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The Preservation of the Native bird Population from Invasive Rats on the Island of Tahuna Iti, Tetiaroa, French Polynesia

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Abstract:

Tetiaroa is a small atoll in the Society Islands in the South Pacific. Along with many places like it around the world, this atoll has an issue with invasive rats colonizing its islands. Tahuna Iti, one of the small islands of the atoll, is rat-free and is therefore home to thousands of nesting sea birds. An analysis of aerial photographs from 1955, 2002, 2006, as well as island delineation data from 2011, found that the island of Tahuna Iti has not only changed shape, but also size and proximity to Rimatuu, one of the rat-colonized islands. Analysis of the change in shoreline proximity indicates a 288m movement between 1955 and 2011, providing conditions that could potentially result in the destruction of the bird population by rats if the islands are connected via a land bridge. From this data we were then able to suggest preventative and combative measures that could be used to save the bird population of Tahuna Iti.

Keywords: Tahuna Iti, Tetiaroa, Invasive Species, Sea Bird, Coastal Island Erosion, Species Management, Rat Eradication

Introduction:

This project looks at the Tetiaroa Atoll in the South Pacific Society Islands of French Polynesia (Figure 1). Tetiaroa is a small atoll located approximately 56.32 kilometers directly north of the more commonly known island of Tahiti (17°07'15"S 149°29'30"W) [1]. Found just below the equatorial divide, between the southern subtropical high pressure zone and the intertropical convergence zone, Tetiaroa is subject to steady Southeasterly Trade Winds and the currents that this wind generates. Due to this constant and anticipated form of erosion, Tetiaroa is continuously being changed and affected. The atoll is currently comprised of 13 small islands, two of which are the predominant focus of this project. Locals call the islands Rimatuu and Tahuna Iti, but those not familiar with French Polynesia remember Tahuna Iti with the simple name of 'Bird Island'.

Tahuna Iti is roughly .0781 kilometers^2 and is home to thousands of sea birds. A study by James Russell and Lucie Faulquier (2009), documented five different species of ground-nesting birds, predominantly the brown noddy (*Anous stolidus*) [2]. Of the five species of birds that inhabit the island, four only inhabit islands that are not also home to one or both species of invasive rats that populate the islands of the atoll. Prior to Polynesian inhabitation, the atoll was home to only bird species and was free of any predators. The atoll itself lacked any form of mammal that could pose a threat until Polynesians colonized the islands (ca. 800A.D.), bringing with them the Polynesian rat, *Rattus exulans*. European colonists also introduced a type of rat upon their arrival to the atoll (ca. 1767-1800) — the black rat or *Rattus rattus* [13].

Currently, Tahuna Iti is rat-free and is able to support the type of ecosystem that these birds need. In a recent trip to this atoll, it was discovered that this island seems to be eroding and shifting, growing closer to that of another island (Rimatuu) and is doing so at an accelerating rate. Rimatuu is currently occupied by the Polynesian rat species and if the islands were to touch, the transmission of rats to Tahuna Iti would represent a potential disaster to the estimated 10,000 birds that inhabit this island. Currently there are no predators for the birds on the island and the introduction of the rats could prove to be even more destructive due to this. The birds do not know what a predator is, nor do they know how to deal with them and the introduction of the rats could be very damaging to their population [9].

This project focuses on the observations that were made on a research oriented trip to the Tetiaroa atoll in the month of May 2011. It was observed when comparing previously dated photographs to that of the island delineation data that was gathered on this fieldwork that the island of Tahuna Iti was encroaching upon the island of Rimatuu. This change in proximity between the two islands may prove detrimental to the thousands of sea birds on Tahuna Iti if the rats present on Rimatuu were able to cross over. Several case studies have shown that the introduction of rats to ground-nesting bird islands is a detrimental change and can seriously impact the bird populations. This project documents the changes in the two islands' proximity to each other, and utilizes a mathematical model to illustrate potential changes to bird populations if non-native rat species were to gain access to Tahuna Iti. The study then makes recommendations with regard to potential measures to stabilize the shoreline, prevent the islands from being joined together, and to combat the rats on the island of Tahuna Iti if they reach the shores of this island.

Material and Methods:

A field investigation was conducted in May of 2011 on the Tetiaroa Atoll. This trip was primarily a preliminary excursion to conduct a rapid environmental assessment to build a geographic information system (GIS) geodatabase in cooperation with the Tetiaroa Society. The team compiled a GIS database framework and founded the basis of an extensive project in collaboration with the Tetiaroa Conservation Society. Upon arriving at the atoll, specifically Tahuna Iti, it was noticed by Dr. Timothy Krantz, who had been to the atoll in 2003, that the island of Tahuna Iti was noticeably closer in proximity to the island of Rimatuu than in previous years. Delineation of the shorelines of all the islands was conducted using the Trimble GeoXH Pocket PC (both the 2005 and the 2008 series), and a Garman GPSmap 60CSx unit as a backup data source. The compilation and manipulation of the data were conducted upon the return of our team to the University of Redlands between May 2011 and January 2012.

In collecting the data specific techniques were used to ensure that data collection was done universally between the different delineation teams. GPS delineations were completed for all islands by walking along the high water mark along their shorelines. Because the atoll is surrounded by a barrier reef, the water marks on the islands are not affected by larger swells as much as they would have been if there was no barrier reef. This allowed for a better and more accurate reading of the high water mark. The type of beachfront at the high watermark was classified as: sand, wave-cut scarp, coral debris, vegetation or aragonite.

Once back at the University of Redlands, analysis of the data was undertaken using ArcMap. Teams were able to compile all of the delineations onto a single map to create accurate shoreline delineations of each island in the atoll. This 2011 shoreline delineation was geographically referenced to three other historical aerial photos (1955, 2002, 2006) using a method called "rubber sheeting". For steps on completing this process in ArcMap see Appendix A. Rubber sheeting these photographs allowed for the locations of the island to be determined by identifying key features within the lagoon and parameter such as coral heads, the "hole" in the lagoon, and the barrier reef location. Using these features as fixed points in every photograph, the aerial shots were then stretched and fixed to show the size and locations of the islands, allowing for comparisons to be made between them.

To give a better understanding of how influential these rat colonists may be on the bird population, an island predator-prey mathematical model was made. The mathematical model was applied to characterize what may happen if a land bridge between Tahuna Iti and Rimatuu is formed and rats were to invade the ground-nesting bird colony on Tahuna Iti. This model illustrates how sensitive the island of Tahuna Iti would be to such an invasion if it were to occur. The model was produced in a Microsoft Excel Spreadsheet which allowed for the complex equation to be composed based on a number of broad, clearly defined assumptions. Some of these assumptions included modeling the island with a single type of bird, the brown noddy, even though there are five different species on the island. This was done due to the fact that more than 99% of the total bird population was a single type of bird even though it is all one ground-nesting bird colony [2]. Another larger assumption that was addressed was that of the total number of rats making it to Tahuna Iti. Using the main equation and certain assumptions, the mathematical model was able to show how the rats may have influence on the bird population of Tahuna Iti if they were to make it.

In order to write the model, the populations were divided into both the bird (prey) population and the rat (predator) population. One-month time increments were chosen as this is a common time period for egg incubation, fledging of juveniles, and can be used after adjustments to rat breeding behavior. Within the bird population, the model evaluates sub-categories of egg, juveniles, and adult age classes. The Brown Noddy lays a single egg one time a year. Therefore, the number of eggs produced is dependent upon the number of female adults (.5*adult population) that are alive in month five in every year of this model, as eggs are assumed to be laid in month six. The number of eggs is also influenced by a natural death rate as well as a predation rate from the rats, but this is taken care of when looking at the juveniles in this model.

