most effectively. As such, governments, conservation organizations, and partners are constantly seeking strategies and technologies to maximize the impacts of their conservation actions (Mace et al., 2007). This conservation challenge is perhaps best displayed in the Lesser Antilles on Maria Major, a 0.1 km^2 islet off the southeastern coast of Saint Lucia, West Indies.

Maria Major is protected as a nature reserve and of all protected areas in Saint Lucia, it contains the most biodiversity of global importance, notably the Critically Endangered Saint Lucia whiptail and the Critically Endangered Saint Lucia racer. The whiptail has received the greater share of conservation attention. Prior to conservation efforts, the whiptail was only known to occur on Maria Major and Maria Minor. In recent decades, through conservationists' efforts, whiptail populations have been successfully established on two additional offshore islands and its population status is increasing (Daltry, 2009). The racer, on the other hand, has received less attention. The racer occurs only on Maria Major and the last published survey estimated its population at less than 50 mature individuals. That study also called for further research and conservation efforts to save the species from extinction (Williams et al., 2016).

In recent years, camera trapping has emerged as a viable means of surveying diurnal reptiles (Welbourne, 2013; Welbourne et al., 2015, 2017; Adams et al., 2017; Neuharth et al., 2020). Camera trapping is now a cornerstone of global biodiversity monitoring allowing for the assessment of species distributions, abundance, behavior, ecology, and community structure. Camera overhead augmented temperature (COAT) camera trapping is a newly developed camera trapping methodology designed specifically to target diurnal terrestrial reptiles (Welbourne et al., 2017). Standardized surveying protocols allow practitioners to obtain replicable abundance data on rare and elusive species and can be used to monitor populations through time (Burton et al., 2015). Compared to traditional snake survey techniques, camera trapping has been found to be as or more effective (Richardson, 2014, 2017; Welbourne, 2016), safer (Richardson et al., 2017), and more cost-effective (Welbourne et al., 2020). There are no records of camera trapping being deployed on Maria Major in the literature.

Research Significance and Objectives

My research was intended to evaluate a population monitoring protocol for the Saint Lucia whiptail and the Saint Lucia racer that will allow conservationists to monitor their population trends through time in a simple, replicable, efficient, and cost-effective manner. Secondly, I aimed to understand the diel and seasonal activity patterns of both species and evaluate how environmental variables influence these patterns.

The objectives of my research were:

- To show that COAT camera trapping can be used to capture images of the Saint Lucia whiptail and the Saint Lucia racer
- To describe the diel and seasonal activity patterns of these species
- To evaluate how environmental variables influence these patterns
- To recommend a camera trapping population monitoring protocol based on these activity patterns to Saint Lucia Forestry Department

Background

The Caribbean ecoregion represents one of the world's great biodiversity hotspots (Myers et al., 2000). While only accounting for 0.15% of the world's landmass, the region contains at least 602 reptilian species, 82% of which are endemic to the region, many to a single island. Since 2010, at least 39 new species of Caribbean reptiles have been described. Of the roughly 400 species to be formally assessed for listing on the IUCN Red List of Threatened Species, 184 species are globally threatened: 72 Critically Endangered, 80 Endangered, and 32 Vulnerable; and 11 species have gone extinct (Wege et al., 2010; Caribherp, 2023). The Lesser Antilles, a group of 33 smaller Caribbean islands situated between Puerto Rico and the South American mainland, contains 128 species of reptiles, 74% of which are endemic. Of these 128 species, 24 (18.75%) are Critically Endangered, nine (7.03%) are Endangered, seven (5.47%) are Vulnerable, seven (5.47%) are Near Threatened, nine (7.03%) are Extinct, and 51(39.84%) are Not Assessed/Data Deficient. Only 21 Lesser Antillean reptiles (16.41%) are not at risk of extinction (Caribherp, 2023).

The factors contributing to declines in Lesser Antillean wildlife populations are human-mediated and include habitat degradation, commercial exploitation, and, most significantly for native reptile populations, the introduction of alien invasive species. Small Asian mongoose, house cats, black rats, Norway rats, pigs, and goats were all introduced to the Lesser Antilles after European colonization. Goats degrade habitat through browsing, pigs prey on reptiles and destroy native vegetation by rooting, black rats and Norway rats prey on small reptiles and compete with larger reptiles for food resources, and house cats are the most effective predator of nocturnal reptilians. But the impact of the small Asian mongoose has been felt most severely (Tolson & Henderson, 2006).

Extinction and Conservation of Lesser Antillean Reptile Species

The small Asian mongoose was introduced to many regions around the world in the late 19th and early 20th centuries. As efficient ground-dwelling, diurnal carnivores, they were brought to the Caribbean between 1870 and 1872 for the purpose of controlling invasive rats in sugar cane plantations and to eradicate venomous snakes (Louppe et al., 2020). They proceeded to cause multiple extirpations, extinctions, and/or dramatic range reductions of many native Lesser Antillean reptiles (Henderson & Powell, 2004).

Ground-dwelling, diurnal reptiles in the genera *Alsophis*, *Ameiva*, and *Erythrolamprus* were particularly hard hit. *A. rufiventris*, *A. antiguae*, *A. antillensis*, *E. cursor*, and *Clelia clelia* have been extirpated or nearly extirpated from Saint Chirstopher and Nevis, Antigua, Maria-Galante and Guadeloupe, Martinique and Rocher de Diamant, and Grenada, respectively. *A. cineracea*, *A. major*, and *C. errabunda* are now extinct from Guadeloupe, Iles de la Petite Terre, and Saint Lucia, respectively, and *E. ornatus* is extirpated from Saint Lucia's mainland. Lastly, *E. perfuscus*, once of Barbados, is now likely extinct (Henderson, 2004). In general, if mongoose have become established on an island, ground-dwelling, diurnal reptiles have been extirpated. In contrast, if mongoose never established on an island, ground-dwelling, diurnal reptile populations are healthy (Powell & Henderson, 2005).

In Antigua, mongooses were introduced in the late 19th century and, by 1936, the Antiguan racer was declared extinct. However, a small population survived on the small mongoose-free Great Bird Island, 2.5 km offshore of Antigua (Powell & Henderson, 2005). Conservation efforts began to remove invasive black rats from Great Bird Island and 14 other offshore islands around Antigua. The Antigua racer population increased from roughly 50 individuals on one island in 1995 to about 1,100 individuals on four islands in 2015 (Daltry et al., 2017).

E. cursor, once common on Martinique and now listed as Critically Endangered by the IUCN, has not been seen since 1968 when a specimen was collected from the offshore island known as Diamond Rock (Caut & Jowers, 2015; Breuil, 2009). The island now has protected status and people have been banned from landing on it since 2008. Occasionally, tourists and fishermen report seeing snakes basking on rocks along the shoreline, but two separate scientific surveys to locate the species, one using several single-day visual encounter surveys (VES; Breuil, 2009) and the other combining baited and unbaited live trapping and VES over eight days, failed to produce any evidence of *E. cursor* (Caut & Jowers, 2015).

Conservation efforts may have come too late to prevent the extinction of *E. cursor*, but they have managed to save the Antiguan racer. Alternatively, *E. cursor* may persist, but the efforts to conserve it have been insufficient. A similar story is playing out in Saint Lucia, West Indies on the small island of Maria Major where conservationists are doing well to save the Saint Lucia whiptail (*Cnemidophorus vanzoi*), but the status of the Saint Lucia racer (*E. ornatus*) is more precarious.

Saint Lucia Whiptail

The Saint Lucia whiptail is the only member of its genus in the Lesser Antilles (Presch, 1971; Schwartz & Henderson, 1991). It was first discovered on Maria Major in 1958 (Underwood, 1962). The species was formally described as *A. vanzoi* in 1966 (Baskin & Williams, 1966) and reclassified to the genus *Cnemidophorus* due to its tongue structure in 1971 (Presch, 1971). In 1977, the Saint Lucia whiptail was discovered on the neighboring offshore island of Maria Minor. These lizards were noted to be smaller and slightly different in coloration than the whiptails on Maria Major (Nichols & Maggio, 1977). No specimens were ever documented on the mainland of Saint Lucia, though it is difficult to imagine that the species colonized the Maria Islands without ever also colonizing the mainland. It is possible that the mainland population was eradicated by invasive predators before one was ever recorded (Baskin & Williams, 1966).

Recognizing the need for conservation action, Saint Lucia Forestry Department (SLFD) and Durrell Wildlife Conservation Trust (Durrell) began taking action to save the whiptail from extinction (Morton, 2009). Invasive species were eradicated from Praslin Island in 1994 and, in 1995, 42 whiptails were translocated from Maria Major to Praslin Island (Dickinson & Fa, 2000). In 2008, a fourth population of Saint Lucia whiptails was founded on Rat Island off the northwest coast of Saint Lucia. These four metapopulations comprise the present-day extent of the species' distribution which totals 0.16 km^2. The most recent published population estimate for the species puts the total population at 2,349 individuals (Daltry, 2009). A distance sampling survey on the Maria Islands produced a population estimate of 1,985 adults and 29 adults on Maria Major and Maria Minor, respectively (Young et al., 2006). In 2008, Praslin Island's metapopulation was estimated to be 185 individuals using a similar methodology (Brown, 2008). Demographic information on the Rat Island metapopulation is not available.

The Saint Lucia whiptail is categorized as Critically Endangered by the IUCN. This is based on the four metapopulations having arisen from a single severely fragmented population and the threat that invasive mammals pose to the survival of the species at all the locations in which they occur (Daltry, 2016).

Saint Lucia whiptail ecology. The Saint Lucia whiptail is a large, highly active, ground-dwelling, diurnal teiid lizard. The species exhibits sexual dimorphism. Males are larger and flashier in coloration. They can reach up to 121mm snout-vent length (SVL) and exhibit a yellow ventral surface and bright turquoise tail. Adult females are smaller and exhibit a more muted brownish-pale coloration (Figure 1; Daltry, 2009). Females are considered adults at an SVL of greater than 76mm and have been documented to reach up to 95mm SVL (Vitt & Breitenbach, 1993). Juveniles of both sexes are similar in appearance to adult females. Juveniles can be sexed in hand by the number of scales above the vent (male n=3, female n=4; Dickinson & Fa, 2000).

The Saint Lucia whiptail is an opportunistic and omnivorous species. When foraging, they scratch at the soil surface and amongst leaf litter searching out prey

(Corke, 1987). Their diet consists primarily of live insects, but they are also known to feed on carrion and fruit (Daltry et al., 2009). Corke (1987) noted that the Saint Lucia whiptail feeding behavior changed in the dry season as they much more readily came to bait, suggesting that dry season food availability is a limiting factor. Dickinson & Fa (2000) observed a decline in abundance and a decline in overall body condition of

Figure 1. Saint Lucia whiptails (*Cnemidophorus vanzoi*).

Photos of an adult female Saint Lucia whiptail, left, and an adult male Saint Lucia whiptail, right, taken during camera station installation. Photo credit: Chris Scanlon.

whiptails during the dry season and posited reduced invertebrate prey during the dry season as a possible explanation.

The whiptail is known to use all habitat types available on the small offshore islands on which they occur (Daltry, 2009). Baskin and Williams (1966) and Nichols and Maggio (1977) documented a preference for woodland and wood edge habitat; Corke (1987) reported the greatest number in low scrub and woodland habitat; and Dickinson et al. (2001) observed a preference for forest and shrub habitats and an avoidance of grasslands. Dickinson et al. (2001) also observed a seasonal shift in activity and habitat use. In the dry season, whiptail activity decreased and grassland habitat was more strongly avoided. Estivation, not reported for this species but does occur within the genus (Casas-Andreu & Gurrola-Hidalgo, 1993), may explain the decreased activity level during the resource-limited dry season (Dickinson & Fa, 2000). Constraints of thermoregulation, with greater sun exposure in open grasslands, may explain the increased avoidance of grasslands in favor of wooded areas during the hot dry season (Dickinson et al., 2001).

Environmental variables that influence lizard activity in tropical seasonal dry forests.

