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Developing UAV monitoring methods for tropical seabirds.

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Abstract

Global seabird populations are declining rapidly. Whilst current monitoring methods are slow and insufficient, the recent emergence of UAV camera technology has the potential to reform the techniques used in the field, by providing a faster and non-invasive alternative to ground counts. A UAV was used to undertake aerial surveys of a mangrove forest in the Cayman Islands, measuring the populations of red-footed booby (*Sula sula*) and magnificent frigatebird (*Fregata magnificens*).

The total populations of the area were estimated to be 1047 red-footed booby breeding pairs and 654 magnificent frigatebird breeding pairs. The estimate for red-footed boobies was considerably lower than expected, whereas the estimate for magnificent frigatebird was considerably higher than previously thought.

Two different counting and GPS marking techniques were compared. Method 1 was much quicker to complete, but did not produce results as accurate as method 2, in which the GPS location of all of the nests was precisely marker in ArcGIS. A smaller ground survey was completed in order to test the accuracy of the aerial counts, whilst also collecting habitat data. The counts produced by the aerial survey were not significantly different to the counts from the ground survey. Red-footed booby nests were found in 6 different habitat types, whereas magnificent frigatebirds showed much greater preference for a specific habitat, as they were only identified in 2 habitat types, red/brown mangrove and dry forest.

Due to the increased efficiency, safety and reduced disturbance of the birds, aerial surveys proved to be a very useful alternative to ground counts.

Word count: 256

1.0 Introduction

1.1 Seabirds

Seabirds are comparatively the most threatened group of birds in world, according to data collated by the IUCN red list (Croxall *et al*, 2012). The populations of seabirds are declining rapidly, due to the threats they face from global warmning, habitat destruction and indirect completion with fisheries (Fretwell, Scofield and Phillips, 2017). Seabirds are important top predators in marine ecosystems, studying seabird populations can therefore tell us about the threats and pressures that their ecosystems face (Mendez *et al*, 2016); they can be a useful indicator of change within their environment. Seabirds often come into contact with marine plastics or fishing equipment, figure 1.1; their populations can be affected by pollution or damage within the marine environment, as a result of global warming or human disturbance (Tavares *et al*, 2016).

Figure 1.1 Magnificent frigatebird (*Fregata magnificens*) entangled in a fishing line in the Cayman Islands. (Photo credit – Rhiannon Meier).

1.2 Current census methods

For most species of seabird, current population surveys are completed using line transects or simple point counts (Chabot and Francis, 2016), however many of these counting methods can be extremely time consuming or expensive. Currently, there is not one single universal method that be applied to all species of seabird. Even seabird colonies of the same species can greatly differ in size, from a few hundred individuals to more than one million (Merkel, Johansen and Kristensen, 2016). Another one of the greatest problems in the field is the inaccessibility of nest sites, surveys are hindered by difficult or inaccessible terrain, such as steep rocky cliffs, figure 1.2. Members of the same species, such as black guillemot (*Cepphus grylle*) or puffins (*Fratercula arctica*), can nest in steep cliff crevices, burrows or even caves (Tschanz, 1990).

Figure 1.2 Merkel, Johansen and Kristensen (2016), used a time lapse camera to measure breeding success in a large colony of thick-billed murre (*Uria lomvia*) nesting on steep cliff faces in Kippaku, Greenland. However, they estimated that it took between 12 and 22 hours to process the images from each plot, this time consisted of visual inspections, image analysis, data preparation and data input.

Another risk involved in surveying seabirds by foot is the damage that might be caused to their environment; many colonies live on totally uninhabited islands, such as the populations of black noddy (*Anous minutus*) and red-footed booby (*Sula sula*) discovered by Titmus, Arcilla and Lepczyk (2017) on Swains Island, American Samoa. Some species thick-billed murres are easily disturbed and do not respond well to any human contact (Merkel, Johansen and Kristensen, 2016), preventing the implementation of a GPS tracking device. In order to improve census efficiency, whilst simultaneously reducing the damaging effect of invasive techniques, the use of camera technology in this field has increased massively in recent years. These include fixed point cameras, camera traps and time-lapse imagery for estimating things such as breeding success (Merkel, Johansen and Kristensen*,* 2016), figure 1.2. Digby *et al* (2013) found that autonomous acoustic recording devices can be a very efficient alternative to point counts when surveying for new bird species.

As the price of digital cameras and unmanned aerial vehicles has decreased, there has been a great emergence in the use of aerial photography in seabird surveys (Chabot and Francis, 2016). The resolution and quality of video cameras has also improved, therefore it has much easier to survey and count birds from the air, using both manned and unmanned vehicles. Mounting cameras on aerial vehicles allows very large areas to be surveyed in a short space of time (Chabot and Francis, 2016). With The use of video recordings can be especially advantageous over taking a single visual account, as the footage can be reviewed and the count can be repeated several times to ensure accuracy. The emergence of new higher resolution satellite imagery, it may even be possible to count each individual seabird by satellite (Fretwell, Scofield and Phillips, 2017). Chilvers *et al* (2015) used a helicopter to produce the first baseline counts for the endemic Auckland Island shags (*Phalacrocorax colensoi*) in New Zealand, whilst Ridgeway (2010) found aerial surveys to be a useful tool in estimating nest density of double-crested cormorants (*Phalacrocorax auritus*) around Lake Huron.

1.3 Seabirds on Little Cayman, Cayman Islands

The Cayman Islands is a British overseas territory in the Caribbean Sea, lying to the north west of Jamaica and south of Cuba. Little Cayman is the smallest of three islands, positioned between the two larger islands, figure 1.2.1. On the south western shoreline of Little Cayman, a small hypersaline lagoon, Booby Pond Nature Reserve, was designated an IBA (Important Bird Area) by Birdlife International in 2007 (BirdLife International, 2017). Most notably, the red-footed booby (*Sula* sula) population on Little Cayman is the largest in the Caribbean; with 4839 breeding pairs in 1997, it was thought to make up over 1% of the global population (BirdLife International, 2017). The Booby Pond Nature Reserve, figure 1.3.2, is also home to breeding populations of magnificent frigatebird (Fregata magnificens), West Indian whistling duck (*Dendrocygna arborea*) and vitelline warbler (*Setophaga vitelline*). Croxall *et al* (2012) stated that IBA breeding sites should be given priority protection in order to conserve seabirds.

Figure 1.3.1 Map of the Cayman Islands, Little Cayman is the smallest of the three islands, located in the middle. (Image credit – Google maps).

Figure 1.3.2 The Booby Pond Nature Reserve on the southern shoreline of Little Cayman. (ArcGIS base map image credit – Cayman Islands Department of Environment).

The breeding colonies of red-footed booby and magnificent frigatebird are located in the mangrove forest to the north west of the pond, nesting in the tops of the trees, figure 1.3.3. The mangrove forest is extremely treacherous terrain; dense vegetation and mud paths interspersed with sharp coral fossils. The arboreal nesting birds usually occupy the very top of the trees, so a further challenge is to accurately observe the contents from ground. These conditions make it very difficult to complete an accurate population survey of Booby Pond on foot.

Figure 1.3.3 Seabirds nesting in the tops of the trees in Little Cayman. (Photo credit – Dr Jonathan Green).

1.4 Red-footed booby (*Sula sula*)

The red-footed booby (RFBs) is an arboreal nesting tropical seabird. As their namesake suggests, RFBs have bright red feet, but there are two colour morphs for their plummage, brown and white, figure 1.4. RFBs are well adapted for diving to catch fish, with lean aerodynamic bodies and long bills (National Geographic, 2017). The colony of RFBs nesting on Little Cayman is believed to be internationally significant, making up over 1% of the global population; although the global population is steadily decreasing, RFBs are still classified as "least concern" on the IUCN Red List (BirdLife International, 2017).

Figure 1.4 Brown (left) and white (right) colour morphs of the red-footed booby (*S. sula*) on Little Cayman. (Photo credit – Jonathan Green)

1.5 Magnificent frigatebird (*Fregata magnificens*)

The magnificent frigatebird (MFB) is a large arboreal nesting seabird. MFBs have large hooked bills and are distinctly sexually dimorphic (All About Birds, 2017); females have dark brown plumage, are larger in size and have a simple white collar, whereas males are slightly smaller but have jet black feathers and a large bright red neck pouch, which they use to attract a mate, figure 1.5. There were thought to be 150-200 MFB breeding pairs in the Booby Pond Nature Reserve, but MFBs are listed as "least concern" by the IUCN Red List (BirdLife International, 2017).

