Activity, Distribution, and Density of Brown Rats (Rattus norvegicus) on Misali Island, Pemba Island, Tanzania

Raegan Hasselbring

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Activity, Distribution, and Density of Brown Rats (*Rattus norvegicus*) on Misali Island, Pemba Island, Tanzania

Raegan Hasselbring

Tanzania-Zanzibar: Coastal Ecology and Natural Resource Management

Fall 2019

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I would like to thank first and foremost my family for patiently listening to everything I had to say about this program and this project and being a rock for me to lean on when I needed it. I would also like to acknowledge the total support received from Dr. Richard Walz and my fellow classmates for my personal and academic endeavors. To the rangers on Misali Island, I hope they are well and I appreciate their hospitality which went as far as bringing us pounds of peanut butter from Chake Chake and chopping up *nazi* every time we asked for it. Also thanks to Mohammad who provided us with Kiswahili lessons.

To my colleagues on Misali Island, thank you for constant positivity and lots of fun and laughs. There would not have been anyone better to spend 3 weeks exploring an uninhabited island with. I want to thank spring tide for getting rid of the sand flies. I would also like to acknowledge neap tide and the scorpion or spider that stung Abby’s leg – both of which do not deserve thanks and ruined the good vibes. Finally, I want to thank my iPhone (and AirDrop) for being basically the only piece of technology that functioned for me on this program, even though it is shattered into eternity.
Abstract

This project investigated the activity, distribution, and density of brown rats (*R. norvegicus*) on Misali Island, Pemba. These factors were studied through field observations conducted over a 21-day observation period. Brown rats were highest in density around areas of human activity, attracted to the detritus, an ample food source. Although highest in density in these areas, a greater total population of brown rats was distributed in the coastal forest due to its proportion of area on the overall island. In the forest, the rats were most active along the coastal sections for unknown and unexplored reasons – possibly due to regular ocean detritus. Based on ad hoc observations, the rats pose some threats to native flora and fauna including disease and out-competition. Brown rats are considered pests on Misali Island, as they destroy human infrastructure and property. The project establishes baseline information to address this problem and reduce the impact of rats on conservation in this protected area.

DHAHANIA

*Utafiti ulichunguza vitendo, usambaaji, na idadi ya Panya wa chakleti (R.norvegicus) katika kisiwa cha Misali, Pemba. Mambo hayo yaliifanyiwa utafiti wa kiuchunguzi katika maeneo yaliotengwa. Utafiti huu ulifanyika kwa muda wa siku 21-uchunguzi ulifanyika wakati wa mchana. Panya wa chakleti (R. norvegicus) walikuwa wengi katika maeneo ambayo watu wanafanya shughuli zao, wanavutiwa na uchafu, mabaki ya vyakula. ingawaje walione kana wengi katika maeneo hayo, idadi kubwa ya panya ilisambaaa katika msitu wa maweni. Kwa kiasi kikubwa Kisiwani mote. Kwa sababu zizizoelewaka na mtafiti– inawezekana ni taka za bahari. kulinganisha na uchunguzi wa “ad hoc “, panya wanawabisha madhara kwa baadhi ya miti na wanyama asilia pamoja na kusambaza maradhi pia na kushidania chakula na wanyama wengine. Panya wa chakleti katika kisiwa cha Misali wanafanya uharibifu wa miundo mbinu na vifaa. Utafiti huu unatoa msingi wa kuendelea na tafiti nyengine siku za usoni kuweza kupunguza athari za Panya katika kuhifadhi eneo la Kisiwa*
Introduction

The islands of the Western Indian Ocean have slowly been introduced to invasive rat populations, which are transported unintentionally by human voyageurs or fishermen who encounter these islands. Due to the adaptability of rat species, they can quickly colonize islands and utilize a variety of food resources that in turn cause deleterious effects to native flora and fauna (Piertney et al., 2015). Invasive rat species in the Western Indian Ocean have been researched to a far lesser extent than those in temperate climate regions. Further research is necessary to guide management of rat populations on tropical islands and examine their effects on native species.

This project has two goals. The first goal is to answer the question of how the activity, density, and distribution of brown rats vary across Misali Island west of Pemba Island. Moreover, the project gives a brief outline of the challenges that invasive rats pose to the island’s ecosystem. The project gathers baseline data and establishes a springboard for future researchers to complete more in-depth studies on the rat’s effects on specific habitats or species on Misali Island. The second goal of this project is to develop an outline of a management plan that can be employed to eradicate the rats on Misali Island. Overall, this project is significant because it takes steps to address the rats on Mislai Island and suggests a plan to reduce their impacts on the conservation area.