Thermoregulation and hydroregulation are the active processes of maintaining body temperature and water balance as close as possible to the levels at which individual performance is maximal. All levels of physiology, from enzymatic reactions to growth and locomotion, rely on the individual's ability to maintain these states within defined target ranges. As ectotherms, lizards have limited capacity to thermoregulate physiologically and, instead, must achieve this through behavioral means. This renders lizards highly susceptible to the environmental conditions of their immediate surroundings (Díaz & Cabezas-Díaz, 2004). Behavioral alterations to achieve thermoregulation include habitat or microhabitat shifts (Hertz & Huey, 1981; Bauwens et al., 1996), retreat-site selection (Webb & Shine, 1998; Kearney, 2002), changes in activity times (Carrascal & Díaz, 1989; Van Damme et al., 1989), variations in the frequency and duration of time spent in full sun (Van Damme et al., 1989; Díaz, 1991), and postural adjustments (Martín et al., 1995; Kearney & Predavec, 2000). Thermoregulation in reptiles is also governed by other life history traits, including reproductive status (Charland & Gregory, 1990; Gregory et al., 1999), food consumption (Saint Girons & Bradshaw, 1981; Shine & Lambeck, 1990), and season (Shine & Lambeck, 1990; Christian & Bedford, 1995), which results in thermoregulation being a tradeoff among these activities.

Environmental variables connected to water balance, such as precipitation and humidity, are also known to influence reptile activity (Hillman et al., 1979; Nielson, 2002). The main mechanisms by which reptiles lose water are via respiration, cutaneous evaporative water loss, and water lost in feces and urine. The rate of water loss is strongly dependent on temperature (Mautz, 1980, 1982) and activity (Nagy 1972, 1973; Minnich, 1977). The capacity to resist or avoid water loss through behavioral mechanisms, however, is less well studied (Davis & DeNardo, 2010; Tracy et al., 2014). Some reptiles are active during periods of high precipitation (Davis & DeNardo, 2010), while others are known to retreat into humid burrows during dry spells (Wilms et al., 2010). Pintor et al. (2016) showed that rainbow skinks (*Carlia rubigularis*) in the tropics actively hydroregulate by selecting cold, wet burrows over warm, dry burrows. The skinks are either purposefully selecting conditions that reduce desiccation or they are lowering their thermal preference when desiccated because, under those conditions, the need to hydroregulate outweighs the need to thermoregulate. Tiger snakes (*Notechis scutatus*) in semi-arid Australia have also been shown to exhibit thermal depression, a decrease in preferred body temperature and average maximum temperatures, in response to dehydration (Ladyman & Bradshaw, 2003).

Tropical seasonal dry forests, characterized by distinct dry and rainy seasons and high diurnal temperatures year-round, represent unique challenges to lizards. The dry season is one of limited resources as reduced precipitation leads to reductions in vegetative growth and insect abundance (Churchill, 1994; Christian et al., 1995, 1999; Griffiths & Christian, 1996). This reduction in resources forces many reptile species to limit their activity and, in some cases, enter a period of estivation (Christian et al., 1996a, 1996b, 1996c, 1996d; Kennet & Chrisitan, 1994). Species or individuals that remain active often limit their energy expenditures through metabolic depression (Christian et al., 1996b, 1996c, 1999a), thermal depression (Christian & Bedford, 1995; Christian et al., 1996c), or reduced activity (Christian et al., 1996b, 1996c, 1999b). Christian et al. (2003) found that blue-tongued lizards (*Tiliqua scincoides*) in a seasonal tropical environment in Australia use behavioral and physiological mechanisms to conserve energy in the dry season. Blue-tongued lizard field metabolic rates were reduced by 70% in the dry season as compared to the rainy season and 66% of the reduction was attributed to decreased activity (Christian et al., 2003). Given the ecological and physiological similarities between lizards and snakes, it stands to reason that the Saint Lucia racer would experience similar challenges in tropical seasonal dry forests.

Saint Lucia Racer

The Saint Lucia racer is a medium-sized smooth-scaled snake inhabiting the small offshore island of Maria Major, Saint Lucia (Figure 2). It can reach up to 1.25m in length from tip of snout to base of tail (Morton, 2009). Dixon (1981) described two color variants: one with alternating yellow and black spots turning into diagonal streaks towards the rear of the body and the other with a broad brownish stripe along the back and yellowish spots on the edges. Recently caught individuals appear to display characteristics of both varieties and they no longer display any yellow coloration (Morton, 2009).

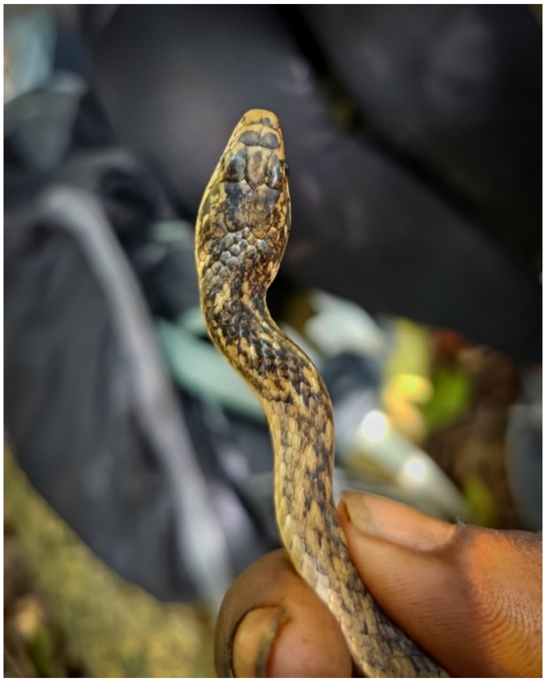

Figure 2. Saint Lucia racer (*Erythrolamprus ornatus*).

Photo of a Saint Lucia racer captured during camera station installation. Photo credit: Chris Scanlon.

Little is known about the life history of the Saint Lucia racer. The habitat of Maria Major is described as a mix of littoral evergreen forest, shrubland, and littoral scrub with cacti. Sightings of snakes and shed skins suggest they use all habitat types (Morton, 2009). Morton (2009) reported that sightings most commonly occur in littoral evergreen forest in areas with plenty of leaf litter and shade which are also preferred by common prey species.

The Saint Lucia racer has been reported to consume the Saint Lucia anole (*Anolis luciae*) and the Maria Islands dwarf gecko (*Sphaerodactylus microlepis thomasi*; Williams et al., 2016; Sherriff et al., 1995). It is thought that the Saint Lucia anole and juvenile Saint Lucia whiptails are its main prey items (Corke, 1987; Sherriff et al., 1995; Morton, 2009).

The Antiguan racer and *A. sibonius*, another West Indian racer species from Dominica, feed on similar prey species in similar environments to the Saint Lucia racer. These other racers use an unusual hunting strategy amongst colubrid snakes; they are diurnal, sit-and-wait predators. During mornings and evenings, they will actively forage for food as well as sit in ambush waiting for prey to come to them (Daltry et al., 2001; White et al., 2009). The Saint Lucia racer may utilize a similar hunting strategy and activity pattern (Morton, 2009).

Conservation status. The Saint Lucia racer, first described by Tyler (1850), was at the time the second most common of the five extant snake species in the country. Nineteen years later, mongooses were introduced to Saint Lucia (Des Voeux, 1903) and the racer was declared extinct by 1936 (Parker, 1936). In 1973, a single Saint Lucia racer was observed on the small mongoose-free offshore island known as Maria Major, 800 m off the southeastern shore of the mainland. All subsequent observations of the Saint Lucia racer have come from Maria Major. Four attempts have been made to study the species on Maria Major since the 1970s, but only one to two individuals were seen during each survey effort (Corke, 1987; Sherriff et al., 1995; Buley et al., 1997; Morton, 2009).

A reassessment of the conservation status of the Saint Lucia racer was recommended by Daltry (2009) and Morton (2009) based on their understanding of the threats faced by the species including invasive predators, climate change, inbreeding depression, and stochastic events. A visual encounter survey (VES) was conducted using passive integrated transponder (PIT) tagging and capture-mark-recapture (CMR) analysis which resulted in a population estimate of likely less than 50 mature individuals (Williams et al., 2016). The Saint Lucia racer was subsequently listed as Critically Endangered by the IUCN and dubbed ‘the world’s rarest snake.’ Conservation and governmental organizations devised a recovery plan that aims to increase the world population to 500 by 2025 by protecting Maria Major from invasive species and by restoring other sites to conditions where racers can safely be reintroduced (Daltry et al., 2014). Ten years have passed since the last survey of the Saint Lucia racer and the status of the population is unknown.

For a species as endangered as the Saint Lucia racer, in which one anomalous year or stochastic event could result in extinction, regular surveying is required to maintain an up-to-date understanding of their population status and additional conservation actions should be considered to bolster the resiliency of the species.

Reptile Survey Techniques

For many reptile species, distributional data exist, but population dynamics data are lacking (Tucker et al., 2020). In fact, in 2016, the IUCN concluded the threat level of 50% of snake and lizard species worldwide to be data deficient. Monitoring populations is crucial for informing conservation measures. Reptiles are challenging to monitor for many reasons including their often-cryptic coloration and behavior, low population densities, low activity levels, habitat preferences, and low detection rates using common sampling protocols (Winne et al., 2007; Durso et al., 2011). As a result, quantitative assessments of perceived declines in many species are lacking. That said, various methodologies have successfully been implemented to survey, monitor, and conserve reptiles for decades.

Conventional Reptile Survey Techniques

Conventional reptile survey techniques fall into one of two categories: active capture methods or passive capture methods. Active capture requires observers searching out free-ranging reptiles. Successful active capture often requires prior knowledge of reptile ecology to inform survey implementation. VES are the simplest form of active capture. Observers walk transects and encounter target animals along the way (Mullin & Seigel, 2011). These are sensitive to observer bias because they rely on the competency of the observer (Rodda & Fritsts, 1992) and may have low repeatability because animal behavior is highly dependent on environmental conditions (Peterson et al., 1993).

Other conventional active capture methods include coverboard turning and road surveying. Coverboard turning involves walking transects and flipping over natural or artificial cover objects to locate animals underneath. To conduct road surveying, roads are driven and spotters look for animals on the road. Though less prone to observer bias than VES, they are not often used for population monitoring (Millin & Siegel, 2011).

Passive capture generally involves trapping individual animals. Conventional passive capture is done with funnel traps in aquatic (Wilson et al., 2005), arboreal (Rodda et al., 1999), and, more recently, terrestrial settings. Terrestrial funnel trap design typically involves wooden box traps paired with drift fences to funnel reptiles towards the boxes (Burgdorf et al., 2005; Todd et al., 2007). Escape rates from traps can be high (Rodda et al., 1999; Thompson et al., 2005) and risk of mortality of captured individuals through heat stress, predation, or drowning often make conventional passive capture techniques for monitoring endangered reptile species unappealing (Richardson et al., 2017).

Conservationists often decide that conventional passive capture techniques are too risky to be utilized for surveying the rarest and most endangered reptile species so active capture, in the form of VES, is the norm.

Conventional surveys of the Saint Lucia whiptail. The first published survey of the Saint Lucia whiptail was conducted on Maria Major by Corke (1986). Corke's population estimate utilized capture-mark-recapture (CMR) and 15-min surveys of 3-m semicircles during the peak activity period for the species which Corke considered to be between 0900-1100 h. This methodology produced an average of 1.0 lizards/27m^2 or 740 individuals on the island. Corke also noted being unable to estimate the population on Maria Minor due to the island being mostly tall grass which made observing the lizard difficult (Corke, 1986).

Dickinson & Fa (2000) studied the abundance and demographics of the metapopulation of Saint Lucia whiptails translocated from Maria Major to Praslin Island three years after release. Whiptails were collected over a 6-month period during wet (October-December) and dry (January-March) seasons. Individuals were sexed, weighed, measured, and general condition was noted. Population size was estimated with Petersen mark-resight analysis (Krebs, 1989) and distance sampling (Buckland et al., 1996). The founder population of 42 individuals had risen to a mean population size of 151.5 ± 25.9 individuals, estimated from pooled overall abundance estimates. Whiptail abundance was significantly different between wet and dry seasons with abundance being greater in the wet season (Dickinson & Fa, 2000). Dickinson & Fa (2000) posited that reduced dry season abundance could be the result of harsher dry season conditions including reduced precipitation, vegetation cover, and invertebrate prey, and increased temperatures. They also suggested that the decrease in dry season abundance is likely true as detectability of lizards should remain the same or improve during the dry season due to reduced vegetation cover (Dickinson & Fa, 2000).

Dickinson et al. (2001) studied the microhabitat use of the translocated metapopulation of Saint Lucia whiptails on Praslin Island. The researchers performed a vegetation analysis and mapped the five major habitat types: two woodland types, a shrub habitat, and two grassland types, before performing transect line distance sampling (Buckland et al., 1996) and pooling observations by season. A significant seasonal pattern was again observed in which lizard abundance decreased during the dry season. The data also showed whiptails utilizing woodland and shrub habitat more than predicted and developing an avoidance of grasslands in the dry season. Dickinson et al. (2001)

speculated that the seasonal shift in habitat use may be due to increased sun exposure in grasslands, making thermoregulation more achievable under woodland canopy cover.

