The impact of Cyclone Pat on the Blue Lorikeet (*Vini peruviana*) population of Aitutaki, Cook Islands.

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World Parrot Trust
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Abstract

The Blue Lorikeet (*Vini peruviana;* hereafter "lorikeet") is a little studied parrot endemic to a few small islands in the South Pacific.

It is unknown how extreme weather events can affect this species due to the lack of ecological knowledge available. The future effects of global climate change include a predicted increase in frequency and intensity of stochastic events such as storms, flooding, and cyclones. These types of disturbances can have strong impacts on small, fragmented populations, especially those endemic to islands. The aim of the present study is to assess the impact of Cyclone Pat on the lorikeet population status of Aitutaki, Cook Islands. In February 2010, Cyclone Pat hit Aitutaki directly and caused a significant loss of over 50% of the lorikeet population, leaving an estimated population of just 1448 birds. The current density of lorikeets is now 86.195 km^2 (± 10.60 SE). The demographic of the population was completely altered as virtually all the juvenile birds were wiped out from the population, as sightings of them on the island were extremely rare. The mean density of lorikeets per 100m in 2010 was 1.68 birds (± 0.14 SE). This is a significant reduction in density especially when compared to the mean density in 2009 of 13.2 birds per 100m (± 1.90 SE). Despite the clear catastrophic impact Cyclone Pat caused, behavioural observations reveal that the lorikeet has benefited from being a habitat generalist. Consequently, the distributions of lorikeets across the island, and habitat and feeding preferences have completely changed from that of previous years. On the basis of these results, it is clear that a relatively large proportion of lorikeets survived the cyclone and that there is every chance the population will increase in number again. However, given the predicted increase in violent storms in relation to climate change, cumulative effects of repeated breeding failures and loss of individuals could dramatically increase the likelihood of extinction. Therefore it is necessary to keep surveying the lorikeet population of Aitutaki over coming years to not only assess population density and abundance but to also increase our understanding of exactly how this species reacts to stochastic events in the long term.

Key Words: *Population dynamics, Vini peruviana, stochastic events, cyclone, population density, Lorikeet.*

1. Introduction

Climates across the globe have become increasingly unpredictable and unstable. This has been attributed to climate change due to negative anthropogenic effects on the environment. Climate change is predicted to lead to an increase in frequency and intensity of storms across the world (IPCC, 2007). Extreme weather events include storms, fires and floods, all of which can significantly reduce population sizes and breeding success, especially when a population is small and unevenly distributed (Hennicke & Flachbarth, 2009). The impact of such events can be catastrophic for small isolated populations, such as those found on islands. The repeated exposure to such detrimental weather conditions can ultimately lead to extinction (Parmesan *et al.* 2000). It is these extreme events which can adversely affect both large and small populations (Saether *et al.* 1998).

It is important to gather information about an organism's abundance, distribution, life history and habitat requirements in order to fully understand threats to a specific species survival (Caughley, 1994; Green, 1995) from stochastic events and athorpogenic disturbances. Environmental stochasticity occurs when a series of almost continuous disturbances negatively affect the death and birth rates of a population (May, 2001). In contrast, catastrophic events, like Cyclone Pat, are large environmental disturbances which produce sudden major reductions in population size (Lande, 1993). Environmental stochasticity can affect small populations more severely than larger ones as the growth rate in smaller populations is more important as this ensures species survival (Lande, 1993).

It is important to understand how these threats can be counteracted and managed to avoid extinction events occurring (Wilson, 2000). Despite an increase in awareness about conservation biology, there is still distinct lack of detailed knowledge about many organisms across a range of taxa (Wilson, 2000) and how they react to such disturbances.

As extreme weather events are predicted to become more frequent (IPCC, 2007), negative environmental impacts upon habitats and its inhabitants will become more commonplace. Nevertheless, many tropical bird species have still received little attention, and insufficient knowledge about bird communities is often quoted as the reason for poor conservation of such species (Brawn *et al.* 1998; Grajal & Stenquist, 1998). Therefore, the aim of the present study is to examine the effects of tropical Cyclone Pat on the population status of the Blue Lorikeet (*Vini peruviana; hereafter "lorikeet")* on Aitutaki, Cook Islands.

1.1 Taxonomic classification

Lorikeets are a species of parrot (Psittacidae) and the *Vini* genus which contains eight lorikeet species that are endemic to the South Pacific (Forshaw, 2006). They are closely related to "Lories" and are classified in the same sub-family (Loriinae) (Forshaw, 2006). Lorikeets are distinguished from lories by their long tapering tail (Low, 1998). Lorikeets and Lories are characterised by their brush–like tongue which they use to eat nectar and soft fruits (Low, 1998).

Lorikeets are distinguished by their dark navy blue colour with a white bib and bright red beak and feet (Appendix I). They have a characteristic call, which is a high-pitched hissing "schee" sound (BirdLife International, 2010) which they repeat continuously whilst flying and foraging for food. They are quite small, only 18-20cm in size and have small wings in relation to their rounded body shape. Juveniles have a greyish-white bib on their chest (Low, 1998). However, there is no way to tell the difference between the male and female of the species visually. This can only be done by DNA analysis (G.McCormack, pers.comm, 2010).

1.2 Global distribution of the Blue Lorikeet

The lorikeet is a small, endangered bird endemic to the South–Eastern Polynesia. It is classed as vulnerable by the IUCN due to its uneven and highly fragmented distribution and is listed in CITES Appendix II. The high risk of predation from black ship rat, *rattus rattus* (BirdLife International, 2010) and predicted increase in the frequency of stochastic events, such as violent storms, are expected to contribute to the future decline of this species (IPCC, 2007).

Lorikeets were once widely distributed throughout South-Eastern Polynesia and could be found in over twenty islands, regrettably, they are now extinct on most of these (Holyoak & Thibault, 1984). The surviving populations are spread across nine islands of southern Polynesia (Holyoak & Thibault, 1984). Eight of these remaining populations live on atolls and islands within French Polynesia and the ninth population is situated in the Cook Islands on the island of Aitutaki (Figure 1, BirdLife International, 2010). Specifically, the lorikeet occurs in the Society Islands of French Polynesia on Motu One, Manuae atoll (~200 and ~350-400 breeding pairs respectively in 1973; Holyoak & Thibault, 1984). The bird was thought to be extinct on the atoll of Maupihaa, but a possible recolonisation event or even a surviving subpopulation has been rediscovered (Te Manu, 1999a; Te Manu, 1999b). The lorikeet is also present in the Northern Atolls of French Polynesia, specifically in the Tuamotu Archipelago (Raust & Ziembicki, 2006). Population data from 2006 estimated ~1000 birds on Rangiroa, ~1000 birds on Kaukura, ~500 birds on Arutua, ~200 on Apataki and ~50 on Tikehau (Holyoak & Thibault, 1984; Lovegrove. *et al.* 1989).

Figure 1: Map of South Pacific Islands, including Cook Islands and French Polynesia (http://www.fatbirder.com/images/map_australasia.gif).

Lorikeets have been surveyed on Aitutaki since the 1980's (Cook Islands Natural Heritage Trust, 2010) but only a handful of times. Basic population data is available but estimates vary considerably due to differences in surveying techniques and accuracy (Cook Islands Natural Heritage Trust, 2010). Recent estimates (from 2009) suggest that about 4,000 individuals were present on the island (Koutsofta, unpub). This is a large increase in estimated population numbers since the 1980's when survey results indicated a total population of a few hundred on the island. When recent survey data is combined the global population of the Blue Lorikeet is estimated between 7,200-9,000 individuals (Raust & Ziembicki, 2006).