The juvenile population is dependent upon the survivability of the eggs to develop and hatch into juveniles. To do so, the eggs must not only survive a natural death (1- the natural death rate), but also must survive being preyed upon from the rats. If the eggs survive this, then they hatch to become juveniles. The adults are very similar to the juveniles in this model, differing in only one way. The adult population is dependent upon the survivability of the juveniles and has a hunted rate at which the rats attack and kill them. The difference is that there is not another stage for the bird to move onto the next month and thus has a factor of the percent that survive each time step and continue their existence as adult noddys.

The rat population is a special case in this model, requiring additional factors in determining the population over the time steps involved. This population has a normal growth rate for the overall population meaning that in addition to being dependent on this factor, the rats are also dependent on the other population (birds) and the subpopulations within this. It was assumed that the rats have a greater preference for food that requires the least amount of work (eggs had a higher hunted frequency than that of the juveniles, and juveniles higher than that of adults). The last factor that affects the rats is that of the proposed solution to trap-and-kill the rats to preserve the bird population.

Results of Geospatial Analysis:

The resultant geo-referenced maps (Fig. 2-4) indicate that the area and shape of Tahuna Iti has changed substantially since 1955. The areas of the island for the four years studied are as follows:

1955: 63377 m^2

2002: 80075 m^2

2006: 83099 m^2

2011: 78181 m^2

Along with the change in shape and area of land mass, the channel between Tahuna Iti and Rimatuu has narrowed from 315.7 to 26.75 meters. In 1955 there were 315.70 meters separating the islands at their closest points. This decreased by 2002 to approximately 145.88 meters and even more so in 2006 when the islands were 63.18 meters apart. As of May 2011 the islands were only a mere 26.75 meters apart as sand spits grew closer to Rimatuu (Fig.7), and channel depth was measured at just .72 meters at its deepest point.

When comparing the location of Tahuna Iti's easternmost side in 1955 to the 2011 delineation (Top of Fig. 4), the 158 meter change to the west is very noticeable. In the same time period, the northernmost point is now 160 meters north of the northernmost point in 1955. This northwestern directional shift is also evidenced on the other southeastern islands of the atoll.

Rimatuu exhibited a shift of 47.3 meters from the southeast to the northwest. Similarly, the southeast side of Reiono shifted a total of 70.9 meters to the northwest at the point of greatest change from 1955 to 2006; the northwest side of the same island had shifted 82.40 meters further to the northwest (Fig. 8). This pattern of erosion from the southeastern sides of islands along with the long shore drift of this sediment is exhibited throughout the atoll with evidence of beach erosion and wave-cut scarps along southeastern shorelines on a majority of the islands.

Results of Mathematical Analysis:

In trying to provide evidence and show the outcome of the birds' survival if the rats had made it to the island of Tahuna Iti from Rimatuu, the mathematical model projects a grim future. According to this model, if any rats were to get onto the island, the bird population would be extirpated in less than two years. As Figure 9 illustrates, after running the model with an introduction of only five rats, the entire population of 10,000 birds was extirpated in just 17 months (1.416 years). The only increase the bird population had was during the month that the young are hatched (month 6). With the addition of more initial rats, the amount of time that the bird population decreases to zero was not significantly altered. (If by chance a swarm of 500 rats, rather than just 5, were to simultaneously get to the island of Tahuna Iti, the amount of time that the bird population would take to get to zero would be decreased by only 6 months (Fig. 10).)

One of the most disastrous and potentially disturbing factors that this model was able to show is that of the sheer destruction the introduced rats could have on the marine bird population on this island. In order to obtain population numbers that were comprehensible and logical, the rate at which the rats killed the adult population of birds had to be extremely low. If the rate at which predation of adult birds were to increase, the destruction of the population of the birds colony would also increase rapidly (Fig. 11 and Fig. 12). The fact that these birds do not have a natural predator on the island compounds their vulnerability. The birds would not be defensive against the newly introduced rats and would allow for the original hunting rate in the model to potentially be low enough that the types of situations seen in Figures 11 and 12 to be realized. The rate at which the adult birds are hunted is the most sensitive parameter in this model and unfortunately, could be the most variable in the real-life scenario on Tahuna Iti. Figure 13 shows that even with the trap or kill rate of the rat population set at 50%, the bird population still ends up dying after two years from the start of the infestation.

Discussion:

The proximity of Tahuna Iti to Rimatuu would not be an issue if it were not for Tahuna Iti being home to thousands of sea birds and Rimatuu having invasive non-native rats. When discussing the influences that these non-native rats may have on the marine bird population on Tahuna Iti, there are some common influential points that should be addressed. First and foremost, it should be noted that there are no predators on Tahuna Iti that pose threats to any of the species of bird on the island. Firsthand accounts describe being able to approach the nesting birds and physically interact with the avian individuals. In regards to the size and proximity of Tahuna Iti to that of the rat infested Rimatuu, American ecologists Robert MacArthur and Edward Wilson argue that there is a direct relationship between the rate of immigration of non-native species (colonists) and that of the distance of the island from its source of colonists; the further the distance, the lower the rate of immigration. These same ecologists also believe that there is another correlation between the size of the island and the rate of extinction of the preyed upon native species; the larger the area, the lower rate of extinction [5].

When translated in terms for Tahuna Iti these theories leave a grim outcome for the birds that are native to this island. Addressing the first theory, the distance between the two islands is shrinking with every wave. The immigration rate of potential colonists is much higher now than it was even ten years ago; going from a distance of 145.88 meters in 2002 to a mere 26.75 meters in 2011. When addressing the second theory there is not much more hope. Though the island has increased its square-meter area in the past 56 years, it is still a rather small island in relation to the surrounding islands. It would not take more than a day for a single rat to cross from the west side of the island to that of the east side. With this smaller area along with the current lack of predator understanding, a higher rate of extinction is likely if rats were to gain access to Tahuna Iti.

In 56 years, Tahuna Iti has moved 289 meters closer to Rimatuu through wind and wave erosion (figure 3). The islands of Tetiaroa are subject to wind and wave driven erosion. Tetiaroa, along with the other Society Islands, lies in the latitudes of the Southeast Trade Winds that are characterized by steady southeasterly winds typically blowing 11 to 13 miles per hour [4]. This wind drives the South Pacific Gyre which contains currents moving in the same direction. These currents produce consistent waves that batter the southeastern shores of the atoll. Strong evidence of this was documented in the delineation of the islands in 2011. On many of the islands within the atoll, wave-cut scarps and beach erosion on the southeast shorelines was observed. In association with this erosion, long shore sediment transport with deposition on sand spits to the northwest was also noted. This trend is seen in the formation of the potential land bridge between Tahuna Iti and Rimatuu, as well as the more long-term product of the shape of Rimatuu itself (Figure 2, 5, 6, 7).

Evidence of this erosion can also be seen in the large shifts that the islands in the atoll are exhibiting as a whole, but the most prime example is that of Tahuna Rahi. Lying almost directly south of Tahuna Iti, this island has dramatically decreased in size since 1955. In following the wind and current patterns of the atoll, it can be implicitly stated that the increase in the size of Tahuna Iti is directly related to that of the decrease in size of Tahuna Rahi. Sediments from Tahuna Rahi have been eroded away and driven north to help extend the sand spits of both Rimatuu and Tahuna Iti.