Background

This project focuses on the effects of invasive species on tropical islands, specifically the brown rat species Rattus norvegicus. This species is found throughout the world’s islands. It
presents an extreme threat to the native flora and fauna, especially on tropical islands where food sources are bountiful and temperatures are stable year-round.

**Invasive Rat Species**

Invasive species are non-native species that have been introduced to a new environment with deleterious results. The invasion of rats across the world’s islands is an example of an successful invasive species event. Three species of rats are most widespread in colonizing the world’s islands: the black rat (*Rattus rattus*), the brown or Norway rat (*R. norvegicus*), and the Pacific rat (*R. exulans*). Their successes can be attributed to their elasticity in diet and ability to reproduce very quickly. Individuals of these species have been found to exclusively use resources found in the immediate habitat where they spend most of their time (Ruffino et al., 2011). Analyses of stomach contents reveal that these rats consume a variety of food items that range from various species of plant life to eggs of seabirds and sea turtles and even sea turtle hatchlings themselves (Caut et al., 2008). Since rats can reproduce and multiply so quickly, their demand for food links to the local extinction of various species of flora and fauna, including 16% of insular small mammalian species since the 1500s (Harris, 2009). The dietary preferences of two rat species - *R. rattus* and *R. exulans* - suggest that, in general, what they consume is similar across these species and the effects on plants and invertebrates are widespread (Duron et al., 2019).

**Invasive Rats in the Indian Ocean**

Invasive rat research, management, and eradication efforts mostly focus on temperate islands rather than tropical regions. Eradication techniques have been developed and refined on temperate islands, as eradication tends to be more successful on islands that have less food
resources and harsher temperatures, that put a greater pressure on the rats to survive than the bountiful resources and stable temperatures of tropical islands (Harper & Bunbury, 2015). However, this is not to say that eradication efforts have not been attempted in the tropics; there have been well-documented efforts in the South Pacific, Mexico, and in the Galapagos Islands of Ecuador (Harper & Bunbury 2015). In the western Indian Ocean, 93% of islands have been introduced to at least one invasive rat species. Eradication efforts have been employed on 45 islands, most of which are territory of the Seychelles and Mauritius (Russell et al., 2016).

Table 1: Rat eradication attempts in the Western Indian Ocean (adapted from Russel et al., 2016: 139). This table shows the number of eradication attempts on various islands in the Western Indian Ocean.

<table>
<thead>
<tr>
<th>Location</th>
<th>Number of eradication efforts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zanzibar</td>
<td>1</td>
</tr>
<tr>
<td>French Southern and Antarctic Lands</td>
<td>5</td>
</tr>
<tr>
<td>Seychelles</td>
<td>38</td>
</tr>
<tr>
<td>Rodrigues</td>
<td>3</td>
</tr>
<tr>
<td>Mayotte</td>
<td>4</td>
</tr>
<tr>
<td>Mauritius</td>
<td>15</td>
</tr>
<tr>
<td>British Indian Ocean Territory</td>
<td>6</td>
</tr>
<tr>
<td>Cargados Carajos</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>74</td>
</tr>
</tbody>
</table>

It is important to note that not all eradication attempts mentioned in Table 1 were successful. Due to the ability of rats to rebound quickly from a reduced population, many islands experienced a repopulation or reinvasion of rats. Due to this ability of rats, larger and more expansive areas - whole archipelagos instead of individual islands - may need to be eradicated of rats to prevent reinvasion (King et al., 2011). However, if islands are closed off to boat traffic or there are substantial measures to prevent rats from rafting from island to island, it is possible to eradicate one island of invasive rats without involving an entire archipelago (Russell et al., 2016). There are many examples of successful eradication efforts in the western Indian Ocean; only one of which, however, was in the Zanzibar Archipelago situated 25-50km off mainland
Tanzania. This eradication was performed on Chumbe Island, approximately 7km from the west coast of Unguja (Table 1).

Chumbe Island Eradication

In 1996, the invasive rat population on Chumbe Island was addressed and eradicated. Rodenticide was used to eradicate the population of rats, and up until the present Chumbe Island has remained free of any invasive rat population. To accomplish this, vessels have been closely monitored when they arrive to the island to avoid reintroductions (Riedmiller, n.d.). Other than the Chumbe Island eradication, there has been little initiative to organize eradications on other islands of the Zanzibar Archipelago. After multiple databases were searched, there was also found to be no published literature on the density, activity, distribution, or even the effects of invasive rats on the Zanzibar Archipelago, including in the urban centers of Stone Town and Chake Chake.