1.3 The Island of Aitutaki

Aitutaki is an atoll island formed from both volcanic rock and coral deposits (See Figure 2). It is one of 15 islands which form the Cook Islands and is grouped with the Southern Cook Islands. Its total land mass area is 18.05km^2 (including outer motus) with a maximum elevation of 123m, which is known as Mt Maunga Pu which is situated in the north of the island (Kloosterman, 1976). The main island occupies an area of just 16.8km^2 (Stoddard & Gibbs, 1975). The atoll is therefore mainly lagoon, which compromises an area of ~50km^2(Kloosterman, 1976).

The vegetation on Aitutaki is heavily influenced my man (as many plants have been introduced) and there is no area on the island which has not been modified by humans in some way (G.McCormack, pers.comm). This was found to be the case even when preliminary scientific expeditions were taking place to the island in the sixties (Stoddard & Gibbs, 1975). The island is compromised mainly of farmland and plantations, mixed woodland, mega-herb grasslands and private gardens (Wilson, 1993). The most common species found on the island include coconut trees (*Coco nucifera*), banana trees (*Musa spp.*), hibiscus flowers (*Hibiscus tiliaceus*), mango trees (*mangifera indica*) and java plum trees (*Syzygium cumini*) all of which provide food sources for the lorikeet (Wilson, 1993).

Aitutaki harbours one of the largest breeding lorikeet populations in the world and was home to approximately 4,000 birds in 2009 (Koutsofta, unpub). This island represents an important breeding area for this species and therefore the future reproductive success of the species. Thus the colony on Aitutaki is of the utmost importance in relation to the total global population of Blue Lorikeets and its future survival.

1.4 Cyclone Pat

On the 10th February 2010 tropical Cyclone Pat hit Aitutaki in the early hours of the morning with winds of 100-180mh^{-1}. The cyclone formed in the Northern Cook Islands, it then moved to the south on the 8th February and reached tropical cyclone intensity by the time it hit Aitutaki head on (Figure 2). The cyclone was classed as a CAT level 3 which caused a state of emergency to be declared (AFAP, 2010). The high winds were mixed with thunderstorms, heavy rain and damaging sea swells from the nearby lagoon (AFAP, 2010). It is thought to be the worst cyclone to hit the area in the past twenty years with up to 60% of homes being damaged to some degree on the island (3News.co.nz, 2010). The worst hit areas were villages in the south and the west coast (Figure 3).

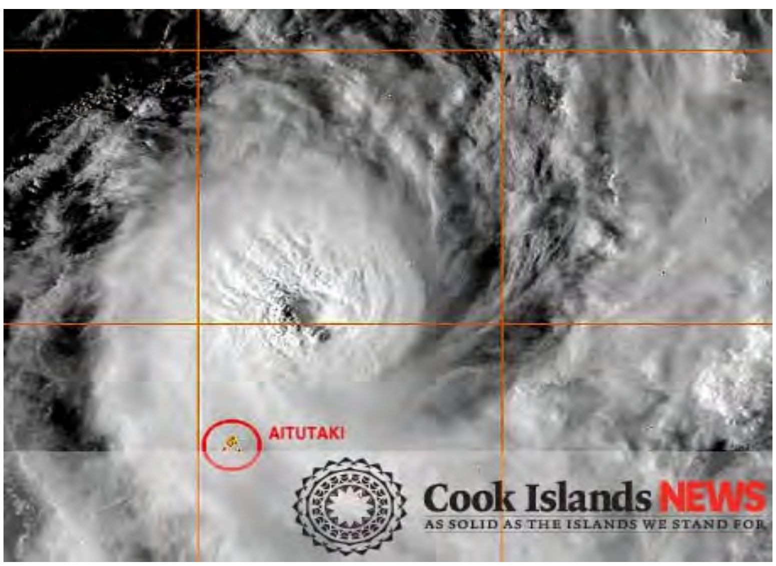

Figure 2: Satellite image of Cyclone Pat approaching Aitutaki (circled). Image from US Navy. Accessed via cinews.co.ck. http://www.cinews.co.ck/images/phocagallery/2010/February/Wed10/thumbs/phoca_thumb_l_USNavy%20Pat.jpg. on 10/8/2010.

The cyclone had caused both long and short-term damage to the island. The immediate problem left in the wake of Cyclone Pat was dry, barren ground as the storm had ripped up vegetation. This prompted officials to release new disaster warnings from fire (Cook Islands.org). However, the dryness was mitigated when another thunderstorm hit the island a few days later (Cook Islands.org). The island was hit by repeated extreme weather conditions that caused the loss of up to 60% of coconut trees, completely decimated mango and other fruiting tree species and de-foliated many common island flowers such as hibiscus (G.McCormack. pers.com, 2010). Agricultural land across the island was also destroyed and as a result many important food sources of the lorikeet were severely damaged.

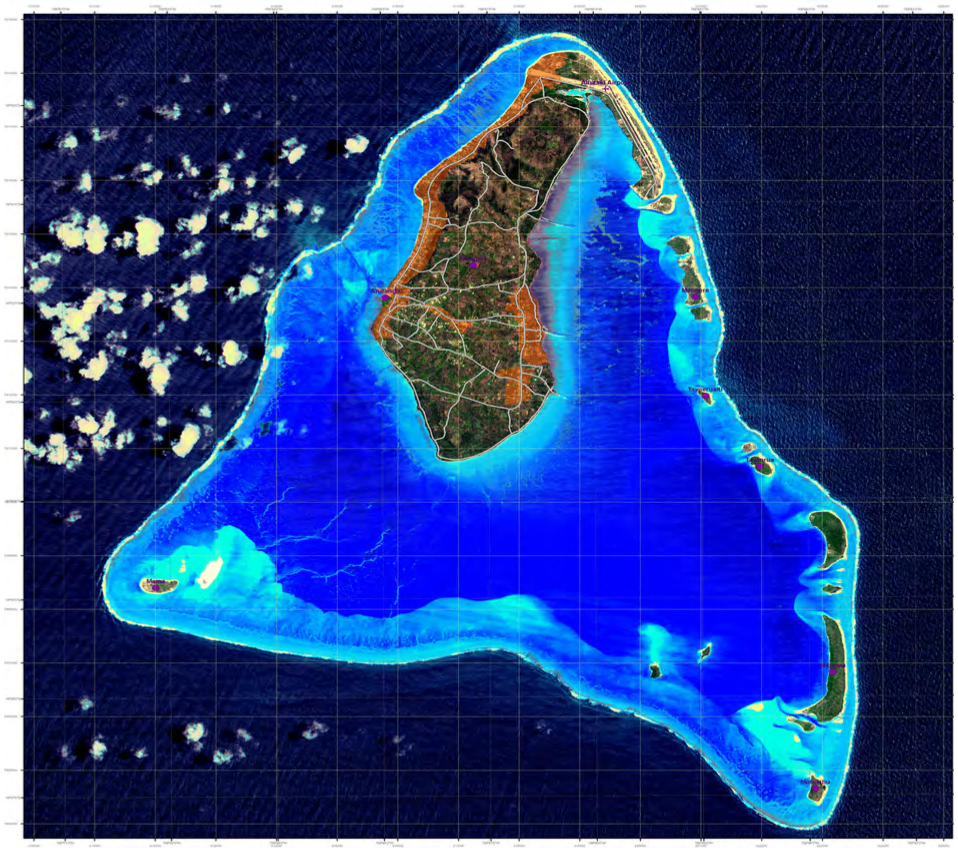

Figure 3: Map of Aitutaki with highlighted areas showing where cyclone damage was highest (http://www.disasterscharter.org/image/journal/article.jpg?img_id=67848&t=1268057340799. Accessed on 5/8/2010).

