DIETARY BEHAVIOR OF THE MANGROVE MONITOR LIZARD (*VARANUS INDICUS*) ON COCOS ISLAND, GUAM, AND STRATEGIES FOR *VARANUS INDICUS* ERADICATION

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF THE UNIVERSITY OF HAWAI'I AT HILO IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

TROPICAL CONSERVATION BIOLOGY AND ENVIRONMENTAL SCIENCE

MAY 2016

By

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Acknowledgements

I would like to thank Guam’s Department of Agriculture, the Division of Aquatic and Wildlife Resources, and wildlife biologist, Diane Vice, for financial assistance, research materials, and for offering me additional staffing, which greatly aided my fieldwork on Guam. Additionally, I would like to thank Dr. William Mautz for his consistent help and effort, which exceeded all expectations of an advisor, and without which I surely would have not completed my research or been inspired to follow my passion of herpetology to the near ends of the earth.

Abstract

The mangrove monitor lizard (*Varanus indicus*), a large invasive predator, can be found on all areas of the 38.6 ha Cocos Island at an estimated density, in October 2011, of 6 *V. Indicus* per hectare on the island. Plans for the release of the endangered Guam rail (*Gallirallus owstoni*) on Cocos Island required the culling of *V. Indicus,* because the lizards are known to consume birds and bird eggs. Cocos Island has 7 different habitats; resort/horticulture, Casuarina forest, mixed strand forest, Pemphis scrub, Scaevola scrub, sand/open area, and wetlands. I removed as many *V. Indicus* as possible from the three principal habitats; Casuarina forest, mixed scrub forest, and a garbage dump (resort/horticulture) using six different trapping methods. Cage traps and garbage barrels were highly effective in capturing medium to large adults, while snake traps were the only trapping method that effectively captured neonate monitor lizards. An air rifle with pellet shot removed the most individual *V. Indicus* and was effective in capturing all sizes of the lizards. Polyvinyl chloride pipe retreats and monofilament live snares were much less effective. After 11 months of trapping and shooting on Cocos Island, *V. Indicus* density was reduced to an estimated one *V. Indicus* per ha. Live captured *V. Indicus* were euthanized then weighed, measured, and dissected to analyze diet. Combined with earlier dietary data, I compared the diet of *V. Indicus* before and after an earlier rodent eradication using a prior diet analysis when rodents were present. In contrast to data published on *V. Indicus* from mainland Guam, rodents did not constitute a large percentage of the *V. Indicus* diet on Cocos Island prior to rodent eradication. However, 20 months post-rodent eradication, there were increased numbers of reptile eggs, earthworms, and insect larvae in the stomach contents of *V. Indicus*. Comparison of

the percent occurrence of ingested items from the three different habitats showed that garbage dump greatly differed from the Casuarina forest and the mixed scrub forest. Comparison of diet between the mixed scrub forest and Casuarina forest revealed that while both populations of *V. Indicus* were consuming high percentages of crabs, the species of crab consumed differed between the two areas. Dietary differences were quantified using the Importance Index, which analyzes prey importance in relation to predator body size. Combined prey Importance Index with the prey frequency Index, showed that birds are the most important prey item followed by crabs. Although birds are found in only 4% of *V. indicus* with identifiable stomach contents, birds are the most important component in terms of dietary energy acquisition.

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Chapter 1:

The Use of Different Removal Methods for Culling the Mangrove Monitor Lizard (*Varanus indicus*) on Cocos Island, Guam

Introduction

The mangrove monitor, or "Pacific monitor lizard" (*Varanus indicus)* is a large carnivorous lizard with an extensive distribution. They are found in northern Australia, New Guinea, the Solomon Islands, the Marshall islands, and throughout various regions of Micronesia, including Guam. With such a widespread and insular distribution, the taxonomic status of *V. indicus* populations is frequently re-assessed (Bennett, 1998). Along with broad distribution, there is a large variation in the size of *V. indicus*. *Varanus indicus* is oviparous. Snout-vent length (SVL) can range from 105mm in hatchlings to 433mm in adults (personal observation on Cocos Island, Guam).

The purpose of this study was to reduce the population of *Varanus indicus* on Cocos Island and compare the effectiveness of different removal methods. This study was conducted on Cocos Island, a 0.39 km^2 island located 1.6 km off the southern tip of Guam. A continuing effort to cull the population of *V. indicus* on Cocos Island began in January of 2009 in preparation for the release and introduction of the endangered Guam rail (*Gallirallus owstoni* (USDA, 2009) to the island. *Varanus indicus* is known to consume native birds on other Pacific islands (Uchida, 1966). Cocos Island is composed of seven different habitats; resort/horticulture, *Casuarina* forest, mixed strand forest, *Pemphis* scrub, *Scaevola* scrub, sand/open area, and wetlands. *Varanus indicus* is considered invasive on Cocos Island and is believed to have been introduced in the mid-1980's by both Guam residents and the accidental release of display specimens from a resort on the island (Rodda et al., 1991). Previous studies used different methods to remove large varanid species from an area. In Cape Coral Florida, Nile monitor lizards (*Varanus niloticus*) have become established in the wild as a result of releases by irresponsible pet owners. Havahart cage traps were modified by attaching fine mesh screening to all sides and front door of the trap, reducing the gaps on the frame of the trap to less than 1/4 inch. These modified Havahart cage traps were successfully employed to remove the large lizards (Enge et al. 2004; Campbell, 2005). Smith (2004) used open-ended PVC traps to catch *V. indicus* in Australia, and Reed et al. (2000) used monofilament snare traps to catch *V. indicus* on the island of Rota. A resort employee on Cocos Island, and local trapper, maintained a baited garbage barrel to catch *V.indicus* for his afternoon lunch. However, no study has successfully implemented a multi-faceted approach to removing all sizes of lizards from a population. Simultaneous application of multiple trapping techniques on Cocos Island raised the possibility of significant interactions occurring among them. However the overall goal of removing as many *V. indicus* as possible required application of all techniques.

Varanus indicus is highly arboreal, sometimes climbing trees to heights over 10 meters (Smith 2004). Arboreal habitats make *V. indicus* difficult to catch, and the large range in size from hatchling to adult makes it difficult to estimate the full size distribution. To make an estimate, I used a 1500m transect line across the island and counted the number of *V. indicus* seen within 3 meters of each side (Figure 1). This survey was carried out for 10 days before initiating trapping and after the 11 months of combined trapping and shooting to determine the effect of the removal methods as a whole.

After comparing the effectiveness of each trapping method, in regards to the number and size of individuals caught, I evaluated 8 factors to be considered when conducting a removal of varanid lizards. These were: size classes of *V. indicus* caught, portability of the trapping method in the field, cost per individual trap, time spent preparing the trap, time spent maintaining the trap per day, trap longevity, number of *V. indicus* caught per day, and possibility of bycatches. These were the most important factors in my fieldwork and I ranked each trapping method by how well they scored with all factors combined.

Materials and Methods

Study Site

Cocos Island, at 38.6 ha, is small but has 7 distinct types of vegetative habitats (Figure 1). A 1500m transect was established [as shown in Figure1]. The transect ran from the West to East traversing each of the 7 habitats.

Population Estimation

An approximate population estimate was made to assess the effectiveness of the removal process. *Varanus indicus* is a highly cryptic and evasive species. In a walking survey of the transect, I recorded every *V. indicus* spotted within 3 meters of each side of the transect line. This transect was used for 10 days before and after an eleven month period of lizard removal. The population of lizards, P, was estimated a $P = s * A/a$, where s = the number of animals counted in the sample, A = the total area of Cocos Island, and a = the area sampled on the transect line. The population number was then transformed total Cocos Island population number to density of *V. indicus* per hectare by dividing by the island area (38.63 ha). The estimate assumes all lizards on the transect area, s, are counted and is thus likely an underestimate of the true number. However, survey estimates before and after removal of the lizards offer a measure of the effectiveness of the *V. indicus* removal process. Each habitat was surveyed during the transect, with larger portions of the transect line occurring in the larger habitat areas (resort/horticulture, *Casuarina* forest, and mixed strand forest).

Removal Methods

An effective strategy for *V.indicus* removal was expected to require targeting all body sizes of the lizards. Therefore I made a concerted effort using six different trapping techniques.

Cage Traps

I used Havahart one-door raccoon traps (32L x 10W x 12H inches) and Tomahawk "Trap-Neuter-Return" cat traps (32L x 10W x 12.5H inches). It takes between a 300g and 400g mass animal to trigger and close the trap depending on the individual trap and how sensitive the closing mechanism is set. On more than one occasion*, V. indicus* were seen triggering the cage door to close and then escaping through gaps in the cage floor or through the open vertical space where the trap door meets the side of the cage. Therefore, I modified the cage traps with fine mesh wire to reduce the numbers of escapees. Cocos Island had between 15-22 Havahart cage traps in use throughout the data collection. Each trap was baited with squid and checked twice daily. A cage trap was placed in each habitat, with majority of the traps being placed in *Casuarina* forest and mixed strand forest.

Pellet Guns

A pump action Beeman pellet pistol was used early on in the removal effort. The pellets I used were lead 0.177 caliber and fired at a velocity of around 400-500 feet per second. A pump action high-power pellet rifle was used later. The air rifle fired 0.177 gold alloy pellets at the estimated velocity of 1200 feet per second. The use of gold alloy was claimed by the manufacturer to increase the velocity of the pellet up to 20%. Pellet guns were carried at all times during data collection, in each habitat, and used for any approximately large lizards sighted.