If management were to be conducted on Tahuna Iti it would have to be immediate in order to preserve the population of marine birds from total extirpation. According to the mathematical model, in order to save the birds, we must prevent the introduction of rats from Rimatuu rather than combat them once they are already on Tahuna Iti. Figures 9-13 all show results of the model (Table 1) through the adjustments of various parameters including number of initial rats, the predation rate the rats have for the different levels of bird and the combative kill/trap rate if we were to try to combat the colonizer on the island of Tahuna Iti. In all model runs, it was concluded that an introduction of rats onto Tahuna Iti would be catastrophic to the bird population within a period of one to several years. Even if it was caught shortly after invasion, there would be no hope for the birds unless 100% of the rats were to be eradicated (figures 9-13); a difficult prospect. If the rats were to get on to this island, the destruction of the bird population may only have anywhere from 1 to 3 years before complete.

Recommendations:

A study by Major et al. found that more than half (54%) of all islands bird extinctions have been caused by introduced rats [10]. In knowing this, the preventative measures needed to prevent the rats from getting onto Tahuna Iti are essential. Taking action is imperative if we are to save the bird population. Seeing that the problem was that of the invasive rats destroying the native bird population by gaining access to Tahuna Iti, there are several remedial actions that could be undertaken. Two of these are preventative measures and the other is a combative measure: dredging the channel between the two islands, preventing further erosion, and trapping/killing the rats are all potential solutions.

The most direct way of preventing the rats from getting from Rimatuu to Tahuna Iti would be to dredge the channel separating the islands. As this is in the inner lagoon with no coralline structures and other biota attached to the sea floor, there would be minimal harm to sensitive biota in this process. By increasing the amount of water separating the islands, one would greatly decrease the likelihood that rats would get to Tahuna Iti and colonize the island. Taking the sand from the channel as well as from the elongating spits and putting it just north of the island, further in the lagoon would both increase the channel width and would prevent the need to continually dredge the channel if we were to return the sediment to the southeast side of the island where it originally came from. Taking the sediment that is eroding from one side of Tahuna Iti and placing it in the lagoon would eventually cause the island to start shrinking in size, which would also be harmful to the bird population if stabilization and reinforcement of the southeast side of the shoreline was not also done in tandem with this measure.

The other preventative technique that should be considered is that of building an artificial barrier around the south, east, and northeastern sides of Tahuna Iti that would act as another fringing reef. This barrier would attempt to slow and disturb the incoming currents that are causing the current erosion. This could be done in a way that could not only benefit the bird populations on the island by preventing further erosion of the physical island, but also would provide habitat for fish and other marine organisms much like reef balls do in degraded reef areas. Many studies have shown that with an increase in reef topographic complexity and benthic structure there is also an increase in reef fish biomass [14]. If a barrier is constructed around these sides of Tahuna Iti, it is still recommended that the channel be dredged to further increase the distance between the islands and to see if the new barrier is enough to help decrease the erosion.

The third technique that could be used as a last resort is to combat the rats once they reach the island with poison. There have been many attempts on islands around the world to rid islands of invasive rats, but not many have done so successfully. Most recently the Republic of Palau has baited (poison bait stations as well as hand thrown bait) their first set of islands in an effort to rid their islands of rats [12]. In Alaska, the Anchorage Daily News issued a story in 2009 that claims after two centuries of infestation, Rat Island is rat free [11]. Rats were first introduced to the island in the late 1700's when a Japanese sailing ship crashed nearby introducing the creatures to the island. Approximately one year after nearly 700 pounds of poison bait and three million dollars were used to eradicate the rats, there still are no signs of the rats on the island. Rat Island is comparable to that of Tahuna Iti as there are no other mammal species on the island and the rats exclusively ate the ground-nesting birds. It was also noted that the nearby islands that lack rats not only have more abundant bird populations, but are also home to a more diverse sea bird population. The baiting of Rat Island did have more of an effect on the birds on the island than originally expected, which could prove to be a large issue on Tahuna Iti as it is the most diverse of all the islands in relation to bird species. For this reason bait stations would prove to be the most useful way of introducing these poisons.

This type of bait and kill program may also be conducted on the other islands where rats are prevalent, including Rimatuu and Reiono. If it were possible to clear Reiono of rats, it then may be possible to try to reestablish this island as a bird island, as it is the most pristine and untouched island in the entire Tetiaroa atoll much like Tahuna Iti is now. Reiono is geographically isolated from all other islands which would eliminate the need to worry about increased erosion and also the ability of rats to swim to this island from nearby islands.

If researchers were to collect additional data for a better model, it is suggested that nesting behaviors and locations of the birds be analyzed, more accurate species data on other species of birds including nesting patterns, incubation periods, and juvenile life periods, in addition to the dispersal patterns of rats on islands and if Tahuna Iti is colonized yet with rats. Once this data is collected, a more precise model including the various types of sea birds as well as more migratory/dispersal factors could be taken into consideration and help track both of the populations. Until both the population of the various species of birds and the potential colonizing species are further studied, this more precise model will be harder to construct.

In summary, it can be concluded that the islands that lie in the southeastern section of the Tetiaroa atoll are being influenced and eroded by wind-driven sea currents. This erosion is negatively affecting the atoll by causing long-shore sediment transport to close the gap between Tahuna Iti (Bird Island) and Rimatuu (which is infested with rats). Through the use of mathematical models, it was shown to be a negative outcome for the bird population on Tahuna Iti if rats were to make it from Rimatuu. In order to preserve this population, immediate actions must be taken to prevent this introduction.

Note:

It should be known that after research and work was conducted for this paper, sources within the Society Islands have informed us that during unusual low tide events the islands of Rimatuu and Tahuna Iti are now connected.

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Appendix:

Appendix A.

Jan 23 2012

Location: L:\Students\special_projects\sean_stanton_capstone_spg_2012
Tetiaroa_Baseline_Project_poly1.mxd

- Input all maps, shape to size, create polygons
  - To input:
    - Open image Location
    - open ArcMap
    - Drag image from location into ArcMap (creating different layers with each map)
  - To shape and size:
    - Click on "Customize" tab on top of screen in ArcMap program
    - Scroll over "Toolbars" to extend larger window
    - Click and activate "Georeferencing" tool bar in drop down menu
    - In new tool bar, select the layer you wish to work with (for this project I used the newest aerial photo available to base all other pictures off of. This means that I would work to shape all other aerials /georeference/rubber sheet all others off of the newest/most current aerial)
    - Use the tools located in the drop down menu directly right of the layer drop down menu (rotate, shift, scale) to fit newly imported photos with base photo using points in inner lagoon and outer atoll that have not moved.
      - Hint: Right click on newly imported map layer
      - Scroll and open "Properties"
      - Select "Display" tab
      - Change "Transparency" from 0% to 35%
  - Create Polygons to show island change
    - Left click "Catalog" tab on far right of screen
    - Use "Tetiaroa_Atoll_xyz" as baseline file
    - Right click on this baseline, scroll to "New". In drop down tab select "Feature Class..."
    - In activated window, name new feature class (use underscore as spaces)
      - Be sure that "Polygon Features" is selected as the type of feature stored in this feature class before clicking next.
    - Choose a coordinate system that corresponds to the baseline file previously chosen.
      - Select "Import" tab
      - Double click your baseline file (Tetiaroa_Atoll_xyz.gdb)
      - Choose any file as they presumably all have same coordinate system and then click "Next" tab

- Leave default numbers alone in "XY Tolerance" as well as "Specifying the data base storage configuration". (same done for 3rd screen with "Field name" and "Data Type"
- Click "Finish"
- Right click on the new feature class and scroll to "Edit Features" to open drop down menu (be sure class in checked on)
- Click "Start editing" ("Create Features" tab and "Editor" toolbar will open)

    - If nothing appears in the "Create Features" tab then:
        - Click on box second from left titled "Organize Templates"
        - In "Organize Feature Templates" window make sure your layer is selected in left column and click "New Template" at top of window.
        - Click "Close"
- Select the feature class you wish to work with as well as the "Construction Tool" you want to use (I used freehand to outline the islands of interest).
- Once the island is outlined, click "Editor" in the editor toolbar to open drop down tab
- Click "Save Edits" and then "Stop Editing"
- Repeat as necessary
    - NOTE: This exact process was also used to make the points of interest in the Georeferencing map using points rather than polygons.