Young et al. (2006) reported updated Saint Lucia whiptail population estimates using unpublished surveys results. These figures recorded the Maria Major population at 1,985 individuals, the Maria Minor population at 29 individuals, and the Praslin Island population at 335 individuals (Young et al., 2006). This represents the last published population estimate for the Maria Islands.

Like Dickinson & Fa (2000), Brown (2008) also investigated abundance, demographics, and habitat utilization of the Saint Lucia whiptail on Praslin Island. This study found that the Praslin Island whiptail population fell from 305 individuals in 2005 to 181 individuals in 2008, the last published population estimate for Praslin Island. Brown (2008) did not find a significant difference in sex ratio between their study and the first study in 1998, however the population did appear to be skewing younger from year to year. Morphometrically, the smallest male to show adult coloration had an SVL of 84mm and all males with an SVL greater than 96mm showed adult coloration. Brown (2008) found that whiptails had a significant preference for woodland habitat and avoided areas of full sun. The study also noted a decline in body condition and abundance of whiptails in the dry season as compared to the wet season.

Conventional surveys of the Saint Lucia racer and similar species. Several attempts have been made to survey for Saint Lucia racer. Neither Corke (1987) nor Sherriff et al. (1995) reported on survey methodology. Personal observation of subadult Saint Lucia racers was reported by Morton (2009), but survey methodology was not.

Buley et al. (1997) performed VES along three transects for Saint Lucia racer throughout the day. Their survey focused more heavily on lower white cedar woodland habitat, periods following heavy overnight rainfall, and early morning surveys as encounters by Corke (1987) and Sherriff et al. (1995) had those characteristics in common. Random searches of all areas of the island were also performed; methods included walking, sitting quietly, stone and log rolling, and leaf litter searches. Fieldwork was conducted over a 26-day period from September to October and resulted in 15 working days on the island. A team of two individuals performed 117 hours of survey effort looking for the snake. This effort yielded one capture that occurred as a chance encounter in the afternoon during heavy rain while walking a transect but not looking for snakes (Buley et al., 1997).

Following the acknowledgement of a need for a review on the status of the Saint Lucia racer, the most detailed study on the species thus far was performed by Williams et al. (2016). Methods were adapted from those used to estimate the population size of the insular Antigua racer (Daltry et al., 2003). Daylight VES for snakes were deployed between October 2011 and March 2012. A team of up to six surveyors repeatedly walked a series of nine trails of varying length that facilitated movement around the island. All trailed were surveyed multiple times over the course of each survey day (0800-1700 h). Attempts were made to capture snakes by hand for all snakes encountered. Captured snakes were sexed, measured, weighed, and PIT tagged. Survey effort totaled 644 man-hours over a 30-day period. Forty-one encounters lead to 16 captures, five of which were recaptures. CMR data were analyzed and Begon’s weighted mean method estimated a population of 17.8 adults and subadults with a standard error of ±9.94 (Williams et al., 2016). This survey represents the most successful study of the three extant Lesser Antillean *Erythrolamprus* species.

One documented attempt to survey for *E. cursor* has taken place on the small offshore island of Diamond Rock, Martinique. A two-person team spent 10 days on the island performing both active and passive survey techniques. VES for snakes, snake eggs, and snake skins were performed during day and night for 12 hours per researcher per day. Additionally, eight baited or unbaited snake-specific traps with cone funneling devices were placed in various habitats throughout the island. After 80 trap-nights no snakes were trapped, but all other reptiles encountered during VES were captured. VES also failed to produce any evidence of snake occurrence and researchers concluded *E. cursor* may now be extinct (Caut & Jowers, 2015).

E. juliae is common in Dominica, which was never invaded by mongoose, but still little is known about their life history (Muelleman et al., 2009). Henderson & Powell (2009) described all West Indian *Erythrolamprus* as being “presumably diurnal.” A team set out to determine the diel activity pattern of *E. juliae* and the ecologically similar *A. sibonius* by conducting 19 days of VES (71.25 survey hours) at the beginning of the rainy season. The team utilized trails in a national park as their transect lines and teams of two to four observers conducted 1.5-4.0 h surveys once or twice daily covering times from pre-dawn to full-dark. Nine *E. juliae* and 165 *A. sibonius* were encountered. Seven of the *E. juliae* encounters occurred on rainy days. Six snakes were on leaf litter, two were on rocks, and one was on both leaf litter and rocks. Eight of the nine snakes encountered were in full shade and one was in a shade/sun mosaic. Most of the snakes that were encountered responded by elevating their heads and fleeing rapidly. The team determined that the *E. juliae* data was insufficient to make definitive conclusions about their activity pattern, but it suggests that activity is unimodal (morning) and somewhat dependent on moisture (Muelleman et al., 2009).

A. sibonius appeared to be diurnal with two activity peaks inversely related to temperature in the mornings and evenings. A depression in activity occurred around midday and activity peaks lengthened on rainy days. The species relied on shade with 73.9%, 23.9%, and 2.3% of morning encounters and 81.3%, 18.7%, and 0% of afternoon encounters occurring in full shade, a shade/sun mosaic, and full sun, respectively (Muelleman et al., 2009).

Camera Trapping for Reptiles

The amount of data obtained through conventional active and passive survey methods on members of the genera *Cnemidophorus* (Colli et al., 2009; Filigonio et al., 2010; Cosendey et al., 2016) and *Erythrolamprus* is sparce (Muelleman et al., 2009; Caut & Jowers, 2015; Williams et al., 2016). In recent years camera trapping has emerged as a successful and cost-effective strategy for monitoring reptile species, specifically terrestrial snakes and lizards (Welbourne et al, 2017). Camera trapping has several advantages over conventional survey methods. Conventional active survey methods are time consuming, labor intensive, and often require groups of people. Individuals within survey groups can differ in their ability to detect target animals which introduces observer bias. Conventional passive survey methods are time consuming and labor intensive in deployment and maintenance of traps. Traps must be checked at least once per day to reduce the risk of mortality from heat stress or predation and traps cannot be used in areas of high rainfall due to the risk of captured animals drowning in the trap

(Richardson et al., 2017). Additionally, larger reptiles have been shown to escape or avoid traps altogether (Thompson et al., 2005).

Remote, automatically triggered cameras, on the other hand, photograph or take videos of animals as they pass through a camera's detection zone so there is no need to confine animals in traps and put them at risk of heat stress or predation. Cameras are operational under a wide range of environmental conditions and can provide additional environmental data such as temperature, date, and time of capture. Despite high initial cost, cameras are relatively easy to install and remain operational for long periods of time with minimal maintenance (Richardson et al., 2017).

Camera trapping for reptiles is not without challenges. Wildlife research cameras typically utilize passive infrared technologies as trigger mechanisms which rely on moving objects with different temperatures to the background passing through the camera's detection zone (Rovero et al., 2013; Welbourne, 2013). Temperature differentials between reptiles and their surroundings may be inadequate in certain ecosystems or at certain times of day because body temperature of the reptile may closely match that of the ground surface (Rovero et al., 2010).

For passive infrared cameras to be effective for reptile surveys, an adequate level of thermal contrast is needed between the animal and the ground surface (Welbourne, 2013). In response to this problem, Welbourne (2013) developed the COAT protocol in which an artificial surface that rapidly changes temperature is placed on the ground underneath a downward facing camera. The artificial surface, for example cork board, is warmer than the surrounding environment and provides the necessary thermal contrast between the reptile's body and the environment to set off passive infrared triggers. When combined with drift fencing to funnel reptiles through the camera's detection zone, this methodology was able to detect small (55mm SVL) and large (2,000mm SVL) species.

In a comparison of camera trap triggers and focal length settings, Welbourne et al. (2019) found that passive infrared triggering outperformed time-lapse triggering for diurnal reptile detection and that modified focal length lenses produce sharper images than factory-set focal length lenses (Welbourne at al., 2017; Welbourne et al., 2019).

Research Questions, Hypotheses, and Specific Aims

The main research question I intended to answer was:

Can COAT camera trapping successfully capture images of the Critically Endangered herpetofauna of Maria Major and, therefore, be a viable means by which to monitor insular populations of these species?

I hypothesized that COAT camera trapping combined with drift fencing can successfully capture images of the Saint Lucia whiptail and the Saint Lucia racer and, therefore, be used to monitor these populations through time.

I also intended to glean ecological information from this data by answering the questions: What are the diel and seasonal activity patterns of the Saint Lucia whiptail and the Saint Lucia racer and how do environmental variables influence these patterns?

To address these ecological questions, I hypothesized that:

1. The Saint Lucia whiptail will exhibit a diurnal unimodal diel activity pattern with increased activity in the morning;
2. The unimodal nature of the whiptail diel activity pattern will be weaker during the rainy season when rainfall moderates midday temperatures;

3. The Saint Lucia racer will exhibit a strong diurnal bimodal diel activity pattern with increased activity levels in the morning and the evening and a decreased activity level in the heat of midday;
4. The bimodal nature of the racer diel activity pattern will be weaker during the rainy season when rainfall moderates midday temperatures;
5. Seasonally, activity will be greater during the rainy season than during the dry season for the whiptail and the racer; and
6. Whiptail and racer activity will be positively correlated with temperature and moisture variables.

Activity level is defined as the proportion of time that an animal spends active or moving about the environment on the surface. It is measured as photographic detection rates. Activity patterns vary depending on scale: the diel activity pattern is based on a 24-hour cycle and the seasonal activity pattern is based on an annual cycle.

Specific Aims

To address my research questions and hypotheses, I:

1. Constructed 12 COAT camera trapping stations on Maria Major.
2. Monitored the camera stations for seven months, beginning in April 2023, to obtain data during both the dry season and the rainy season.
3. Performed maintenance and data management once per month: these procedures included image recovery, image translation, and metadata extraction.
4. Created an Excel file of all whiptail and racer capture events and recorded date, time, and camera ID.

5. Created an Excel file of daily environmental data including time of sunrise and sunset, high and low temperatures, precipitation totals, mean cloud cover, mean dew point, mean wind speed, mean soil temperature, and mean volumetric soil water.
6. Performed data analyses to determine activity patterns.
7. Produced visual representations of activity patterns.
8. Made recommendations to Saint Lucia Forestry Department and Durrell Wildlife Conservation Trust on how to use the results of this research to continue to monitor the Saint Lucia whiptail and Saint Lucia racer.

Chapter II

Methods

The interested parties involved in the conservation of the Critically Endangered herpetofauna of Saint Lucia are SLFD, Saint Lucia National Trust (SLNT), Durrell, and Fauna & Flora International. In 2015, I spent six months volunteering with Durrell on various endangered species conservation efforts throughout Saint Lucia. During that time, I met and worked alongside personnel from all parties. Conversations with these individuals that took place in late 2022 led me to believe that the interested parties were eager to learn more about the ecology of the racer to inform future conservation efforts and those conversations were the impetus for the development of this research project.

Study Site

Maria Major (13.724337°, -60.931579°) is a small, uninhabited island located within the Maria Islands Nature Reserve. It is about 1 km offshore of Pointe Sable near Vieux Fort in the south of Saint Lucia, West Indies. The nature reserve was established by the Government of Saint Lucia and vested in SLNT in 1982 in recognition of the unique fauna and flora that occur there. Eight species of terrestrial reptiles can be found within the reserve, six of which are endemic species or subspecies. The endemic reptiles include the Saint Lucia anole (*A. luciae*), the Saint Lucia pygmy gecko (*S. microlepis microlepis*), the Saint Lucia threadsnake (*Tetracheilostoma breuili*), the rough-scaled worm lizard (*Gymnopthalmus pleii nesydrion*), the Saint Lucia whiptail, and the Saint

Lucia racer (Buley et al., 1997). The whiptail (IUCNa, 2023) and racer (IUCNb, 2023) are Critically Endangered.

Maria Major is approximately 0.1 km^2 and its peak reaches roughly 90 m above sea level (Figure 3). Habitat types include woodland, woodland with cactus, cactus covered rocks, scrub, grass, windswept slopes, cliffs, and sand beach. The eastern side of the island is characterized by steep, windswept slopes and rocky cliffs projecting down into the open ocean. The western side of the island is more sheltered from the elements. It is landward-facing and slopes at about 30° to the horizontal. At Maria Major's peak, scrub and cactus-covered rock habitats give way to woodland and woodland with cactus habitats, which extend down towards cliffs and/or sand beach. Grassland habitat exists at the northern and southern ends of the island (Corke,1987).