Monofilament Bird Snare

This monofilament snare design was based on Reed et al. (2000). Squares of chicken wire were cut to 50cm x 50cm pieces and 15lb test fishing line was used to create 6 rows of 6 nooses per trap. Defrosted squid was placed on the underside of the chicken wire, and snare traps were secured to tree trunks with cable ties. Two monofilament snare traps were placed on the Southern end of Cocos Island in the mixed strand forest and 15 snare traps were set along a transect in the North of Cocos Island in the *Casuarina* forest.

Snake Traps

The snake traps used on Cocos Island are the standard 2 entrance modified minnow traps used on mainland Guam (Vice et al., 2005). Seventy traps were placed in a stratified haphazard manner throughout Cocos Island in every habitat. These served to both to detect the presence of any brown treesnakes (*Boiga irregularis)* that may have gained access to the island and as a means of catching *V. indicus*. Snake traps were baited twice a week with dead mice. Later on in the study, the traps were baited with squid.

Polyvinyl chloride (PVC) Retreats

The PVC retreat design was taken from Smith (2004). One-meter long sections of 150mm diameter PVC were cut and then sealed on one end with rubber endcaps. Small holes were drilled into the bottom of the endcaps and into the bottom 3 inches of the PVC pipe to prevent flooding from rainfall. The retreats were secured vertically to trunks of trees, at varying heights with duct tape, and were baited twice a week with large amounts of squid. Each retreat was checked twice a day by holding a mirror to the open end of the PVC. The PVC retreats allowed lizards to go in and out. I set 15 PVC traps for 3 weeks on the Northeastern end of the island where *V. indicus* were less dense. With no captures in 2 weeks of trapping, I changed bait from squid to dead whole fish and still had no captures. I also changed the heights of the traps so that the opening ranged from 1 meter above the ground to 3 meters above the ground. The PVC traps were also set on the Southwestern end of Cocos Island, where the population of *V. indicus* had a higher density.

Garbage Barrel Trap

The garbage barrel trapping method is used by local residents to catch large *V. indicus* and requires a large empty plastic garbage barrel and food scraps. The garbage barrel is tilted on a 60-90 degree angle against a tree or wall. There was one garbage barrel trap used on Cocos Island throughout my study and was placed in the resort/horticulture area. If a *V. indicus* was captured, and the local trapper did not feel like eating lizard that day, I was permitted to remove the lizard and make measurements for my study. The local trapper did remove an unknown number of lizards for his personal consumption. Bait for the garbage barrel included dead cane toads, old chicken and fish bones, fried rice with vegetables, and any other odiferous leftover food that was available. Since the trap was installed and maintained by local residents prior to my arrival, the use of squid bait was not employed.

Data Collection

Data collection was performed on Cocos Island 5 days a week between the hours of 8 and 10:30am. All cage and snare traps were set on Monday morning and closed on Friday morning. Snake traps, and PVC traps were active 7 days a week because there was no threat of native birds being caught in the traps.

Once in hand, *V. indicus* were euthanized via decapitation and immediate pithing of the brain. Lizards were then placed in 20 Gallon GLAD zipper bags and the date, location, and method of removal was written on the outside of the bag. To cool down the lizard carcass and preserve stomach contents for further data collection, I froze about 3L of water in a flexible plastic vessel the previous evening and then inserted the block of ice into my field pack on the morning of data collection. The ice insert kept the lizard samples cold, until I could return to the lab and place the samples in a freezer. After thawing, lizards were dissected, measured for snout-vent length (SVL) and total length (TL), sexed, and weighed. Snout–vent length was used instead of total length in future analyses, because a number of lizards were missing the end of their tails.

Comparing Trapping Methods

Trapping methods were compared using eight factors influencing success at capturing lizards or facilitating operation. For each factor, I gave each trapping method a score of 1, 2, or 3. A score of 3 was for a trapping method with the most beneficial results, a 2 was given to trapping methods with intermediate results, and a 1 was given to the trapping methods with the least beneficial results as described below. Therefore, using 8 factors, 24 would be the highest score attainable and the most effective over all factors, while a score of 8 would be the lowest score possible and the least desirable.

Factor 1. Size Classes of V. indicus Caught

The SVL measurements of *V. indicus* caught were divided into 3 categories: small, medium and large. Any SVL less than 300mm was considered small, an SVL from 300mm - 399mm was considered medium, and any SVL above 399 mm was considered large. Each trapping method was given a point for each size class caught. For instance, if a trap caught only medium lizards it was given a 1 and if a trap caught medium and large size lizards it was given a 2.

Factor 2. Portability of the Trapping Method in the Field

Each trapping method was given a score of 3, 2, or 1 depending on the size and weight of each trap. If a number of traps could easily be carried for a long distance it was scored a 3, and a large heavy trap that could only be carried one at a time was scored a 1.

Factor 3. Cost per Individual Trap

I compared the cost of each trap using the normal advertised price. I gave the trap score 3 if the individual trap cost less than $10, 2 if the price was between $10 - $30, and 1 if the trap cost more than $30. I gave score 3 to the "shooting" category, because I shot more than 50 lizards, making the cost per lizard less than $10.

Factor 4. Time Spent Preparing the Trap,

A score of 3 was given to trapping methods that took less than 10 minutes to prepare before being considered active, 2 was given to trapping methods that took between 10 and 30 minutes to prepare, and 1 was given to traps that took longer than 30 minutes to prepare.

Factor 5. Time Spent Maintaining the Trap per Day

Once a trap was set and considered active in the field, it would often have to be re-baited and reset if a lizard or other animal (by-catch) was caught. I assigned a 3 to the traps that required more than 30 minutes for a person to maintain, 2 was given to traps that took between 10 and 30 minutes, and a 1 to traps that took longer than 30 minutes. A 1 was given to the shooting category because a person needs to carry the gun throughout the day.

Factor 6. Trap Longevity

A score of 3 was given to trapping methods that lasted more than a month before needing to be taken out of the field for extensive repair or replacement, a 2 to traps that lasted between one week and one month, and a 1 to traps that needed to be replaced or heavily repaired in less than one week.

Factor 7. Number of V. indicus Caught per Day

A score of 3 was given to trapping methods that caught more than 0.5 lizards per day, a 2 to trapping methods that caught between 0.1 and 0.49 lizards per day, and a 1 to trapping methods that caught less than 0.1 lizards per day.

Factor 8. Possibility of By-catches

Scores of 1, 2, or 3 were given to trapping methods based on the number of different by-catches. For example, if a trapping method only caught *V. indicus* it was given a 3, if a trapping method caught one or two different types of by-catches (i.e. frogs and crabs) it was given a 2, and if a trapping method caught more than two different types of by-catches (i.e. frogs, crabs, and geckoes), it was given a 1.

Statistical Analyses

To provide a measure of the strength of the relationship between lizard SVL and Total body mass I used a linear regression to compute the r^2 value. I also used the one-way ANOVA F-test for explained variance between males and females. To determine SVL between-group variability I used the ANOVA F-test. Once significance was found using the F-test, I compared means using the Fisher LSD test. The Mann-Whitney U test was applied to *V. indicus* seen before and after removal methods to test for significance in the removal of the lizards.

Results

A total of 143 *Varanus indicus* were removed from Cocos Island; 99 by shooting, 20 by cage traps, 16 by snake traps, 5 by garbage barrel traps, 2 by monofilament snare traps, and 1 by hand capture (Table 1). The sizes of *V. indicus* caught ranged from 105mm – 433mm SVL and from 12g – 1772g Total body mass (Figure 2). There was a strong correlation between log transformed body mass and log transformed snout-vent length ($r^2_{(1,141)}=0.94$, $p < 0.005$). There was also a significant difference ($F_{(1,131)}=13.4$, $p=0.005$) between the mean SVL of males (300.8mm) and females (263.8mm.)

The pellet gun effectively took all sizes of *V. indicus* (Figure 3). Snake traps caught smaller lizards (mean =199mm SVL) than the cage traps (mean = 336mm SVL), although there was a small overlap in the sizes of *V. indicus* caught (Figure 4). The PVC traps failed to catch any *V. indicus*.

There was a significant difference among of means of trapping methods ($F_{(5,137)}= 10.14$, $F_{(5,137)} =2.28$, $p < 0.005$). After meeting the criteria of finding significance in the F-test, I used the Fisher LSD test to compare means. There was a significant difference in the mean SVL of *V. indicus* caught in the cat traps versus shooting, the cat traps versus the snake traps, the garbage barrel traps versus the snake traps, and shooting versus the snake traps. There was no significant difference in *V. indicus* SVL means ($F_{(3,139)} = 0.33$, $p=0.81$) across the three sampled habitats on Cocos Island: North, South, and Dump. In the Southwest part, shooting caught the most *V. indicus* per day (0.80), while cage and snake traps were found to be the least effective (Table 3). The North transect had poor results with only 2 catches overall (Table 4). In comparing the different factors of the 5 removal methods, with 24 being the highest score possible, the results were: Shooting = 22, Garbage Barrel Trap = 17, Snake Trap = 16, Cage Trap = 15, and Snare

Trap = 15 (Table 5). Hand capture was not included in the results because of the low sample size of 1. Population estimates show a large change from 6.3 *Varanus indicus* per ha in the beginning to 1.0 *Varanus indicus* per ha after 11 months of hunting and trapping (Table 6).