Appendix B:

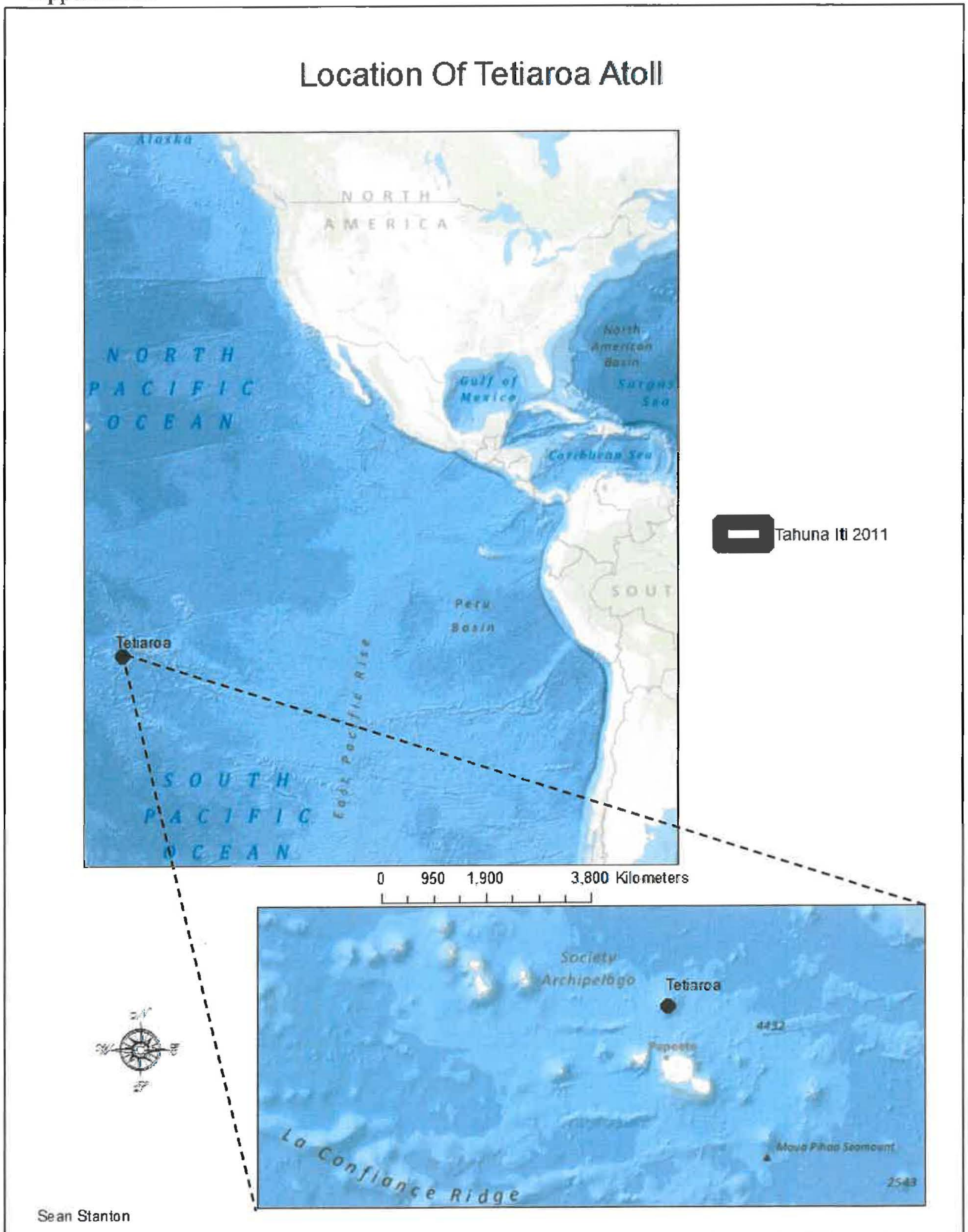


Figure 1: Geographic location of the Tetiaroa Atoll in South Pacific

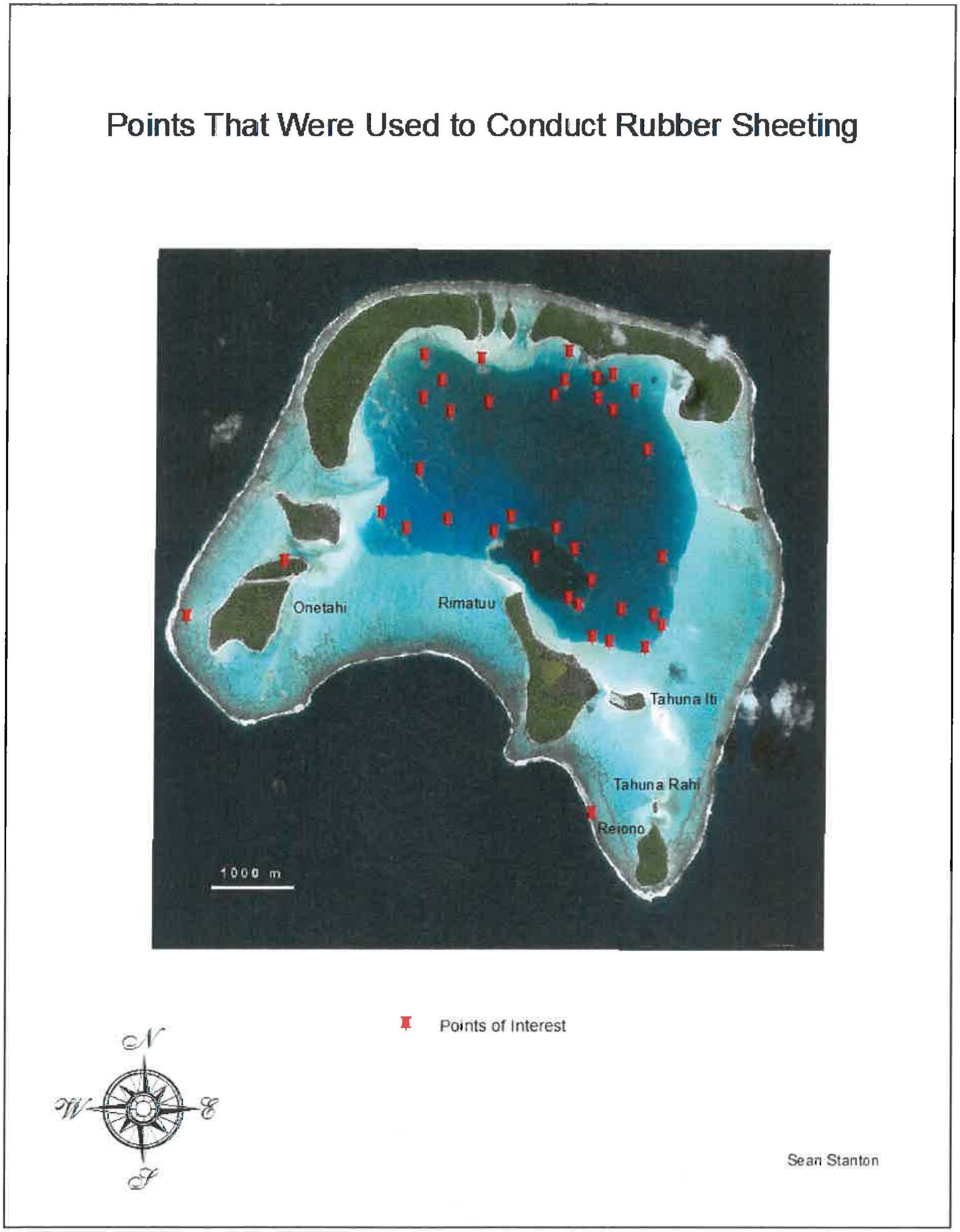


Figure 2: The 37 points that were used as reference points in order to conduct rubber sheeting of