Figure 1.5 Males (left) and female (right) magnificent frigatebirds (*Fregata magnificens*). (Photo credits – Federico De Pascalis, left, and Jonathan Green, right).

1.6 Aims

1) Achieve accurate counts that can be added to baseline data for red-footed boobies (*Sula sula*) and magnificent frigatebird (*Fregata magnificens*).

2) Assess how useful image drone camera systems can be in collecting seabird population data.

3) Establish the most effective seabird census method by comparing ground and aerial surveys.

4) Analyse the efficiency of two different counting and data processing techniques.

5) Test the influence of habitat type on nest abundance, and identify the most important tree species and habitat types for the two seabird species.

Introduction word count: 1355

2.0 Methods

2.1 Capturing video footage using a UAV

In order to survey the whole colony area surrounding the Booby Pond, a total of 37 GPS point flight lines were created in ArcGIS (ESRI ltd), flight lines measured between 280 and 730 metres in length. The base image for ArcGI was provided by Cayman Islands Department of Environment. The model of UAV was a DJI Inspire 1 and the video was recorded using a Litchi autonomous flight app, whilst an Apple iPad 2 was used for the interface. The flights took place from 24-28th February 2017, and lasted between 6 and 10 minutes long. The drone autonomously followed each individual flight line, with the camera pointed directly at the floor, capturing 1080p video footage. The drone generally flew at around 2.5 m/s, and 14 m off the ground.

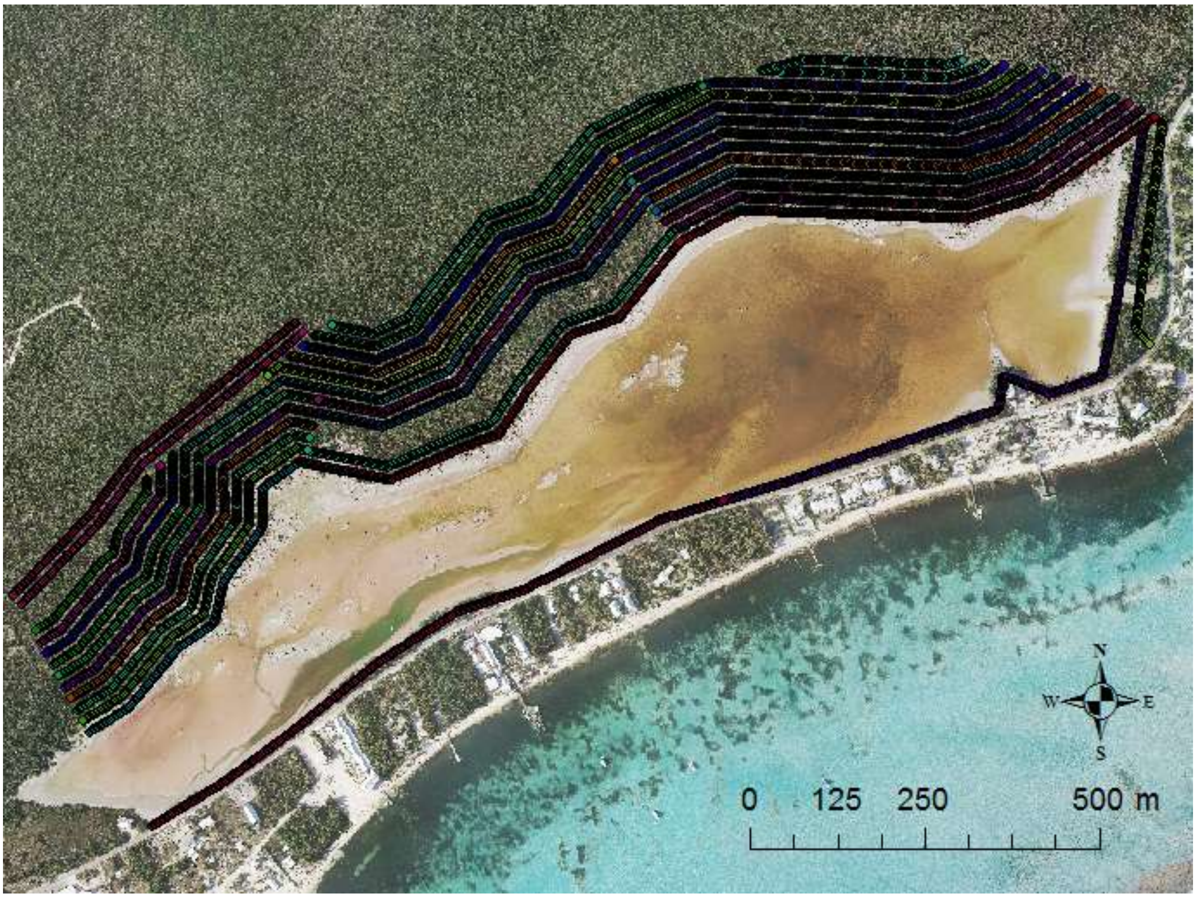

Figure 2.1 37 GPS flight lines to survey the full colony area surrounding Booby Pond. (Base image credit – Cayman Islands Department of Environment).

2.2 Ground transect data collection

9 ground transects, measuring 250 metres long and 20 metres wide (5000 m^2), were surveyed from 20-24th February 2017. Transects ran perpendicular to the flight lines; from the pond directly into the mangrove forest. The specific location of each transect was selected based on population density estimates from a short survey completed in 2016. 3 transects were located in high density areas, 3 in medium density areas and 3 in low density areas. All trees and bushes were searched thoroughly whilst slowly walking from side to side up the length of the transect, the location and species of any occupied nest was recorded using a handheld GPS device. Each transect was further divided into 50 individual 10 x 10 metre grid cells. The specific habitat type or tree species present within each individual grid cell was also recorded whilst searching for nests. A chi squared table was created to test whether the seabirds showed a preference for building their nests in specific habitat types. The expected values for each habitat type in the chi-square table, were found by calculating the corresponding proportion of the total number of nests found on the ground survey.

