A rapid assessment of the avifauna of Isla Del Rey, Las Perlas Archipelago, Panama.

Andrea Gear

Thesis submitted for the degree of
MSc Conservation
Department of Geography,
UCL (University College London)

August 2007

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES i
LIST OF APPENDICES ii
ACKNOWLEDGEMENTS iii
ABSTRACT iv

CHAPTER 1 – INTRODUCTION 1
1.1 Conservation biology 1
1.1.1 Background and the Convention on Biological Diversity 1
1.1.2 The Darwin Initiative 2
1.1.3 The need for simple methodologies 2
1.2 Case study: Las Perlas, Gulf of Panama 4
1.2.1 The Darwin Initiative in Las Perlas 4
1.2.2 The need for research 7
1.2.3 The birds of Panama 9
1.2.4 The birds of Las Perlas 9
1.2.5 Censusing birds 11
1.2.6 Aim and Objectives 12

CHAPTER 2 – METHODOLOGY
2.1 Field methodology 13
2.1.1 Study site 13
2.1.2 Recording location and target species 14
2.1.3 Method justification 16
2.1.4 Line transects and point counts 17
2.1.5 Audio and visual recordings 18
2.1.6 Vegetation description 18
2.2 Analytical methodology 19
2.2.1 Species richness, composition and distribution 19
2.2.2 Species diversity 19
2.2.3 Bird density 20
2.2.4 Species relative abundance 20
2.2.5 Multivariate analysis 21
2.2.6 Additional test on environmental data 22

CHAPTER 3 – RESULTS
3.1 Species richness, composition and distribution 23
3.2 Species diversity 27
3.3 Density and relative abundance 27
3.4 Exploring associations between variables 28

CHAPTER 4 – DISCUSSION
4.1 Ecology 32
4.1.1 Density compensation on El Rey 32
4.1.2 Habitat preferences of the avifauna of El Rey 33
4.1.3 Endemism on El Rey 33
4.1.4 Human activity and the avifauna of El Rey 34

4.2 Rapid assessment **35**
4.2.1 The need for rapid assessment **35**
4.2.2 Strength and weaknesses of the rapid assessment technique **36**
4.2.2.1 Line transects **36**
4.2.2.2 Vegetation description **37**
4.2.2.3 Point counts and density calculations **38**
4.2.2.4 Audio and visual identification **40**
4.2.2.5 MacKinnon lists **42**
4.2.3 General comments **42**
4.3 Recommendations for management **42**
4.3.1 Current threats to the avifauna of El Rey **42**
4.3.2 Future threats to the avifauna of El Rey **43**
4.3.3 Utilising local knowledge and involving the community **44**
4.3.4 Ecotourism on El Rey **46**

CHAPTER 5 – CONCLUSION **47**

References

Appendices

List of Figures and Tables

List of figures

Figure 1.1 Outcomes of Darwin Initiative projects worldwide 3
Figure 1.2 Location of the Las Perlas archipelago 5
Figure 1.3 Las Perlas Special Management zone 6
Figure 1.4 Map of Isla Del Rey with land use classification 8

Figure 2.1 Study site 13
Figure 2.2 GIS map showing transect locations 15
Figure 2.3 Dendrogram of species groupings 22

Figure 3.1(a) Pie chart of species composition of non-intervened habitat 23
Figure 3.1(b) Pie chart of species composition of intervened habitat 24
Figure 3.2 Histograms of species composition of each transect 25
Figure 3.3 Scatter plots showing distribution and abundance of endemic subspecies 26
Figure 3.4 Regression plot of abundance and distance 27
Figure 3.5 CA biplot 29
Figure 3.6 CCA triplot 30
Figure 3.7 CCA following Monte Carlo permutation test 31

Figure 4.1(a) Evidence of hunting 35
Figure 4.1(b) Evidence of burning 35
Figure 4.2 *Allamanda cathartica* 39
Figure 4.3 Sound recording during a point transect 39
Figure 4.4 Changes in forest cover on El Rey since 1974 41
Figure 4.5(a) A villager shares his knowledge of birds 45
Figure 4.5(b) A villager with the endemic subspecies *Columbina talpacoti* 45

List of tables

Table 2.1 Contrasting advantages of point count and line transect methodologies 16

Table 3.1: Number of recordings using each methodology for each species 24
Table 3.2 Relative abundance index of each species in both habitats 28

List of Appendices

Appendix 1 Birds of the Las Perlas Archipelago 60
Appendix 2 Daily averages for rainfall and temperature during study period 63
Appendix 3 Environmental parameters recorded 64
Appendix 4 MacKinnon lists 65
Appendix 5 Number of individuals recorded of each species in each transect 67
Appendix 6 Species and families recorded on Isla Del Rey 68
Appendix 7 Species of birds known to be on Isla Del Rey 69
Appendix 8 Scatter plots showing distribution and abundance of species with distance from town 71
Appendix 9 Regression outputs (distance and diversity) 74
Appendix 10 Outputs of four diversity indices 76
Appendix 11 Outputs of t-test (diversity between habitats) 77
Appendix 12 CA with full suite of species 78
Appendix 13 ANOVA outputs (environmental comparisons) 79

Acknowledgements

I would like to thank Dr James Mair of Heriot-Watt University (UK) and Dr Hector Guzman of the Smithsonian Tropical Research Institute (Panama) for their technical and logistical support during field work. I am also grateful to the Darwin Initiative for providing the funding to make this research possible. I would also like to thank Dr Helene Burningham and Dr Jan Axmacher for their academic guidance and words of encouragement during dissertation write-up.