aerial photographs from the years 1955, 2002, and 2006. (No aerial photos were used for the 2011 delineation data)

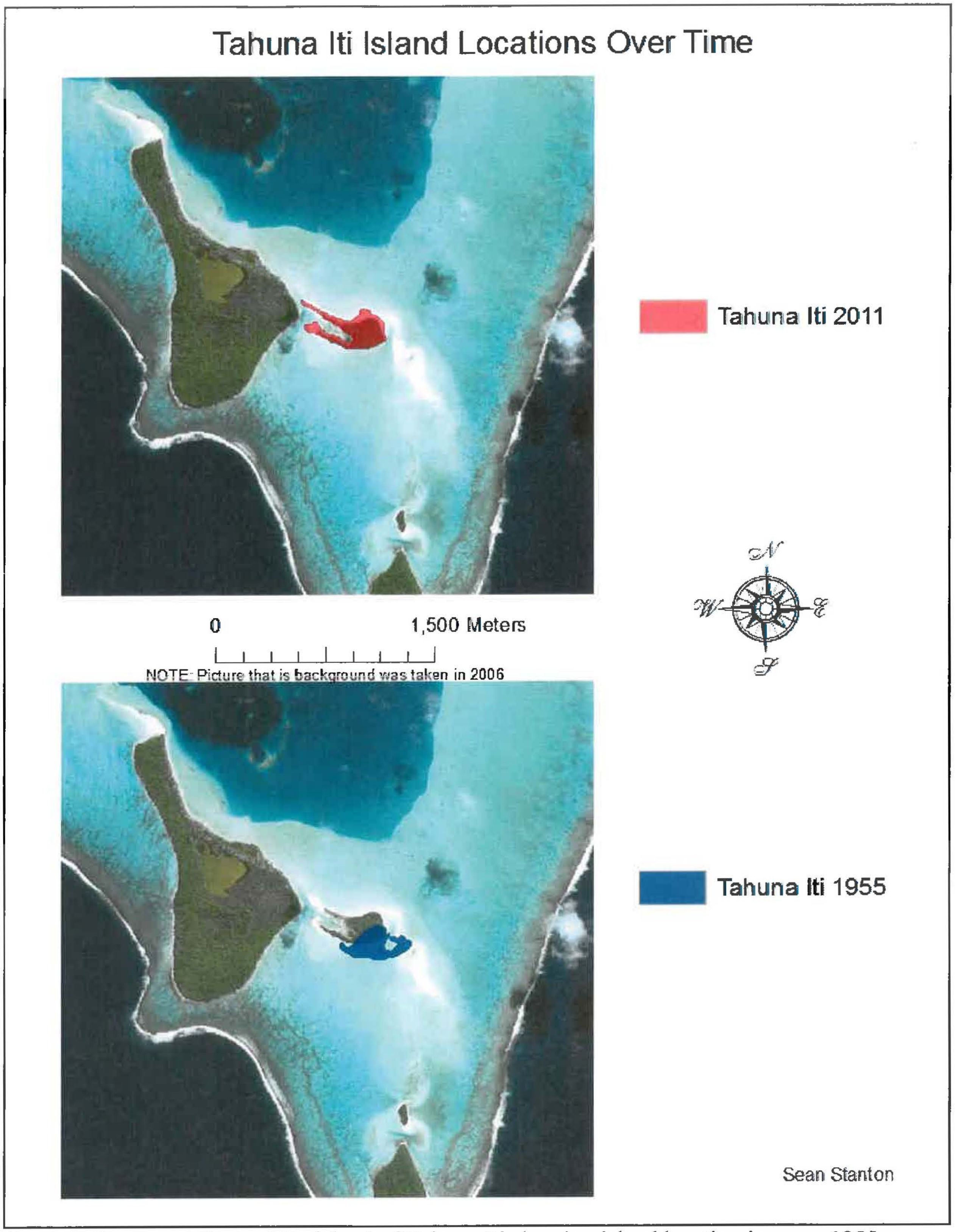


Figure 3: Representations of the island of Tahuna Iti showing island location in years 1955, 2006, and 2011.