Discussion

Shooting *V. indicus* was a very effective means of removal of these lizards, and scored the highest in the rating of all the trapping methods. The pellet gun was successful in stunning *V. indicus*, much the way rubber bands work with smaller size lizards. When shot with a pellet gun, the moderate sized *V. indicus* were sufficiently stunned for the shooter to capture, restrain, decapitate, and pith the animal. However, the pellet gun was ineffective in stunning larger lizards, because of their thicker skin and skull. Therefore, the pellet gun was best replaced with a high power air rifle (1200 feet per sec.). In contrast to the pellet gun, the air rifle often killed the lizard immediately, including the larger individuals. In situations where the lizards are to be captured without harm it is important to use a less lethal method. One benefit of using traps, instead of pellet guns, is that a trap can be set and then left alone. The traps in this study were set in shaded areas to protect caught lizards from exposure. Failure to properly shade a trap can result in the death of the captured varanid (Reed et al., 2000)

Cage traps and snake traps caught the largest number of individual lizards by trapping, yet there were more of these traps in operation than the other trap designs. The number of each trap design was not equally distributed in each habitat and therefore trapping success may have been influenced by habitat.

A trap line was run on the North end of the island with 15 cage traps, 15 PVC traps, and 15 snare traps, and only one lizard was caught after 3 weeks of trapping. The PVC traps did not catch any *V. indicus* or non-target species, although modifications of technique were made trying to improve trap performance. Despite Smith (2004) having excellent results catching *V. indicus* with the PVC traps, I did not. Campbell (2005) also had no success with PVC traps in his attempt to catch *Varanus niloticus*. The garbage barrel traps intercepted lizards, but I recovered only four. I assume more individuals were caught using these traps, but the local trapper often checked the traps prior to my arrival and admitted to removing a number of individuals for personal consumption. This trapping method caught larger sized *V. Indicus*, and may be more effective than the data indicated. However, in a large removal project it would be cumbersome to deploy a significant number of such barrel traps.

Snare traps are very inexpensive and highly portable. It took between 1 - 1.5 hours to make one trap, and they are very easy to transport into the field. The largest problem I found with using snare traps is the high number of by-catches. Cocos Island is home to numerous crabs and within one week's time, these crabs destroyed the 15 traps I set in the Northern end of the island. The two snare traps I used in the Southern end of the island each caught a *V. indicus* within 24 hours. However, I was unable to use more snare traps on the Southern end of Cocos Island for fear that the endangered Guam Rail might become entangled in a snare trap. The *V. indicus* caught in the snare traps were of moderate to large size, 220mm and 324mm SVL, and with modifications to the size of the nooses and the thickness of the fishing line it is likely the snare traps can catch very large lizards (Reed et al., 2000). The two *V. indicus* I removed from the snare traps did not show any sign of bodily harm.

Snake traps caught only very small *V. indicus* (mean = 204mm SVL). These traps are easy to transport and easy to maintain. This is the most effective removal method for neonate lizards, because small *V. indicus* can escape a cage trap and it is difficult to shoot a small, fast moving lizard with a high-power air rifle. In one event, a small *V. indicus* was seen escaping under thick refugia so a snake trap was immediately placed there. The following day, a lizard of similar size was found inside the snake trap. A beneficial tactic may also be to set a few snake traps around an area where a large female has been removed. If the female deposited fertile eggs, there is a chance the snake trap will catch her offspring when they hatch. In regards to non-target species I found cockroaches, locusts, hermit crabs, geckos, and skinks in the snake traps. No by-catches were injured and each caught species was promptly released. The limitation of snake traps is that they cannot catch medium to large size *V. indicus* lizards due to the small diameter of the trap entrance.

Cage traps are commonly used to humanely capture small mammals, like rodents and squirrels, and also larger mammals like cats and dogs. These traps are the standard in removing invasive species, and when modified to the proper size the cage traps work well in capturing varanid lizards (Campbell, 2005). Cage traps are simple to use and easy to transport. In Campbell's 2005 study, three different size cage traps were developed to accommodate the long tails of varanid lizards. The cage trap entrance should be free from obstruction to engage the door locking mechanism and fully close. The unmodified short length of my cage traps may be why I did not catch as many large lizards as I had expected. Using different sizes of cage traps might increase the variety of different size lizards caught.

I was only able to catch one *V. Indicus* by hand. The lizard I caught had its tail exposed and I was able to grab it before the lizard saw me. Since I carried an air rifle with me at all times, I always attempted to shoot lizards before trying to grab them by stealth. Other removal methods like pitfall traps and leg-hold traps have been successful in capturing large lizards, but I did not use these methods because of the high probability of capturing unintended, possibly threatened and endangered species (Michalski et al. 2007; Bennett 1998).

Conclusion

Cocos Island was a difficult environment from which to remove lizards. Areas with a high density of terrestrial land crabs proved difficult, because of the high number of by-catches and trap disturbances. Hermit crabs, land crabs, and coconut crabs are notorious for stealing bait from traps on islands (Uchida, 1966). The release of the Guam rail (*Gallirallus owstoni*) during the study also proved to be a difficult factor to work around. However, through the use of different trapping methods applied to particular sites, a substantial number of *V. indicus* were successfully removed from Cocos Island. The population estimate is probably lower than actual numbers, because of the difficulty of spotting neonates or individuals residing in treetops. However, the change from 6.3 *V. indicus* per ha to 1.0 *V. indicus* per ha following the removal effort was a substantial change in lizard numbers.

There are a number of considerations for implementing an effective removal method for varanid lizards: cost, time, physical feasibility, effects on non-target species, and the welfare of the individual lizards captured. All these factors are important elements to be addressed before a removal plan is implemented. This study showed how when a large species like *V. indicus* needs to be removed from an area, it is important to design a method that works with the adults and the smaller growth stages of the species. In cases where an adult individual can be more than 10 times larger than the neonate, one trapping method will not be successful for all sizes. This study is beneficial in expanding current knowledge on methods to remove invasive varanids from an area. The use of a high-power pellet rifle, in conjunction with multiple trapping methods targeting juveniles and adults, can be highly effective management tools in the removal of large lizards.

The culling of *Varanus indicus* on Cocos Island proved fruitful. There is now a reproductively active population of Guam rails on the island in large part because the population of *V. indicus* has been culled. *Varanus indicus* is believed to predate on local wild birds on Pacific islands, and the reduction of *V. indicus* on Cocos Island should reduce this probability (Uchida, 1966). While removing *V. indicus*, techniques for removing invasive lizards have been evaluated and improved. The use of air rifles for killing large invasive lizards and the use of garbage barrel traps are currently being implemented in other areas of the Pacific as a direct result of my research.

Chapter 2:

The Dietary Behavior of the Mangrove Monitor Lizard (*Varanus indicus*) on Cocos Island, Guam

Abstract – The mangrove monitor lizard (*Varanus indicus)* consumes different prey in different habitats. This study examines these differences on Cocos Island among three different habitats; Casuarina forest, mixed strand forest, and a garbage dump. The significance of each prey type was calculated using the Importance Index, which includes the mass of the prey item in relation to the predator's total mass. The data collected were compared to *V. indicus* stomach contents recorded before a rodent eradication on Cocos Island. While *V. indicus* consumed more crabs, reptile eggs, and insects than other prey types, birds and crabs were the most important prey when considering the amount of energy gained per ingested item. *Varanus indicus* collected in the garbage dump area consumed large amounts of human food waste and insects, while the *V. indicus* in the Casuarina forest and mixed strand forest consumed large numbers of crabs. The crabs in the *V. indicus* diet in the Casuarina forest were a different species than the crabs consumed by *V. indicus* in the mixed strand. The removal of rodents from Cocos Island resulted in a large increase in bird and reptile eggs, arthropods, and earthworms consumed by *V. indicus*.

Introduction

Cocos Island has a diverse population of animal species, including 13 species of lizards (Perry et al. 1988). These lizards comprise the most diverse reptile fauna of any island in the Mariana archipelago (McCoid, 1996). The largest of these lizards, the mangrove monitor lizard (*Varanus indicus),* is a large, territorial lizard with a small home range. The average *V. Indicus* moves between 35 - 65 meters a day, and after consuming a large meal it is common for *V. Indicus* to climb to the top of a tree and not move for upwards of 7 days (Smith and Griffiths, 2009). Smaller habitats used by lizards may differ in the amount of food available for consumption, and when there is a large food supply, lizards tend to have smaller home ranges, (Alberts 1993; Smith 1998; Smith and Ballinger 2001; Stanner and Mendelssohn, 1987).

Varanus indicus can be found in all 7 habitats characterized on Cocos Island (Figure 1) but is most often observed in the mixed strand forest or in the garbage disposal area of the resort and horticulture activity (pers. obs.). The mixed strand forest has the thickest undergrowth of any habitat on Cocos Island and although the garbage dump area is very small compared to the rest of Cocos Island, *V. indicus* were commonly sighted there. Resort employees emptied kitchen food scraps into the garbage dump area on a daily basis. Varanid lizards readily eat discarded human food and are often found in higher numbers near open disposal areas where they also find refugia (Auliya, 2003; Shine, 1986; Uyeda, 2009; Stanner and Mendelssohn 1987; Auliya, 2003). In areas where human garbage is available, *V. indicus* will consume food material as well as paper, plastic, and aluminum foil (McCoid and Witteman, 1993).