Study Site

Misali Island is a small island located 8km from the west coast of Pemba Island within the Zanzibar Archipelago, Tanzania. In 1988, the Misali Island Marine Conservation Area (MIMCA) was established. Soon afterwards a non-extraction zone was incorporated in which recreational activities and research is permitted, but extraction of natural resources is not permitted (Poonian, 2008). In 2006, Misali’s MPA boundaries were expanded to create a chain of MPAs along the west side of Pemba, which became known as the Pemba Channel Conservation Area (PECCA) (Jones et al., 2019). There are no permanent residents on the island, but there are two rangers who enforce the non-extraction zone. Additionally, there are two
fishermen’s villages which are both occupied at different points during each month depending on the tidal cycle.

Misali Island is approximately 1.75km across as its longest point (N-S) and 800 meters across at its widest point (E-W). There is a dense coral rag forest surrounded by beaches or coral rag cliffs and fringing reefs in its near shore waters. The island is mostly flat and has a notable diversity of terrestrial and aquatic wildlife. Fishermen and tourist boats provide a way for new species to raft to the island. It is highly likely that the population of *Rattus norvegicus* (brown rat) on Misali Island was introduced by rafting on fishermen or tourist boats, as, for instance, fishermen routinely camp on the island. When the rat introduction took place is unknown, but it was reported that the population of rats seemingly exploded in fall 2018 (Mattanovich, 2018).

Misali Island has been influenced by human activity, which makes it ideal to compare rat activity in the influenced areas to the activity observed in its uninfluenced (or less influenced) coral rag forest. The small size of the island also makes it an ideal laboratory to study rat activity, distribution, and density.
Figure 1: Misali Island is located in the Zanzibar Archipelago east of mainland Tanzania; Misali is indicated by the blue marker just off of the east coast. Google Earth, accessed December 1, 2019.
Figure 2: Misali Island located 12km off the west coast of Pemba Island (top). Satellite image of Misali Island (bottom). Misali is indicated by the blue markers. Google Earth, accessed December 1, 2019.

**Methods**

Multiple methods were employed to make scientific observations of *R. norvegicus* and to calculate its overall population and density. Methods included measuring environmental zones, walking transects, and observing rats at distinct locations.
Niche and Transect Measurements

On Misali Island, observations were carried out from November 8 to November 27, 2019. On November 8 to 10, different niches and transects were measured using a known stride length. In order to calculate the density of rats per hectare and the overall population in the forest and the areas of human activity, the length of the area observed in each environmental zone on the island had to be documented. Four environmental zones were measured: the two largest beaches, the mangrove forests, the areas of human activity, and the expansive forest. Two subsections of the forest were also distinguished by location and floral characteristics and then measured for project purposes.

To determine the length of the forest transect, the number of steps required to complete the transect was recorded and then converted into meters. As part of the transect through the forest also ran through the beachfront and an area of human inhabitation (the eastern fishermen’s camp) where rats would not be recorded, these were omitted in the calculation of the transect length. The area of human activity was measured by finding the length of two sides of the polygon and then finding the overall area from those measurements. There are two distinct areas of human activity on the island, both of which were measured by stride, but only one of which observed to collect data. The ranger station and northern fishermen camp were used for ad hoc observations, but due to the presence of fishermen in the eastern fishermen camp, it was not studied in detail. In estimations for population, the area of the eastern fishermen’s camp was incorporated and it was assumed that rat activity in this area would be similar to the northern fishermen’s camp so that an estimate of the population could be made without direct observation. The beach was measured by stride length during spring low and high tides and then the area of
each was averaged. Due to the density of the mangrove forest, measurements were taken from a previous survey done in the Spring of 2019 (Benson, 2019). The total area of the island was calculated by using the Google Earth measurement feature.

Figure 3: The Google Earth measurement tool was used to estimate the total area of the island, 780,843.6m². Image obtained from Google Earth. Accessed November 30, 2019.

After the total area of the island was determined, the areas of human inhabitation, mangrove, and beachfront were subtracted from the total to find the area of the remaining forest. Within the forest, there were two distinct areas: a dense area of forest often found far from the coast, and a sparse area of forest found closer to the coast. The sparse area was identified by the absence of thick brush and presence of smaller trees and was also measured using stride length and converted to meters (Figure 4, Image A).
Figure 4: Sparse (top, A) versus dense (bottom, B) sections of forest. The sparse areas are characterized by absence of thick brush and presence of smaller trees, the dense area had very thick low-lying brush and larger trees relative to the sparse forest.
Transects

Due to the density of the forest on Misali Island, the trail system that had already been established was used as a 2.5km transect around the island.