Abstract

A combination of rapid assessment methodologies were used to generate baseline data on the avifauna of Isla Del Rey, Las Perlas Archipelago, Panama. Non-intervened habitat was found to support 28% more species than intervened, and had a higher density by 17 birds per/ha. Diversity was also found to be higher in the non-intervened habitat according to the Simpsons index (p=0.026) and Fisher's alpha (p=0.017). Although significant, these findings appear to be subject to a more powerful gradient of distance from the main settlement of San Miguel. All species, other than those identified as anthropophillic or 'urbanisation-enhanced' (Crooks *et al.,* 2004:451), increased in abundance with distance from the village. Avian diversity was also found to increase significantly with increasing distance from San Miguel using regression on values calculated by Simpsons index (p=0.001) and the Berger-Parker index (p=0.023). Due to data limitations, a relationship between distance and bird density could not be tested.

The species-list method combined with distance sampling during point counts and audio recordings allowed accurate statistical calculations of diversity, density and relative abundance. Rapid assessment has the potential to be more standardised, flexible, efficient and comparable than other one-dimensional methodologies frequently practised. It has the potential to be a very powerful tool for study of avian communities in the tropics, leading to conservation assessment and management. The hydrological reserve of El Rey is a centre of avian endemism, and provides a fascinating site in which to study biogeography, ecology and genetic differentiation. Habitat fragmentation and climate change are the greatest threats to the avian species of El Rey, which will undoubtedly be exacerbated by the increasing population of the islands, and the arrival of ecotourism in the near future. Management of the newly designated hydrological reserve needs to focus on maintaining the genetic diversity of avian populations to increase resilience to future change. The establishment of an annual monitoring scheme that integrates rapid assessment to gauge the health of the avian communities is recommended.

1 Introduction

1.1 Conservation Biology

1.1.1 Background and the Convention on Biological Diversity

The human population is greater than two and a half times the size it was in 1930, each year growing by a number equivalent to the combined populations of the United Kingdom, Ireland, Iceland, Belgium, Denmark, Norway, Sweden, and Finland (Brussard and Ehrlich, 1992). In addition, the impact of each individual on the natural environment (approximated by per-capita energy use) has more than doubled since 1930 (Holdren, 1990). Projections of population growth indicate that either a miracle or a disaster is required to arrest the rise in human numbers (Haub *et al*., 1990). Furthermore, a 10-fold increase in economic expansion will be necessary to provide basic amenities for the additional people and to alleviate increasing poverty (Bruntland, 1988). The burden of this expansion will inevitably be shifted to natural communities, many of which are already fragile. Whole ecosystems will be further disrupted, destroyed, polluted, exploited and fragmented to provide agricultural land, infrastructure, mines, hydroelectric power, and other services for the escalating human race.

Although debates regarding the enormity and precise causes are ongoing, the reality that earth's biodiversity faces a major crisis that will pilot a significant proportion of species to extinction this century has been recognised for some time (Dubois, 2003). This acknowledgement of a global biodiversity crisis spawned the discipline of conservation biology, which throughout its relatively short history has been described as "value-laden," "mission-oriented," and "crisis driven," amongst other terms (Noss, 2007). Despite criticism and many reforms the field continues to evolve, drawing on established disciplines and integrating them in the pursuit of a unified goal: the protection and perpetuation of the Earth's biological diversity (Meine *et al.,* 2006).

Although ethical considerations and a sense of moral obligation continue to motivate many practitioners of conservation biology, the idea that more could be achieved by promoting an anthropocentric argument was well developed by the mid 1980's (Ehrlich, 2001). Biological diversity became increasingly presented as an economically valuable resource requiring managed exploitation (Freeman, 1998; Perrings, 1995). For example, the use of biodiversity, or more specifically genetic diversity, has resulted in considerable financial gain for the pharmaceutical sector, raising moral and political dilemmas regarding the 'ownership' of biodiversity as an exploitable resource. Ethics aside, there is no doubt that the economic drive provided by such industries proved paramount in irrevocably securing biodiversity a specific niche within the political arena.