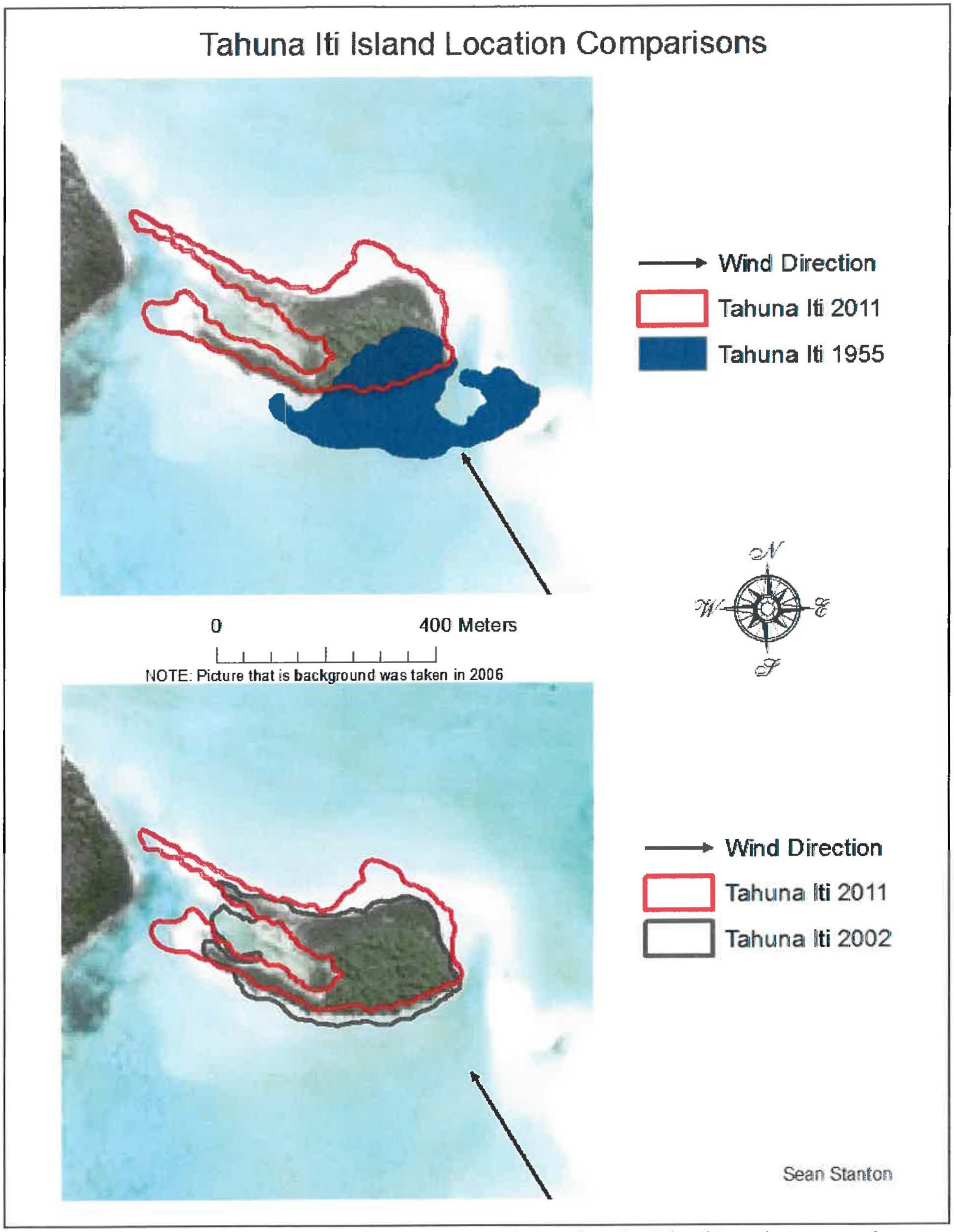


Figure 4: Representations of the island of Tahuna Iti showing the island location comparisons between 1955, 2006 and 2011 (top) and 2002, 2006, and 2011 (bottom). Prominent wind direction also shown.

Appendix C:

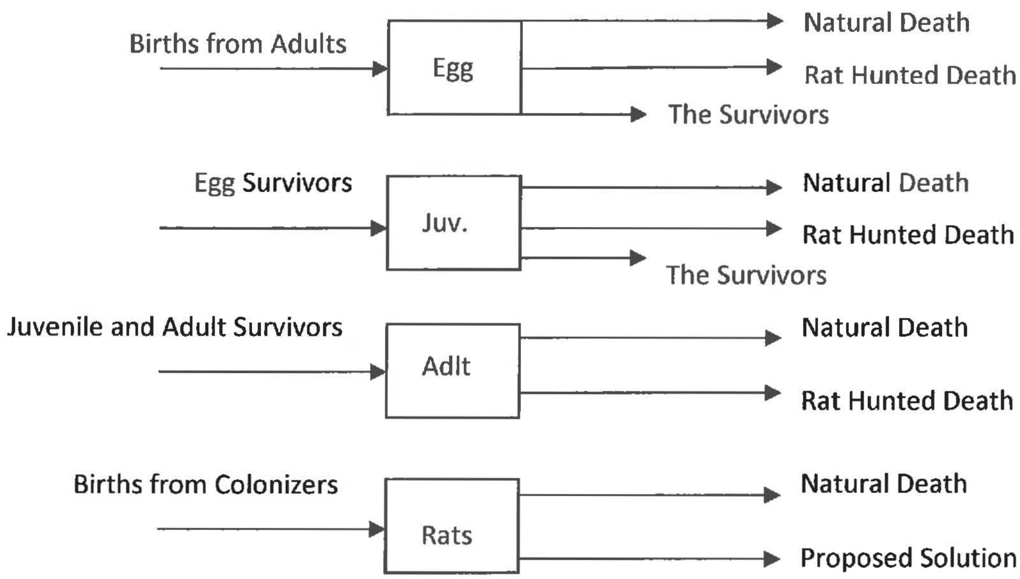
Figure 5: South side of Tahuna Iti facing East demonstrating unremitting erosion and island shift. (Taken May 6, 2011)

Figure 6: East side of Tahuna Iti facing North showing wave scarp and erosion exposing roots of established mature plants. (Taken May 10, 2011)

Figure 7: Facing East on Western most tip (newest portion) of the Northern sand spit in the Island of Tahuna Iti. (Taken May 6, 2011)


Figure 8: Southern Reiono facing West showing extreme erosion as the most South-Eastern island in the atoll, taking the brunt of the presumed erosive factors.

Appendix D



Eggs: $E(n+1)=G*A(n)$

Juvenile: $J(n+1)=S*E(n) - F*R(n)*E(n)$

Adult: $A(n+1)=I*J(n) + K*A(n) - M*R(n)*A(n) - H*R(n)*J(n)$

Rats: $R(n+1)=N*R(n) + F*R(n)*E(n) + H*R(n)*E(n)+ M*R(n)*E(n) -P*R(n)$

Variable (parameter)	Name
E(n)	Egg population
J(n)	Juvenile population
A(n)	Adult population
R(n)	Rat population
G	Egg birth rate (only produced in month 6)
S	Egg natural survival rate(1-those that die naturally)
F	Egg hunted rate
I	Juvenile survival rate(1-those that die naturally)
K	Percent of adults that survive each time step
M	Adult hunted rate
H	Juvenile hunted rate
N	Rat population growth rate
P	Trap/kill as proposed solution (percent of population)

Table 1: Equations and parameter names for the mathematical model used to model the introduction of rats on Tahuna Iti.