Figure 3. The Maria Islands, Saint Lucia.

A photo of the Maria Islands with Maria Major in the foreground and Maria Minor in the background. Image courtesy of <https://saintlucianationaltrust.com/sites/protected-areas/maria-islands-nature-reserve/.

The climate of Saint Lucia is characterized as tropical with distinct dry and rainy seasons. The dry season lasts six months from December through May. February and March are the driest months of the year with an average of about five days with at least 1 mm of precipitation and average monthly rainfall totals around 30 mm. The rainy season lasts six months from June through November. October is the wettest month, with an average of 13 wet days accumulating an average of 145 mm of rain. Temperatures typically vary between 24.4°C and 30.5°C and rarely drop below 22.8°C or exceed 31.7°C. The Hewanorra International Airport weather station is approximately 2 km northwest of Maria Major. High and low temperature and precipitation data for this project was sourced from this station. Given its proximity to Maria Major, it should provide fairly accurate temperature and precipitation data (www.en.tutiempo.net). Cloud cover, dew point, wind speed, soil temperature, and volumetric soil water data were sourced for the center of Maria Major (13.72312048, -60.93096247) and purchased from an online historical weather archive (www.meteum.com).

Camera Station Locations

I utilized Google Earth Engine to randomize 12 camera station locations on Maria Major (Figure 4). I used the “draw a shape” feature to create the survey area. The eastern slope, high elevation center, and southern portion of the island were excluded from the survey area due to accessibility and safety concerns. The code used to create the random camera station locations in Google Earth Engine is as follows, where the “geometry” layer is the survey area and the “random points” layer contains the 12 camera station locations:

```
print(geometry);

Map.addLayer(geometry, {}, 'geometry');

var randomPoints = ee.FeatureCollection.randomPoints(geometry, 12);

Map.addLayer(randomPoints, {}, 'random points');

Map.centerObject(geometry);
```

Figure 4. Camera station locations.

Camera station locations on Maria Major. Due to accessibility issues and safety concerns, the eastern, high elevation middle, and southern portion of the island were excluded from the survey area; Google Earth Pro.

Camera Station Design

Camera station design incorporated elements from Adams et al. (2017) and Welbourne (2016). One camera station was installed at each of the 12 camera station locations. Each camera station consisted of a Reconyx Hyperfire 2 Professional Covert IR camera (www.reconyx.com), a 6-ft studded steel T-post with anchor plate, a Reconyx T-post camera mount (www.reconyx.com), a 32-in. x 22-in. cork board, and two 9-ft drift fences. Each camera was attached to a T-post using a T-post camera mount at a height of 36 in. above the ground and positioned such that it was facing directly down at the ground (Figure 5). Directly beneath the camera, a cork board was laid on the ground and secured to the ground using weed mat pins (Welbourne, 2016). Two 9-ft drift fences were installed around each camera in a "---•---" formation to funnel reptiles onto the cork board (Adams et al., 2017). Wooden stakes and weed mat pins were used to secure the drift fences into the ground in trenches dug to a depth of 6 inches by pickax and shovel.

Each camera was loaded with 12 batteries (Energizer Ultimate Lithium) and one high-capacity SD card. Cameras were factory-modified to a focal distance of 36 in. Cameras were set on the highest sensitivity setting and set to use the internal passive infrared motion trigger. They were set to record one image per trigger with no quiet period between triggering events.

Figure 5. A camera overhead augmented temperature (COAT) camera station.

The COAT camera station set up as used in this study with the camera facing directly downward at a corkboard at a height of 36in and drift fences positioned alongside the corkboard to funnel animals below the camera. Photo credit: Chris Scanlon.

Field Research

I visited Saint Lucia in late March of 2023 to set up the project. The smaller materials (i.e. cameras, mounts, batteries, SD cards, hard drives, cork boards, weed mat pins, hand tools, and miscellaneous other materials) were brought to Saint Lucia via checked baggage on the plane. The larger materials (i.e. rolls of drift fence and T-posts) were sent via container ship. A private boat was chartered from Pointe Sable to Maria Major each day from March 27 to March 31 to shuttle personnel and supplies to the island. Camera station installation was completed on March 31. All cameras were tested in the field prior to study initiation by turning them on, triggering several photos, removing the SD card, and checking the images on site with a laptop. Camera position adjustments were made as necessary. Once cameras were properly positioned, they were turned on. The study was initiated on April 1, 2023.

Camera stations were serviced about once per month by personnel from SLFD and/or Durrell. SD cards were swapped out at every service visit. A new set of batteries was installed when cameras were below 30% charge at the time of service. Service visits also involved clearing vegetative debris from the cork boards and silt fences and performing silt fence maintenance as needed. SD cards that were collected during service visits were brought into the lab and the data was copied over onto two 5TB Rugged USB-C Lacie external hard drives (www.lacie.com). Field research was decommissioned after 209 days on October 26, 2023.

Data Analysis

Prior to analysis, the data needed to be processed. Each image was visually inspected to determine the cause of triggering. Images that did not contain whiptails or racers were considered empty and removed from analysis. When a target species (i.e., a whiptail or racer) was identified, camera number, date, time, species, and group were recorded in an Excel spreadsheet. Group was used to differentiate between adult male (blue) and adult female and juvenile (brown) whiptails. Because it was not possible to confidently differentiate between adult female whiptails and juvenile whiptails with this methodology, females and juvenile whiptails were grouped together. Color and markings (i.e. condition of the tail) were used to differentiate individuals.

Detections of the same species that occurred within 30 seconds of the first detection were excluded from the analysis as likely detecting the same individual, unless it was clear that the later detection was of a different individual. Size was not used as images were distorted towards the outside of the picture frame, so size estimation was not reliable. Temperature, as displayed on the camera trap image, was not recorded as the values were often inaccurately high due to the sun heating up the camera thermometer above the ambient temperature.

Once all the camera trap images were processed, meteorological data were gathered, processed, and recorded in Excel. Meteorological data included daily high and low temperatures, daily precipitation totals, time of sunrise and sunset, hourly cloud cover, hourly dew point, hourly wind speed, hourly soil temperature, and hourly volumetric soil water. Hourly data were averaged from 0800-1800 for each day of the study period to produce mean estimates for each day. Meteorological data were recorded for each day and pooled by month to show weather variation throughout the survey period. Monthly mean high and low temperatures and cloud coverage ± one standard deviation were determined (Figure 6a & b).

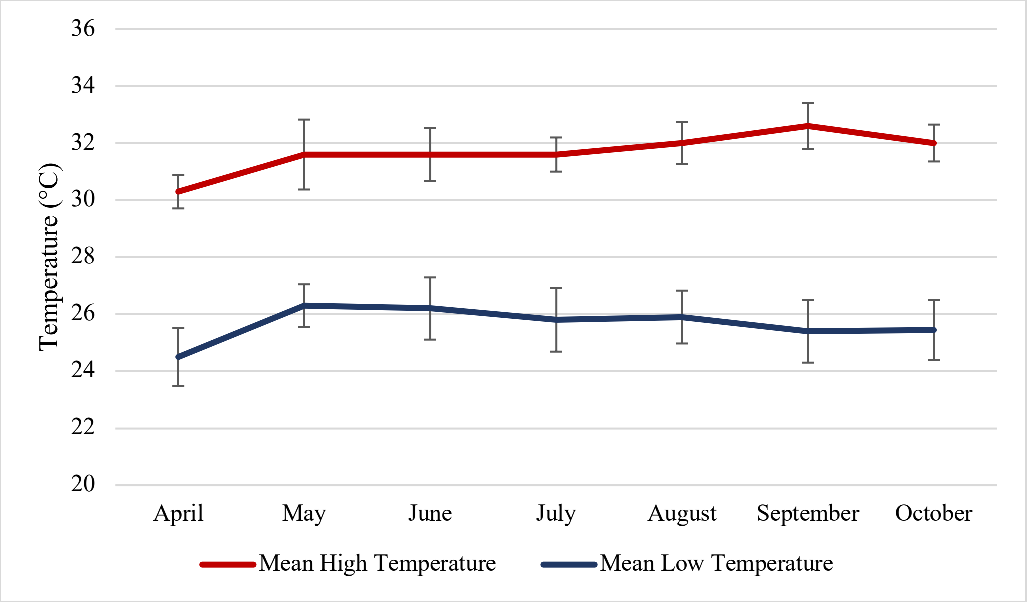

Figure 6a. Monthly mean high and low temperatures.

This figure depicts monthly mean high (red) and low (blue) temperatures ± one standard deviation during the study period.

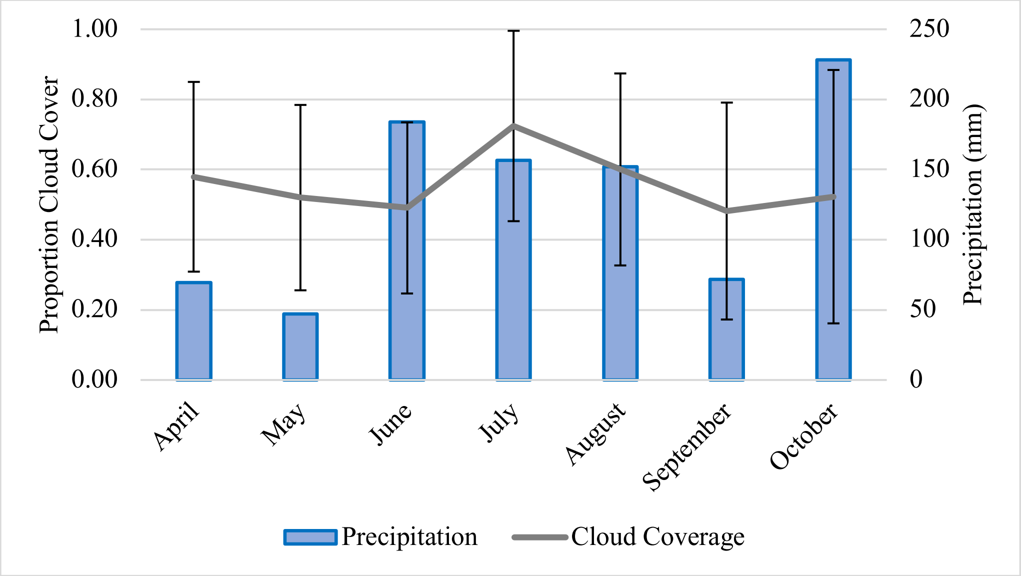

Figure 6b. Monthly mean cloud coverage and precipitation.

This figure depicts monthly mean cloud coverage (gray) ± one standard deviation created via mean hourly cloud coverage data from 0800-1800 for each day and monthly precipitation totals (blue).

To examine diel activity pattern, I sorted detections by time and graphed detections per unit time throughout the course of the day. To determine if diel activity pattern varied by season, I converted detections per unit time into percent of total detections to nullify the discrepancy between total dry season camera-days (697 days) and total rainy season camera-days (1666 days) and graphed detections per unit time. I then performed chi squared tests for all detections, male detections, and female+juvenile detections to determine significance in seasonal variation in activity pattern.

To examine the seasonal activity pattern, I pooled April and May (dry season) detection data and June through October (rainy season) detection data. To account for the difference in seasonal survey effort, I converted total detections into detection rate (detections/camera-day) and graphed the resulting data. A chi squared test was performed to determine if there was significance between the seasonal activity pattern of male and female+juvenile whiptails.

Variation in activity pattern was also analyzed with multiple linear regression analyses to determine what, if any, environmental factors influenced activity. Count daily detection data were square-root transformed and daily precipitation data were logarithmically transformed to better fit the normality assumption for regression. Daily high temperature, daily low temperature, daily mean soil temperature, daily mean volumetric soil water, daily mean dew point, daily mean wind speed, and daily mean proportion of cloud coverage were also used in the models. Means were determined for each day based on hourly data from 0800 to 1800.

Chapter III

Results

The study was active for 209 days, amassing data for 2,363 of a possible 2,508 camera-days. The number of working dry season camera-days was 697 and the number of working rainy season camera days was 1,666. The mean ± one standard deviation of working camera-days per camera was 197±18.6, with a range of 160-209 days. The mean number of daily functioning cameras was 11.3±1.0 with a range of 9-12 functioning cameras. During the study period 45,354 images were produced (Table 1). Whiptail detections totaled 836 and zero racers were conclusively detected. Empty images accounted for 98.2% of the total images. Most of the empty images were triggered by vegetation, birds, and/or snails. Saint Lucia anoles triggered several images and on two occasions unidentified reptiles were detected.