Once the transect was established, it was walked three times per day, from 8-8:40AM, 11-11:40AM, and 5:30-6:10PM. On these walks, any rat that was observed within 5m of either side of the transect was recorded along with the weather, time, distance from the transect, and any other interesting observations about its behavior, if necessary. Part of the transect crossed the beachfront and areas of human activity. If any rats were observed in these areas or within 10m of these areas, they were not counted in the data collection.
After the transect was completed, the ranger station, tourist area, and campsite (the area of human activity/influence) were observed for rats. Since the forest transect would take 40 minutes to walk on average and the area of human activity was smaller than the forest transect, a ratio was used to find the time to observe the area of human activity that would match the forest transect, which was 14 minutes. No circuitous path through the area of human activity had been established, so general reconnaissance was conducted through this location for 14 minutes. Care was taken to not retrace any steps to lower the chance of double counting of rats. The forest transect ended directly at the beginning of the area of human activity. After the forest was walked, the area of human activity was observed from 8:40-8:54AM, 11:40-11:54AM, and 6:10-6:24PM. The transect through the forest and the area of human activity were observed three times a day every other day for 16 days (8 days of observations). This resulted in 24 data points for each area.

Location Observations

Every other day (in opposition to the transect walks), five locations around the island were observed for 10-minutes each three times per day. The locations were selected for areas where rats had been seen frequently and all were placed in different environments along the forest transect.
Location 1 was just off of the beach, location 2 was situated close to a known active burrow and within the forest, but still close to the waterfront, location 3 was within a dense part of the forest far from the waterfront, location 4 was located in the fishermen’s village, and location 5 was at the trash pile behind the rangers’ kitchen. Each location was observed for 10 minutes between the hours of 8-9:30AM, 11-12:30PM, and 5:30-7:00PM. The number of rats observed and any other interesting observations were recorded. These locations were observed for a total of eight days, resulting in 24 data points for each location. Refer to the appendix for examples of data tables and the overall work schedule.

*Ad hoc Observations*

Ad hoc observations were employed during the 21-day study period. Sections of forest and areas of human activity were baited during night and day. There were night walks through the forest and along the beach and a general reconnaissance of the mangrove forest and West
Island. In addition, there were observations of rat activity at night in the campsite. Ad hoc observations periods were not scheduled.

Results

When relevant, comparisons were made among time, weather, and location conditions and their effects on rat activity. These findings and their relationships were tested statistically for significance.

Density and Population Estimates

The highest number of rats seen in any one forest and human activity transect walk and the measured areas of each were used to calculate the density to rats per hectare (Table 2).

<table>
<thead>
<tr>
<th>Niche</th>
<th>Area (m²)</th>
<th>Estimated population</th>
<th>Percentage to total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area of human influence</td>
<td>23343.4</td>
<td>26</td>
<td>4.9%</td>
</tr>
<tr>
<td>Forest</td>
<td>685,564.8</td>
<td>503</td>
<td>95.1%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>708,908.2</strong></td>
<td><strong>529</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

Transects
Forest and human activity transects were walked 24 times total over an 8-day period and observed for rat activity. The total number of brown rats seen during each time period is shown in Figure 7. These results demonstrate that there is a significant difference in rat activity based on the time of day, with more rats seen in the evening along both the forest and human activity transects.

![Total Number of R. norvegicus Documented in Forested and Human Activity Areas During Three Time Slots](image)

Figure 7: Total number of brown rats observed in forest and human activity transects during three time slots, 8-9AM, 11-12PM, and 5:30-6:30PM. One-way repeated measures ANOVA for rats observed in each time slot (forest), $F = 54.392$, df = 21, $p < .00001$. One-way repeated measures ANOVA for rats observed in each time slot (human activity), $F = 45.176$, df = 21, $p < .00001$.

The weather was also recorded during each transect walk and the number of rats seen during each type of weather condition were compared in Figure 8. During sunny and cloudy weather conditions, the number of rats observed was 129 and 120, respectively; during rainy conditions, the number of rats observed was 37, but there were significantly less rainy days than sunny or
cloudy days. It is important to note that an ANOVA with repeated measures was unable to be performed because of the unequal number of days. The one-way ANOVA performed still showed no significant difference in activity between weather conditions regardless of the variation in available data. In-field observations also support that there is no difference in activity based on weather conditions.

**Figure 8**: Total numbers of brown rats seen on transect walks during sunny, cloudy, and rainy conditions.

A comparison between the forest transect and the area of human activity was also performed. Due to the differences in area, the number of rats seen was reduced to per 1000m² to equalize the area. Figure 9 shows a significant difference in the activity of rats on a daily basis between the human activity and forest transects with many more rats being observed in the human activity transect.
**Figure 9**: Brown rats observed in forest and human activity transects per 1000m$^2$. T-test assuming unequal variance, df = 7, $p = .0053$.