Available prey and the ability to catch that prey are two of the most important factors determining diet of a varanid lizard (Auffenberg 1981; Bennett 1998; Smith and Griffiths 2009). In habitats with few refugia, the potential for these lizards to capture prey is higher than in a habitat with large amounts of cover (Bartlett and Gates, 1967). A comparison of *V. indicus* in different habitats should help elucidate the effect small changes in environment have on a varanid diet. Dietary variation is often the direct result of variation in prey availability in the ecosystem (McCoid and Witteman 1993; Bennett 1998). Varanid lizards have a highly varied diet, not only between individual species but also between populations of the same species (De

Lisle, 1996). This intraspecific variation depends on habitat and other factors such as prey ability, season, and ontogenetic variations (Losos and Greene, 1988). *Varanus indicus* reportedly consumes mammals, birds, eggs, lizards, snails, crabs, insects, fish, and various other items including food waste left by humans (Dryden, 1965: Shine, 1986: Losos and Greene, 1988).

Many species of rodents are invasive predators that can have devastating effects on endemic insular species, frequently causing extinction of native fauna (Atkinson 1985; Howald et al. 2007). The Polynesian rat or “Pacific Rat” (*Rattus exulans*) is known to eat both plants and animals (Baker 1946; Strecker and Jackson 1962; Williams 1973), and the diverse diet of *R. exulans* can have devastating effects, particularly on smaller islands (Atkinson and Moller, 1990). Predation on local flora and fauna by *R. exulans* can lower numbers of endemic animals through predation and through the reduction of formerly suitable habitat (Craig 1986). *Varanus indicus* is known to consume *R. exulans*, the only rat species found on Cocos Island. In 1965, Dryden examined the food and feeding habits of *V. indicus* on Guam. He collected 86 individuals over the course of 2 years and found *Rattus spp.* in 17% of *V. Indicus* with identifiable stomach contents. A more recent study, conducted by McCoid and Witteman in 1993, analyzed 27 *V. indicus* collected from Guam and the neighboring island of Rota between 1989-1991. Their results showed *Rattus spp.* to be present in 11.5% of *V. indicus* stomachs.

Varanid lizards have diets that are highly reflective of the available prey in their environment (McCoid and Witteman 1993; Philipp and Phillip 2007). Rodents constitute between 11-17% of the *V. Indicus* diet on mainland Guam, and it is logical to expect that if rodents are also available on an island 1.6 km off the coast of Guam, then *V. indicus* should consume this invasive prey species.

The prey consumed by *V. Indicus* varies in size, and some varanid lizards are known to take large prey items (Auffenberg, 1981). Although *V. indicus* consumes large numbers of small prey, it is the large prey that offer the most significant sources of energy in their diet (Losos and Greene, 1988). The actual size of prey in relation to the size of predator is usually not presented in diet studies (Losos and Greene, 1988). Instead, studies often use frequency index to define the diet of a particular species (Dryden 1965; Philipp and Phillip 2007; Uchida 1966). Frequency index is the percent occurrence of a prey type per total sampled specimens. While frequency index determines presence or absence of a particular prey item, the method fails to show the importance of the prey item in meeting the energy requirements of the predator (Pianka 1994). Losos and Greene (1988) examined the diet of *V. indicus* on the species level using the Importance Index. The measure incorporates the size of the prey in relation to predator size and is thus indicative of the energy value a predator can acquire per meal. The Importance Index can be beneficial in understanding *V. indicus* foraging behavior because it includes the fact that a larger animal will seek larger prey.

This study examines a number of factors that may affect the dietary habits of *V. indicus* on Cocos Island. I compared the diet of *V. indicus* before and after a successful rodent eradication, the difference in stomach contents between different habitats, and the size of ingested prey in relation to the predator. I also compared the commonly used frequency index with the Importance Index. The *V. indicus* on Cocos Island are considered invasive, and the data collected help elucidate the dietary habits and foraging behavior of a large invasive varanid that has established itself in a non-native environment. There are migratory birds, and a population of coconut crabs that live on Cocos Island, and the removal of rodents could cause *V. indicus* to start consuming one of these sensitive species.

Materials and Methods

Study Site

Cocos Island is a small 0.39 km^2 island located 2.6km off the southern tip of Guam, in the Pacific Ocean. It contains small bodies of fresh water, endemic and invasive vegetation, and a diverse set of reptile species. There are 13 species of lizards on the island, as well as ghost crabs, land crabs, hermit crabs, and coconut crabs. Non-native Cane toads (*Bufo marinus*) and greenhouse frogs (*Eleutherodactylus planirostris*) are also present, while green sea turtles (*Chelonia mydas*) frequent Cocos Island and nest on the beach.

The island can be divided into 7 different habitats; resort/horticulture, *Casuarina* forest, mixed strand forest, *Pemphis* scrub, *Scaevola* scrub, sand/open area, and wetlands (Figure 1). This study compares stomach contents of lizards taken from the Casuarina forest where there are tall trees with little undergrowth, the mixed scrub forest where there are more heavily branched trees with dense undergrowth, and the garbage dump where there is one tree shading a heap of scrap metal, discarded furniture, cardboard boxes, and decaying human food refuse.

Data collection

Each *V. Indicus* collected was sexed and weighed (g), and the snout-vent length (SVL) mm and total length (TL) mm were measured. Fat bodies were weighed (g), the presence or absence of egg follicles was recorded, and the entire digestive tract was dissected. Ingested items were separated, weighed, and classified to ordinal, familial or generic level. Intact mass of partially digested prey items were calculated from the mass of live prey items recorded on the island or from prey items that were consumed fully intact. Partial items, where intact comparison weights were not available, were not included in the Importance Index data. Likewise, any human food waste *V. indicus* digested was not included in the Importance Index data analysis because there was no way of determining the original mass of the item at time of ingestion. Once all prey masses were measured, the prey mass was divided by the predator mass to derive the prey/predator mass ratio (MR). The Importance Index was calculated by taking the sum of all MRs for a particular prey class and dividing that number by the total sum of all prey MRs. Non-intact prey items were given the mean MR for that type in the species.

The stomach contents of *V. indicus* pre-rodent eradication came from data on 22 individuals collected by Gary Wiles between 1992-1996. Another 5 *V. indicus* were collected and frozen by the USDA just prior to the April 2009 rodent eradication. *Varanus indicus* data were then compared to data collected 18 months after rodents were extirpated from Cocos Island.

Results

I collected 140 *V. indicus* from throughout Cocos Island. Ninety-nine *V. indicus* had identifiable stomach contents. Of the 99 *V. indicus* with identifiable stomach contents, 17 were removed prior to the rodent eradication and 82 were removed post-rodent eradication. Only 1 rodent was found in the stomach contents of *V. indicus*. The frequency index values of the *V. indicus* stomach contents, pre and post-rodent eradication, are shown in Figure 5. Dietary differences after rodent eradication included an in increase in Arthropods from 5.9% to 12.2%, an increase in earthworms from 0 to 7.3%, and an increase in bird and reptile eggs from 5.9% to 25.6%. The number of *V. indicus* with garbage in their stomachs decreased from 23.5% to 8.5%.

Of the 82 *V. indicus* collected post rodent eradication, identifiable stomach contents were found in 51 from the mixed strand forest, 19 from the *Casuarina* forest, and 12 from the Dump area. The frequency indices of prey types found in *V. indicus* are shown in Figure 6. Notable differences include almost half the *V. indicus* from the Dump area were consuming human garbage, while *V. indicus* found in the *Casuarina* and mixed strand forest were consuming significant amounts of arthropods, eggs, and crabs. *Varanus indicus* from the mixed strand forest appear to have a more varied diet, but this is possibly due to the much larger sample size of lizards from the mixed strand forest.

The mixed strand forest and Casuarina forest both had crabs as the most frequent prey item in the *V. indicus* diet. However, the type of crab consumed in each area differed. Figure 7 illustrates the percent occurrence of each crab species found in the diet of *V. indicus* from the two different areas. Eighty six percent of the crabs consumed in the Casuarina forest were land crabs (*Cardisom carnifex*) whereas the crabs consumed by *V. indicus* in the mixed strand forest were 83% ghost crabs (*Ocypode spp.).*

The frequency index of prey consumed per individual can be seen in Figure 8. The sample size used for the Importance Index was reduced down to 75 after subtracting garbage and prey items that did not have an intact comparison to calculate the MR. The particular prey found, the prey's percent occurrence, and prey frequency are shown in Table 7. Data were then converted to the Importance Index. The comparison of *V. indicus* Importance Index data between Losos and Greene (1988) and my data from Cocos Island are shown in Table 8. The data for the Importance Index indicate that birds have the highest importance value in the *V. indicus* diet.