During the study period, ambient temperature ranged from 22.6°C to 36.9°C and total precipitation was 909 mm. Mean monthly temperature did not change much throughout the study period, however mean high temperature did gradually rise, while mean low temperature peaked in May and decreased during the rainy season. Mean monthly cloud coverage ranged from 48% to 72%. The precipitation total during the dry season months of April and May was 116 mm. Precipitation increased substantially in the rainy season where 793 mm of rain fell. October was the wettest month with 228 mm of rainfall.

Table 1. Summary of raw survey data by camera station.

	Cam 1	Cam 2	Cam 3	Cam 4	Cam 5	Cam 6	Cam 7	Cam 8	Cam 9	Cam 10	Cam 11	Cam 12	Totals
Dry Season Camera-days	61	61	26	61	61	61	61	61	61	61	61	61	697
Rainy Season Camera-days	148	148	148	148	149	99	148	148	148	124	111	148	1,666
Total Camera-days	209	209	174	209	209	160	209	209	209	185	172	209	2,363
Total Images	3,034	3,732	2,981	10,478	1,159	1,987	2,264	2,164	1,397	2,267	12,157	1,734	45,354
Whiptail Detections	50	53	83	155	69	4	220	16	38	38	97	13	836
Whiptail Detections/Camera-day	0.24	0.25	0.48	0.74	0.33	0.03	1.05	0.08	0.18	0.21	0.56	0.06	0.35
Racer Detections	0	0	0	0	0	0	0	0	0	0	0	0	0

This table displays a summary of the raw data produced at each camera station during the study period of April 1, 2023 to October 26, 2023.

Saint Lucia Whiptail Diel Activity

This study produced 836 images of whiptails (Figure 7). No whiptails were detected during the nighttime or in the periods after sunrise or before sunset. The trendlines indicate that whiptails were more frequently detected towards the end of the study period and that, as the study progressed, detections occurred later in the day.

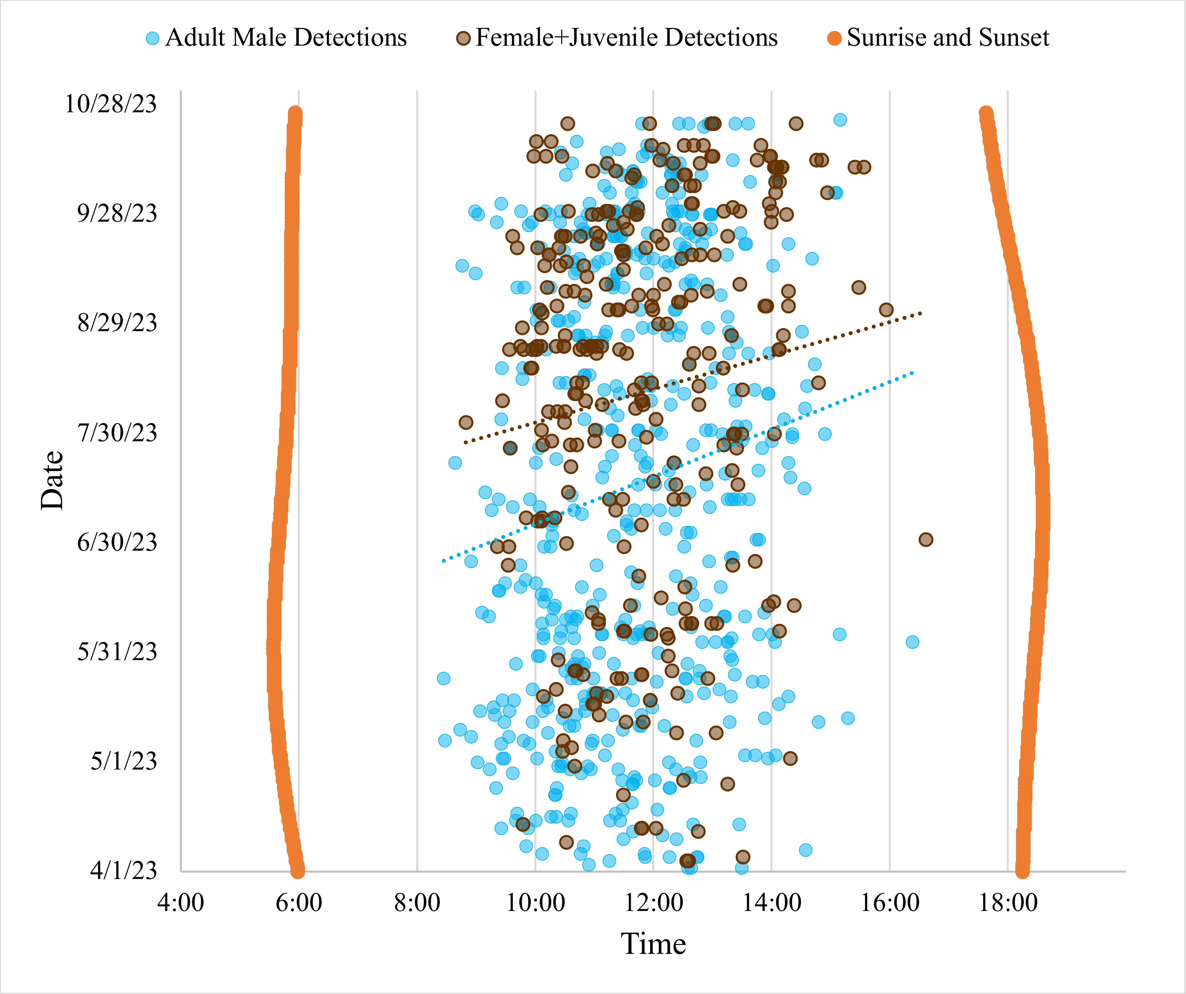

Figure 7. Date and time of Saint Lucia whiptail detections.

This figure depicts the date and time of whiptail detections. Adult male detections (light blue), female+juvenile detections (brown), and the time of sunrise and sunset (orange) are displayed. Male and female+juvenile trendlines were added to show seasonal changes in activity.

Whiptail diel activity was unimodal. The earliest whiptail activity occurred during the 0800 hour. Diel activity rose sharply during the 1000 hour, peaked during the 1100 hour, and gradually declined from 1200-1500. The period of greatest activity coincided with the period of the day in which the ambient temperature rose from early morning lows (Figure 8).

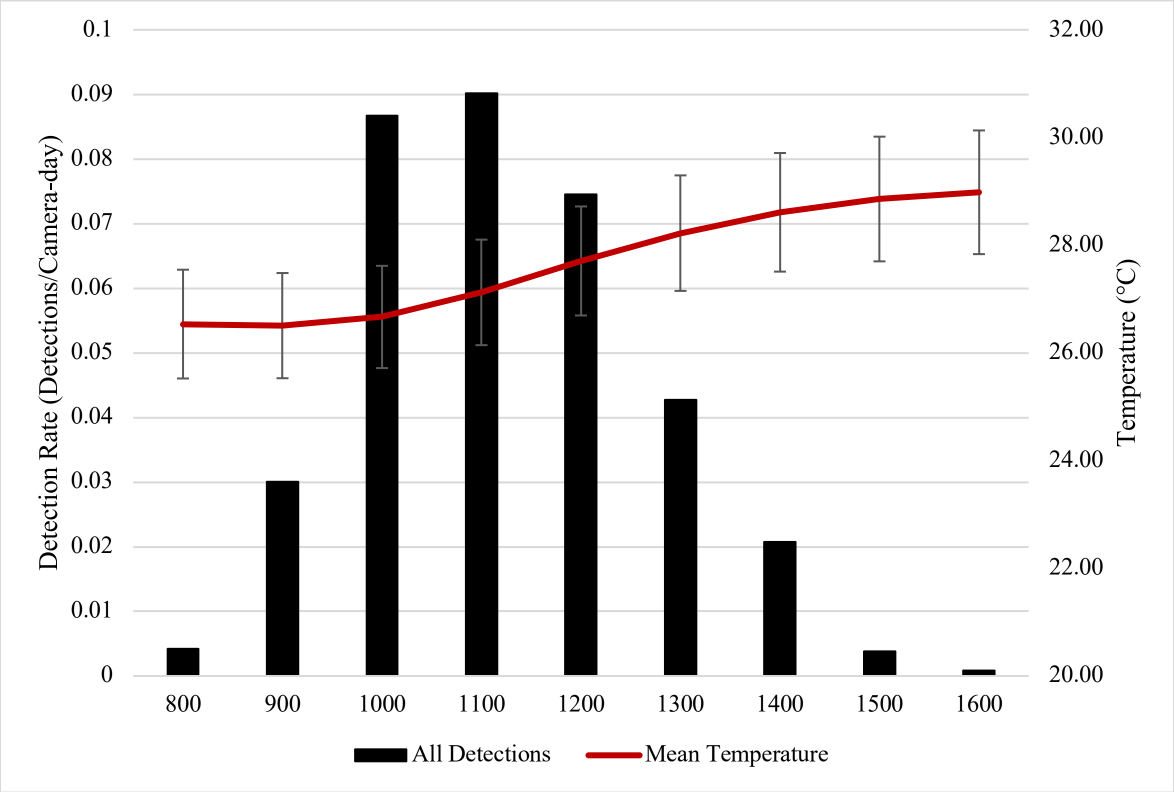

Figure 8. Saint Lucia whiptail diel activity.

The activity pattern of the Saint Lucia whiptail in the form of detection rate (black) throughout the course of the study period. Mean temperature (red) ± one standard deviation was included to show the relationship between temperature and activity.

Seasonal differences in whiptail diel activity were observed (Figure 9). During the dry season, activity peaked during the 1000 hour, whereas during the rainy season, peak activity shifted into the 1100 hour. Additionally, the peak activity period (80% or greater of the max hourly detection rate) during the rainy season lasted for three hours, whereas during the dry season, the peak activity period lasted for only one hour.

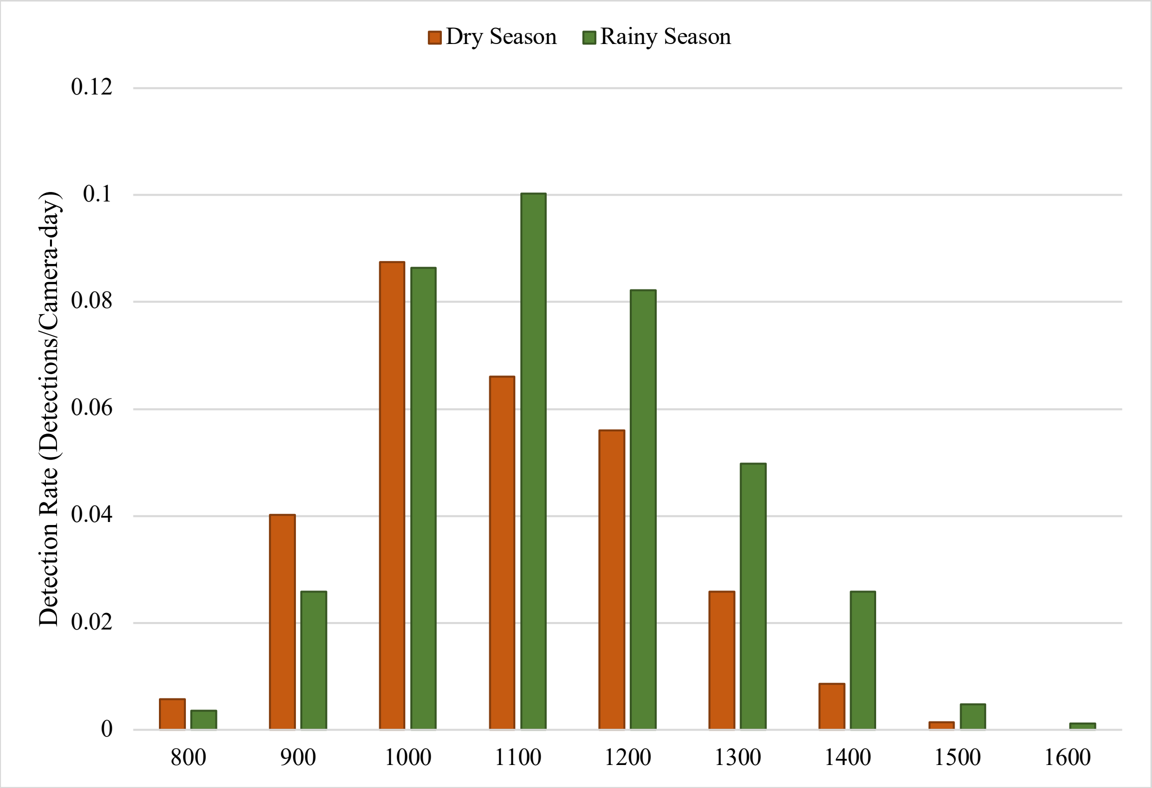

Figure 9. Saint Lucia whiptail diel activity in dry vs rainy seasons.