Additionally, as mentioned before, the forest contained areas of sparse and thin forest depending on their proximity to the coast. This was also compared in Figure 10 by equalizing the areas of each to rats per 1000m$^2$. There is a significant difference between rats observed in these two niches of forest, with many more rats being recorded in the sparse forest near the coast.
Figure 10: Number of brown rats seen in sparse and thin forest per 1000 m$^2$. T-test assuming unequal variances, df = 7, p = .0026.

**Locations**

As with the transect walks, each of the locations were observed 24 times over an 8-day period. Rat activity was found to be higher at night and highest overall at location 5: the trash pile. Location 4 also had high activity, situated in the fishermen’s village, and location 2 had high activity in the evening as compared to the other locations (1 and 3) in the forest.
Figure 11: Total number of brown rats observed at each time slot and location over the 8-day observation period.

<table>
<thead>
<tr>
<th>Location</th>
<th>8-9:30AM</th>
<th>11-12:30AM</th>
<th>5:30-7:00PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>15</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>30</td>
<td>40</td>
</tr>
</tbody>
</table>

The time slots for the number of rats observed at each location were summed and compared. They showed no significant difference in rat activity between times. Thirty-nine, 24, and 103 total rats were observed between 8-9:30AM, 11-12:30PM, and 5:30-7:00PM, respectively (Figure 12).
Figure 12: Total number of brown rats counted during three time intervals while observing the 5 locations. ANOVA repeated measures, $F = 4.209$ df $= 12$, $p = .0564$ (not significant at $p<.05$).

Each of the five locations was also compared with tests of significance. Activity based on location was found to vary significantly. The most rat activity was seen at locations 5 and 4, the two areas of human activity observed. Sixty-five rats were observed at location 5 and 62 rats were observed at location 4. In contrast, only three rats were observed at location 1, which was the least active location of the five areas studied (Figure 13).
Figure 13: Total number of brown rats observed at each location over the 8-day observation period. ANOVA repeated measure, $F = 22.746$, df = 35, $p<.00001$.

*Ad hoc Observations*

Over the 20-day period, ad hoc observations were recorded. Anything observed that appeared out of the ordinary activities for *R. norvegicus* was recorded.
Table 4: Ad hoc observations and number of times each was recorded.

<table>
<thead>
<tr>
<th>Observation</th>
<th># of times observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nearby water pool</td>
<td>2</td>
</tr>
<tr>
<td>Jumping</td>
<td>18</td>
</tr>
<tr>
<td>Climbing</td>
<td>9</td>
</tr>
<tr>
<td>Entering/Exiting burrow</td>
<td>5</td>
</tr>
<tr>
<td>Chasing</td>
<td>6</td>
</tr>
<tr>
<td>Tumor growth</td>
<td>16</td>
</tr>
<tr>
<td>Eating forest resources</td>
<td>6</td>
</tr>
<tr>
<td>Interactions with other species</td>
<td>4</td>
</tr>
<tr>
<td>Eating detritus</td>
<td>27</td>
</tr>
<tr>
<td>Seen in mangroves</td>
<td>2</td>
</tr>
<tr>
<td>Seen on West Island</td>
<td>1</td>
</tr>
<tr>
<td>Climbing on tent</td>
<td>6</td>
</tr>
</tbody>
</table>

In addition to ad hoc observations performed on rats, any other mammal observed was also recorded. In the future, if a management plan was to be employed and rodenticide was used on the island, it is important to note that other mammals may be affected. Other mammalian species include vervet monkeys (*Chlorocebus pygerythrus*), the greater galago (*Otolemur crassicaudatus*), and a shrew which is thought to be the Asian musk shrew (*Suncus marinus*) but would require genetic testing to confirm (Packenham 1984). The Asian musk shrew is likely an introduced species to the Zanzibar Archipelago, originating in Asia (Kingdon 1997).
Discussion

Possible explanations for results and errors are discussed for niche measurements and calculations, transect walks, location observations, and ad hoc observations.

*Niche Measurements, Density, and Population*

Due to the size of the island, the niche measurements were restricted to being estimated by foot or on Google Earth. Although there is likely to be some error associated such as miscounted steps when walking or failing to get an exact measurement on Google Earth, the use of this method for estimation was adequate. These measurements were used to calculate the density and population for the forest area and human activity area. As expected, the density of rats in the forest was much lower than the density of rats in the area of human activity. The rats were drawn to the detritus that was left behind from meals eaten on the island or from trash generated by the human activity on the island. The *population* of rats, however, is projected to be much higher in the forest as the forest comprises about 90-95% of the total island’s area. The rat population and density were estimated by using the highest count of rats taken from each transect walk because it was assumed to be the best representation of the number of rats present on the island.