1.5 Impact of Cyclones on island populations

Stochastic factors can affect the demography of populations which in turn can increase the likelihood of extinction. Demographic stochasticity affects populations of all sizes as time to extinction is related to the carrying capacity of a population (Lande, 1993).

Large disturbances on small islands tend to depress species carrying capacity for a short period and can contribute to "successional turnover" within the ecosystem, especially in plant species (Whittaker, 1995). This results in successional habitat changes over time (Whittaker, 1995). This kind of secondary effect from cyclones to vegetation can create completely new habitats and therefore reduce the type of habitat there was found there before. As a consequence, many cyclone prone islands contain bird species that have a greater ability to shift their habitat preference, which gives them a selective advantage over their continental counterparts after stochastic events have occurred (Wunderle, 1995).

1.6 Objectives

This study combines three central objectives.

Objective 1: To assess the surviving population of lorikeets on Aitutaki by estimating density and abundance. On the basis of these results I hope to be able to fully assess the current status of this bird on the island and in relation to global figures available.

Objective 2: To assess cyclone damage and its effect on the of the surviving lorikeet population in terms of distribution and habitat preference by answering the following questions:

-How does lorikeet distribution vary according to habitat type?

-In which habitat are lorikeets most abundant?

-Has Cyclone Pat altered lorikeet behaviour?

Objective 3: This study also aims to understand the full effect that an extreme stochastic event can have on a lorikeet population by comparing all results with data from previous surveys conducted on the island.

2. Methods

2.1 Study Site

The island atoll of Aitutaki is situated in the South Pacific Ocean (18.85° 51' 0"S 159° 79' 24'W) and is one of fifteen islands which form the Cook Islands. It is situated in the Southern Cook Islands. Aitutaki lies in the subtropical region and contains several different habitats (Wilson, 1993). The main island habitats include coconut tree forest and farmland, along with large heavily managed private gardens (Wilson, 1993).

2.2 Line transect Surveys

During the study period, 31st May-2nd July, line transect surveys were carried out along eleven routes which covered various island habitats (Figure 4). The routes were all between 2 – 4km long covering both primary (paved) and secondary (unpaved) roads. Distance measurements were recorded for all lorikeets seen or heard along all the transect routes. All detected birds were recorded, when they were seen or heard, regardless of how far they were from the transect line. This increased the overall sample size (Buckland *et al.* 2001). Demographic observations were also noted as to whether the bird detected was an adult or juvenile. Transects were sampled in the morning (7:00-10:30 UTC-10) and afternoon (15:00-18:30 UTC-10) in order to ensure data quality and to minimise error. All routes were sampled a total of six times, three times in the morning and three times in the afternoon. Rangefinders were used to measure the distance to a single bird or flock of lorikeet(s). Temperature, wind speed and weather conditions were also recorded. All routes dissected different habitat types, some more than one. The habitat types were then grouped into common categories to allow them to be compared.

Transect routes were grouped and data pooled according to habitat type. The following categories were used: Coastal forest, inland forest, urban, grassland (i.e. airport and the surrounding area) and "mixture" (which contain similar proportions of agricultural, housing and forest land).

2.2.1 Statistical Analysis

I used the DISTANCE program (Thomas *et al*. 2001) to analyse the data from the line transect surveys to get a density estimate per km^2 and detection probabilities. The data was evaluated by fitting detection models (half normal, negative exponential and hazard rate key factors with cosine, simple polynomial and hermite polynomial parameter adjustments). Model selection was centred on Akaike's Information Criteria (AIC: Burnham & Anderson, 1998). Distance results used were selected on the lowest AIC value, p value ($p < 0.05$) and percentage coefficient (<20%) which ensured the data had the best fit possible to the model.

In 2009, a student from the University of Leeds surveyed the Blue Lorikeet population on Aitutaki (Koutsofta, unpub). The results of this survey provide up to date baseline data of the lorikeet population and were used to assess the damage impact of Cyclone Pat on the lorikeet population. However, the sampling technique used in 2009 was different from the one used in this survey and so data from the current survey period had to be manipulated.

To assess population density further all abundance data collected per transect were calculated to represent birds per 100m to allow direct comparison with the 2009 dataset as different transect routes were taken in 2010 compared to 2009. Density was estimated per 100m and analysed in SPSS using a Mann-Whitney U Test. As the 2009 dataset was not collected using the distance method, the current dataset had to be adjusted by disregarding any observations over 30m. The 2009 survey consisted of sampling either side of the line transect to a 30m width (Koutsofta, unpub). Therefore just over half of the original observations had to be disgarded (only when comparing data to 2009 results, at all other times the full data was used).

In order to test whether abiotic factors were having an effect on bird detection frequency, time of day, wind speed and temperature were analysed using a univariate General Linear Model in SPSS which tested for individual and any interactions between the covariates (SPSS 17.0).

2.3 Behaviour observations

Types of behaviour were recorded when a Lorikeet was detected along a transect route. Activities were grouped into different categories including: Flying, Eating, Resting or Heard. When Lorikeets were observed eating, the food source was identified and recorded. The results were then compared with a previous study carried out on the island (Koutsofta, 2009, unpub) to see if foraging behaviour has changed since the cyclone. The differences pre- and post-cyclone behaviour were analysed using a chi-square test to test if any behaviours were observed significantly more or less compared to the 2009 survey of lorikeets on Aitutaki.

2.4 Vegetation Surveys

Vegetation surveys were conducted on a purely observational basis to assess cyclone damage as local people tend to burn dead trees. Therefore it would be extremely difficult to try and quantify the degree damage to the vegetation as the any results would have underestimated the true extent of any damage originally sustained on the island. Species that were extensively damaged were noted down along with the type of damage suffered. Common observations included branch damage and uprooting of trees (Everham & Brokaw, 1996). Damage classes included (most severe – least) a broken trunk, tree uprooted, tree partially uprooted, and major branch breaks (Wunderle *et al.* 1992). Vegetation was also assessed for re-growth throughout the study period. This was not quantified but any interesting observations were noted down.

Figure 4: Route map of Aitutaki, Cook Islands. Created on GoogleEarth, 2/8/10.
*Route 11 is the airport strip on the upper right.

3. Results

In order to fully evaluate the current status of the lorikeet, data collected from this survey was compared with data from 2009.

3.1.Pre-Cyclone Data

3.1.1. Density Estimates

Data from 2009 estimated the population of lorikeets on the island at 4,200 individuals (Koutsofta, unpub) with a mean density of 13.2 birds per 100m (± 1.87 SE).

Transect	Density (per 100m)
1	11.68
2	16.76
3	13.28
4	17.28
5	7.00

Table 1: Density per 100m of Blue Lorikeets per transect in 2009 (only includes birds seen within 30m either side of the transect route).

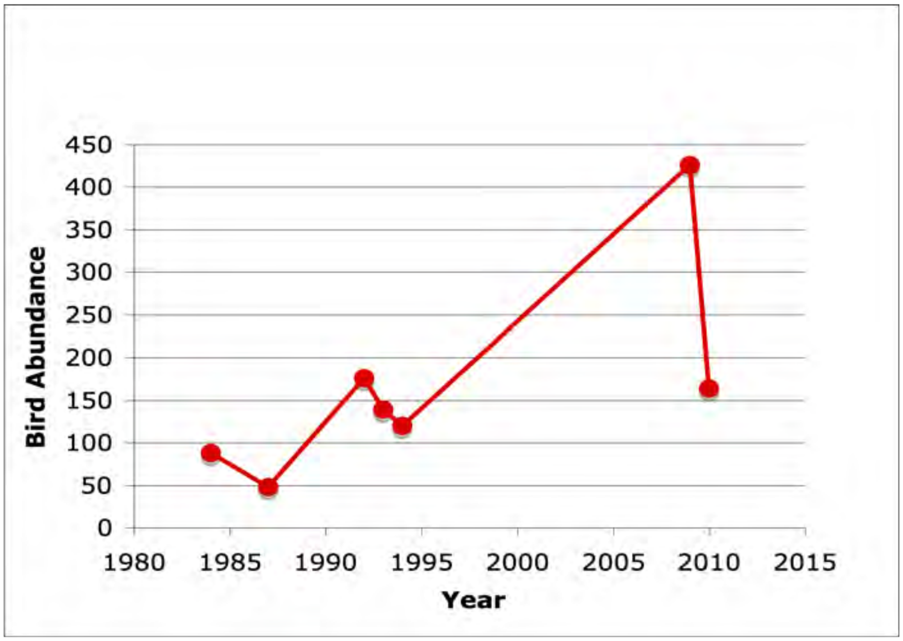

Figure 5: Average abundance of the Blue Lorikeet from 1987-2010 using raw count data from surveys conducted in 1984,1987,1992-4,2009 and 2010.