This figure depicts the activity patterns of the Saint Lucia whiptail in the form of detection rate in the dry season (burnt orange) and the rainy season (green).

In addition to seasonal differences in total whiptail activity, seasonal differences were observed between adult male whiptails and female+juvenile whiptails. In the dry season, adult males became active an hour earlier and activity peaked an hour sooner than female+juvenile whiptails (Figure 10a). In the rainy season, both groups became active during the same time period and female+juvenile activity peaked an hour before adult male activity (Figure 10b).

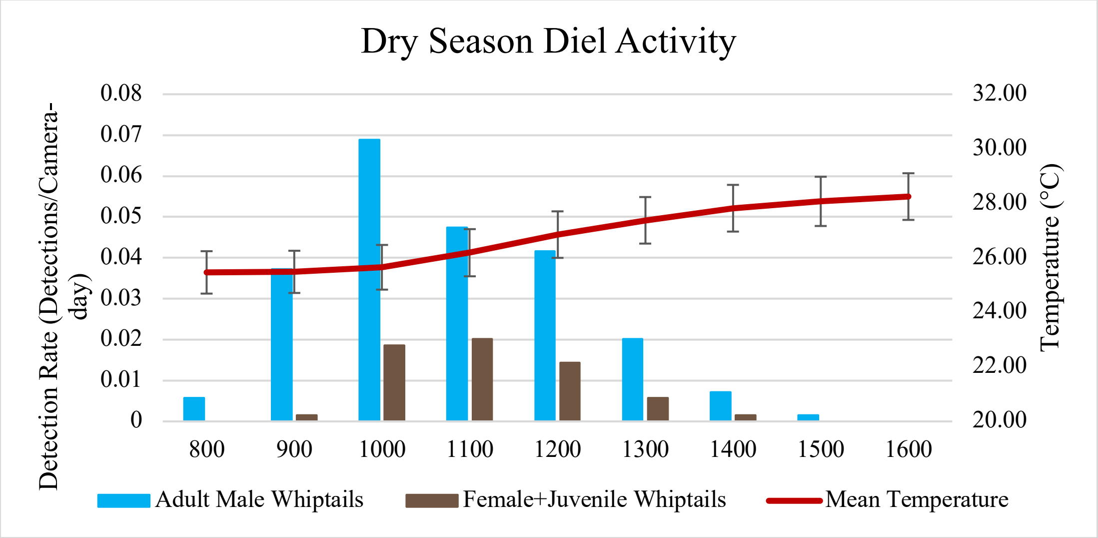

Figure 10a. Saint Lucia whiptail diel activity in the dry season.

This figure depicts adult male and female+juvenile Saint Lucia whiptail diel activity pattern in the dry season in the form of detection rate during hourly time periods of the day. Mean temperature ± one standard deviation was included to show the relationship between activity and temperature.

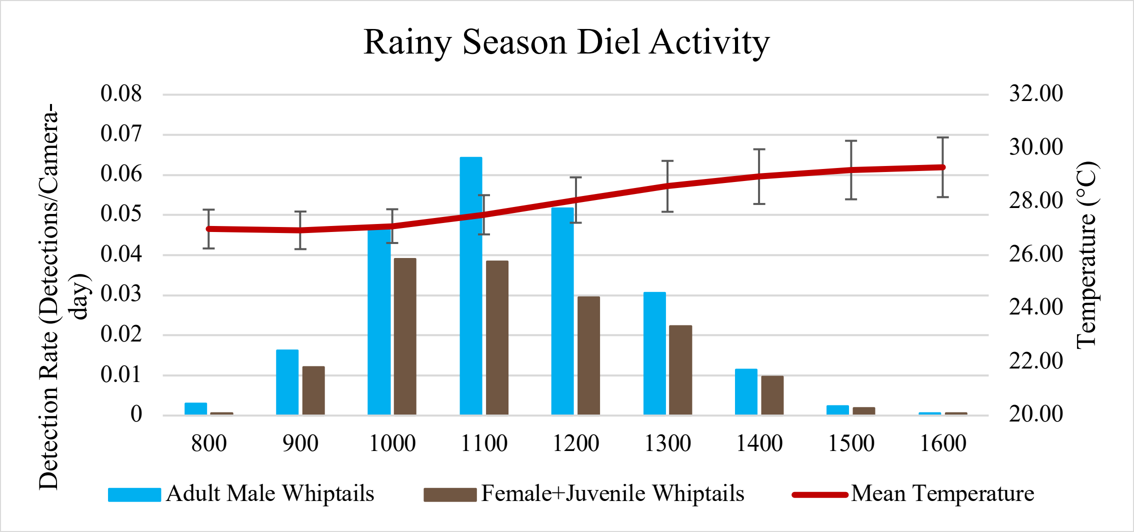

Figure 10b. Saint Lucia whiptail diel activity in the rainy season.

This figure depicts adult male and female+juvenile Saint Lucia whiptail diel activity pattern in the rainy season in the form of detection rate during hourly time periods of the day. Mean temperature ± one standard deviation was included to show the relationship between activity and temperature.

Several chi-squared tests were performed to determine the statistical significance of the seasonal difference in Saint Lucia whiptail diel activity pattern (Figure 9). First, I tested the seasonal difference in activity pattern of all whiptail detections. The results indicate a significant difference in the diel activity pattern of the Saint Lucia whiptail between seasons ($\chi^2 = 20.82$, df = 5, p = .001).

I also performed chi-squared tests to determine the statistical significance of the seasonal difference in adult male activity pattern and female+juvenile activity pattern (Figures 10a & b). There was a significant seasonal difference in the diel activity pattern of adult male whiptails ($\chi^2 = 21.91$, df = 5, p = .001), but there is insufficient evidence to conclude that female+juvenile whiptail diel activity also varies by season ($\chi^2 = 5.74$, df = 5, p = .333).

Saint Lucia Whiptail Seasonal Activity

There were several interesting findings relating to the seasonal activity pattern of the Saint Lucia whiptail. Overall activity increased from the dry season to the rainy season with detections per camera-day of all whiptails increasing from 0.29 to 0.38 detections per camera-day. However, breaking the data down by group into adult male detection rate and female+juvenile detection rate illuminated an intriguing difference. Adult male detection rate remained constant at 0.23 detections per camera-day while female+juvenile detection rate increased 150% from 0.06 detections per camera-day in the dry season to 0.15 detections per camera-day in the rainy season (Figure 11). The difference in seasonal activity between adult male and female+juvenile whiptails was supported by chi-squared analysis ($\chi^2 =.82$, df = 1, p < .0001).

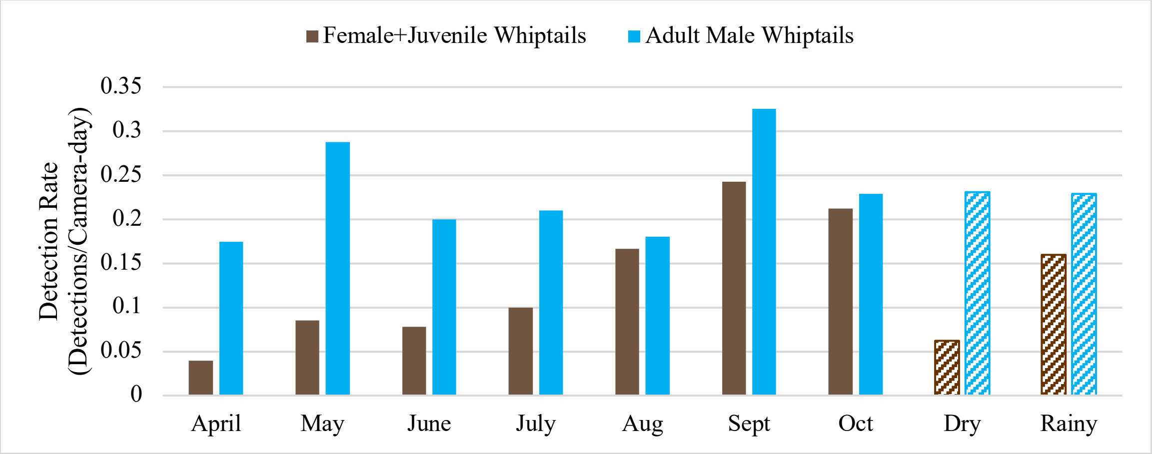

Figure 11. Saint Lucia whiptail seasonal activity.

This figure depicts the seasonal activity pattern of the Saint Lucia whiptail. Brown bars represent female+juvenile activity and blue bars represent adult male activity. Patterned bars are used to depict mean seasonal activity. Detection rate is used to negate the difference in survey effort between time periods.

Regression Analysis of Activity Patterns and Environmental Factors

Several multiple linear regression analyses (Table 2) were performed to evaluate the relationship between various environmental factors and the activity patterns of the Saint Lucia whiptail. The environmental factors included in the analyses were daily rainfall accumulation, daily low temperature, daily high temperature, daily mean soil temperature, daily mean volumetric soil water, daily mean dew point, daily mean cloud coverage, and daily mean wind speed. Rainfall was logarithmically transformed, and number of detections per day, the response variable, was square-root transformed to better fit the models.

The global model included all detections and all environmental variables (Table 2). The intercept was not statistically significant (p = 0.413), suggesting that with the given values of the predictors, the expected number of whiptail detections in a given day

Table 2. Summary of multiple linear regression analyses.

Model	Dependent Variable	Sample Size	Environmental Variable	Estimate	Standard Error	P-value	Model R^2
Global Model: All Whiptails, Full Study, All Environmental Variables	All Detections	209 survey days	Intercept	-1.80	2.19	0.413	0.21
			Precipitation	-0.33	0.13	0.010*	
			Cloud Cover	-0.63	0.20	0.001*	
			High Temperature	0.07	0.06	0.295	
			Low Temperature	-0.06	0.05	0.283	
			Dew Point	0.01	0.07	0.924	
			Soil Temperature	0.12	0.11	0.267	
			Volumetric Soil Water	1.92	2.28	0.400	
			Wind Speed	-0.05	0.04	0.239	
All Whiptails and Full Study	All Detections	209 survey days	Intercept	-0.58	1.61	0.716	0.19
			Precipitation	-0.24	0.11	0.032*	
			Cloud Cover	-0.67	0.18	0.0002*	
			High Temperature	0.11	0.05	0.022*	
			Wind Speed	-0.1	0.03	0.005*	
All Whiptails and Dry Season	All Detections	61 survey days	Intercept	-6.86	2.52	0.009*	0.26
			Cloud Cover	-0.44	0.23	0.064	
			Soil Temperature	0.29	0.09	0.001*	
			Volumetric Soil Water	13.65	6.04	0.028*	
All Whiptails and Rainy Season	All Detections	148 survey days	Intercept	-11.1	4.05	0.007*	0.22
			Precipitation	-0.33	0.14	0.018*	
			Cloud Cover	-0.57	0.24	0.017*	
			Soil Temperature	0.43	0.13	0.0009*	
			Volumetric Soil Water	7.58	2.98	0.012*	

Model	Dependent Variable	Sample Size	Environmental Variable	Estimate	Standard Error	P-value	Model R^2
Male Whiptails and Dry Season	Adult Male Detections	61 survey days	Intercept	-5.37	2.50	0.036*	0.18
			Cloud Cover	-0.28	0.23	0.237	
			Soil Temperature	0.23	0.09	0.008*	
			Volumetric Soil Water	11.95	5.98	0.051	
Male Whiptails and Rainy Season	Adult Male Detections	148 survey days	Intercept	-6.48	3.44	0.062	0.10
			Cloud Cover	-0.42	0.19	0.032*	
			Soil Temperature	0.27	0.10	0.015*	
			Volumetric Soil Water	4.26	2.53	0.095	
Female and Juvenile Whiptails and Dry Season	Female+Juvenile Detections	61 survey days	Intercept	-0.87	0.98	0.377	0.12
			Cloud Cover	-0.30	0.17	0.090	
			Low Temperature	0.08	0.04	0.037*	
Female and Juvenile Whiptails and Rainy Season	Female+Juvenile Detections	148 survey days	Intercept	-10.76	3.40	0.002*	0.18
			Precipitation	-0.25	0.11	0.024*	
			Cloud Cover	-0.39	0.20	0.044*	
			Dew Point	0.12	0.09	0.182	
			Soil Temperature	0.30	0.10	0.003*	
			Volumetric Soil Water	5.00	2.43	0.041*	

*This table displays a summary of the results of the multiple linear regression analyses. The * symbol indicates values that are below the 5% significance threshold. The environmental variables with insignificant P-values contributed to the best performing multiple linear regression analysis for the given dependent variable and were included in the table.*

is not significantly different from zero. Rainfall (coefficient: -0.3294, $p = 0.0104$, $n = 209$) and cloud cover (coefficient = -0.6317, $p = 0.0014$) showed statistically significant negative coefficients, suggesting that as rainfall or cloud cover increase, independent of other variables, whiptail detections decrease. All other variables were not statistically significant. This model had an R-squared value of 0.209, meaning that 21% of the variance in whiptail activity was explained by the combination of rainfall and cloud cover.