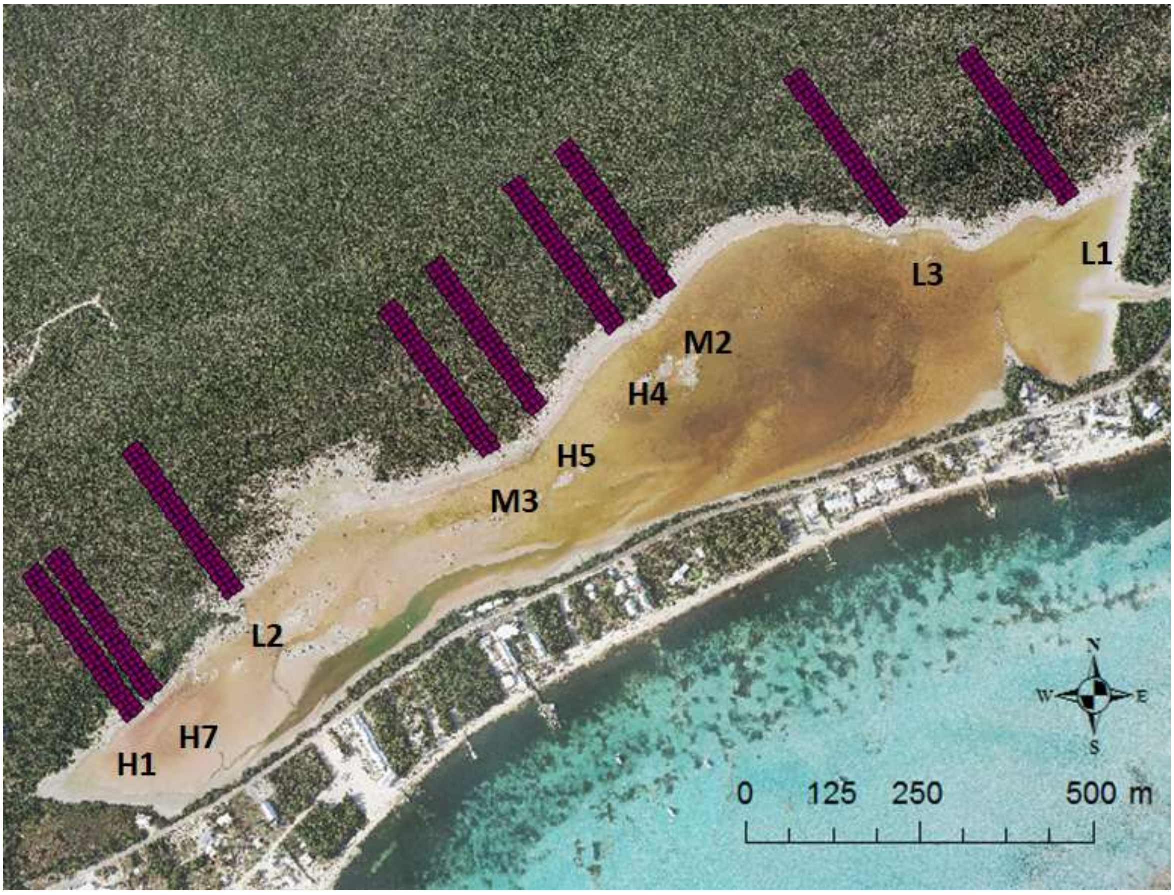

Figure 2.2 9 ground transects stretching 250 metres from the Booby Pond, into the mangrove forest.

2.3 Method 1 - initial counting technique

In order to assess the viability and accuracy of different techniques, two different counting methods were performed. Firstly, the video footage captured by the drone was watched carefully, the time (in seconds) and species of any occupied nest was recorded. The footage was usually viewed at 0.75x speed, whilst looking for the contrasting colours of the bird or nest against the green background of leaves, although it was still possible to spot nests in bare trees as they contrasted against the sand on the floor below. The playback speed was reduced further to 0.5 or even 0.25x if there was a nest that was hard to identify and areas with high nest density were watched repeatedly.

The time of each nest within the video corresponded to a specific GPS location along the flight path, therefore an Excel file was created for each flight line, and a nest tally for each species was added to the corresponding GPS point. A 12 x 8 m rectangular box was created to surround each GPS point; this was the estimated frame size of the camera. The CSV file for each flight line was exported from Excel to create a shapefile showing these boxes in ArcGIS, figure 2.3. Each box had a specific nest count for each species, this gave a total nest count for each species, as well as displaying the approximate location of the nests.

Figure 2.3 Rectangular boxes displaying the cameras field of view on each flight line, on ArcGIS.

2.4 Method 2 – precise GPS marking

As method 1 only marked the approximate location of the nests, a second method was need to increase the accuracy. Instead of just recording the time within the video, a dual screen was used whilst viewing the footage method 2; the precise location of a nest was immediately pinpointed on ArcGIS. The GPS points along the flight lines were used to identify the approximate area of the nest, then zooming in on the high resolution satellite image allowed certain landmarks or distinguishable trees to be matched with those in the video footage, ultimately allowing the nest to be marked accurately. Further information, such as species, flight line and time within the video, was added to the ArcGIS attribute table for each nest point. Nests that fell within the ground transect areas were spatially isolated using the "joins and relate" tool on rectangular shapefiles that represented the ground transect area.

2.5 A second unbiased counter

In order to validate the detectability of nests and the methods used, a second counter viewed short sections of the drone video footage, concentrated around the ground transect areas. The second counter only viewed the drone video footage once, as opposed to the first viewer who had viewed the footage several times. The nests were then simultaneously marked in their correct GPS location, using method 2.

The attribute table for the point shapefile, including latitude and longitude, was exported to create a CSV file that displayed second counters results in Excel. The second viewer's total counts, and individual species counts, were compared to the first viewer's, and the ground transect counts. The performance of the second counter in regards to high, medium and low density transects was also analysed.

2.6 Scaling up counts

A shapefile that displayed the approximate colony area was drawn out on ArcGIS, the area that this covered was then calculated, in m^2. Each GPS point file for the flight lines was converted into a polyline on ArcGIS, the "buffer" tool was then used to add 6 m either side of the polyline, creating a 12 metre polygon that spanned the length of the flight transect. These polygons represented the total area surveyed by each drone flight. In addition to the area surveyed aerially, a no-fly zone close to the local airport was surveyed by foot, as this was thought to be an important high nest density area. The area of every flight line and the ground transects in the no-fly zone were combined to give an estimated total survey area, in m^2. The results of the counts from method 2 were added to no-fly zone ground count and scaled up to give a total colony count.

2.7 Data Analysis and statistics

All of the GPS point marking of nests, along with the creation of ground transects and flight lines was completed in ArcGIS (ESRI ltd). Microsoft Excel was used to create graphs, analyse count data and create any additional shapefiles for ArcGIS. Microsoft Excel was also used for further statistical analysis of the data, such as chi square and ANOVA analysis.

Methods word count: 1149

3.0 Results

3.1 Method 1 count results

A total of 819 nests were found using method 1, 428 red-footed booby (RFB) nests and 391 magnificent frigatebird (MFB) nests. Method 1 also displayed the approximate location of each nest (accurate to at least 8 metres) when the boxes were imported into ArcGIS to make a shapefile. The 12 x 8 m boxes, representing the view of the video camera each second, were coloured based on the number of nests present within them, figure 3.1.1 and figure 3.1.2.

RFB nests were more widespread, as they were identified on 24 out of 37 flight transects, including both sides of the pond, figure 3.1.3. MFB nests were only found on the northern side of the pond, particularly the western side of the mangrove forest too, figure 3.1.4. MFB nests were only identified on 12 out of 37 flight transects. The greatest number of nests found on a single transect was 167 on C4L1, 62 RFB nests and 105 MFB nests.

Figure 3.1.1 Boxes that represent a 12 x 8m video frames, displayed on ArcGIS. The key on the left shows how density of RFB nests within the frame is displayed, increasing intensity of red displays more nests within the area.

Figure 3.1.2 Boxes that represent a 12 x 8m video frames, displayed on ArcGIS. The key on the left shows how density of MFB nests is displayed, increasing intensity of grey displays more nests within the area.

Figure 3.1.3 RFB nests were very widespread across Booby Pond, although the area of highest density appeared to be the central part of the mangrove forest on the northern side of the pond.

Figure 3.1.4 MFB nests were only found on /37 flight transects. They were clustered together in two distinct areas, a small area in the far south west of the pond, and a slightly larger area directly in the centre.

3.2 Method 2 results

A total of 1089 nests were found using method 2, 654 RFB nests and 435 MFB nests. RFB nests were far more widespread than MFB nests again, as MFB nests were not identified on the southern shore or the eastern side of the mangrove forest, figure 3.2.1. RFB nests were found on 27 out of 37 flight transects, compared to only 11 out of 37 for MFB nests. The GPS points of the nests were being marked on ArcGIS whilst simultaneously watching the video footage; it was possible to achieve much greater accuracy. The exact tree, and even the exact branch, was tagged on ArcGIS, figure 3.2.2.