To determine if there was a difference in foraging success in *V. indicus* pre (n=17) versus post-rodent eradication (n=82), I compared numbers of prey items in the individual lizard stomachs. Pre-eradication mean items/stomach was 2.53 ± 2.43 SD while post-eradication mean was 2.40 ± 2.04 SD. The variances were not significantly different ($F_{16,81} = 1.41$, F crit. = 2.04), nor were the means significantly different ($t_{97} = 0.20$, p=0.84).

Discussion

Invasive species are often generalists in their diets (Dukes and Mooney, 1999; Marvier et al. 2004; Murdoch, 1969). *Varanus indicus* is a generalist predator that consumes prey indicative of environmental availability (McCoid and Witteman, 1993). The diet of varanid lizards reflects not only the diversity of available prey but also the relative abundance (De Lisle, 1996). This is an important concept to understand when trying to define the impact an invasive species might have on an ecosystem. *Varanus indicus* is considered invasive on Cocos Island, and to determine the negative impact the species may have on the native habitats, it is important to evaluate the diet and diversity of *V. Indicus* among habitats.

Unlike the *V. indicus* studies conducted on the main island of Guam, the data presented here support the idea that rodents on Cocos Island did not account for a large portion of *V. indicus* diet. Since Cocos Island rodents were not significant prey items themselves, any changes in *V. indicus* diet would probably result from rodents affecting the numbers of other available prey in the habitat. While changes between pre and post eradication were observed (Figure 5), the small sample size of lizards obtained before eradication makes it difficult to attribute the change to rodent removal. The most notable change observed between pre and post rodent eradication in this study was the large increase in the frequency of skink and gecko eggs found in the stomach contents of *V. indicus* following rodent removal. Studies have shown that population densities of insular lizards with *Rattus exulans* present are significantly lower than lizard densities in the absence of *R. exulans* (Towns 1972; Whitaker 1968). Lizard densities in the absence of of *R. exulans* can reach up to 25 times those of islands with *R. exulans* present (Whitaker, 1973). Whether this is due to the lizards and their eggs being consumed by rats, or another pressure applied by the rodents, is not clear. *Rattus exulans* are also known to decrease the population of nesting shore birds, and islands with invasive *R. exulans* have significantly less sea bird populations than islands that are free from these invasive predators (McCallum, 1986). The negative effects of *R. exulans* on native flora may also be a reason for the decline of lizard densities in a particular area (Craig, 1986).

Rattus exulans consumes significant amounts of insects and earthworms (Bettesworth 1972). The large increase in the frequency of reptile eggs consumed by *V. indicus* post-rodent eradication might be correlated to *V. Indicus* reaching higher densities as a result of the invasive pressure of *R. exulans* being relieved. Unfortunately, no lizard density or abundance studies were performed on Cocos Island before the rodent eradication, so there is no definite way of testing this hypothesis. In addition, the small sample size of 17 *V. indicus,* pre-rodent eradication, may not thoroughly represent the earlier diet of *V. indicus* on Cocos Island.

The decrease of garbage being consumed by *V. indicus* appears somewhat counter-intuitive. There were no apparent changes in garbage dumping quantity or quality observed during the study. Rodents are known to eat garbage and their removal from Cocos Island would logically lead one to expect that *V. indicus* would consume more garbage. However, unlike the Norwegian rat (*Rattus norvegicus*), *R. exulans* prefers wild food to garbage (Kami, 1966). Therefore, the removal of *R. exulans* from an environment should not affect the amount of garbage available for other scavenger species. It is important to consider that the garbage dump is not a natural habitat, but is maintained by humans and offers high caloric energy organic waste to scavengers. It may therefore have a particularly large effect on the surrounding ecosystem, despite its very small area. There was a high density of *V. Indicus* at the garbage dump due to the human food waste attraction of scavenging monitor lizards, and there is also a large number of refugia for lizards to find shelter.

Fifty percent of the *V. Indicus* from the garbage dump had human food waste in their stomach contents. This is extremely high compared to the 5.26% of food waste found in the stomach contents in the Casuarina Forest and the 0% found in the mixed strand forest. Not only are *V. Indicus* in the dump area consuming garbage, but also they are eating very little else. Monitor lizards require having a varied diet to meet their nutritional requirements (Bennett, 1998). Whether consumption of garbage meets the nutritional requirements for *V. Indicus* is unknown, but with the high number of individuals in the area and large representation of garbage in the diet, garbage is clearly an attractant. Other varanid species are known to increase population density in areas where human garbage is available (Uyeda, 2009). The large numbers of *V. Indicus* at the garbage dump on Cocos Island suggests that improper garbage disposal by humans facilitates an increase in the population of *V. indicus.*

The garbage dump may also increase populations of other species of lizards on Cocos Island. The stomach contents of *V. Indicus* in the area show increased numbers of lizard eggs consumed. Lizard eggs were found in 41.7% of the *V. Indicus* found the garbage dump, compared to 15.8% in the Casuarina forest and 25.5% found in the mixed strand forest. This increase in egg consumption supports the possibility that there are increased numbers of smaller lizards in the dump area than in the other two sampled areas, and geckos were commonly observed in the garbage dump. The garbage dump offers numerous places for small lizards to hide. Most small lizard species are dependent upon such refugia for predator avoidance (Ruby, 1986). Increased cover provides microhabitat diversity for thermoregulation and it is therefore easier to conserve energy and resources (Bartlett and Gates 1967; Huey 1991; Porter and Gates

1969). Increased numbers of small lizards may explain the lower prey diet variability in the *V. indicus* of the area. Eggs are a high-energy resource and if are abundant and accessible in the garbage dump, *V. indicus* may select eggs over insects in the dump area. Populations of *V. indicus* from the mixed strand forest and Casuarina forest consume significant amounts of insect larvae, cockroaches, and orthopterans, and it is remarkable that the *V. indicus* from the dump area do not. The garbage dump may have changed the food web in regards to biomass of trophic levels per unit area and accessible prey items, but further research is needed to affirm this.

Philipp and Phillip (2007) found crustaceans in 63% of the *V. indicus* they dissected. A finding of 57.9% of crabs in the stomach contents of *V. indicus* from the *Casuarina* forest and 45.1% of crabs in the stomach contents of *V. indicus* from the mixed strand forest is not surprising because of the dense numbers of crabs in the area. What is remarkable is the actual species of crabs being consumed. Eighty six percent of the crabs consumed in the *Casuarina* forest were land crabs and 83% of the crabs consumed in mixed strand forest were ghost crabs (Figure 7). Both crabs are present in each environment, but land crabs are known to live more inland, whereas the ghost crabs live closer to the shore (Burrows and Hoyle 1973; Wood et al. 1986). There is a large body of fresh water in the *Casuarina* forest and the area from which I removed *V. indicus* is further from the beach than in the mixed strand forest. This 100m difference in relation to the ocean appears to result in a dramatic difference in the species of crab being consumed.

The Importance Index is a favored method for analyzing the behavior behind a predator's dietary choices, because it takes prey mass and thus food energy acquisition into account. Large *V. indicus* continue to eat small invertebrates despite their smaller prey to predator weight ratio (Dryden, 1965). A frequency index shows if a lizard eats an insect but, it does not include information on whether the lizard was a juvenile or an adult nor does it explain if the insect consumed was large or small. For instance, a 12g neonate *V. indicus* might consume a 4g grasshopper or an 1800g adult *V. indicus* might consume a 1g grasshopper. The prey/predator mass ratio for the two items are 0.33 and 0.001, meaning the small lizard just consumed 33% of its own weight while the adult consumed only 0.1%. This very large difference would not be apparent in a simple frequency index. While this example appears extreme, it is not unrealistic. *V. indicus* adults and juveniles consume prey items that produce an even larger range of prey to lizard mass ratios. One problem I found using the Importance Index is that one or two consumed prey items can drastically affect the results. In my study, I found a *V. indicus* that consumed a 150g bird and another lizard that consumed a 50g bird. These are the only 2 accounts I have of intact bird predations, and those events alone make birds the highest importance for *V. indicus*. The Importance Index would be significantly different if I did not have, by chance these two birds in my data, or had additional birds consumed. The Losos and Greene (1988) diet study found no birds in *V. indicus* stomach contents. This may be why our results significantly differ. If I were to find 2 large geckos in the stomach contents of 2 *V. indicus,* instead of 2 birds, my results would quite parallel the results of Losos and Greene. In dietary analysis cases in which very low numbers of very large prey items may be consumed, it is critical to have large sample sizes of individual stomach contents for analysis.

Conclusion

This study showed how diet analysis using both frequency index and Importance Index help determine what and why an animal is eating a particular prey type. Comparing my data with Losos and Greene (1988) adds support to the claim that lizard diets differ geographically over small areas of habitats. Most lizard diets are composed of numerous small invertebrates and a few larger vertebrates (Shine, 1986). My study supports the general observation that, with a few exceptions, there is no correlation between body size of a varanid lizard and size of prey (Auffenberg 1981; Weavers 1989). Other than the bird consumption events, crabs and reptile eggs appear to be the dominant prey type consumed by *V. indicus* on Cocos Island but the diet of these lizards also included small insects. The analysis of *V. indicus* diet on Cocos Island also demonstrates how invasive varanid lizards can exploit native fauna as prey and suggest that using stomach contents, from predators with a broad diet, might be an effective technique for assessing changes in the level of available prey in an area. The change in diet between *V. indicus* in the garbage dump site and the 2 forest sites adds support to how improper disposal of human food waste can change the predator prey dynamics in an environment.