One of the outcomes of this political platform was the 1992 Convention on Biological Diversity (CBD), an international agreement with a substantial and robust agenda capable of promoting international co-operation in biodiversity for years to come (Naggs *et al.*, 2005). The CBD came into effect in December 1993, ratified by 152 nations entering into a wide range of commitments with regard to 'the conservation of biological diversity, the sustainable use of its components and the fair and equitable

sharing of the benefits arising out of the utilization of their indigenous biodiversity' (United Nations, 1993:5).

Central to the conceptual backbone of the treaty is the recognition that whilst nations are obliged to record and conserve biodiversity, flexibility for individual countries to decide how they will implement the broad objectives is essential. This is a pivotal concept of the new wave of environmental conventions, and has led to great creativity on the part of developing nations (McNeely, 1999). A legal commitment between the developing nations to become guardians of their native flora and fauna, and the industrialized countries to provide the necessary funds to enable them to do so has resulted in some highly successful partnerships.

1.1.2 The Darwin Initiative

In the UK the Department of the Environment's Darwin Initiative (DI) was launched in 1992 as a direct response to the CBD. The DI uses UK expertise working with local partners to help countries rich in biodiversity but poor in resources to fulfill their commitments under the CBD. Since 1992, the Initiative has committed over £45m to over 450 projects in over 100 countries (Wortley and Wilke, 2005).

The CBD also instigated the launch of the Global Taxonomy Initiative (GTI), which aims to overcome the ‘taxonomic impediment’, a term that describes knowledge gaps in our taxonomic system, the shortage of trained taxonomists, and the impact these deficiencies have on our ability to sustainably manage and use biological diversity (Environment Australia, 1998). Fifty of the 450 DI projects have involved heavy emphasis on taxonomy as part of a contribution to the Global Taxonomy Initiative (GTI). Figure 1.1 shows some examples of DI funded, taxonomy focused projects that have contributed to that country meeting their commitments under the CBD.

1.1.3 The need for simple methodologies

Overcoming the taxonomic impediment is not simply a matter of funding. The ever growing need for urgency in our exploration and documentation of the earth’s biodiversity demands low cost, quick and effective methodologies. These methodologies also need to be easily repeated in order to contribute to ongoing monitoring, an essential element of successful management. Debates about the most efficient, appropriate and scientifically rigorous approaches to monitoring are ongoing. One of the main constraints to optimal monitoring is lack of

Figure 1.1: Outcomes of Darwin Initiative Projects Worldwide

Source: Map from www.maps.com, information adapted from Wortley and Wilkie (2005)

compatibility between data sets due to the use of different methodologies (Pereira and Cooper, 2006). The systems of interest in monitoring range from species, to populations, to communities, and the variables of interest may include species richness, species diversity, biomass and population size. As a result a whole host of methods have been devised (see Conroy *et al*. (1990) for a comprehensive review), and there is no single all encompassing methodology.

One of the more popular methodologies, especially in areas rich in biodiversity and poor in funds, is a simple census. Although a census of the species present in a geographical location does not provide enough information to enable the long term protection and sustainable management of those organisms, it is often an improvement on current knowledge. In this respect inventories can certainly be a positive step towards providing baseline data from which appropriate management plans can be generated for an area, and a monitoring programme initiated.

One type of approach to censusing organisms that has had increased interest in recent years is the 'rapid assessment technique'. This technique combines a number of simple methodologies in order to maximise data collection with limited funds, time and expertise. Rapid assessment also allows comparability between studies without rigid standardization (Herzog *et al.*, 2002). This approach has been used successfully in a number of studies (Parker and Bailey 1991; Poulsen *et al*., 1997; Krabbe, 1998) and may hold great potential as a tool for helping to overcome the 'taxonomic impediment', particularly in tropical regions. Proponents emphasize that this technique is meant as 'a preliminary screening to precede, but not replace, lengthier scientific inventories' (Abate, 1992:486).