Appendix E

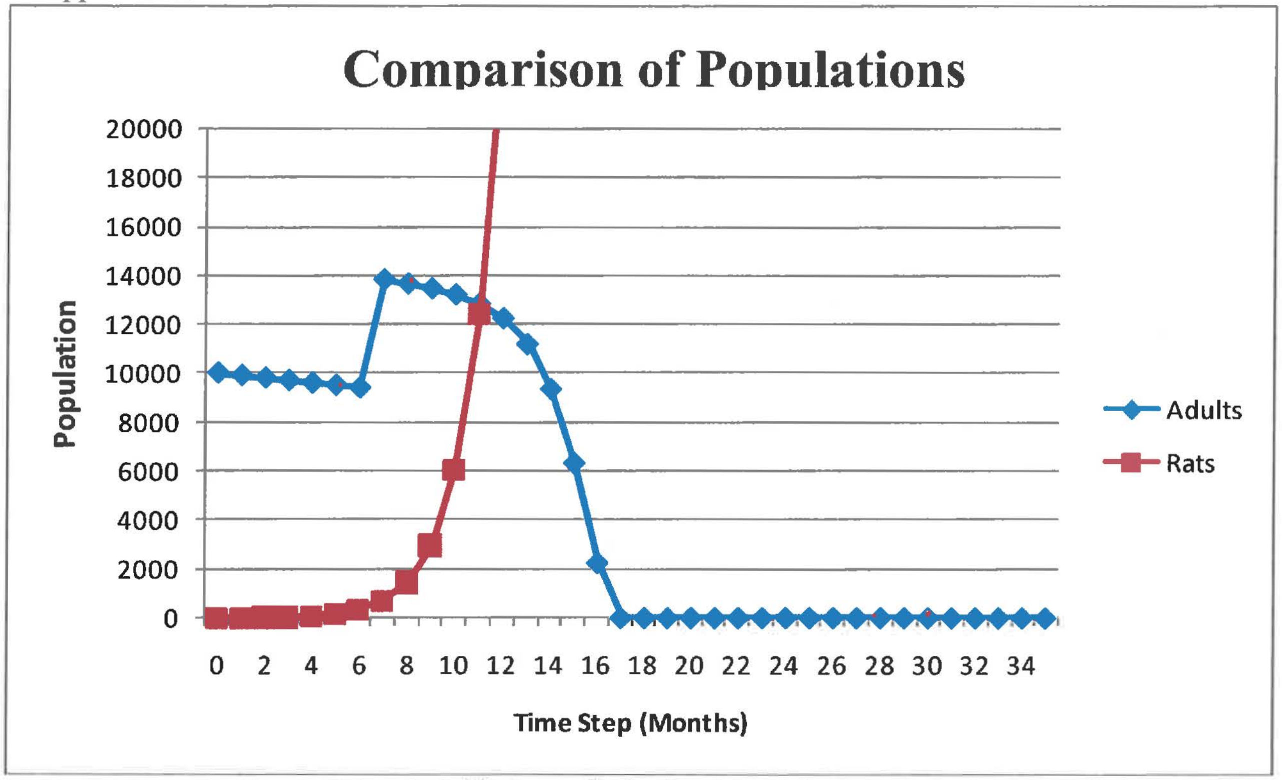


Figure 9: A comparison of the adult bird population to that of the introduced rat population (Initial values: Bird-10,000; Rat-5).

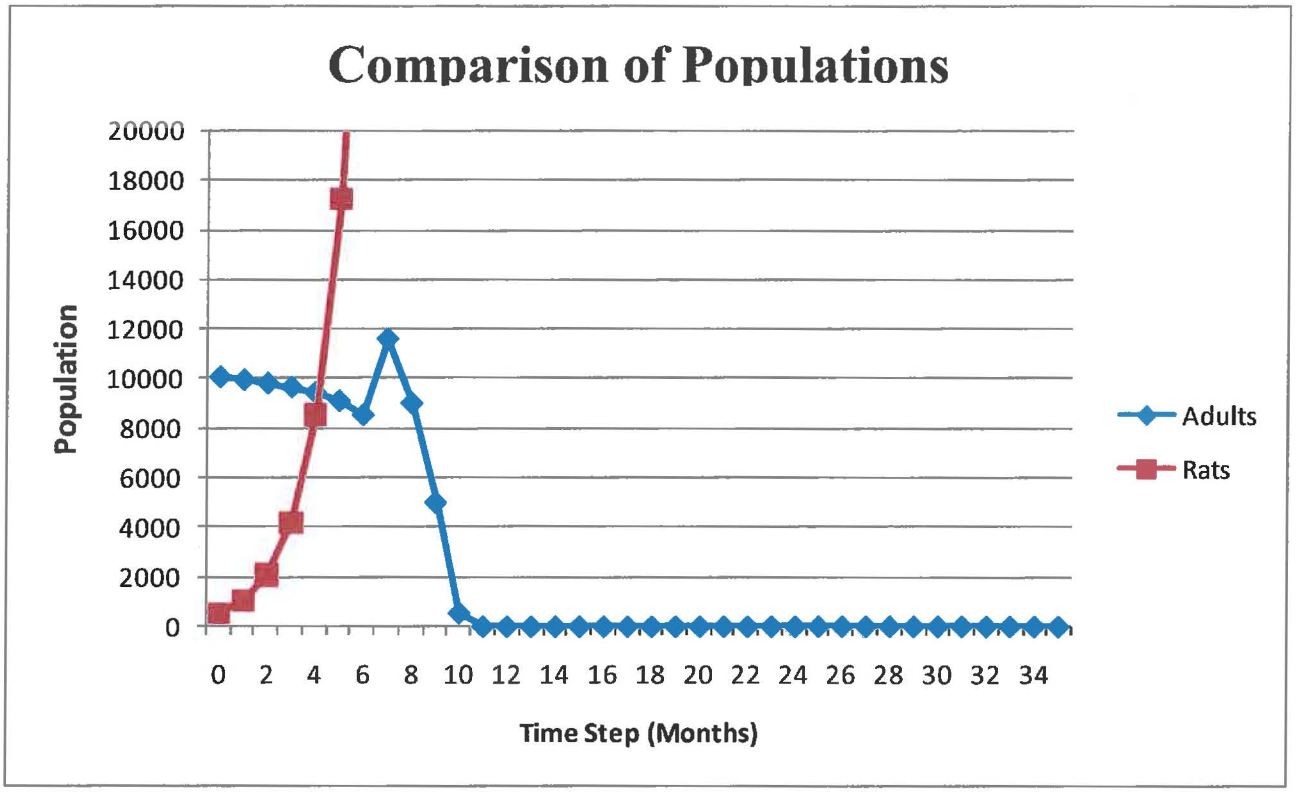


Figure 10: A comparison of the adult bird population to that of the introduced rat population (Initial values: Bird-10,000; Rat-500).

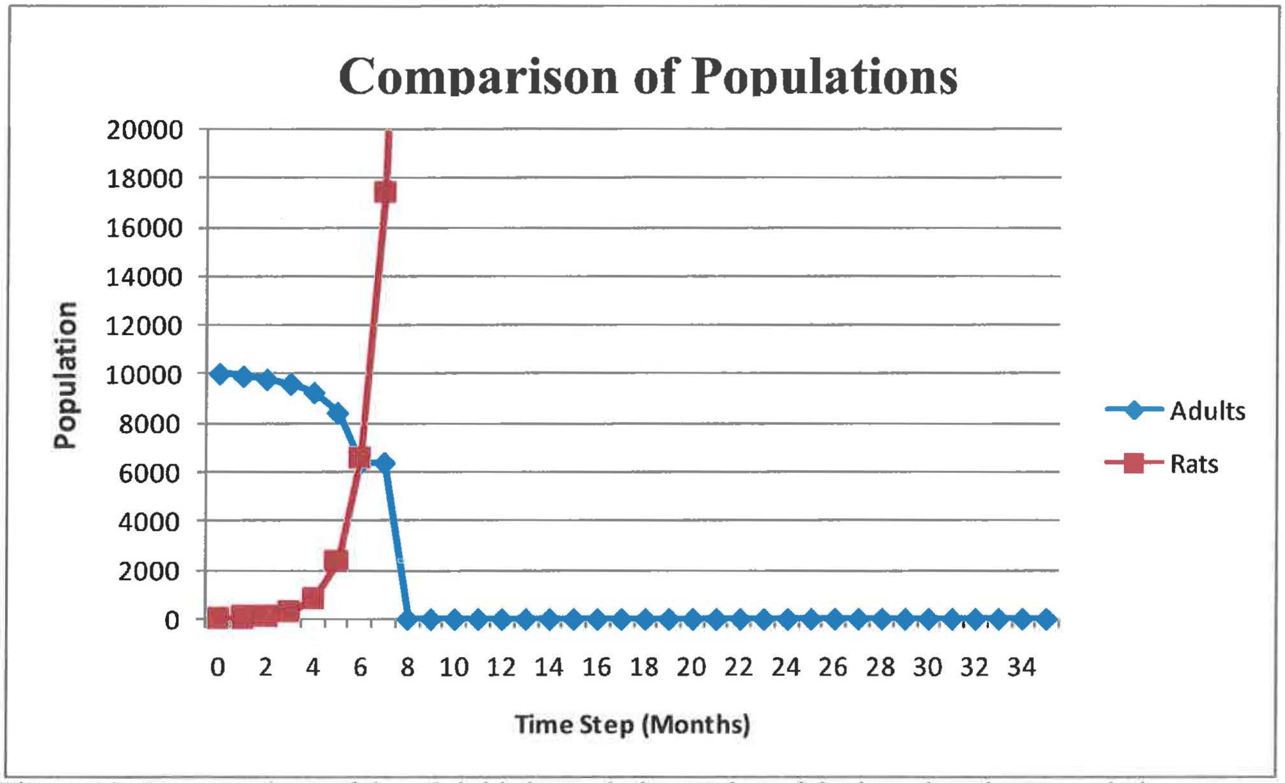


Figure 11: A comparison of the adult bird population to that of the introduced rat population (Adult bird hunted rate dropped to .0001 from .000001)