The abundance of lorikeets on Aitutaki since 1984 has varied considerably (Figure 5). This can in part, be attributed to varying census techniques (Cook Islands Natural Heritage Trust, 2010) which have been used over the years (Appendix II). From 1994 until 2009 the lorikeet was not surveyed regularly, however the rate of change in population density can be classed as positive and significant.

3.1.2 Feeding Preferences

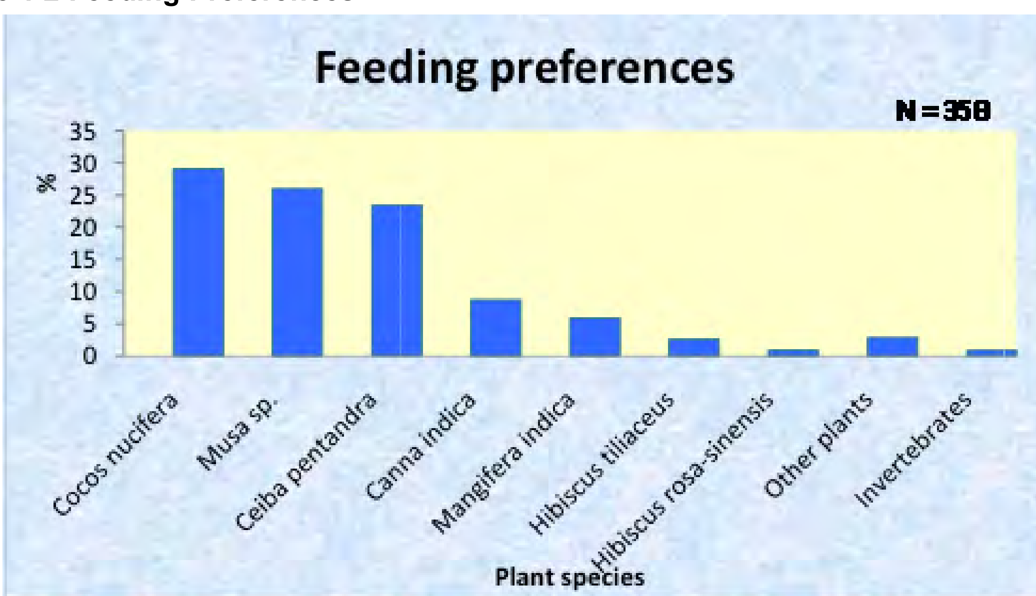

Figure 6: The feeding preferences of the Blue Lorikeet in 2009 in percentages (taken from Koutsofta, unpub, Fig.7 pg 23).

Feeding preferences in 2009 were a lot more varied than those observed in 2010 (Figure 9) due to the lack of flowering and fruiting plants. 2009 data shows a relatively even feeding preference towards coconut (*Cocos nucifera*), banana (*Musa sp*) and kapok (*Ceiba pentandra*) species.

3.2. Post-Cyclone Data

3.2.1. Current Blue Lorikeet Density

For the 2010 survey, lorikeet density is estimated at 86.195 individuals/km^{-2} (± 10.60 S.E, 95% CI: 67.502-110.07) and the current population size is estimated at 1,448 individuals for the island of Aitutaki. The model used to analyse the all the pooled 2010 data gave a coefficient variation level under the 20% (CV% 12.30%) suggesting that the data collected was a good fit to the model. Density per 100m was also calculated for each transect and resulted in a mean value of 1.67 birds per 100m (± 0.14 SE, Appendix II).

The population decline post cyclone is particularly dramatic with a loss of over half the population when compared to 2009 census data (2009: n = 1650, Koutsofta, unpub; 2010: n = 985). The population decline is significant (p=0.01) for both adults and juveniles within the population (x^2 = 276.26,1 d.f). A Mann-Whitney U Test revealed that at the p = 0.05 level of significance, there is enough evidence to assume that there is a significant difference in 2009 and 2010 densities $100m^{-1}$ (p = 0.02, Table 2).

Transect number	Density (per 100m)
1	1.41
2	1.23
3	1.58
4	1.36
5	1.30
6	2.46
7	2.25
8	1.71
9	2.03
10	1.14

Table 2: Density per 100m of Blue Lorikeets per transect in 2010 (only includes birds seen within 30m either side of the transect route). See Appendix II.

3.2.2. Cluster Size

Average cluster size for all transects combined is 1.24 birds (%CV: 1.53; 95%CI: 1.21-1.28) when analysed in DISTANCE. This is to be expected as lorikeets tend to forage by themselves and were frequently observed flying alone. Unfortunately, there is no prior data to compare the average group size to.

3.2.3. Damage to Vegetation

Cyclone Pat passed across all sampled habitat types on Aitutaki causing varying degrees of damage to vegetation and as a result it has altered the importance of some habitats to the lorikeet and thus altered its distribution (Figure 7) compared to 2009.

Figure 7 was complied by using the data from Table 2 to grade habitat importance in relation to Lorikeet density. Only results which were collected within 30m either side of the transect were used to allow comparison with the 2009 dataset (Koutsofta unpub). Habitats were graded from very important (red) down to unimportant (purple) i.e. no bird sightings. The relative habitat importance for 2010 was found to be different from that of 2009. This change in “importance” of certain habitats coincided with a high level of cyclone damage.

Areas that suffered the most damage included the vegetation in and surrounding the villages of Tautu and Nikaupara in the South of the island. The coastal vegetation in the south also suffered a high degree of damage with heavy felling of trees including coconut (*Cocos nucifera*), mango (*Mangifera indica*) banana (*Musa. sp*) and java plum (*Syzygium cuminii*). The west coast, which is one of the most densely populated areas on the island, also suffered high levels of damage. This included large numbers of coconut trees with snapped trunks or ones that had been fully uprooted. As a result of this a lower density than expected was recorded along the west coast (mean density 2009: 11.68 birds per100m, mean density 2010: 1.72 birds per 100m). Large numbers of coconut trees has also been uprooted or damaged along the east coast. Inland damage to vegetation did not seem to be as severe compared to coastal areas which further increased the importance of this habitat.

Overall, 75% of coconut trees were estimated to have been damaged and up to 75% of large trees (mainly java plum, mango and kapok) with severe branch damage (G.McCormack, pers.comm). Most trees had at least one large branch missing, if not them all. This resulted in unusual re-growth of tree foliage (Appendix I). This can be compared to previous years where tree density was high resulting in large areas of the island covered in dense tree canopy (Appendix I), this was not the case post-cyclone.