The model with the greatest number of significant variables for all detections over the full study period incorporated only rainfall, high temperature, cloud cover, and wind speed as predictor variables (Table 2). This model differed from the global model in that low temperature, soil temperature, volumetric soil water, and dew point were excluded from the analysis. The intercept ($p = 0.716$) was not statistically significant, suggesting that with the given values of the predictors, the expected number of whiptail detections in a given day is not significantly different from zero. Rainfall (coefficient = -0.2425, $p = 0.032$, $n = 209$), cloud cover (coefficient = -0.6681, $p = 0.0002$), and wind speed (coefficient = -0.0964, $p = 0.0051$) showed statistically significant negative coefficients, suggesting that as rainfall, cloud cover, or wind speed increase, independent of other variables, whiptail detections decrease. High temperature (coefficient = 0.1121, $p = 0.0051$) had a positive coefficient, which suggests that as temperature increases, whiptail detections increase. The R-squared value of this model was 0.194, meaning that the combination of rainfall, cloud cover, high temperature, and wind speed accounted for 19% of the variance in whiptail activity in the full study period.

The best performing dry season model included cloud cover, soil temperature, and volumetric soil water as predictor variables (Table 2). In this scenario, the intercept (p = 0.0087) was statistically significant, suggesting that with the given values of the predictors, the expected number of whiptail detections in a given day is significantly different from zero. Soil temperature (coefficient = 0.2934, p = 0.0012, n = 61) and volumetric soil water (coefficient = 13.6504, p = 0.0278) were statistically significant. This suggests that higher soil temperatures and greater volumetric soil water are associated with greater whiptail activity. Cloud cover (p = 0.638) was not statistically significant. The R-squared value of this model was 0.262, meaning that it accounts for 26% of the variance in dry season whiptail activity.

The best performing rainy season model included rainfall, cloud cover, soil temperature, and volumetric soil water as predictor variables (Table 2). The intercept (coefficient: = -11.1033, p: 0.0068) and all variables (rainfall: coefficient = -0.3336, p = 0.0176; cloud cover: coefficient = -0.5704, p = 0.0169; soil temperature: coefficient = 0.4346, p = 0.0009; volumetric soil water: coefficient = 7.5766, p = 0.0121) were statistically significant. An increase in rainfall or cloud cover, independent of the others, is associated with a decrease in whiptail activity while an increase in soil temperature or volumetric soil water is associated with an increase in whiptail activity. The R-squared value of this model was 0.216, meaning that it accounts for 22% of the variance in rainy season whiptail activity.

Chapter IV

Discussion

The original research questions were twofold. Firstly, can COAT camera trapping capture images of the Critically Endangered herpetofauna of Maria Major and, therefore, be used to monitor these species? Secondly, assuming the first to be true, what are the diel and seasonal activity patterns of the species and how do climatic factors influence these patterns?

The COAT camera trapping methodology successfully captured many images of Saint Lucia whiptails and proved itself to be a viable means by which to monitor the lizard (Figure 12). However, its failure to confidently capture any images of the Saint Lucia racer will be discussed below in Research Limitations.

Saint Lucia Whiptail Activity Patterns

I predicted that the Saint Lucia whiptail would exhibit a diurnal unimodal diel activity pattern with a peak in activity occurring in the morning and that the strength of this pattern would be weaker in the rainy season. I also predicted that overall whiptail activity levels would be greater in the rainy season than the dry season. Each of these hypotheses were supported by the data.

The data indicated that the Saint Lucia whiptail is an entirely diurnal species which is active mainly around midday. Analysis of diel activity throughout the study period indicated that activity rose sharply in the hours before noon and then gradually declined and eventually ceased in the afternoon. The sharp increase in activity occurred

Figure 12. Camera trap images of Saint Lucia whiptails.

This figure shows examples of camera trap images of the Saint Lucia whiptail. The top image shows a brown whiptail. Based on its size it is likely an adult female, but it is also possible that it is a male that has not yet started to color change. The bottom image is of an adult male whiptail.

directly after ambient air temperature began to rise. This finding supported the first hypothesis which expected whiptails to reach peak activity in the morning and to reduce activity during the hottest period of the day. This same sort of diel activity pattern has been observed in many *Cnemidophorus* species (*C. nativo*, Vieira Peloso et al., 2008; *C. ocellifer*,; *C. abaetensis*, Dias & Rocha, 2004; *C. cryptus, C. gramivagus, C. lemniscatus, C. parecis, C. ocellifer*, Mesquita & Colli, 2003; *C. littoralis,* Hatano et al., 2001; Teixeira-Filho et al., 1995), though the Saint Lucia whiptail has one of the broader ranges of activity (0800-1630). Despite its broader diel activity range, Saint Lucia whiptail activity is largely concentrated between 0900-1400 which aligns with most *Cnemidophorus* species. The use of camera traps in this study allowed for equal survey effort during the species' fringe activity periods which is generally atypical of standard VES surveys, so this apparent broader range of activity may be more of a result of study design than a unique characteristic of the species.

As predicted, analysis of the time of whiptail detections in the dry season as compared to the rainy season indicated a weakening of the unimodal diurnal diel activity pattern during the rainy season. This was evidenced by the peak activity period (hourly periods where detection rate $\geq$ 80% maximum detection rate) during the rainy season being stretched out over three hours, while the peak activity during the dry season lasted for only one hour.

There are several environmental factors at play that may explain why a prolonged peak in diel activity is observed in whiptails in the rainy season. The rainy season is characterized by increased water, food, and microhabitat availability. Increased rainfall during the rainy season leads to higher humidity levels and more abundant water resources. Increased cloud cover and precipitation during the rainy season can moderate midday temperatures, making ground and air temperatures more favorable to lizards for a longer portion of the day. Increased vegetative cover provides greater microhabitat heterogeneity which can aid lizards in thermoregulation, and increased insect availability provides greater incentive and reward for remaining active for a longer portion of the day (Ryan et al., 2016).

The last Saint Lucia whiptail hypothesis was that overall seasonal activity would be greater in the rainy season than the dry season. This hypothesis was supported by the overall detection rate increase from 0.29 detections/camera-day in the dry season to 0.38 detections/camera-day in the rainy season. However, a closer examination of seasonal variation in whiptail activity indicated a more nuanced pattern. Male activity remained constant between seasons, while female+juvenile activity increased 150% from the dry season to the rainy season.

There are several possible explanations for the increase in female+juvenile activity in the rainy season. One possible explanation is that a portion of female and/or juvenile whiptails estivated during the dry season. Estivation is a state of dormancy, similar to hibernation, that some animals enter during hot and dry periods which allows them to survive through periods of resource scarcity. When food and water resources are scarce, thermoregulation can be difficult, and the potential for desiccation is high. Estivation could also be part of the whiptail's reproductive strategy where pregnant females estivate during a certain period of their reproductive cycle, such as egg development or nesting, which would protect the eggs from environmental stress. Estivation towards the end of the dry season for reproductive purposes could align hatchling emergence with the beginning of the resource rich rainy season giving hatchlings the greatest chance of survival.

Another possible explanation for the increase in female+juvenile activity in the rainy season is that the Saint Lucia whiptail may utilize a reproductive strategy in which hatchlings emerge during the rainy season, whether estivation is involved or not. By synchronizing their reproductive activities with the timing of the availability of resources, hatchlings emerge into an optimal environment for growth and survival (Figure 13). If females are protective of their nesting sites, they may exhibit minimal activity leading up to the rainy season because they are busy keeping watch over their eggs.

Adult males, on the other hand, were equally active during the dry season and the rainy season with a detection rate of 0.23 detections/camera-day in both seasons. This could suggest that male whiptails are not resource limited. There is either sufficient food and water available throughout the year or male whiptails can survive off their fat reserves through periods of resource scarcity. The larger size of male whiptails, and the fact that they do not spend energy on egg production or oviposition, could allow them to remain active through resource scarce periods when female whiptails with less fat reserves are forced to estivate. This pattern of behavior may also suggest that male Saint Lucia whiptails engage in year-round reproductive activity or that breeding is not linked to seasonal patterns, but rather occurs opportunistically. Because there is a statistical significance in the difference between adult male and female+juvenile whiptail seasonal activity, I would predict that the causality is behavioral or physiological given that environmental conditions are the same for both groups.

Figure 13. Camera trap images of young Saint Lucia whiptails.

This image displays examples of camera trap images of young Saint Lucia whiptails. The top image is of a whiptail that is in the process of color changing into its blue adult male coloration. The bottom image is of a juvenile whiptail. It is one of the smallest whiptails detected throughout the study period.

Various multiple linear regression analyses were performed to evaluate the relationship between environmental variables and whiptail activity patterns. The best performing model for all detections over the full study period showed significant negative relationships between rainfall, cloud cover, and wind speed and whiptail activity and a significant positive relationship between high temperature and whiptail activity. The best performing model for all detections in the dry season showed a significant negative relationship between cloud cover and whiptail activity and significant positive relationships between high temperature and volumetric soil water and activity. Lastly, the best rainy season model showed significant negative relationships between rainfall and cloud cover and whiptail activity and significant positive relationships between soil temperature and volumetric soil water and whiptail activity. These relationships all seem intuitively reasonable as whiptails are ectotherms relying on external sources of heat to regulate their body temperature. Rainfall, cloud cover, and wind speed have cooling effects which would reduce activity, while high temperatures and soil water would allow whiptails to be more active under a reduced threat of desiccation.

Despite the intuitive nature of these relationships, they only explained a small degree of the variation in whiptail activity (full study period: 19%; dry season: 26%; rainy season: 22%). A more complete environmental model may help explain a greater degree of variance in activity. The inclusion of daily mean relative humidity and mean daily wind speed could provide more nuanced hydration-related metrics. Including soil temperature measurements or air temperature measurements taken just above the surface could improve the explanatory power of the effect of ambient temperature on the activity patterns of the whiptail. The addition of a measure of vegetation density or structural complexity could improve the model. The inclusion of a measure of prey availability may have the most profound effect on the explanatory power of the model. However, some of this unexplained variation is certainly due to the small daily sample sizes of detections, and the high variance in mean detection rates among the 12 cameras.

Research Limitations

While the investigations into the efficacy of using camera trapping for monitoring the Saint Lucia whiptail and using camera trapping to understand its activity patterns performed well, they were not without limitations. The research limitations can be categorized into three categories: study design, data collection and processing, and data analysis.

When developing the study design for this project, it became apparent that I was time constrained and would not be able to collect data over a 12-month period, the ideal scenario. This would have allowed analysis of the species' activity patterns over a full dry season-rainy season cycle. Because this research began in April and ended in late October, data were collected for the last two months of the dry season and the first roughly five months of the rainy season. The dry season months likely represented whiptail activity at the most resource constrained period of their annual cycle. An evaluation of the entire calendar year could have provided additional interesting insights into the species' activity as resources depleted into the dry season.

Another study design related research limitation was that only about half of the island was able to be included in the study area. A large portion of the island was inaccessible due to safety concerns associated with navigating steep slopes while carrying heavy equipment. We were unable to install camera stations in other areas because the amount of ground disturbance required would have negatively impacted the quality of the habitat or because the ground was simply too rocky or too densely vegetated to navigate through. This resulted in the northwestern half of the island being over surveyed and the southeastern portion of the island being unsurveyed. Ideally, I would have liked to create a grid over the island and randomly select 12 of the squares to place camera stations in. Because this was not possible, I was not able to determine the extent of the island that the whiptail occupies.