Tables

TABLE 1. Summary of *Varanus indicus* removed from Cocos Island.

	n	SVL Range (mm)	SVL Mean (mm)	SVL Standard Deviation
Shooting	99	106 – 430	272	65
Cage Trap	20	264 – 433	336	43
Snake Trap	16	105 – 285	199	58
Garbage Barrel	5	289 – 423	335	55
Snare Trap	2	220, 324	272	74
Hand Capture	1	340	340	N/A

TABLE 2. Summary of Fisher LSD Test

Group vs. Group (Contrast)	Difference	Test Statistics	p-level	Accepted or Rejected
Cat Trap vs. G.B. Trap	1.7	0.05	0.96	Rejected
Cat Trap vs. H. Capture	-3.6	0.06	0.95	Rejected
Cat Trap vs. Shot	64.6	4.30	0.00	Accepted
Cat Trap vs. Snake Trap	137.0	6.67	0.00	Accepted
Cat Trap vs. Snare	64.5	1.42	0.16	Rejected
G.B. Trap vs. H. Capture	-5.2	0.08	0.94	Rejected
G.B. Trap vs. Shot	62.9	2.24	0.03	Rejected
G.B. Trap vs. Snake Trap	135.4	4.32	0.00	Accepted
G.B. Trap vs. Snare	62.8	1.23	0.22	Rejected
H. Capture vs. Shot	68.1	1.11	0.27	Rejected
H. Capture vs. Snake Trap	140.6	2.23	0.03	Rejected
H. Capture vs. Snare	68.0	0.91	0.37	Rejected
Shot vs. Snake Trap	72.5	4.39	0.00	Accepted
Shot vs. Snare	-0.1	0.00	1.00	Rejected
Snake Trap vs. Snare	-72.6	1.58	0.12	Rejected

(H. Capture = Hand Capture, and G.B. Trap = Garbage Barrel Trap).

TABLE 3. Number of *V. indicus* caught per trapping method in the South transect.

	***V. indicus* Caught**	**Trap Days**	***V. indicus* Caught per day per Day**
Shooting	40	50	0.80
Cage Trap	8	911	0.01
Snake Trap	6	750	0.01
Garbage Barrel	3	14	0.21
Snare Trap	2	10	0.20

TABLE 4. Number of *V. indicus* caught per trapping method in the North transect.

	***V. indicus* Caught**	**Trap Days**	***V. indicus* Caught per day per Day**
Shooting	0	14	0
Cage Trap	2	210	0.01
Snake Trap	0	210	0
PVC Trap	0	210	0
Snare Trap	0	31	0

TABLE 5. Rating of trapping methods.

Method	Size Classes Caught	Trap Maneuverability	Cost per Trap	Time Spent Prepping	Time Spent on Trap per Day	Trap Longevity	Catches per Day	Possibility of By-catches	Total
G.B. Trap	2	1	2	3	3	3	2	1	**17**
Cage Trap	2	2	1	2	3	2	1	2	**15**
Shooting	3	3	3	3	1	3	3	3	**22**
Snake Trap	2	2	1	3	3	3	1	1	**16**
Snare Trap	2	3	3	1	1	1	2	2	**15**

(G.B. Trap = Garbage Barrel Trap).

TABLE 6. Population Estimate of *V. indicus* on Cocos Island.

	Number of *V. indicus* seen in 10 days	Average Seen per Day	Total Area/Sampled Area (m^2)	Average seen x Total Area/Sampled Area	Number of *V. indicus* per hectare
Beginning of Removal	57	5.7	42.92	244.64	6.33
After 11 months	9	0.9	42.92	38.63	1.00

Number of *V. indicus* seen per sampled area was multiplied by 42.92 to estimate the total number of *V. indicus* for the entire island. The Mann-Whitney U test when applied to the number of *V. indicus* seen at the beginning of removal compared to 11 months later showed a significant difference at the level of $p<.05$ ($Z=2.419$; $p=0.016$).

TABLE 7. Stomach content data from *Varanus indicus* on Cocos Island.

Stomach contents of 99 *V. indicus*	n	% Total	Frequency	Mean per Stomach ± S.D.
Pisces				
Unidentified	20	20.2	5	4.00 ± 4.80
Reptilia				
Eggs				
Unidentified	47	47.5	23	2.04 ± 1.40
Sauria				
Gekkonidae				
Hemidactylus frenatus	2	2.0	2	1.00
Lepidodactylus lugubris	1	1.0	1	1.00
Gehyra oceanica	1	1.0	1	1.00
Scincidae				
Carlia ailanpalai	3	3.0	3	1.00
Cryptoblepharus poecilopiturus	1	1.0	1	1.00
Unidentified	8	8.1	8	1.00
Testudines				
Cheloniidae				
Chelonia mydas	1	1.0	1	1.00
Aves				
Eggs				
Unidentified	2	2.0	2	1.00
Charadiformes				
Anous stolidus	1	1.0	1	1.00
Passeriformes				1.00
Passer montanus	1	1.0	1	1.00
Unidentified	2	2.0	2	1.00
Arthropoda				
Arachnida				
Chilopoda	8	8.1	5	1.60 ± 0.55
Crustacea				
Decapoda				
Anomura				
Birgus latro	2	2.0	2	1.00
Coenobita sp.	4	4.0	4	1.00
Brachyura				
Cardisoma carnifex	12	12.1	11	1.09 ± 0.30
Ocypode sp.	24	24.2	22	1.09 ± 0.43
Unidentified	12	12.1	12	1.00
Insecta				
Blattoidea				
Periplaneta americana	14	14.1	13	1.08 ± 0.28
Coleoptera	10	10.1	8	1.25 ± 0.46
Orthoptera				
Locusta migratoria	13	13.1	13	1.00
Unidentified larvae	26	26.3	13	2.00 ± 2.31
Annelida				
Haplotaxida				
Lumbricidae	11	11.1	6	1.83 ± 0.40
Human garbage waste	9	9.1	9	1.00
Total	235		169	1.39 ± 1.28

TABLE 8. Comparison of importance indices for the diet *Varanus indicus*.

Importance Index for *Varanus indicus*		
Prey types	Losos & Greene	Present Study
Lizards	**0.261**	0.077
Lizard Tails	0.000	0.014
Reptile eggs	**0.106**	**0.111**
Turtle head	0.000	0.005
Frogs	0.015	0.000
Mammals	**0.116**	0.000
Fish	**0.125**	0.019
Orthopterans	**0.219**	**0.051**
Beetles	0.000	**0.111**
Roaches	0.011	**0.055**
Earthworms	0.000	0.008
Unidentified Larvae	0.001	**0.057**
Spiders	0.025	0.000
Centipedes	0.000	0.009
Crabs	**0.110**	**0.205**
Crabs Claws	0.000	0.009
Molluscs	0.012	0.000
Birds	0.000	**0.265**
Bird Eggs	0.000	0.002
Vertebrates	**0.623**	**0.361**
N	18	99
# Items	25	235

The Losos and Greene (1988) data are compared to the present study. Bold type reflects prey types with percentages higher than 5%.

Figures

FIGURE 1. Microhabitats on Cocos Island. Transect line was run from West to East.

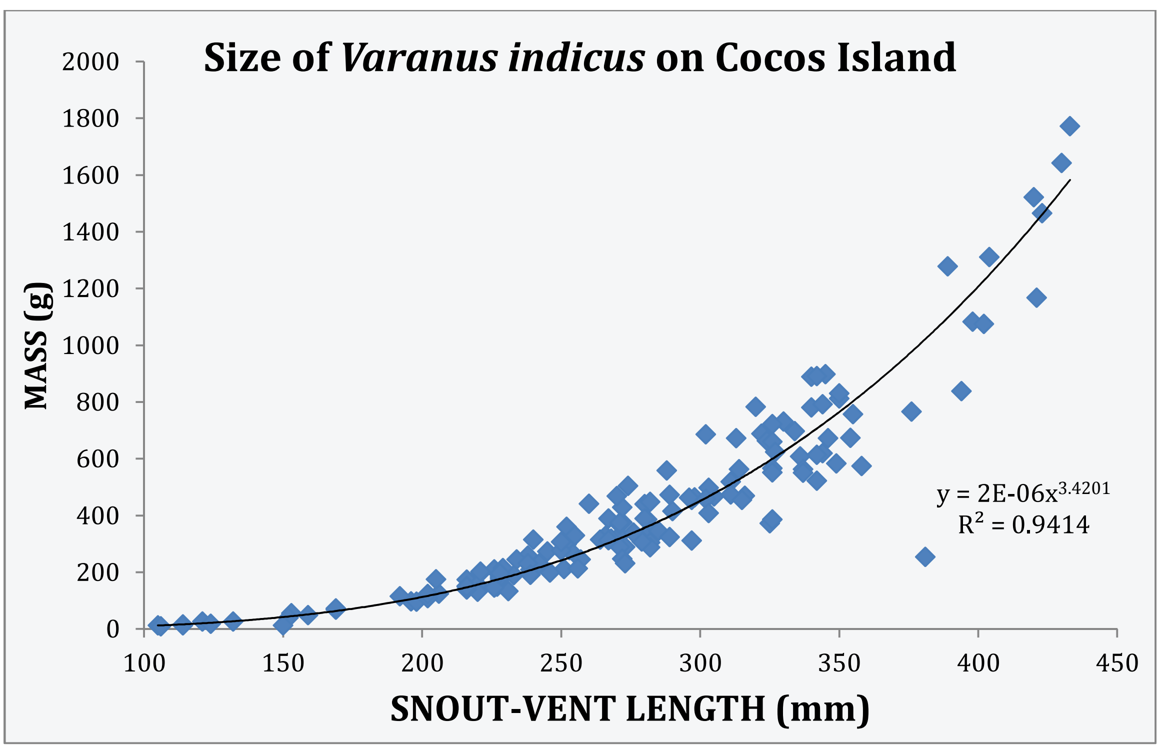

FIGURE 2. Size of all *Varanus indicus* removed from Cocos Island.