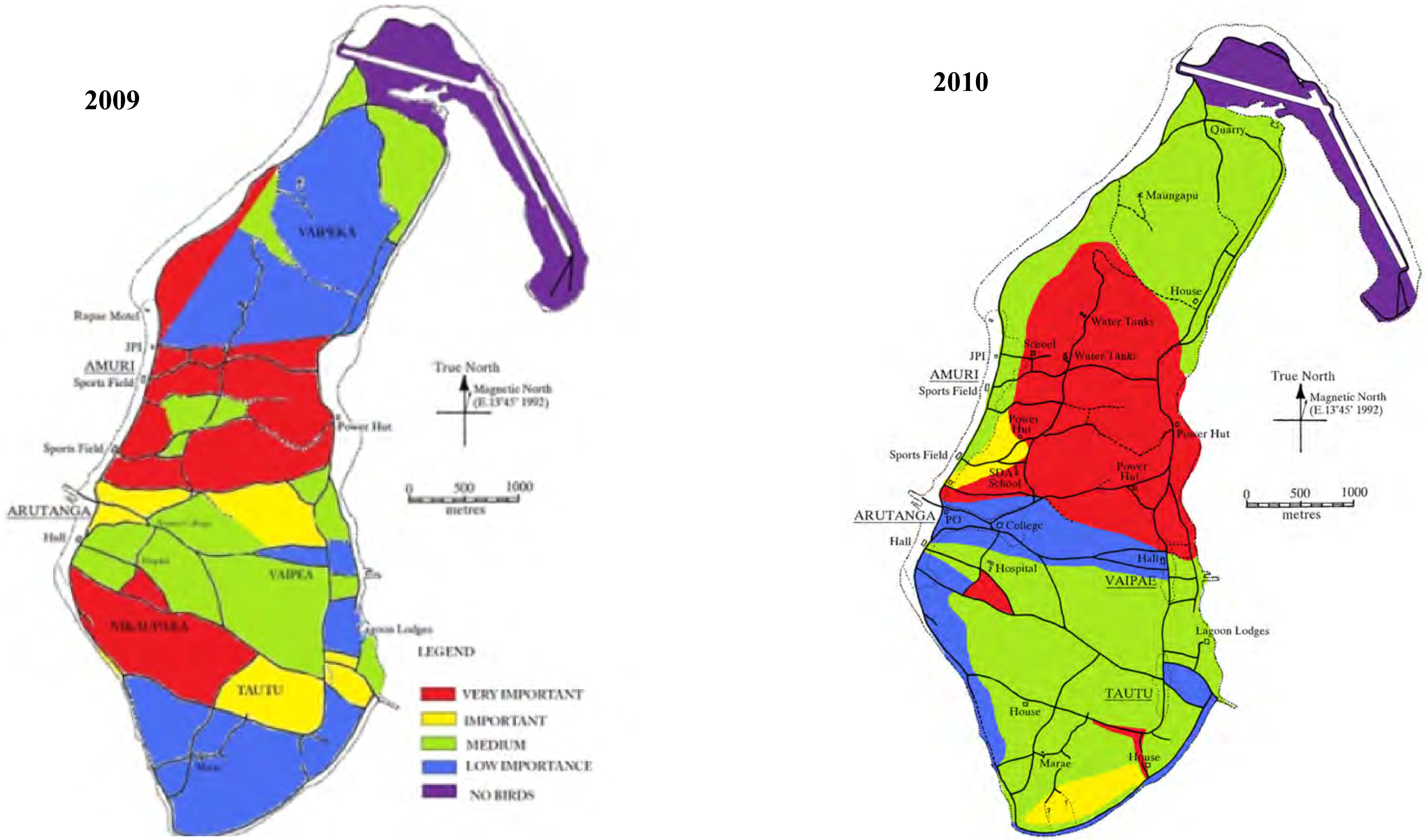

Figure 7: Maps comparing habitat importance in relation to Blue Lorikeet distribution from the 2009 pre-cyclone and 2010 post-cyclone surveys on Aituatki (2009 map taken from Koutsofta, unpub,Fig.4 pg 20).

3.2.4. Habitat preference

Population analysis was carried out on all habitat types separately (except the airport habitat) and combined for density per km^2. The airport was not included in the data analysis as there were no lorikeets observed there throughout the study period. Lorikeet density was highest in the mixed habitat with a density value of 75.449 km^2 (± 8.5 SE, Table 3).

Habitat Type	AIC[a]	Density (km^2)	% Coefficient
Coastal Forest	1615.463	53.857	15.30
Urban	1444.544	53.758	16.71
Mixture (forest, farm, housing)	3206.875	75.449	11.26
Inland forest	810.8115	928.11 [b]	21.84

Table 3: Analysis of models showing density (km^2) of Blue Lorikeets in relation to the importance habitat type.
[a] Minimun AIC value from all models conducted per habitat type.
[b] Inland forest has an unrealistically high-density value.

3.2.5. Abiotic Factors

A Univariate General Linear Model showed a significant relationship between time of day (morning and afternoon) and temperature in relation to the numbers of birds observed. However, the variables (time of day, temperature and wind speed) when tested alone were not significant. The interaction between time of day and temperature showed a significant (p = 0.012) effect on bird abundance along all transect routes. This type data was not available for comparison with the 2009 dataset.

3.2.6. Detection Distance

Detection probability remained high in the first five categories for all habitats except inland forest. The mean effective detection distance (including inland forest observations) is 31.38m (n= 803 ±1.02 SE).

All habitat types displayed significant *p* values and low percentage coefficients that were below 20%, therefore the all data displayed a good fit to all the models selected. This was not true however for the inland forest habitat which had a high percentage coefficient (21.84%) despite a significant *p* value (p = 0.3671). The inland forest habitat showed a highly distorted detection probability (Figure 8). This suggests that the data was a bad fit to the model and this is further emphasised by the clumped distribution in detection probability graph (see Figure 8) and high-density value (D= 928.11km^2) from the model. This density value is out of proportion with all the other density values for habitat type. It was not possible to truncate the data, as this is usually done when objects seen at larger distances skew the density estimate. This was not the case with the inland forest habitat as observations were made a larger distances as well as very close to the transect line. Truncating the data did not really alter the density value significantly. It would have been impossible to decide which values to remove at closer detection distances without seriously compromising the validity of the whole dataset. The inland forest transect therefore highlights the limitations of using the distance method to get an accurate estimate of bird density.

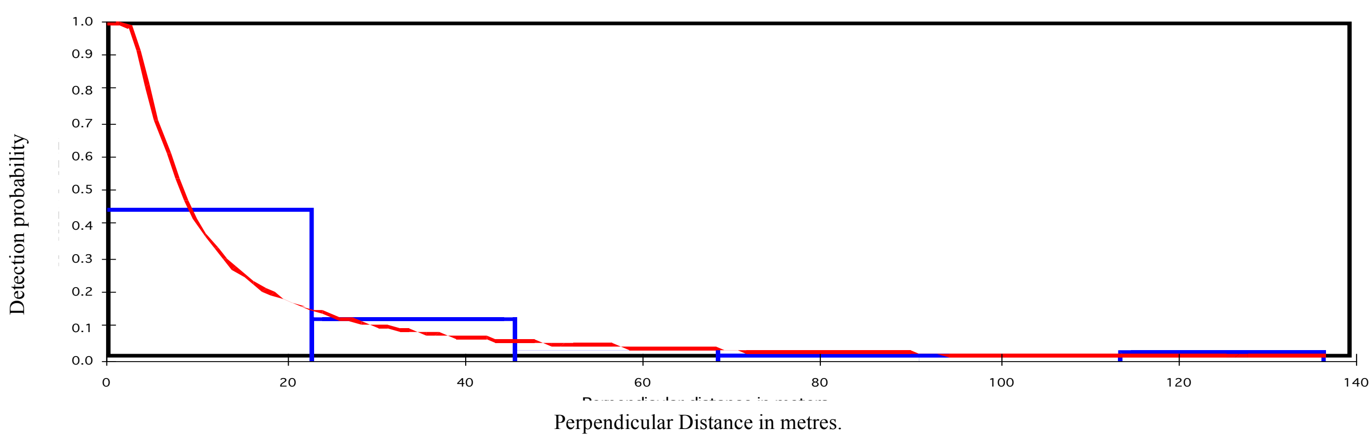

Figure 8: Distance (*r*) and detection probability of (*g*[*r*]) of Blue Lorikeets based on inland forest (Transect 9) line transect survey data using the hazard key function with no parameters adjustments still did not provide an adequate fit to the model.