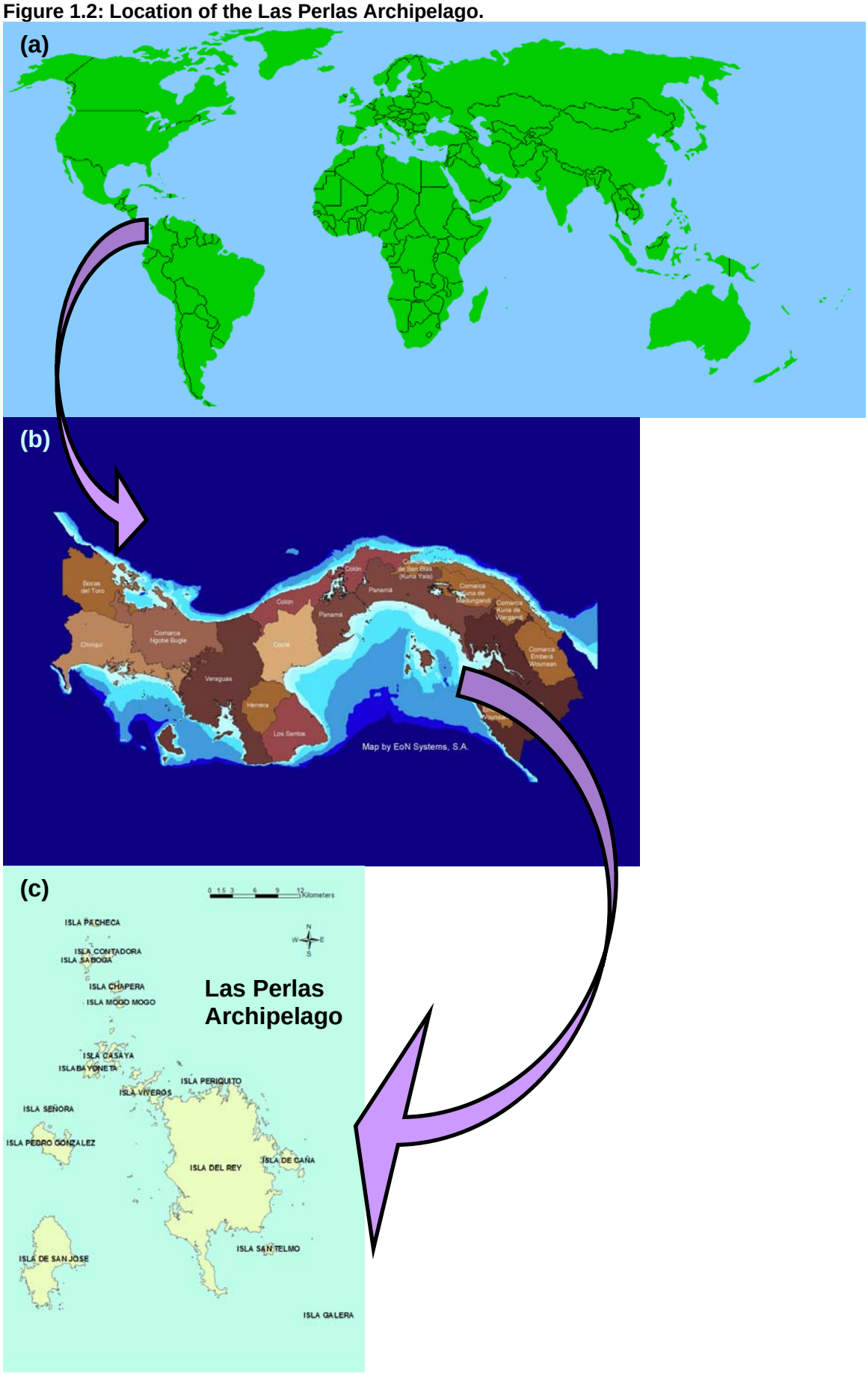
1.2 Case study: Las Perlas, Gulf of Panama

1.2.1 The Darwin Initiative in Las Perlas

One of the Darwin Initiative's projects can be found in the Las Perlas archipelago, a cluster of little known islands nestled in the Gulf of Panama (figure 1.2). This conservation venture arose from a partnership between the Smithsonian Tropical Research Institute and Heriot Watt University (UK). To date the majority of the research has focused on marine issues, and there has been considerable data gathering with a view to better understanding benthonic communities, marine pollution, and fisheries, to name but a few (Campbell, 2005).