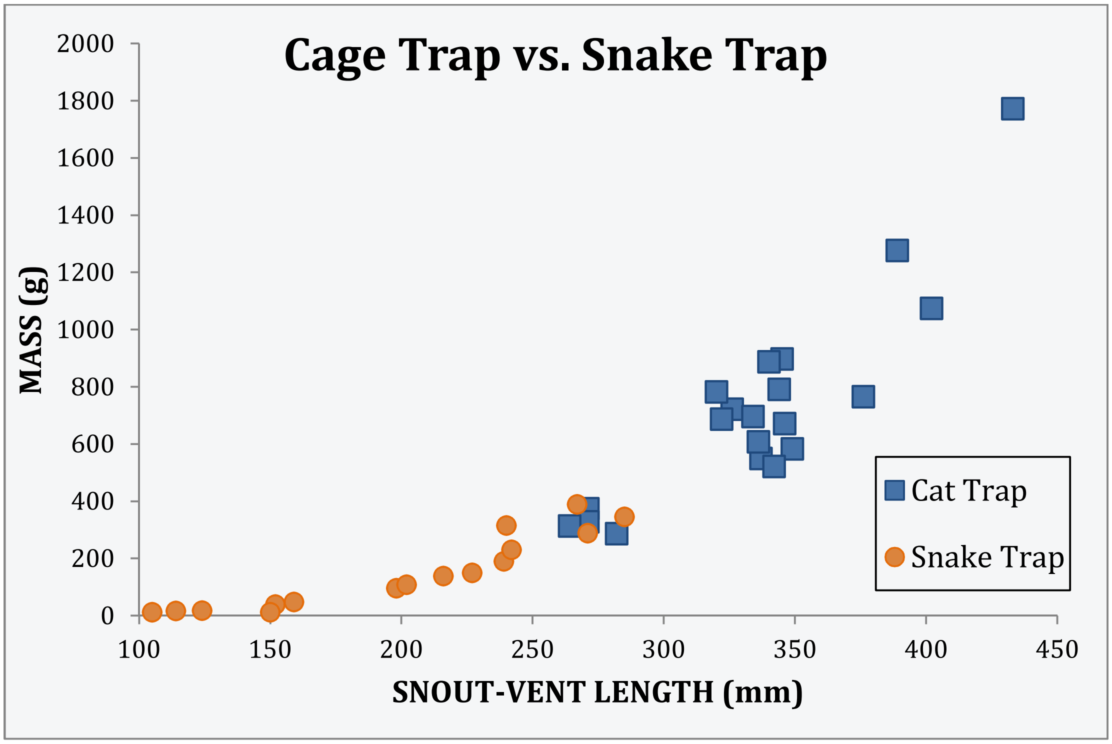

FIGURE 3. Size of *Varanus indicus* removed from Cocos Island by pellet gun.

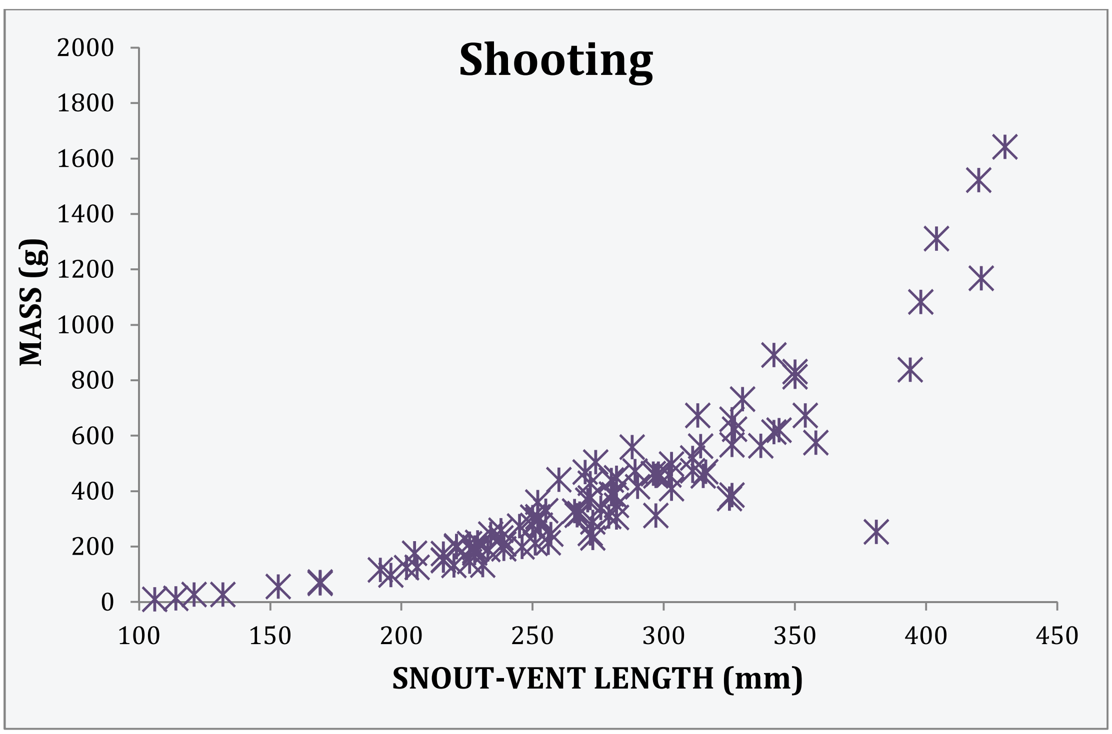

FIGURE 4. Size comparison of *Varanus indicus* removed using cage traps and snake traps.

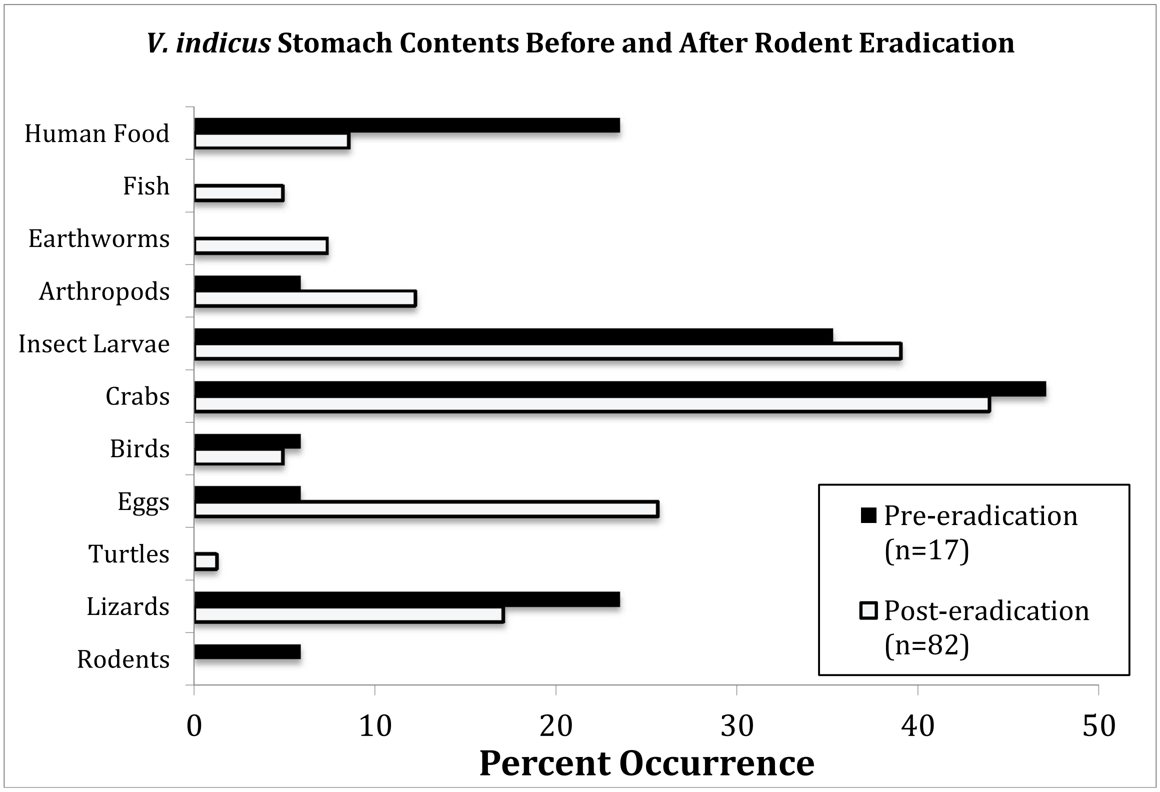

FIGURE 5. The Frequency Index of prey type in the stomach contents of *Varanus indicus* on Cocos Island before and after a rodent eradication.