3.2.7. Behaviour

Various behaviours were observed and split into the following categories: Resting, feeding, flying and heard (calling). The 2010 dataset was reduced to include only observations within 30m either side of each transect, so that all observations could be fully compared with the pre-cyclone dataset (Koutsofta, unpub). There was a significant difference (p= 0.01) in behaviour between the years (x^2=1298.3 1.d.f). Plant use varied according to behaviour type (Figure 9) with some plants being used for either just feeding or resting. Species such as mango (*Mangifera indica*) and kapok (*Ceiba pentandra*) were only used for resting by the lorikeets as they were not flowering at the time of the survey. In contrast to 2009, lorikeets preferred to feed from coconut trees (*Cocos nucifera*) compared to any other species and it is therefore an important species in ensuring lorikeet survival.

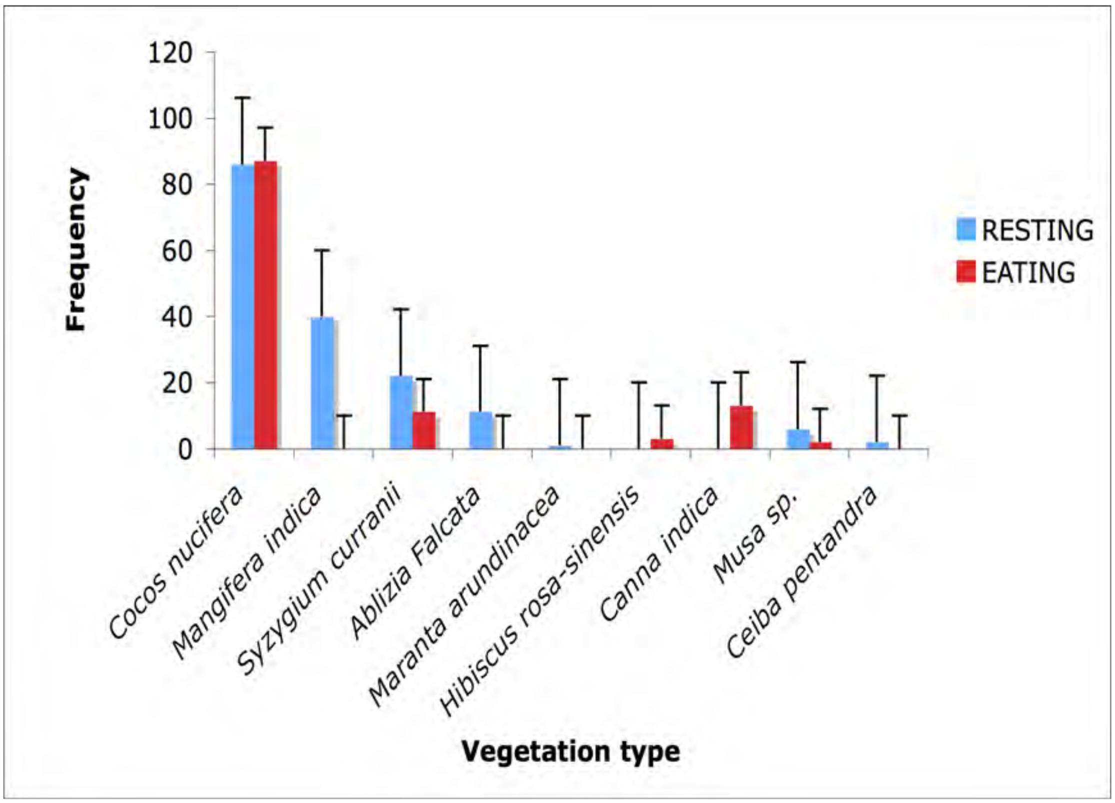

Figure 9: Observed plant use for feeding and resting behaviours of Blue Lorikeets during 2010 survey on Aitutaki (+1 S.D).

Figure 10 shows a larger proportion of birds resting in 2009 compared to 2010. This change in behaviour coincides with the high number of birds observed flying in 2010. Food availability has been low since the cyclone and as a result more birds have to forage over larger distances for food compared to previous years and as a consequence cannot afford to rest for as long.

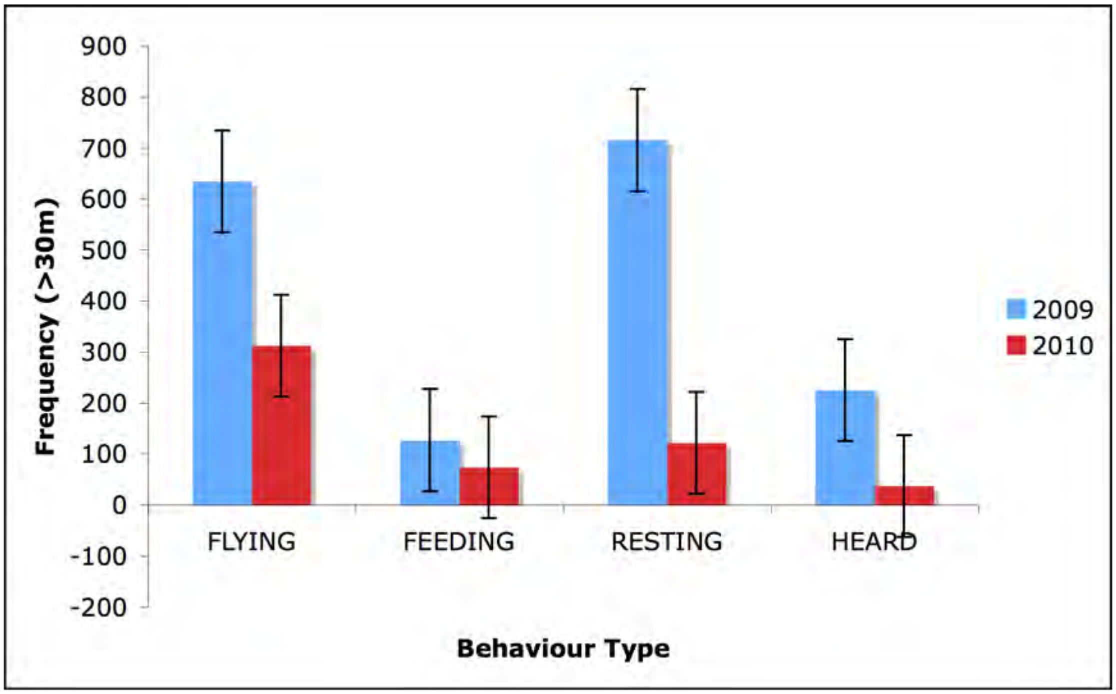

Figure 10: Frequency of behaviours displayed by Blue Lorikeets during pre- and post-cyclone surveys within 30m either side of each transect on Aitutaki (± 1 S.D).