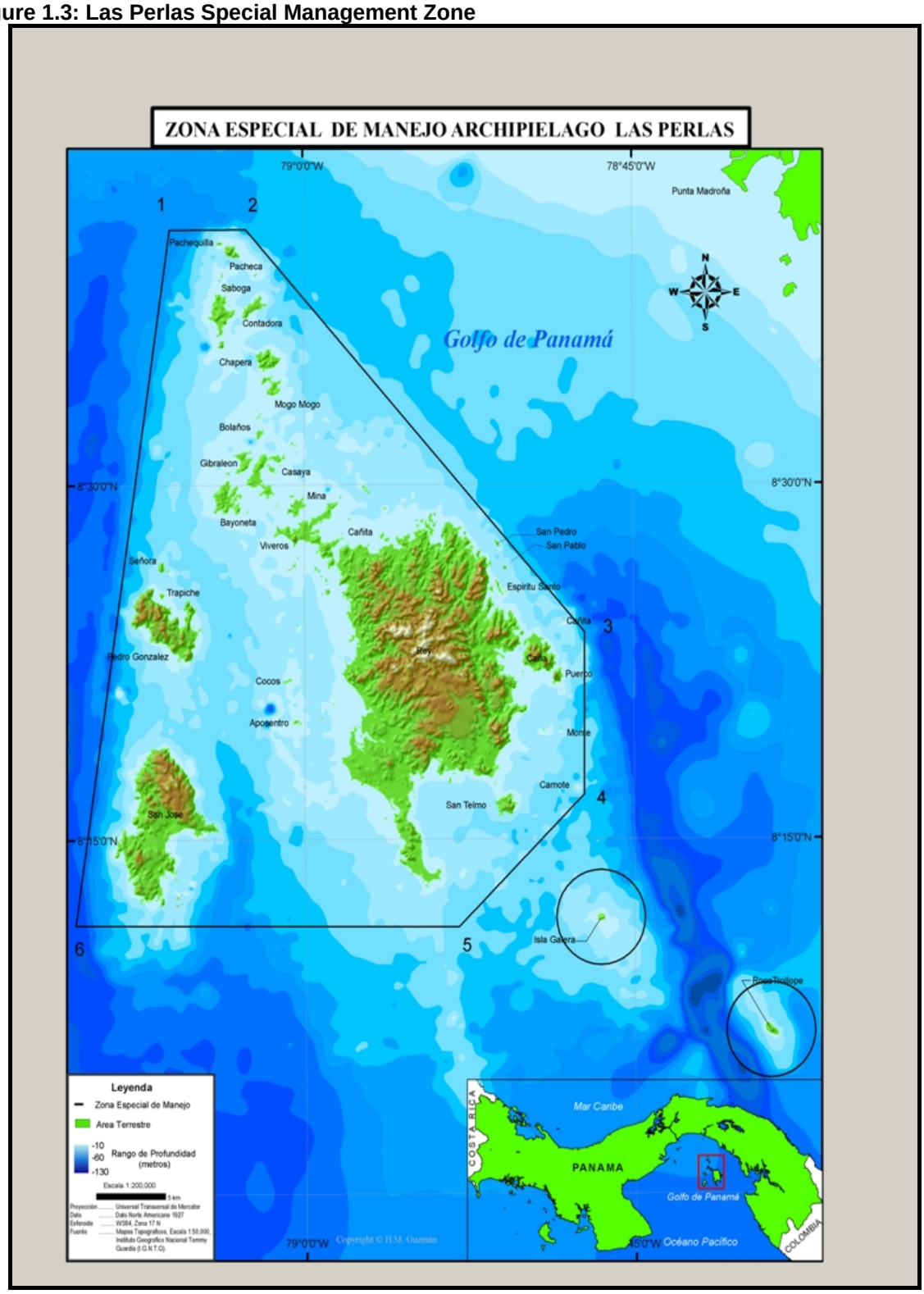
Mapping and assessing key marine habitats has led to a vastly better understanding of the dynamics and biodiversity of the islands and have been the primary driving force behind the establishment of Las Perlas SpecialManagement Zone which encompasses 168,771 hectares of the archipelago (see figure 1.3) and complements an already well established network of protected areas in Panama (STRI, 2007). It is hoped that the Darwin project team, stakeholders and the local community will oversee the management and sustainability of this Zone through continued scientific research and collaboration.

Figure 1.2: Location of the Las Perlas Archipelago.



Source: www.mapworld.com (a and b), Dr Hector Guzman ©, STRI (c).

Figure 1.3: Las Perlas Special Management Zone



Source: Dr Hector Guzman ©, STRI.

Despite many achievements concerning the marine environment, there has been little investigation into the terrestrial aspects of the archipelago, other than a habitat mapping project using remote sensing (Guevara, 2005). Representatives of both STRI and HW University decided that 2007 would be the first year in which a terrestrial aspect was fully introduced into the research arena. The flora and fauna of the archipelago is poorly studied, and without simple baseline data such as species presence/absence, relative abundance, density and habitat preference it is problematic to draft even basic management plans for the hydrological reserve, which was designated on the largest island of the Archipelago in 2006.