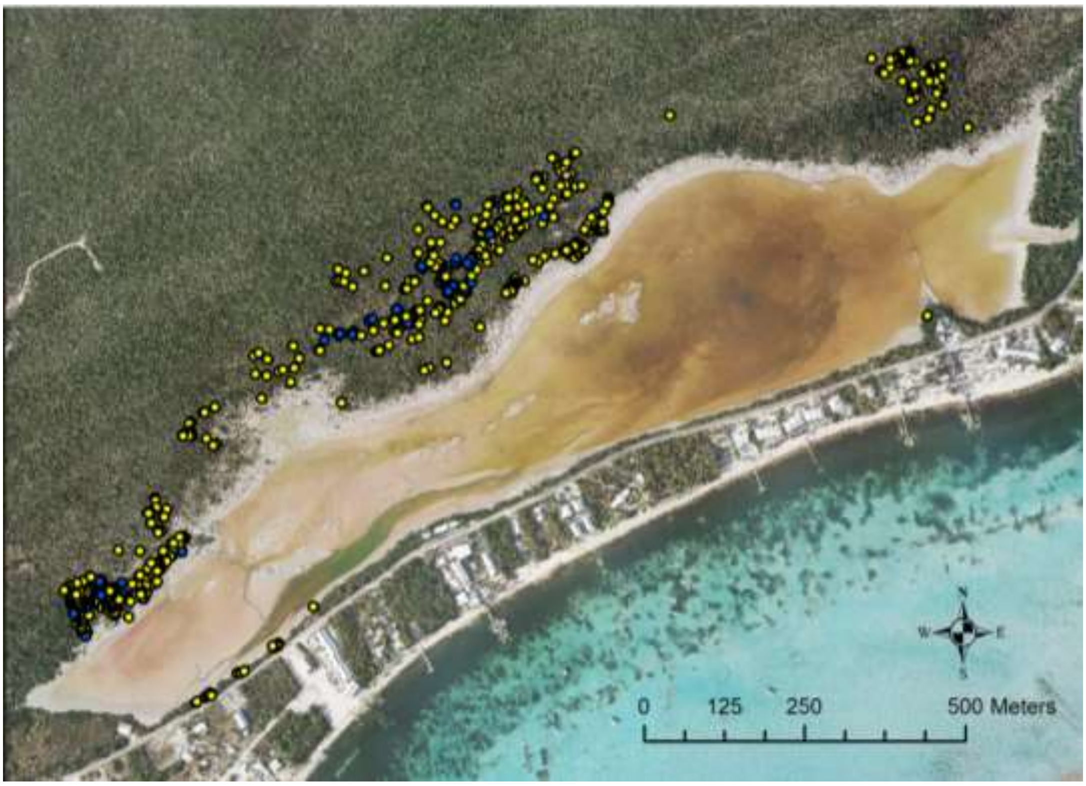

Figure 3.2.1 RFB and MFB nests around Booby Pond, yellow dots represent RFB nests and blue dots represent MFB nests.

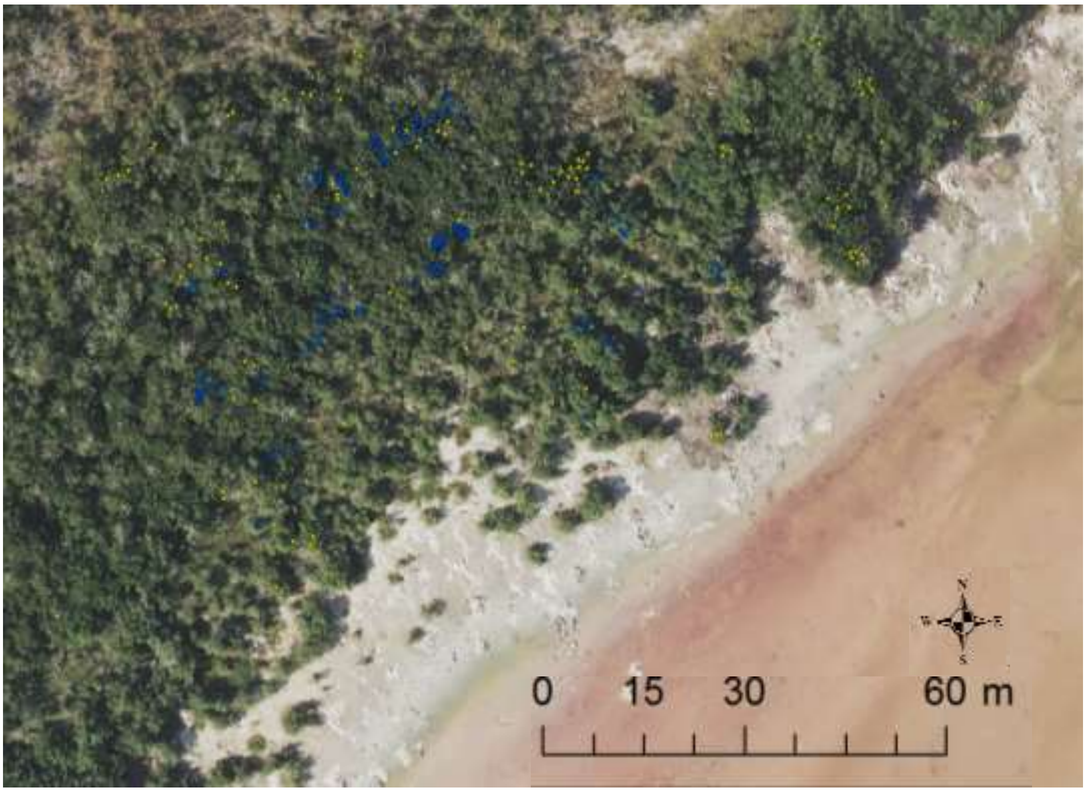

Figure 3.2.1 A detailed view displaying the greater precision of the nest point marking using method 2, yellow dots represent RFB nests and blue dots represent MFB nests.

3.3 Method 1 vs. 2

The total nest count increased from 819 after method 1, to 1089 after method 2, an increase of 33.0%. A further 226 RFB nests were found using Method 2, compared to only 44 additional MFB nests, figure 3.3. RFB nests were found on two extra flight transects in method 2, an increase from 25 to 27 flight transects. Whereas, MFB nests were found on less flight transects in method 2, only 11 transects compared to 12 in method 1.

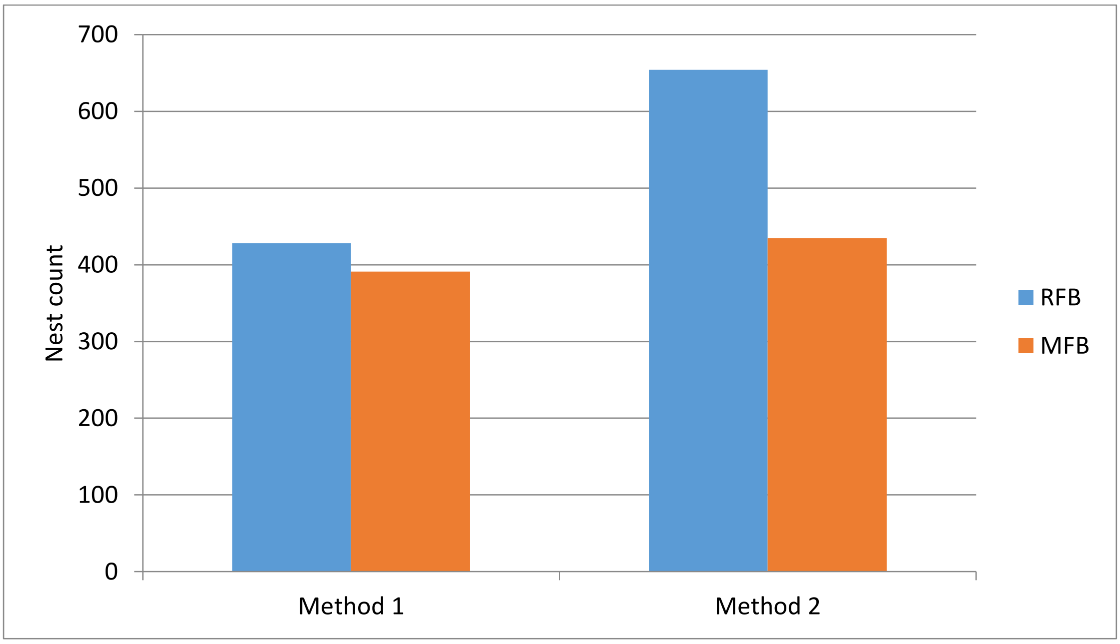

Figure 3.3 There was a 33.0% increase in the total number nests found after method 2, including a 52.8% increase in RFB nests. There was a less significant increase in the number of MFB nests, only 11.2%.

The location tagging of method 2 was notably more precise than method 1; nests were possibly tagged with as much as 8 metres of inaccuracy in method 1. However, method 1 took significantly less time to complete. Around 6 working days were needed for method 1; this included the initial counts, creating Excel files and uploading them all to ArcGIS to make shapefiles. Method 2 took significantly longer to complete, at least 10 working days were required to mark the location of every nest, despite it being the second time that the footage had been viewed.

3.4 Aerial counts vs. ground transect counts

Using the "joins and relate" tool on ArcGIS, nests that were found within the ground transect areas were isolated from the other nests found in method 2. A total of 262 nests were found within these areas, compared to 297 that were found whilst searching on the ground. Far less RFB nests were found on the aerial surveys, 119 compared to 200 that were found on the ground transects. However, far more MFB nests were identified, 143 compared to only 97 on the ground transects, figure 3.4.1.