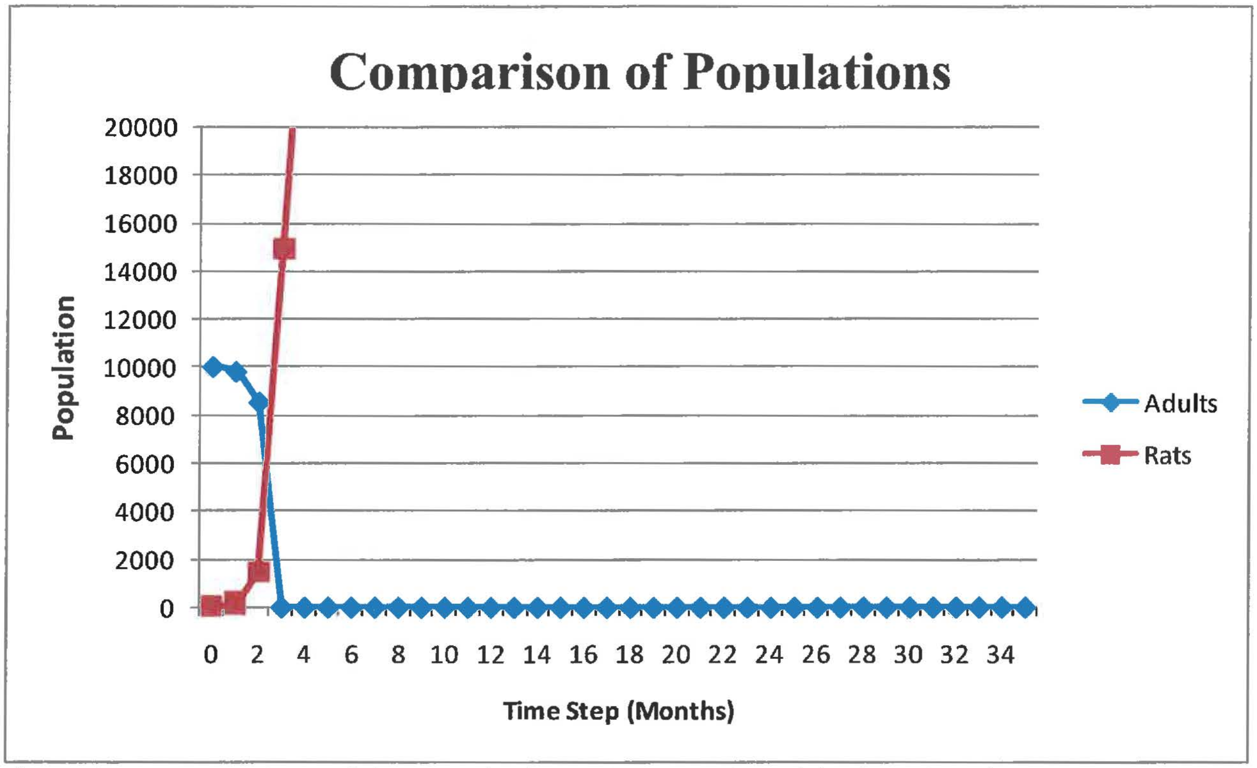


Figure 12: A comparison of the adult bird population to that of the introduced rat population (Adult bird hunted rate dropped to .001 from .000001)

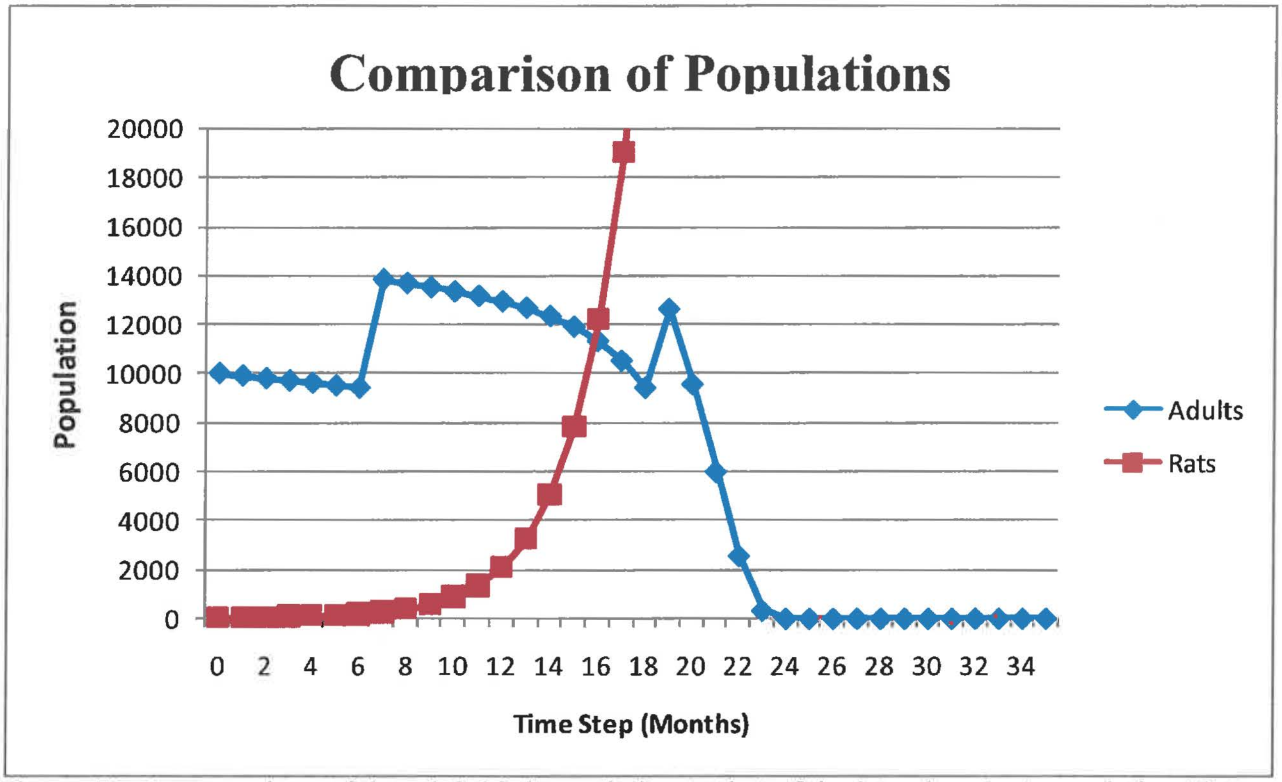


Figure 13: A comparison of the adult bird population to that of the introduced rat population (Rat trap/kill rate set at killing 50%) This trap/kill rate is still not enough to stop the destruction of the bird population and the growth of the rat population, but only delays it.