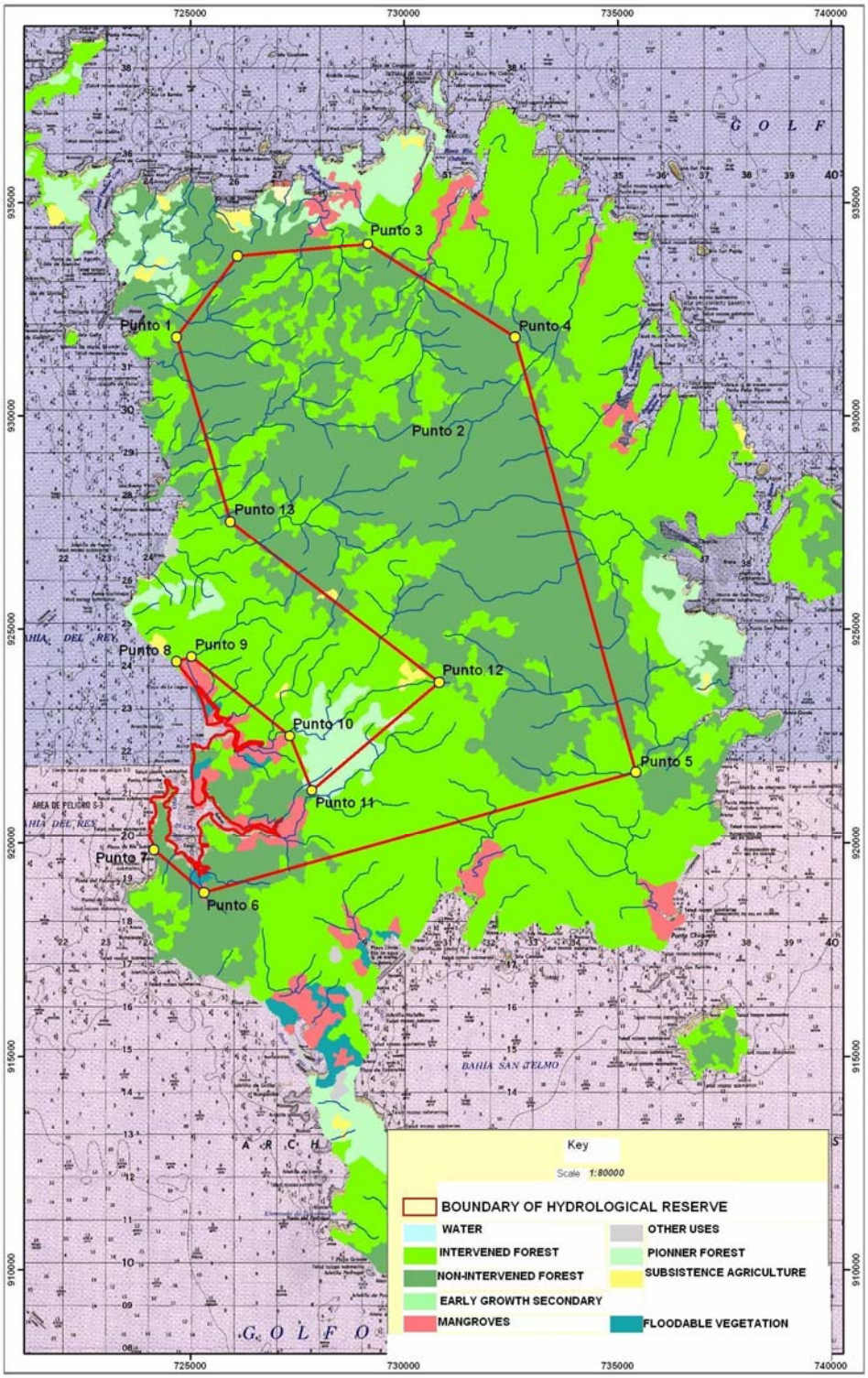
1.2.2 The need for research

An initial budget of $50,000 for the management plan of this reserve has been allocated, supported by UNEP (United Nations Environment Program) and the Global Environmental Facility (GEF) (STRI, 2006). However, to avoid the generation of a 'paper park', management plans must be well drafted and successfully implemented. Such efficiency is only likely if proposed action or inaction has a solid scientific foundation. The necessity for a well managed park is likely to gain importance over the coming decade as the Las Perlas islands become an increasingly popular destination for ecotourism (pers. comm.. Guzman).

The reserve delimits the protection of hydric resources, ecosystems, habitats and associated species to 9,822 hectares and encompasses the most important forest cover of El Rey Island (STRI, 2006). Prior to the designation much of the forest on the island was cleared by the inhabitants, and in some areas near the settlements it is highly fragmented. There remains a core of 'non-intervened' forest in the centre of the island, surrounded by a belt of, and to some extent interspersed with, 'intervened' forest (figure 1.4).

For this study the avifauna of the island was chosen for rapid assessment, partially from personal preference but also because of the pivotal role birds play as indicators in wider ecosystem health (Furness and Greenwood, 1993). Major centres of avian endemism are often closely related to the patterns of other terrestrial biodiversity (Stattersfield, *et al.,* 1998). Whitney & Smith (1998) noted that because birds are important for dispersing seeds and pollination, they can be crucial in keeping stable the structure and variety of plant communities. Weeks (2000) points out the significant role played by birds as both prey and predators, in addition to involvement in a number of host/parasite relationships. Birds are also highly sensitive to environmental

Figure 1.4: Map of Isla Del Rey showing land use as classified by remote sensing.



Source: Dr Hector Guzman and Jose Guevara ©, STRI.

change, and are often one of the first groups to noticeably respond, and therefore alert conservation managers, to ecosystem disturbance (Gregory *et al*, 2006; Venier and Pearce, 2004).

1.2.3 Birds of Panama

Birds are arguably the most studied of any major taxonomic group (Chek *et al.,* 2001) and are exceedingly well represented in the Isthmus of Panama, which offers a varied and attractive avifauna. In the western and central areas there are tropical species found throughout Central America and in San Blas and Darién to the east there are numerous species affiliated with South America. In the winter many species of migrants also come to join the residents, or pass through en route to more distant regions (Wetmore, 1974). At the land bridge between North and South America many Northern species reach their Southern limit and vice versa, this faunal intermingling in part explaining the wealth of species found in Panama. In addition, the rugged topography of the country allows very distinct habitats to be found in close proximity.