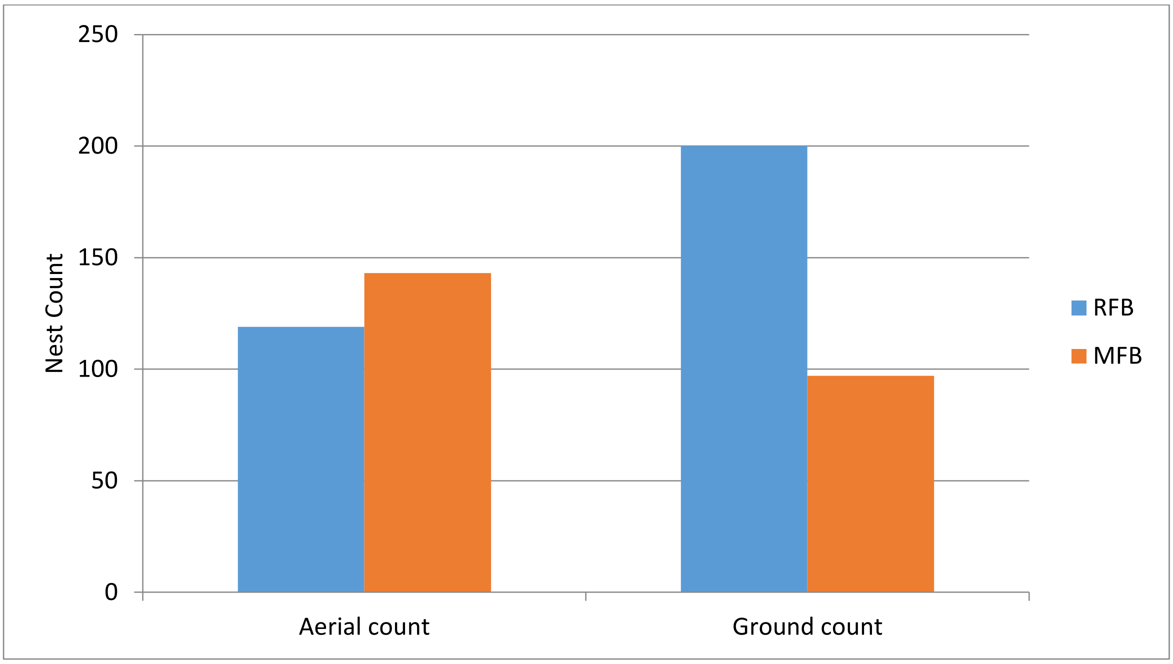

Figure 3.4.1 81 less RFB nests were found on the aerial survey, compared to the ground survey. Although 46 more MFB nests were found on the aerial survey.

The average time taken to walk a 250 m ground transect was 85 minutes. However, time taken to walk through the mangrove forest to the start point and back home from the finishing point, along with time spent processing the data, meant that a maximum of only two transects could be completed per day.

Nests were not identified on transects L2 and L3 using either technique, figure 3.4.2. The similarity of counts differed greatly between different transects, but the ground count was always higher or at least the same as the aerial counts, besides in transect H7, where there were 9 (31.0%) more nests found using the drone. The transects with a higher total number of nests seemed to show greater similarity between aerial and ground counts, represented by the trendline in figure 3.4.2. The difference between the two counts for the transects with the highest nest density, H5 and H1, was 1.9% and 2.4% respectively.

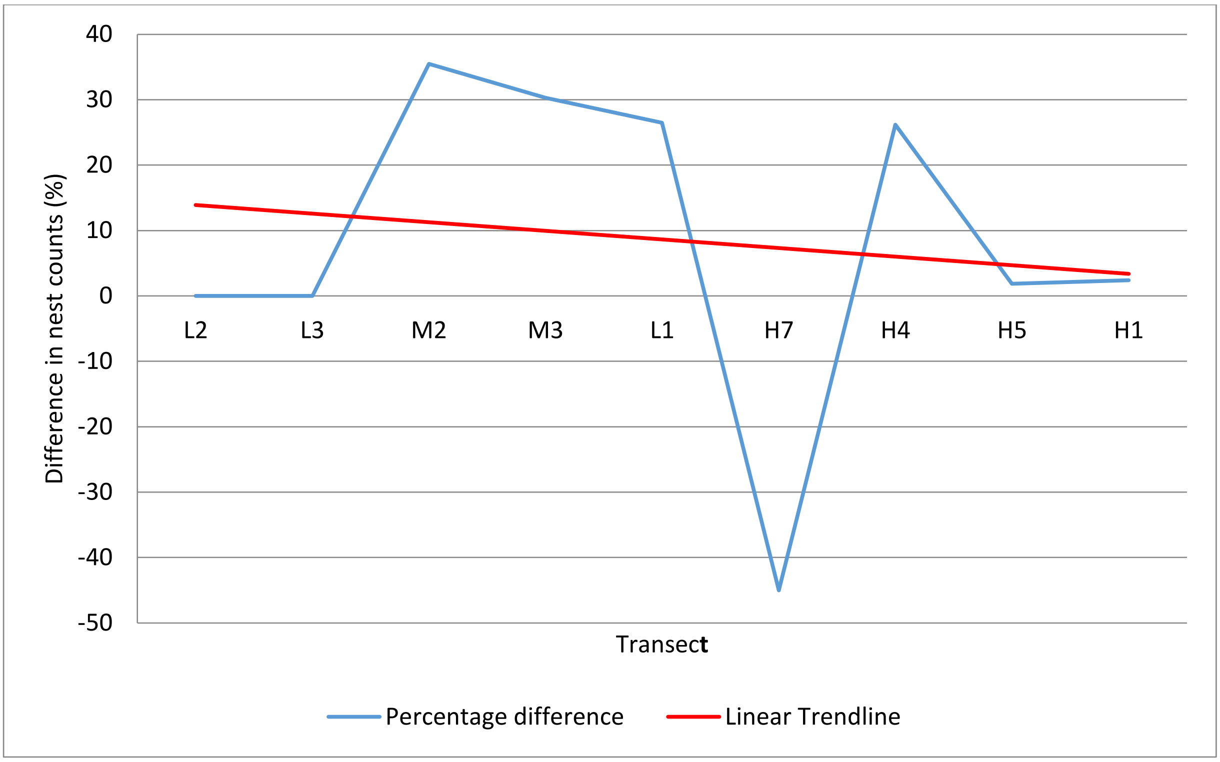

Figure 3.4.2 The percentage difference between method 2 aerial counts and ground counts. The transects were ordered by increasing nest count, from left to right.

3.5 Results of a second unbiased viewer

In order to validate the detectability of nests within the video footage, a second viewer watched the footage that covered the ground transect area. The second counter was successful in identifying the two low density transects that represented negative controls, L2 and L3. Besides the next lowest density transect, L1, counter 2 found a greater number of nests on every transect, when compared to Counter 1 and the ground counts figure 3.5.1. There was no significant difference between the counts when they were analysed with a One-way ANOVA test, $F(2,24) = 0.64$, $P = 0.54$.