There were also several research limitations relating to data collection and processing that occurred during study. Overall, the cameras performed very well. They were active for 2,363 of a possible 2,508 camera-days. Data was lost from four cameras for three reasons. A camera service error occurred resulting in the loss of 35 camera-days of data, two cameras fell over resulting in the loss of 73 camera-days of data, and vegetation filled one camera's memory card with empty images resulting in the loss of 37 camera-days of data. Given that so much data was collected on the whiptail, a 5.8% reduction in survey effort because of lost camera-days is unlikely to have impacted the results.

Missed detections when processing the data, on the other hand, could very well have affected the results. Female and juvenile whiptails, being more cryptic in coloration and smaller in size, were more difficult to detect when processing the images. It is likely that a greater proportion of female and juvenile whiptails were missed than adult male whiptails which would bias the results towards greater adult male activity. Additionally, as the study progressed later into the rainy season, fast growing vegetation moved into many of the frames and blocked out portions of the images, so any wildlife passing beneath the vegetation went undetected.

Research limitations relating to data analysis were likely the most limiting in terms of evaluating the activity patterns of the whiptail and the environmental factors that influence their behavior. The inability of this survey methodology to confidently differentiate between female and juvenile whiptails reduced the explanatory powers of the analyses by creating two separate but inequal groups: one being adult males and the other being juvenile males, juvenile females, and adult females. This limited the ability to confidently make inferences on the reproductive strategy of the species or to fully understand the behaviors of adult female or juvenile whiptails or to evaluate if male and female juveniles differ in behavior.

Another way by which data analysis was limited in this study was through the sourcing of environmental data and the incomplete set of environmental parameters used in the statistical analyses. Temperature and rainfall data came from Hewanorra International Airport. The weather station is likely 1.4 miles away from Maria Major atop the main airport building. The property on which the airport lies is anywhere from 0.75-2.3 miles from Maria Major, so the weather station is likely within about two miles of the island. Rainfall is often highly localized in the tropics, so the rainfall data used in the analyses may have been imprecise. However, imprecise rainfall data may have evened out over the course of a month so monthly mean rainfall accumulation could be fairly accurate. Ambient air temperature data at Hewanorra International Airport may not be too dissimilar from the ambient air temperature on Maria Major; however, the temperatures experienced by whiptails may not be accurately represented by daily high and low temperature or hourly temperature data.

The addition of several environmental variables to the regression analyses could have increased their explanatory power. Incorporating ground temperature data and temperature of the air just above surface level, which are the temperatures that whiptails experience, instead of or in addition to would likely have improved the explanatory power of temperature on whiptail activity. Additionally, incorporating relative humidity could have improved the model's ability to explain the species' hydration requirements. The inclusion of a measure of insolation or habitat complexity could have provided a more nuanced metric to help explain the relationship between temperature and hydration. Lastly, the inclusion of a prey density metric might have had the greatest explanatory power of all the environmental data that could have been used in these analyses and no such data were gathered during this research.

Further Study on the Saint Lucia Whiptail

This research has brought to light several unanswered questions and areas for expansion. The most glaring is continued study for the remainder of the year. This would allow for the analysis of a complete annual cycle of Saint Lucia whiptail activity and reveal how activity declines from rainy season to dry season.

I think it would also be prudent to conduct a study on insect prey availability over the course of a year and to evaluate how environmental variables influence prey availability. This data could be compared to the whiptail activity data to see if whiptail activity aligns with insect prey availability. Additionally, conducting a yearlong whiptail fecal sample collection survey would reveal what food resources are utilized throughout the year.

I also think it could be valuable to explain why some camera stations outperformed others. The mean detection rate for each camera was 0.35 detections/camera-day. Three of the 12 cameras had detections rates below 0.1 detection/camera-day and the best performing camera had a detection rate of 1.05 detections/camera-day. By determining which environmental factors whiptails respond positively to and which they respond negatively to, it could be possible to determine how much of the island is preferred habitat for whiptails. This will likely become increasingly important to understand as the climate changes and microhabitat characteristics change as a result. This could be achieved by conducting a study on the environmental conditions at each camera station using environmental sensors to collect temperature, weather, insolation, and soil data.

Recommendations for the continued monitoring of the Saint Lucia whiptail. COAT camera trapping proved to be a viable methodology by which to monitor the Saint Lucia whiptail and, thus, I believe it can continue to be used to monitor the population trend of the species through time. I recommend experimenting with the camera station design to find the simplest COAT camera trapping methodology that still yields a detection rate similar to what was achieved in this study.

There are several modifications that I would recommend trialing. The first would be to remove the silt fences to determine if the cameras and corkboards alone are able to detect a similar number of whiptails. The silt fences will deteriorate over time and will require replacement. Purchasing replacement silt fences will be costly and they may prove difficult to source on the island. Additionally, the installation of the silt fences is one of the more labor-intensive aspects of camera station installation and requires the most ground disturbance. If detection rate without silt fences is comparable to detection rate with silt fences, I would highly recommend excluding the silt fences from the camera station design.

I would also recommend trialing the use of modified corkboards. I would recommend putting a light coat of white outdoor paint over the corkboard. As the study progressed, the corkboards got dirtier and darker and it became increasingly difficult to locate whiptails amongst shadows, stains, and vegetative debris in the images. In theory, using white-painted corkboards would reduce the likelihood of falsely recording a whiptail detection as an empty image which would increase the accuracy of the data. In addition to painting the corkboards white, I would draw a grid of horizontal and vertical lines spaced 50 mm apart on the boards. This may make it possible to estimate the size of detected individuals more accurately, especially as whiptail size and shape was increasingly distorted the farther the detected individual was from the center of the camera frame. Any conclusions drawn from data where sex and age class were estimated in this way would have to be made warily, but it would be interesting to trial.

This study produced many thousands of empty images. Roughly 20,000 empty images were triggered by live vegetation growing into the field of view of the camera and eventually growing up the T-post. Once vines started growing up the T-post, the camera fired, almost continually until the memory card was filled. I would recommend clearing all vegetation within a 5-foot radius of each camera upon camera station installation and maintaining this live vegetation-free zone at each camera station maintenance visit. Thousands of other empty images were likely triggered by vegetative debris blowing through the camera detection zone. I would recommend washing the corkboard clean at each visit and raking away nearby the vegetative debris.

Once the simplest effective COAT camera trapping methodology is determined I would select a subsample of camera stations to become official Saint Lucia whiptail monitoring stations. I would recommend selecting camera stations that cover a wide range of detection rates (i.e. Camera 8: 0.08; Camera 2: 0.25; Camera 5: 0.33; Camera 3: 0.48; Camera 11: 0.56; and Camera 4: 0.74), while excluding the worst performing and best performing cameras as possible outliers. At the selected subset of camera stations, I would install permanent T-posts anchored into the ground with cement. I predict that six camera stations would be sufficient to monitor the relative abundance and population trend of the species over time which would allow the remaining six cameras to be used for further study elsewhere. Additionally, by using the same camera stations during every survey, changes in detection rates at these locations over time could suggest that environmental conditions at the microhabitat level of the camera station are changing and that the changes are impacting the activity and, potentially, the survivability of the whiptail.

It is not necessary to continually monitor the whiptail on Maria Major year-round and year after year. Rather, I would suggest running the cameras for the same few months every few years. As this research has suggested, it is important to use the same time of year for each repeated survey as activity levels of the Saint Lucia whiptail are seasonally dependent. I recommend using the period of peak activity, which for this study was

August through October. In reality, whiptail activity might have continued to increase further into the rainy season and even into the beginning of the dry season, so if that is found to be true, I would use the three consecutive months with the greatest activity and survey for whiptails during that time period every three to five years.

For example, if one was to use the data from the six aforementioned cameras for the months of August, September, and October 2023, the survey would have detected 189 whiptails in 466 camera-days for a detection rate of 0.41 detections/camera-day. Camera 8 would have detected seven whiptails; Camera 2, 17; Camera 5, 17; Camera 3, 56; Camera 11, 31; and Camera 4, 61. Any large deviations from this detection rate in future surveys could suggest the population is increasing or decreasing. Small deviations would suggest it is stable. This process could be repeated on Praslin Island and Rat Island to monitor the whiptail populations there as well.

Notes on the Saint Lucia Racer

The original goal of this research project was to obtain ecological data on the Saint Lucia racer and, in that respect, the project was a failure. There are many possible reasons as to why I was unable to conclusively capture any images of the racer. I believe the overarching reason is that the camera station design was not compatible with their behavior and ecology (Figure 14).

The Saint Lucia racer is believed to be semi-fossorial and observations most often come from the southern portion of the island where they are observed moving amongst dense clusters of tree roots (pers comm.). The chosen camera station methodology required locations with 20-plus linear feet of ground clear of trees, major roots, large rocks, and cactuses with a soil depth of at least several inches. Therefore, we were unable to install any cameras directly above the preferred microhabitat of the racer which likely severely limited the ability to obtain any racer detections.

Figure 14. Unidentified reptiles burrowing underneath the corkboards.

This image displays two detections of unidentified reptiles. Both reptiles (circled in white) appear to be burrowing underneath the corkboards. This camera trapping methodology is incongruous with their ecologies.

At all camera station locations, the ground was a mix of soil, rock, and tree roots. The center of each camera station required a two-foot by two-foot hole to be dug to a depth of 16 inches to install the T-post and two nine-foot-long trenches that were dug out from opposite ends of the hole at a depth of about six inches for the silt fences to be installed. Upon installation of the T-posts and silt fences, the excavated soil, rock, and vegetative debris was packed back into the holes and trenches, but, because the soil was so dry and irregular, it was exceedingly difficult to pack the excavated materials back in tightly around the T-posts and silt fences. It is very possible that racers moved through the camera stations beneath the silt fences and corkboards rather than moving between the silt fences on top of the corkboards.

I still believe it could be possible to use camera trapping to capture images of the Saint Lucia racer. I would recommend performing racer VES and installing a camera at each sighting location as well as installing cameras at historic racer observation locations. Rather than installing an entire camera station as with this research, I would simply strap a camera to a tree facing the site of the observation or I would utilize the T-posts and camera mounts to position the cameras. Note that the cameras are modified to a focal length of 36 inches, so they should be installed 36 inches from the target area. I would trial this methodology for several months. If it proves to be successful in capturing images of racers, I would continue identifying camera locations with positive racer detections until 12 locations have been identified. I would then run the cameras for a full year. If this study were to yield sufficient information about the racer's diel and seasonal activity patterns, it could greatly enhance conservationist's ability to perform future ecological, behavioral, and physiological research on the snake.

Conclusions

This research represents the first time that camera trapping has been used to evaluate the diel and seasonal activity patterns of a Critically Endangered reptile and the environmental variables influencing those patterns. The data showed that the Saint Lucia whiptail exhibits a unimodal diurnal diel activity pattern with a peak in activity occurring in late morning and the strength of this activity pattern is weaker in the rainy season. Adult male whiptails were shown to be equally active in the dry season and rainy season, while the combined female+juvenile group of whiptails were much more active in the rainy season than the dry season. Whiptail activity was negatively correlated with precipitation, cloud cover, and windspeed, which are all variables that would reduce temperature over the short term, and positively correlated with high temperature, soil temperature, and volumetric soil water. Thus, Saint Lucia whiptail activity appears to be governed by both thermoregulation and hydroregulation. Reduced dry season activity in the female+juvenile group of whiptails may be the result of a hydroregulatory process and could suggest that a portion of the population undergoes estivation during the resource limited dry season. Potential avenues for further research on the Saint Lucia whiptail include investigating the reproductive strategy of the species, determining if the reduction in dry season female+juvenile activity is due to estivation, evaluating the activity patterns of adult females and juveniles independent of each other, and including prey availability, relative humidity, and insolation in the environmental variable analyses of activity patterns.

While this methodology proved unsuccessful at monitoring a semi-fossorial ground snake, it was very effective at monitoring and evaluating the activity patterns of a ground-dwelling diurnal teiid lizard. This methodology could be deployed to monitor other endangered lizards in insular systems. The Caribbean ecoregion, alone, has two additional Critically Endangered teiid lizards, three Endangered teiids, one Vulnerable teiid, four Near Threatened teiids, and nine Data Deficient teiids that this camera trapping methodology could deployed to monitor and study to help ensure the continuity of this ecologically important family of species for generations to come.

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