A total of 972 species have been recorded in Panama's 75, 500km², which exceeds the number for the USA and Canada combined (Angehr, 2006). Some of these species are long distance migrants, some are pelagic and only occur as nonbreeding visitants and others have been recorded just once. A particularly notable influx of species rarely or never before recorded in Panama occurred during an exceptionally strong 'El Niño' in 1982. The phenomenon resulted in a 'remarkable ornithological event' which temporarily changed bird communities and distributions to an unprecedented extent (Ridgely and Gwyne, 1989:12).

1.2.4 The birds of Las Perlas

In 1901, Outram Bangs surveyed the birds of San Miguel Island, the largest island in the Pearl archipelago, now named Isla Del Rey (Bangs, 1901). This information was updated in 1905 when Bangs worked with Thayer on the mammals and birds of the archipelago (Thayer and Bangs, 1905), and in 1920 Hilamar Rendahl undertook further survey work (Rendahl, 1920). It was then not until 1947 that Alexander Wetmore included the Pearl Islands in his mission to document all Panamanian avifauna (Wetmore, 1947). Despite this inventory work resulting in complete faunal lists for at least the main islands, no effort was made to understand the birds in a conservation context until the IBA (Important Bird Area) program arrived in Panama in the late 1980s.

Developed by Birdlife International, the IBA program was a response to a growing recognition that a wide range of species need to be researched simultaneously (through multispecies surveys) due to limited funding and research time in many biodiversity rich areas. It embraces a more holistic approach to biodiversity conservation, rather than a single species targeted strategy. Fieldwork undertaken as a result of the IBA program informs us that in the Las Perlas Archipelago there are 14 endemic subspecies of bird, all of which have been recorded on El Rey (Angehr, 2003). In addition, *Chlorostilbon assimili* (Garden Emerald), a species of hummingbird locally common on the Pearl Islands is biome-restricted, and the nationally vulnerable *Amazona ochrocephala* (Yellow Crowned Amazon) and

nationally endangered *Formicivora grisea alticincta* (White Fringed Antwren) are also found there (see appendix 1).

Due to the efforts of the Panama Audubon Society and the IBA program the bird records from the Pearl Islands are reasonably up to date. However, an understanding of their ecology is lacking and there have been no efforts to identify any current or potential threats to their survival thus far. Merely having a species list with no appreciation for abundance, distribution, density or habitat preference leaves a vast gap in the database. This is a huge handicap to successful, sustainable management and must be rectified.

Some information regarding the basic ecology of the Las Perlas birds can be gleaned from the older literature. MacArthur had visited the islands whilst forming his ideas on island biogeography and suggested that some bird species may be 'land-bridge relicts'. Such species would have crossed from the mainland when the archipelago was still joined during the Wisconsin glaciation (MacArthur, 1972). These 'relicts' were indeed shown to be present by Wright *et al.* (1985), but only on the larger islands of the archipelago.

An important finding of MacArthur and Wilson's 1960s studies of island biogeography is that species number and island area are directly related. Wright *et al.* (1985), found the slope of this relationship in the Pearl archipelago to be peculiarly low for oceanic islands, which implies that immigration rates are high and/or extinction rates are low. It is possible therefore, that the islands may exhibit high diversity.

Endemism has also been linked to island size and isolation, with the proportion of endemic species in island avifauna being highly variable (Mayr, 1965). A study by Alder found 'the islands of the tropical Pacific to have an avifauna exceptionally rich in endemic species' (Alder, 1992:303). Despite this study including 30 archipelagos in the Pacific Ocean, the Pearl islands were not suveyed.

According to MacArthur *et al.* (1972), a species may increase its population density on a species-poor island compared to a species-rich mainland due to the presence of fewer competing species. This increase might occur without a niche shift, or alternatively, density increase may arise as a result of niche shifts as species utilize more space (a wider range of altitudes, or habitats, or vertical foraging strata). It may be expected then, that the bird populations of the islands will exhibit high density.

1.2.5 Censusing birds

Globally, it is clear that to date not enough has been done to establish the basic parameters of distribution and relative numbers of species. This is particularly the case in species diverse tropical areas, where better data is necessary to both comprehend change, and react to it. Quite apparent also, is the need for straightforward methodologies. In developed nations of the northern hemisphere, it is possible that use of more complex approaches has meant researchers not recognising the potential of less sophisticated methodologies for primary recording and documenting (Bibby, 2004).

In geographical areas where the bird life is understudied the most relevant type of study to conduct is liable to be a multispecies survey, in which the composition and quantities of avifauna are documented. Where studies are examining the fragmentation of habitat, gauging the quantity of species is an important survey tool. Where the birds' habitat is natural or influenced by man, questions can be raised about how those differing habitats influence the variety and abundance of species (Sutherland *et al*., 2004).