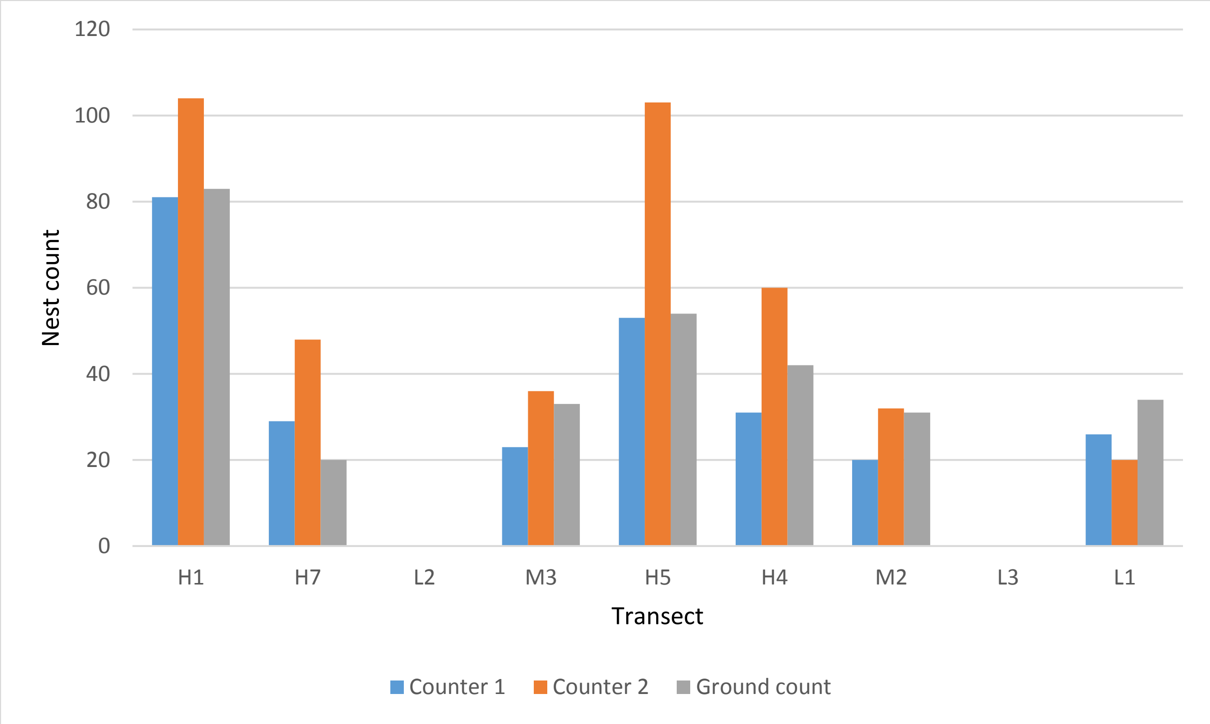

Figure 3.5.1 The transect area nest counts of both species combined, counts were performed by two different aerial counters and a ground counter walking the transect.

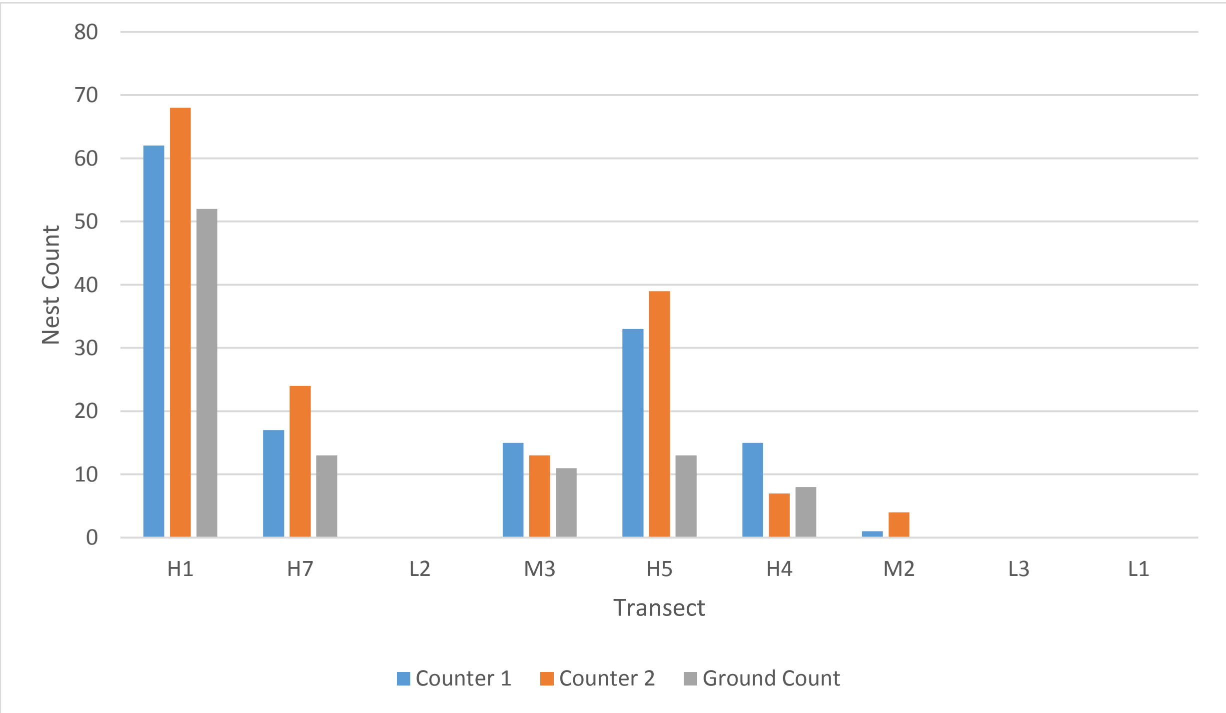

Figure 3.5.2 The MFB nest counts within transect areas. There is a much greater similarity between the three different counts when the RFB data was removed from the graph.

3.6 The influence of habitat type

A total 7 different habitat types were recorded during the survey of 450 different 10 x 10 metre grid cells. The most frequent of which was dry shrubland (172 cells), followed by dry forest (101), white mangrove/ buttonwood (90), red/ brown mangrove (52), pond (16), plopnut (15) and succulents (4).

The null hypothesis would assume there would not be any preference in where a bird builds a nest. The expected nest counts, shown in blue on figures 3.1 and 3.2, were calculated based on the number of cells for each habitat type, described in section 2.2. As 38.2% (172/450) of the ground transect cells were dry shrubland, 38.2% of the 199 RFB nests (76 nests) found on ground transects should be found in the dry shrubland cells, if there was no preference.

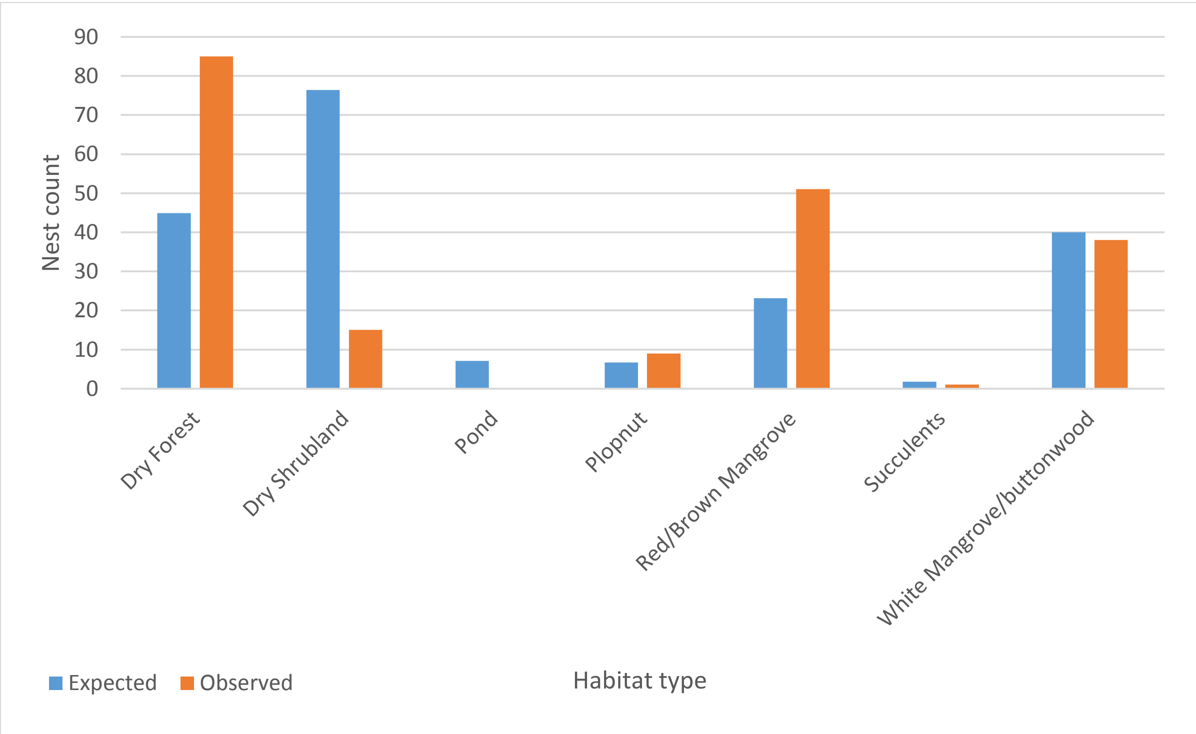

Figure 3.6.1. The expected vs. observed RFB nest counts for 7 different habitat types.