One error in estimating the population for the human activity area is that no data was collected at the eastern fishermen’s camp, but the area measured for this camp was still used in calculations. The assumption that the activity of rats in this area is the same as the northern fishermen’s camp may not be accurate because fishermen do not consistently occupy this specific camp, while in the north there is always some human activity whether it is fishermen, tourists, or rangers. Additionally, although the highest observation count was used for estimating
density and population, this could still prove inaccurate, as rats are burrowing creatures. The observations made only took into account rats that were visible – above ground. Catch and release methods were unable to be utilized in this study for safety reasons, which would have been much more accurate for a population census than observation. Due to this, it is likely that there is ten times the number of rats than what was estimated from observations, meaning the actual population could be around five to ten thousand (Richard Walz, personal communication, December 9, 2019).

**Transects**

Data from transects were used to compare different time slots, weather conditions, niches, and forest types. Comparison from the different time slots showed significant differences in the amount of rat activity based on the time of day. This was expected because rats are nocturnal creatures (Kurle 2008). Although they also were active during the day, especially in locations with human influence, their activity was generally highest during the evening periods of the study.

Weather conditions were also compared for rat activity but based on observations there was no difference in rat activity whether it was sunny, rainy, or cloudy. There were not an equal number of days for each weather condition to statistically determine differences, but in-field observations made it apparent that there was no weather preference for rat activity on Misali Island.

As mentioned previously, rat activity and density were higher in areas of human activity. The two niches - forest and human activity - were directly compared with statistical measures, showing a significant difference in rat activity between these areas. Presence of human litter allowed the rats to get an easy meal and supported a larger density of rats in a smaller area. For
evidence of this trend, refer to the ad hoc section for observations on rats within the area of human activity.

Another comparison done was on the two distinct areas of the forest: denser, inland forest and sparse, coastal forest. Rat density was higher in the sparse areas of forest. The reason for this preference among rats is unknown and remains examined. The sparse areas may be preferred because of a greater availability of food (possible ocean detritus) or ease of building burrows due to soil type and fewer tree roots.

Ideally, catch and release would have been used for density estimates, but observations along transects were suitable for measuring the forest in regard to rat activity. The possibility of double counting a rat on one walk through the forest or the area of human activity was low as no steps were retraced. A source of error to note was that no transects or observations were run during complete darkness. This cut the time when rats were likely at their highest activity. Due to this, the estimation of density was likely lower than reality. When comparing the sparse sections of forest to the dense sections, it was sometimes difficult to determine whether a section of the forest was “dense” or “sparse” as the criteria were vague. This transect ran through many of the “sparse” areas of the forest, which were only present along the coast, but the majority of the forest itself would be classified as dense. Due to this, and the significance in the change of the activity of the rats between these two forest niches, the calculation for density in the forest was likely skewed. Rat activity was higher for the coastal areas, which was not taken into account when the overall density was calculated.

Locations

As with the comparison between the forest and the areas of human activity transects, the locations observed also showed higher rat activity where humans had greater influence over the
environment. Rat activity based on time and locations were compared for the data collected at the five observation locations. Although had an impact on rat activity, the time of day did not have as significant an effect as it did when the transects were walked. This is likely because two of the five locations were placed in areas were rat activity was expected to be very high. These two locations - 4 and 5 - were in areas of high human influence. Often times there was food or litter left behind from human meals and activities during the day, which likely caused the rats to be more active in seeking out resources during daylight hours. Although the rats were more active at night, they were still active in the morning in areas of human activity.

Locations themselves were also compared and found to significantly impact rat activity. Since locations 4 and 5 were nearby human habitation, they were much higher in activity than locations 1, 2, and 3. Location 1 had the lowest activity, as it was close to the beach and brown rats on Misali Island had an apparent aversion to the beach unless entering the campsite. Location 2 was next to an active burrow, which was inactive during the day, but rats would often be seen entering and exiting the burrow from the hours of 5:30-7:00PM. Location 2 was removed from areas of human influence and the rats in this area did not seem to be nearly as active during the daylight as those in areas of human influence. Location 3, situated in dense forest, was oftentimes not active either. Like the transect walks, the locations were never observed after dark. It is clear rat activity was higher at dusk. In the future, it would be useful to observe rat activity after dark.