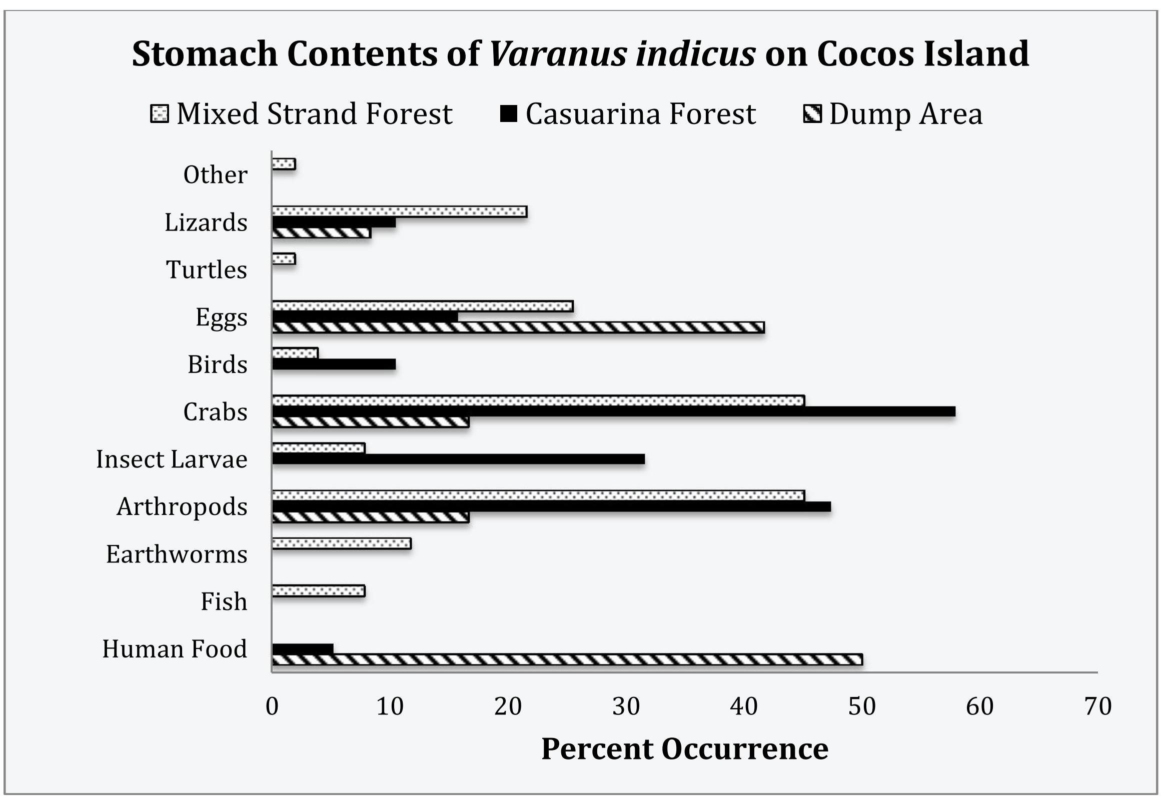

FIGURE 6. Frequency Index of *Varanus indicus* stomach contents on Cocos Island.

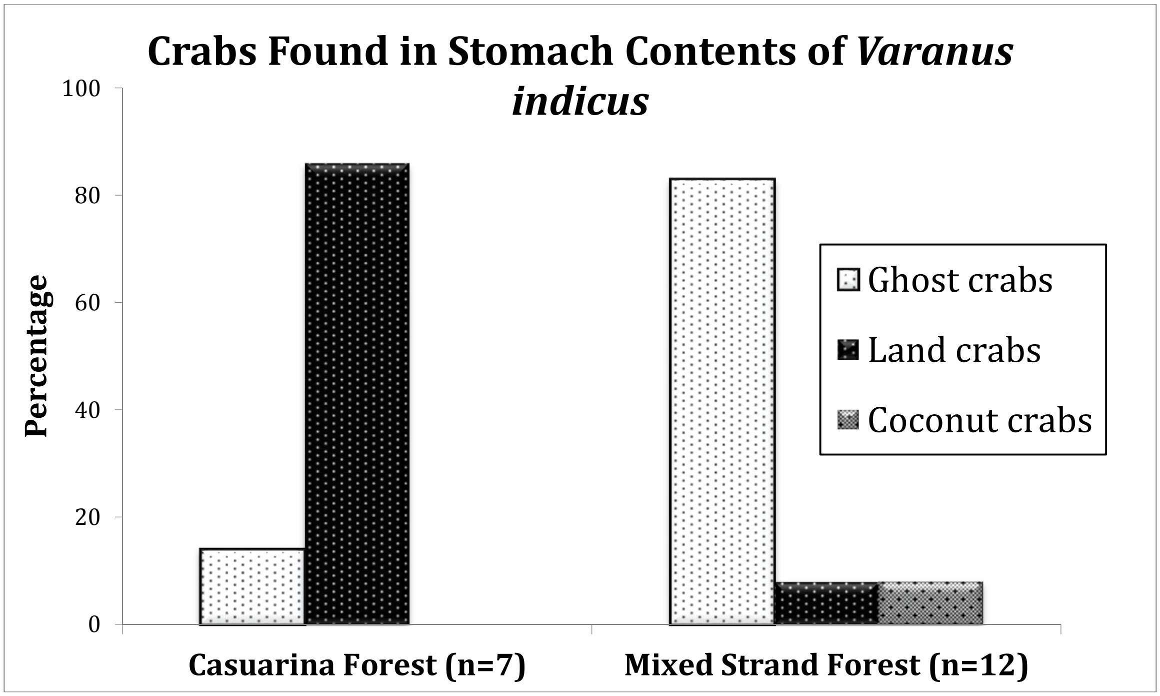

FIGURE 7. The Frequency Index of three crab species found in the stomach contents of *V. indicus* from two different habitats on Cocos Island.

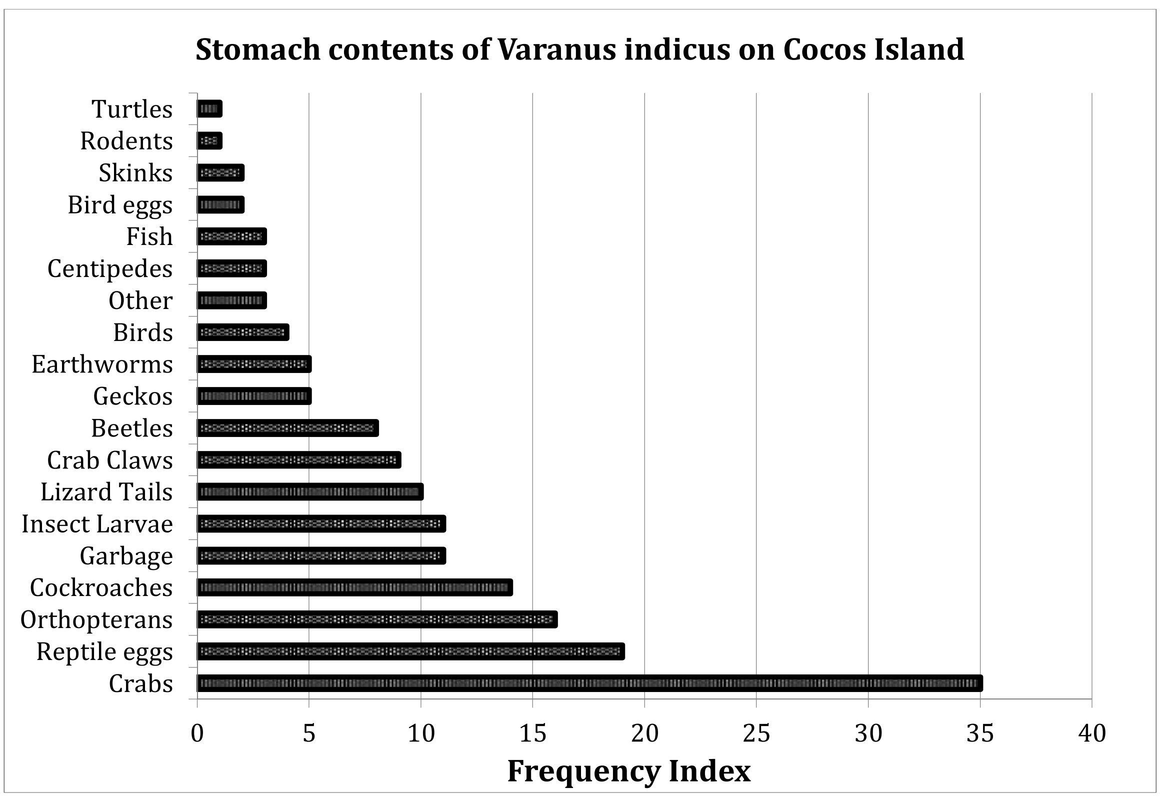

FIGURE 8. Data from 99 the stomachs of *V. indicus* that contained identifiable contents. If bait used from trapping was found in the stomach, it was not included in the data.

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