RFB nests were found in 6 different habitat types, their preferred habitats were dry forest and red/brown mangrove, in which the observed counts, 85 and 51, were significantly higher than the expected counts of 44 and 22. The observed value was significantly lower than the expected value in dry shrubland, only 14 nests compared to 76.

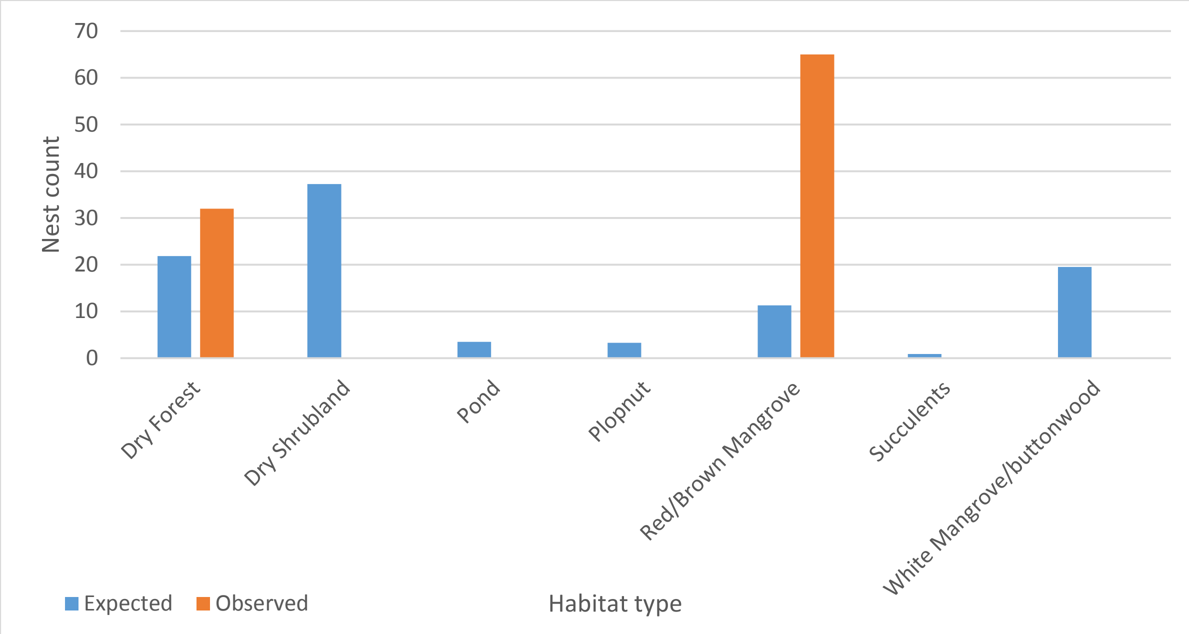

Figure 3.6.2. The expected vs. observed MFB nest counts for 7 different habitat types.

MFB nests were only found in 2 habitat types. The observed count for red/brown mangrove, 68 nests, was significantly higher than the expected count of 11. Dry forest was the only other habitat type in which MFB nests were found, a total of 32 were found in dry forest.

A chi square analysis showed there was very strong correlation between habitat type or tree species, and the abundance of nests within the area. The null hypothesis was strongly rejected for both species of seabird, for RFB $X^2_{(6)}$, $p = 4.71 \times 10^{-25}$, and for MFB $X^2_{(6)}$, $p = 2.77 \times 10^{-67}$.

3.7 Total population of the colony

The total colony area was estimated to be 402,685 m^2. The area surveyed by drone, including the area south of the pond, was estimated to be 272,682 m^2. In addition to the area surveyed by drone, a 15,000 m^2 area within the local airports no-fly zone was surveyed by foot. The total area surveyed was therefore 287,682 m^2, 71.44% of the estimated total area of the colony. A further 94 RFB nests and 48 MFB nests were found in the no-fly zone, resulting in a total of 748 RFB nests and 483 MFB nests that were actually found. Scaling up to the whole colony area gave an estimate of 1047 RFB nests and 676 MFB nests.

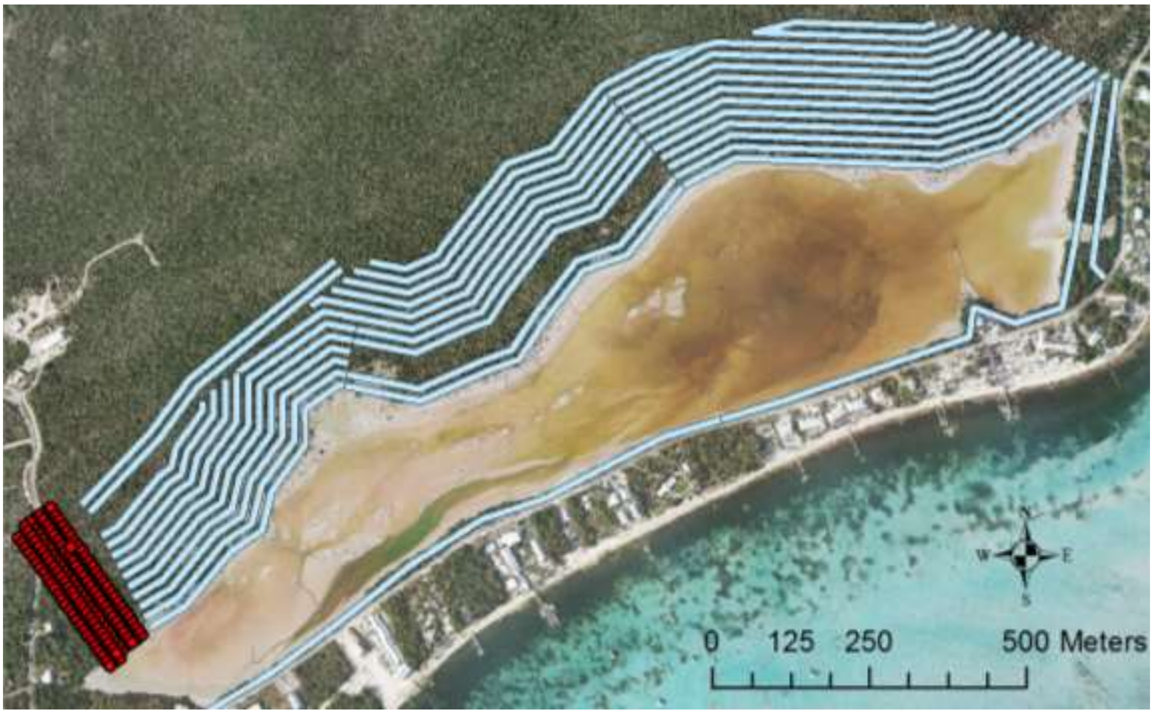

Figure 3.7 The total area surveyed was 287,682 m^2. This consisted of 272,682 m^2 from the aerial survey (flight survey area displayed in blue) and three additional 5000 m^2 ground transects, H2, H3 and H8 (displayed in red).

Results word count: 1638

4.0 Discussion

4.1 Method 1 vs method 2.

A far greater amount of nests were found using method 2, when compared with method 1. Although method 2 was much more thorough and accurate with the GPS marking, the difference in technique might not necessarily have been the reason for the increase in nest count. The difference could simply be a result of the greater amount of time spent viewing the footage. It was at least the second time that the footage had been viewed by the same counter, as the high density areas were watched repeatedly, usually in slow motion. Nests that were previously missed or well-hidden may have been spotted in method 2. Of course, there will be a limited number of nests that can be found in the area, therefore the possibility of finding new nests will eventually be exhausted, or subsequent reviews of the footage will make very little difference to the counts. A useful follow-up experiment could test for the optimum number of times that footage should be reviewed.

As method 1 was chronologically first within the project, it is likely that species identification skills improved in throughout project. This may have been shown by figure 3.3, there was a 33.0% increase in the number of RFB nests found, but only an 11.2% increase in MFB nests found. This theory is supported by the fact that the number of transects that MFB nests were found on reduced from 12 out of 37, to 11 out of 37 after method 2. However, it is also possible that the dark/ black plumage of MFBs contrasted more against the background of trees, when compared to the light brown plumage of RFBs.