Ad hoc Observations

Ad hoc observations of rat behaviors were performed, unscheduled, throughout the 20-day observation period. Throughout this period, rats were seen primarily in forested areas and areas of human influence, but twice they were sighted in the mangrove forest and once on West
Island, which is a small island off of the west coast of Misali Island. Since West Island is only made accessible during low tide, brown rats may have inhabited the small island, or one may have accessed it during low tide. Since the mangroves were inundated with salt water, the rats seen there likely were looking for food resources. Rats were never observed on the beach except when entering the researchers’ campsite where they would sift through researchers’ possessions for anything edible. The rats were also observed climbing the researchers’ tent between the hours of 9PM-4AM. Oftentimes, rats would climb trees or onto roofs of structures as high as 8m from the ground. Many times, the trees were used as a way to escape potential predators, especially humans. No organism on the island was observed to hunt rats, but they would often run from humans within 2-3m.

During the night, areas of human activity were often baited and would attract six to seven rats at a time. Specifically, the trash pile behind the ranger’s kitchen was often teeming with rats, as food was routinely thrown there after meals at a regular time of day. This trash pile not only attracted about ten to fifteen rats per night, but also coconut crabs, hermit crabs, and the greater galago, In the daytime, vervet monkeys and one species of shrew, likely the Asian musk shrew, were also attracted to the open waste pile. Oftentimes the rats would not interact with other species around the trash pile, even though they coexisted there. Only four inter-species interactions were observed, which included rats grabbing food from hermit crabs twice, a coconut crab advancing towards a rat attempting to take its food, and a vervet monkey scaring a rat from the trash pile during daylight.

Rats also were observed consuming resources in the forest. By sifting through leaf litter, the rats were able to find juvenile plants, fungi, and roots they were able to consume. The consumption of roots and young plants prevents many species from growing to adulthood or kills
off already mature plants, causing harm to the native habitat. Rats on Misali Island may also put strain on the native species by outcompeting them for resources. For example, the coconut crab (*Brigus latro*) has seen its population numbers decline on Misali Island since 2006. From 2006-2018, population estimates have declined from 390 to 57. In part, this reduction can be attributed to increased populations of brown rats. Misali Island is one of the strongholds for coconut crabs in the western Indian Ocean, as it has little overall influence from human activities. If pressures are not eased for the coconut crabs, it is highly likely its population on Misali Island will disappear.

In higher density areas, multiple rats had a large swelling (tumor) on the back of the body. Rats carrying this swelling typically performed as normal; however, one which looked particularly close to death would not move away when approached and was followed by a group of flies. It appeared that only rats in the area of human influence were infected with this affliction, as it was never observed in any of the rats recorded in the forest. A possibility for this observation could be a cancer growth from consuming toxic trash at the waste pile. This also suggests that brown rats could be substantial disease vectors for other mammals on Misali Island, including humans.

The high density of rats around the tourist drop-off as well as the competition between species for food makes rats an influential invasive pest. There is likely a connection between the decrease in the population of coconut crabs and the activity of the brown rat on Misali Island. In addition to negative effects on other species, the rats would cause damage to temporary residents’ belongings on the island. Most tourists had a negative reaction when the rats were spotted. Eradicating rats on Misali Island would likely ease the pressures they place on native species, infrastructure/property, and tourism.
Management of the Invasive Rat Population

Brown rats are widely distributed on Misali Island. The most effective way to manage the population is a complete eradication. The rodenticide that employed on Misali Island will have negative effects on other mammalian species, but the constant pressures from rats placed on all flora and fauna will have a greater negative effect in the long term than a one-time use of poison, from which the other species will rebound. The same methods used on Chumbe Island in 1997 can be followed to complete a successful eradication on Misali Island. However, monitoring Misali Island will be more challenging than it was on Chumbe since boat traffic to Misali Island tends to be less controlled. Over six months with an arbitrary budget of 25,000USD, research, trial, and monitoring can be applied to eradicate brown rats.

The first step of the process will be to select and test a rodenticide that would least effect other mammalian species on Misali Island and that will be approved for use by the Government of Zanzibar: Department of Pest Control. It is also important to remain within the project budget. Two to three months should be spent testing the poison and its effects on the island’s species. After the rodenticide is cleared for use, it should be deployed for one to two months by setting traps all around the island, taking careful care to place more traps in areas of high density and in trees. The rangers on Misali Island can be trained to employ these methods. An additional two months should be used to monitor the island for rat activity after the first use of the rodenticide. Like on Chumbe Island, sticks soaked with coconut oil or baits can be used to monitor any rat activity that may persist. It is crucial that all individual rats are eradicated; if they are not, the population will likely rebound very quickly and the eradication efforts will fail (Russell et al., 2016).
Figure 14: Estimation of brown rat rebound beginning from a population of ten. This figure is an example of how quickly the rat population could rebound if ten rats are left from eradication efforts. The estimation was made assuming half are female, and pregnancies are every two months (Boschert, 2019). Death rate was ignored.