4. Discussion

4.1 Density and Abundance

A mean density of 86.2 birds km^2 (± 10.600 SE, CI: 67.502-110.07) gives an estimated population size for the whole island of 1448 individuals. I believe that the status of the Blue Lorikeet is growing increasingly precarious as unpredictable weather conditions have caused a large significant decrease in the number of birds now found on Aitutaki. The average density of lorikeets in 2010 was 1.67 birds $100m^{-1}$ (± 0.14 SE) compared to 13.2 birds $100m^{-1}$ (± 1.87 SE) in 2009. The density of lorikeets is significantly lower than in recent years. Other threats to the lorikeets on the island are low, such as the presence (and thus interspecies competition) with Indian Mynah birds (*Acridotheres tristis*) and the maintained absence of Ship rat (*Rattus rattus*) on the island. Consequently, the main threat to the birds is from the predicted increase in frequency of high intensity environmental stochastic events (Webster *et al.* 2005). This study does show that the Lorikeets have survived the cyclone, however, it cannot predict be used to predict how long it will take the lorikeets to recover, thus a more long term study of the birds is necessary.

The population on Aitutaki has seemed stable in recent years and has trebled in size since the early nineties (Figure 5) when intensive agriculture on the island was reduced (McCormack, pers comm, 2010). The huge increase in size was beneficial as a relatively large number of birds survived the cyclone. This will prove to be beneficial for the future reproductive success of the bird on Aitutaki, as inbreeding in unlikely to occur in such a large remnant population. However, if a cyclone of the same magnitude was to hit Aitutaki again in the upcoming wet season, then this could prove to be catastrophic to the lorikeet population of the island, as fecundity would be severely reduced and extinction risk for the species globally would be increased as Aitutaki contains one of the largest breeding populations.

4.1.1 Detection rate

Detection rates varied between all habitats, suggesting that lorikeets preferred a certain habitat type post-cyclone. The results indicate this was the mixed habitat perhaps this was because it contained the highest diversity of plant species out of all the habitats sampled and consequently could support a higher number of lorikeets.

However, the inland forest habitat had an unusually high detection rate and this is clearly visible on the detection probability graph (Figure 8), as many birds were either observed in very close proximity to the route or very far away. This can be attributed to the transect running through the centre of the island along a ridge where elevation was the highest. This resulted with birds being detected either very close due to high secondary forest coverage or very far away when both visibility and elevation were both high.

4.2 Vegetation assessments

Large cyclones can have many detrimental effects upon plant communities by causing mortality and structural damage (Everham & Brokaw, 1996). Damage can also occur from other abiotic effects including salt stress from sea spray (as was the case on Aitutaki) resulting in the loss of foliage from many plant species (Gardner *et al.* 1991). Biotic factors can also affect plant susceptibility to damage from high winds, however, many of these factors (E.g. stem size, age) are cancelled out by extremely high wind intensities (Everham & Brokaw, 1996).

Plant species can recover from catastrophic wind in various ways, including by regrowth which usually takes the form of sprouting. This form of growth is commonly called “direct regeneration” (Boucher, 1989; Everham & Brokaw, 1996).

Despite many species of plants being damaged by the cyclone many of them had begun to regenerate by the time fieldwork commenced. Many trees and shrubs were refoliated and were beginning to flower again. However, new unusual sprouting regrowth had begun to occur on many trees (Appendix I) due to the high level of branch damage (pers. Observation). Fruits had not begun to reappear on many species including mango (*Mangifera indica*) and banana (*Musa sp*) which compromise as two of the main food sources for lorikeets. Coconut trees (*Cocos nucifera*) were observed to be flowering but not in abundance, however by the end of the study noticeably more were in flower (pers. observation). Also banana trees (*Musa sp*) had begun to flower again at the start of July, and it was only at this time that lorikeets were observed resting on them.

Since the cyclone, large gaps have formed in the canopies of previously densely forested areas which has caused an increase herbaceous plant growth (pers. observation). On Aitutaki the vine-like plant, *Merremia peltata,* has invaded many areas of open habitat within forest systems (Appendix I). The effect this plant may have on the island ecosystem is impossible to say, but secondary succession in the form of vine establishment often restricts the recruitment and regrowth of trees (Wood, 1970; Everham & Brokaw, 1996) which in turn would reduce future food availability for the lorikeets. Hence, the secondary effects on vegetation since the cyclone passed are just as important as the immediate direct impact (Wunderle *et al.* 1992) the cyclone had on the lorikeets.

4.3 Distribution and Habitat preference of the Blue Lorikeet

Cyclone Pat had a strong negative impact on the population of Blue Lorikeets on Aitutaki. The cyclone caused a high level of vegetation damage, resulting in about 75% of all trees being affected on the island by either being uprooted, snapped in half or by losing multiple branches along with fruits and flowers (G.McCormack. pers comm, 2010). Consequently, this led to major changes in all habitats across the island, as many had been completely destroyed by the cyclone. Food availability was reduced immediately after the cyclone and had still not reached pre-cyclone abundance five months later. The cyclone destroyed large areas of known primary lorikeet habitat including areas along the west coast, specifically that of Amuri village and areas in the south including the villages of Tautu and Nikaupara (Wilson, 1993; Koutsofta, unpub).

The damage caused by the cyclone has changed the distribution of the lorikeets across the island (Figure7) in comparison to previous surveys, and has resulted in a more widespread distribution across the island which is less clumped (Wilson, 1993; Koutsofta unpub, Cook Islands Natural Heritage Trust, 2010). The more widespread distribution (in 2010) shows that lorikeets had to expand their foraging range in order to find sufficient food. This coincides with the fact that the most observed behaviour of the lorikeets during this study was flying. The most important habitat for the lorikeets is now in the centre of the island with a few smaller areas scattered around the island.

Lorikeets seem to prefer a mixed habitat i.e. that which contained similar proportions of agricultural, forest and housing (with private gardens). The AIC analysis emphasised this with higher density values compared to other habitats across the island ($75.49km^2 \pm 8.5$ SE). Lorikeets were not found in areas lacking tree coverage and this may explain why no lorikeets were observed in the airport area of the island due to the large expanse of open space. High wind speeds also deter lorikeets from foraging and this reason may also contribute to the lack of lorikeets observed in this area.

Therefore, areas of mixed habitat may now be preferred by the lorikeets as more food sources are available within these areas. This type of habitat is beneficial to the lorikeets as it ultimately reduces the time and energy a lorikeet has to spend foraging for food as species diversity is generally higher in this habitat. It also highlights the fact that lorikeets are habitat generalists which seem to be able to cope, if not thrive (in previous years) in areas which contain a high percentage of introduced plants and shrubs.

4.4 Behaviour

Pre- and post-cyclone behaviour are completely different with more birds observed flying than any other behaviour. This observation fits with the reduced density of lorikeets in areas of known importance, and suggests that there is a high level of inter-habitat movement to optimise foraging performance.

4.4.1 Plant Use

Plant use by the lorikeet varied according to behaviour. Many plant species were used for either resting on or feeding from. The most widely used plant was the coconut tree (*Cocos nucifera*) which was used for both resting and feeding. This was probably due to the fact that it was one of the only trees in flower so soon after the cyclone and is one of the most abundant plants on the island. However, Gerischer & Walther (2003) state that lorikeets rely almost solely on coconut trees for food, nesting and shelter. Nevertheless, lorikeets were also observed feeding from smaller, shrub species including Hibiscus (*Hibiscus rosa-sinensis*), Yellow Bells (*Tecoma stans*), Pink Powderpuff (*Calliandra surinamensis)* and Canna Lillies (*Zantedeschia aethiopica*). These smaller plant species seemed to have recovered from the cyclone quicker. However, it is extremely difficult for lorikeets to feed from these flowers, as they have to nip the base in order to eat the nectar as their necks are too short to feed from the top. This shift in foraging behaviour is a short-term response of the remaining population to shortages in food (Wiley & Wunderle, 1994). Surviving lorikeets seemed to have adapted fully to the changes in their environment since the cyclone, this it not unusual as many island birds tend to use a wider range of habitats compared to continental avian species (Crowell, 1962; McArthur *et al.* 1966, Wunderle, 1995). It is this attribute that seems to favour post-cyclone survival in island birds (Wunderle *et al.* 1992).