4.2 Aerial counts vs ground count

The ground count for each transect was always higher than the corresponding aerial count for the transect, besides in the two transects where no nests were found, L2 and L3, and one other transect, H7. As an average of 85 minutes was taken to complete each ground transect, it is likely that a greater accuracy was achieved on ground counts. The counter argument, and possibly one of the explanations for the H7 transect result, is that a UAV above the trees might provide a better view of the nests that were high in the tree tops. Alternatively, errors in the handheld GPS device (which is particularly susceptible whilst under trees), may have led the ground survey into the wrong area. These results do not support the findings Chilvers *et al* (2015), who found that helicopter counts for Auckland Island shags (*Phalacrocorax colensoi*) were 26% higher than those produced by a ground based survey in New Zealand.

Although it could be related to a greater ability to find nests from the ground, the increase in nests found could be a result of aerial counts needing to be scaled up. When the counts were scaled up in section 3.7, the calculations considered the small gaps between flight lines, as well as the larger areas that did not get surveyed. As there was a different number of flight lines running through each ground transect, and the smaller area meant it would have difficult to achieve accuracy, the counts within the transects were not scaled up independently. Therefore, a different method of scaling up would be required in order to directly compare ground and aerial counts.

As it was described in section 3.4, there seemed to be greater similarity in the counts when they were performed in a higher density area. This could indicate that the greatest error arose from simply missing nests within the video footage, as higher density areas may have triggered a higher concentration level in the viewer. It could have been useful to have used better video viewing software for this project, particularly one that that would allow for zooming in during the video, this could help identify nests that the viewer was uncertain about. However, it was also found that a faster initial playback speed was useful as the movement of birds within their nests was particularly noticeable. This suggests future surveys should use a combination of full speed and slow motion viewing in order to perform counts.

The use of an unmanned drone was very effective in covering such a large survey area in an otherwise inhospitable environment. The UAV provided a safer alternative to walking through the difficult terrain; it was far more efficient too. A total of 5 days were required to walk the 9 transects, and this only covered a very small area of the forest. A far greater area could have been surveyed by the drone in this time; using method 1, almost the entire pond could have been surveyed and counted within 5 days. This view of increased efficiency was supported by Grenzdorffer (2013), who used a UAV to survey a common gull colony in Langenwerder, Germany, and found it far quicker than manually counting the colony whilst on foot.

4.3 The influence of habitat type

RFB nests were found in all recorded habitat types, besides pond. Mostly due to the fact that there were not many trees in the water. However, MFB nests were only found in 2 out of 7 habitat types, dry forest and red/brown mangrove; suggesting MFB nests require trees of a specific size, strength or species, possibly due to the bird's greater size and weight. The density of nesting within the MFB colony seemed to be much higher than that of the RFB colony, this could suggest MFBs were outcompeting RFBs for nest material.

Whilst viewing the aerial footage, it was actually possible to detect the type of habitat from the air, plopnut trees or the low lying shrubland areas were particularly obvious. Although it would be difficult to measure the exact area within the camera frame, ie 10 x 10 m grid cells; if it was possible to accurately estimate habitat type from drone footage, or even using the colours in a satellite image, this would even further remove the need to complete surveys on foot.

The arboreal nesting behaviour of the birds on Little Cayman highly resembles the behaviour of those described in Titmus, Arcilla and Lepczyk (2017). There were very few nests found in low-lying shrubs or ground plants, and once again, the nests were predominantly found high in only two species, similar to the MFB nests that were found in Booby Pond. It is also possible that MFB nests were only found in highly specific locations, and at the tops of the trees, because of the threat of predation by feral cats (*Felis catus*) on Little Cayman, figure 4.3. Feral cats were a large problem on Swains Island, “introduced predators may have powerful negative impacts on the birds” (Titmus, Arcilla and Lepczyk 2017).

It seems that the driving factors in determining nest locations were the competition for the highest/strongest trees (particularly with MFBs), competition for nest material and the location of invasive predators, feral cats.

Figure 4.3 Evidence of a feral cat (*Felis catus*) predating a MFB on Little Cayman. (Photo credit – Cayman Islands Department of Environment).

4.4 Limitations.

The greatest limitations in this study were most likely the misidentification of nests or simply failing to spot nests in the videos. As the results of the second counter suggested, described in section 3.5, there was great difficulty in distinguishing between the two species from the drone.

Figure 4.4 RFB chick in a nest. As the chicks of the MFBs are also bright white in colour, it is possible that nests containing the larger MFB chicks were misidentified as those belonging to the white RFB morph. (Photo credit –Jonathan Green).

It is possible that there was error in the overall scaled up estimates. The survey area estimates only considered one size of video frame, the height of the drone camera was not perfectly consistent, but the height of the trees was very inconsistent. There was essentially a different survey area for every flight transect. Additionally, the scaling calculations did not consider how MFB were only found only in very specific areas of the Booby Pond, it was assumed that their population would increase in line with an increase of area.

4.5 Future recommendations.

The techniques used in this study could certainly be adapted for measuring the population of other seabird colonies. If the colony is expected to be very large, the results of this project would indicate that method 1 would be suitably accurate, without taking too long to complete. However, smaller more precise surveys could use method 2. The methods used to capture drone footage were largely successful, but at times the camera wasn't quite close enough to allow for confident species identification. Grenzdorffer (2013) reported that a UAV was able to fly within 15 m of a gull colony, without seemingly disturbing them. As there was also no apparent disturbance by the UAV throughout this project, it could be useful for the drone to fly even closer to the trees in future surveys. Alternatively, the techniques used in this project could be most useful when surveying an area that contains only species of seabird; this would help reduce any error that may have emerged from the misidentification a species.

As a greater number of nests were found when reviewing the footage for a second and third time, it could be useful to design an experiment that would find the optimum number of times a counter should review the footage. This could help identify the most efficient method for future bird census studies.

The single greatest improvement to aerial population surveys could be the development of an autonomous counting technique that would automatically detect birds. Chabot and Francis (2016) suggested that aerial surveys might actually take longer than using manual techniques, if the images are not analysed autonomously. Whilst surveying a large colony of Thick-billed Murres (*Uria lomvia*), Merkel, Johansen and Kristensen (2016) stated that the development of automated image analysis software would be critical in making their method “a realistic long-term monitoring technique”. It is now possible for computer software to detect the presence of a bird within an image, particularly when there is high colour contrast, such as a white bird on a brown background. Spectral thresholding can be used to isolate a seabird from the image background (such as trees or rocks) by setting threshold values for the colour of the pixels produced by the bird, as described in Chabot and Francis (2016). When the colour a bird does not strongly contrast with the background, it can even be isolated using the shape and size as well as colour. McNeill *et al* (2011) filtered for the roundness of pixel clusters within an image; they used this technique to produce counts of Adélie Penguins (*Pygoscelis adeliae*) in a large breeding colony. It could be possible to design software that could isolate the shapes of bird nests from the green background of the mangrove forest, whilst simultaneously filtering for darker or lighter colours, in order to distinguish between RFBs and MFBs.

4.6 Conclusion

By combining information that was collected on both ground and aerial surveys, this study was ultimately successful in completing the first aim of the project, to produce population estimates for the seabird colony in Booby Pond Nature Reserve. After the scaling up calculations, the final estimates were 1047 RFB nests and 676 MFB nests. This is far less than the Birdlife International

(2017) estimates of 4839 RFB breeding pairs, but far greater than the estimate of only 150-200 MFB breeding pairs. In addition to population estimates, the GPS location of each nest was marked precisely, these GPS tags will allow for even easier future monitoring.

The secondary aims of this project were to compare multiple analysis and counting techniques, in order to ultimately establish the most effective method. Both counting techniques used were found to be sufficiently accurate when compared to ground counts. With a few minor changes in the UAV flight or even scaling up procedure, method 1 could be sufficient for most bird colonies and research budgets, whilst method 2 could be used if a smaller more accurate count is required.

The seabird populations on Little Cayman seem to be facing an increasing threat from anthropogenic activity, such as fishing equipment, marine plastics and invasive species (feral cats). Even high intensity tropical storms, such as the recent Hurricane Irma, present a growing threat to marine ecosystems in the Caribbean (Reyer *et al*, 2017). It is clearly a very important time to establish the best seabird census techniques, so we can begin to regularly monitor our current populations.

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5.0 References

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