Due to the high boat traffic to and from Misali Island, intense monitoring must be done on all boats arriving to the island. A mooring station should be set up so that no boats can directly dock on the island. Instead, passengers will be brought to the island by the rangers on a known rat-free boat. This will prevent rats from accessing the island by boat. Additionally, fishermen’s boats must only be repaired on mainland Pemba Island, as this would require docking on Misali Island. For ease of monitoring, the two fishermen camps should be combined into one on the north side of the island. Waste is also a crucial management point. Detritus must either be sent to mainland Pemba Island or contained in such a way on Misali Island that wild animal species cannot access it. Allowing there to be an open trash area supports a higher population of the invasive rat species due to ample food sources, but it also changes the behavior of all things accessing it, including all of the mammals mentioned as well as the endangered coconut crabs.
Conclusion

Invasive rat populations across the world’s islands pose a threat to native species due to out-competition and predation. There has been limited information gathered on rats in the tropics, and even less in the Zanzibar Archipelago. This study collected baseline data on the distribution, activity, and density of *R. norvegicus* across Misali Island. There was found to be rat high activity at dusk and in areas of human influence, such as the two fishermen’s camps, the ranger’s station, and the tourist campsite. Activity was also found to be higher along the coast of the island for unexplored reasons that could be attributed to soil type or unique food resources. Ad hoc observations showed that the brown rats caused damage to human resources, property, other species, and natural resources found in the forest, particularly young plants and plant roots.

The goal of this study was to address the question of where brown rat activity was most intensive on Misali Island while simultaneously providing a brief outline of challenges, a rat density and population estimate, and the outline of management and eradication plan. The data gathered in this study is significant because it is the only baseline data collected on invasive brown rats in the Zanzibar Archipelago. This study establishes a foundation for future studies to be conducted in further detail on the effects or rats. This project also poses multiple rationales to eradicate the rat population on Misali Island, principally because it would benefit conservation of the protected area.

Recommendations

This project would have been more accurate if it had employed catch-and-release methods to estimate the rat population. Due to the exclusive use of observation, the population of rats burrowing was eliminated from calculations. In addition to catch-and-release, this project
would have benefited from studying rat activity during darkness to compare against rat activity during daylight hours.

Future studies should work to develop a greater understanding of the challenges brown rats pose to the habitats, native species, human infrastructure, and tourism. These studies would provide data that would influence the decision to eradicate rats on Misali Island. Developing a specific study that connects coconut crabs and brown rats would prove to be interesting and would support the conclusion that rats are, in some manner, causing the population of coconut crabs to decline.

A point of major concern on Misali Island is waste and how it influences animals’ behaviors. Rats, coconut and hermit crabs, vervet monkeys, the greater galago, and the Asian musk shrew are all impacted by the regular availability of human food waste that leads to behavioral changes. A study on behavioral changes between habituated and unhabituated counterparts could demonstrate, if managed improperly, how waste disposal helps to conserve wildlife. A study like this could also influence the decision to properly clean-up the waste piles on Misali Island.
References


Appendix

Table 5: Example of data table used to record data during transect walks (forest). Transect walks in the human activity area did not include distance.

<table>
<thead>
<tr>
<th>Weather</th>
<th>Time</th>
<th>Distance</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet, rainy</td>
<td>8:23AM</td>
<td>2m</td>
<td>climbing</td>
</tr>
</tbody>
</table>

Table 6: Example of data table used to record data during location observations

<table>
<thead>
<tr>
<th>Weather</th>
<th>Time</th>
<th>Location</th>
<th>Number of rats seen</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunny, dry</td>
<td>5:30-5:40</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5:44-5:45</td>
<td>2</td>
<td>2</td>
<td>Exiting burrow</td>
</tr>
<tr>
<td></td>
<td>5:57-6:07</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6:15-6:25</td>
<td>4</td>
<td>5</td>
<td>Eating material</td>
</tr>
<tr>
<td></td>
<td>6:30-6:40</td>
<td>5</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

Table 7: Example of schedule.

<table>
<thead>
<tr>
<th>Nov 12</th>
<th>Nov 13</th>
<th>Nov 14</th>
<th>Nov 15</th>
<th>Nov 16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location observations</td>
<td>Forest and h/ac transects</td>
<td>Free day</td>
<td>Location observations</td>
<td>Forest and h/ac transects</td>
</tr>
</tbody>
</table>