4.4.2 Interspecies Interactions

Lorikeets did not behave aggressively towards any other bird species on the island, most notably the Indian Mynah bird (*Acridotheres tristis*), which can have a negative effect on some lorikeet species such as the Rimatara lorikeet (*Vini Kuhlii*). Gerischer & Walther (2003) also witnessed that the birds displayed placid and playful behaviours to one another and other species.

4.4.3 Breeding Season and Breeding Pairs

Cyclone Pat has proved detrimental for the 2009-2010 breeding season on Aitutaki, as only one juvenile was recorded. This is significant decline in juveniles compared to 2009. Blue Lorikeets have been recorded breeding from October – January, usually laying 1-2 eggs and stay in the nest for up to 60 days (del Hoyo *et al.* 1997)

However this conflicts with other breeding information which states the parrot breeds from May-July (Low, 1998: WPT, 2010). The lorikeets have only been observed to breed once a year in captivity (Low, 1998). If the breeding season is from October- January, any young chicks from the recent breeding season are likely to have still been in the nest, very small in size and heavily reliant on their parents for food. Therefore it is safe to assume that chick mortality was high from exposure to the extreme weather and in the following weeks as food resources were scarce, resulting in starvation since chicks have high energy requirements for thermoregulation (Langham, 1986).

It is impossible to assess the damage incurred by breeding pairs, as it is difficult to find lorikeet roosts. However, one can speculate due to the low number of juveniles and the low overall density of birds surviving (D= 86.195 ± 10.60 SE) that the cyclone would have severely reduced the number of breeding pairs. This is reflected in the number of birds seen together which was also low with an average cluster size of 1.24 (CI: 1.2063-1.2811). As a result this will reduce the reproductive success of the 2010 breeding season (if it is either May-July or October –January), as there will be a reduced number of adults nesting this season compared to previous years.

4.5 Sampling success

Distance sampling proved to be a satisfactory framework to sample lorikeet populations using both primary and secondary roads, as the birds show only a slight clumped distribution in some areas of the island and island-wide surveys would be difficult without the use of roads. Despite this, it is necessary to re-sample transect routes in order to obtain relatively accurate density estimates (CV ≤ 20%) for habitat areas (Rivera-Milan *et al*. 2003) and thus the island as a whole.

May – July is an excellent time to survey the lorikeets as it is the dry season in the Cook Islands and the temperature and wind speed are not too high, so there is ample opportunity to see lorikeets most days as rain, high wind speed, and very hot temperatures cause the lorikeets to shelter (pers. observation). Sampling in these conditions could cause large underestimations to be made about lorikeet density.

However the Distance method does have its limitations, as demonstrated by the results analysis of the inland forest habitat, which resulted in a highly skewed density estimate due to the number of lorikeets observed very close to the transect route. This highlights the restrictions of Distance, as just like many other statistical methods it is based on specific assumptions (Bachler & Liechti, 2007). The most important of these is that birds near or far from the transect route have to be detected with certainty (assumption of g[0]=1; Buckland *et al.* 2001). However, it is common for this assumption to be violated especially in bird surveys as it is extremely difficult to get an accurate estimate of g[0] (Hutto & young, 2003; Bart *et al.* 2004). Bird detection in the field can be influenced by the researcher as birds can be flushed from habitats without being noticed by the observer (Bachler & Liechti, 2007).

4.6 Future implications of research and recommendations

4.6.1 The Current Status of the Blue Lorikeet

The main objective of this study was to collect reliable density estimates of the bird in order to quantify lorikeet abundance and disseminate how Cyclone Pat has affected the population. The results show a significantly reduced number of birds survived the storm compared to previous population data and as a result the total global population of Blue Lorikeets has been severely damaged. The loss of over half the population this year significantly impacts upon the global status of the bird. It is highly unlikely that the remnant population on Aitutaki could survive another storm of the same magnitude and with today's increasing unpredictable climate, there is a high chance of more stochastic events damaging the biodiversity of the Southern Cook Islands even more over the next few years. As the population on Aitutaki is one of the largest breeding populations in the world, it is necessary to carefully monitor this population to ensure its full recovery and future survival.

4.6.2 Extinction mitigation

If the wet season next year begins to show signs of increased cyclone/storm activity, it may be necessary to take extra precautions regarding the species and remove a small number of individuals to another suitable island within the Cooks to create a separate sink population in order to protect the species.

Other threats to the species include predation from Ship rats (*Rattus rattus)* which increases the likelihood of extinction by reducing the breeding success of the lorikeets, as the rats prey on their eggs (McCormack, 1996). If rats should be found on the island at this time it could result in another unproductive breeding season which will slow down the recovery of the species to pre-cyclone numbers.

Aitutaki port Authority should carefully monitor all ship imports as supplies to the island have increased since Pat struck as rebuilding is necessary. The islanders themselves need to remain vigilant in recognising signs of the rat, such as coconuts with large holes in them, and report it immediately (G.McCormack, pers.comm, 2010).

Therefore every possible measure needs to be taken to ensure that Ship rat does not gain access to the island and more importantly if it ever does, an action plan needs to be in place and executed immediately to prevent it from becoming established.

Habitat degradation and loss are also factors which can negatively effect parrot survival. Since a large proportion of the habitat has been degraded since the cyclone, it may be a wise for local people to be encouraged to plant flowering and fruiting shrubs and trees which are favoured by the lorikeets to provide more foraging habitats for the birds as important sites have been considerably reduced since the cyclone.

The future of the Blue Lorikeet is currently in a rather precarious state, as the population on Aitutaki are heavily isolated This study shows a reasonable number of lorikeets have survived the cyclone but it will be necessary to survey the population again over the next few years to be certain that the species is fully recovering from Cyclone Pat.

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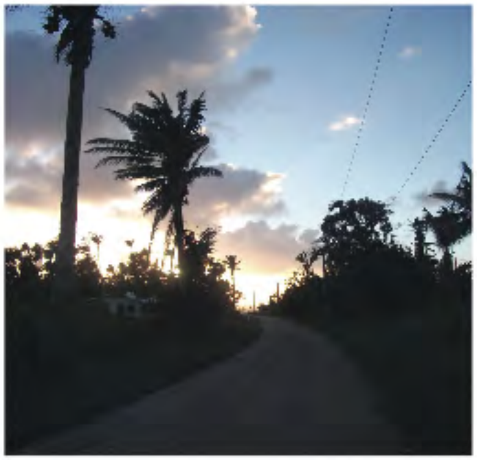
Appendix I

Top left: Adult Lorikeets resting on Banana leaves. Top right: Sprouting mango tree. Middle left:Damaged coconut tree. Middle right: Damaged mango trees on transect showing re-growth. Bottom left:Damaged coconut trees. Bottom right: Vine *Merremia peltata* dominace.



Left: vegetation density in 2010. Right: vegetation density in 2009.

Appendix II

transect	total count	Density p100m		Transect length km
1	53	1.413333333		3.75
2	29	1.234042553		2.35
3	61	1.584415584		3.85
4	46	1.356932153		3.39
5	30	1.298701299		2.31
6	69	2.455516014		2.81
7	80	2.253521127		3.55
8	63	1.716621253		3.67
9	87	2.027972028		4.29
10	48	1.424332344		3.37
				3.01
	mean	1.676538769	s.e	0.135274

a)Raw data for density per 100m, 2010.

adult	juvenile
2010=998	1
2009=1679	26

b) Raw data for Chi-Square

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