Methodologies need to match not only the survey's purpose, but also the available levels of skill, personnel, and finance. The methods also need to be accepted by the observers themselves, in order to generate higher rates of data capture. In nations with plenty of ornithologists, whether professional or amateur, the fact that most do not participate in surveys is not problematic, as sufficient numbers will assist. Conversely, in countries poorly endowed with ornithologists, it is important that they all accept the methodologies, which should therefore be simple (Bibby, 2004).

With these considerations in mind, the rapid assessment technique (mentioned in 1.1.3) was chosen for this study, incorporating components such as point and line transects, vegetation profiling, visual and auditory recordings, distance sampling, MacKinnon Lists, and the use of local knowledge. The simplicity and effectiveness of the technique was really 'put to the test' as the study suffered from time constraints, logistical and technical difficulties, highly variable weather, and the avifauna and territory were completely unfamiliar. It is an ideal time to be undertaking this study as the reserve is newly designated (December 6th, 2006) and the management plans have yet to be finalised (pers. comm. Guzman). It is a rare opportunity to assess the condition of a community just as it enters the realms of statutory protection, and if annual or biannual monitoring using rapid assessment continues, many interesting comparisons, inferences and lessons may arise.

1.2.6 Aim and Objectives

The aim of the study is to use a rapid assessment technique to gather valuable baseline data on the avifauna on Isla del Rey in the Las Perlas archipelago. This research can then contribute, in combination with studies of other taxa, to the generation of a wider management plan for the hydrological reserve. The research follows six objectives:

- To record species richness, composition and abundance in the two main types of forest habitat on the island.

- To use this information to calculate species diversity and bird density for these habitats.

- To relate any findings to environmental, anthropogenic, or other factors.

- To appreciate these findings in a biogeographical and ecological context.

- To explore the potential of the rapid assessment technique as a tool for gathering baseline data on avifauna in the tropics.

- To recommend policies for management of the hydrological reserve based on any significant findings.

2 Methodology

2.1 Field Methodology

2.1.1 Study site

The study was conducted on El Rey, the largest, and one of the few inhabited islands in the Las Perlas Archipelago. The archipelago is an amalgamation of roughly 90 islands and 130 islets and cays (Delgado, 2006) on the Pacific-side of the Panama Isthmus, (between 8° 11'31"N 78° 46'22"W and 8° 40'16"N 78° 08'40"W) (Levings *et al.*, 1986) (see figure 2.1). The island complex provides much potential for ecological study due to the wide range of contrasting physical conditions occurring there(Glynn and Stewart, 1973).

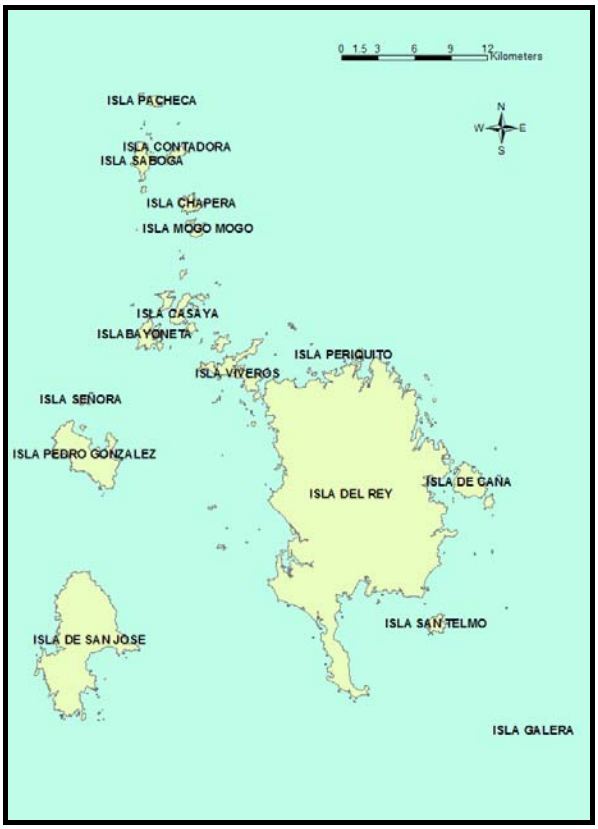


Figure 2.1: The islands of the Las Perlas archipelago.
Source: Dr Hector Guzman©, STRI.

Like the rest of the Gulf of Panama, the eastern lowlands are subject to the climatic changes induced by the Intertropical Convergence Zone (ITCZ). The study was undertaken at the beginning of the rainy season, occurring during the months of May to December, when the ITCZ is located over or slightly to the north of the country (Mitchell and Wallace, 1992). The wet season begins in late April and is characterized by light, variable winds and heavy rainfall (Forsbergh, 1969). During the study period the temperature ranged from 26.81-30.26 °C and rainfall ranged from 0-115mm (daily averages) (appendix 2).

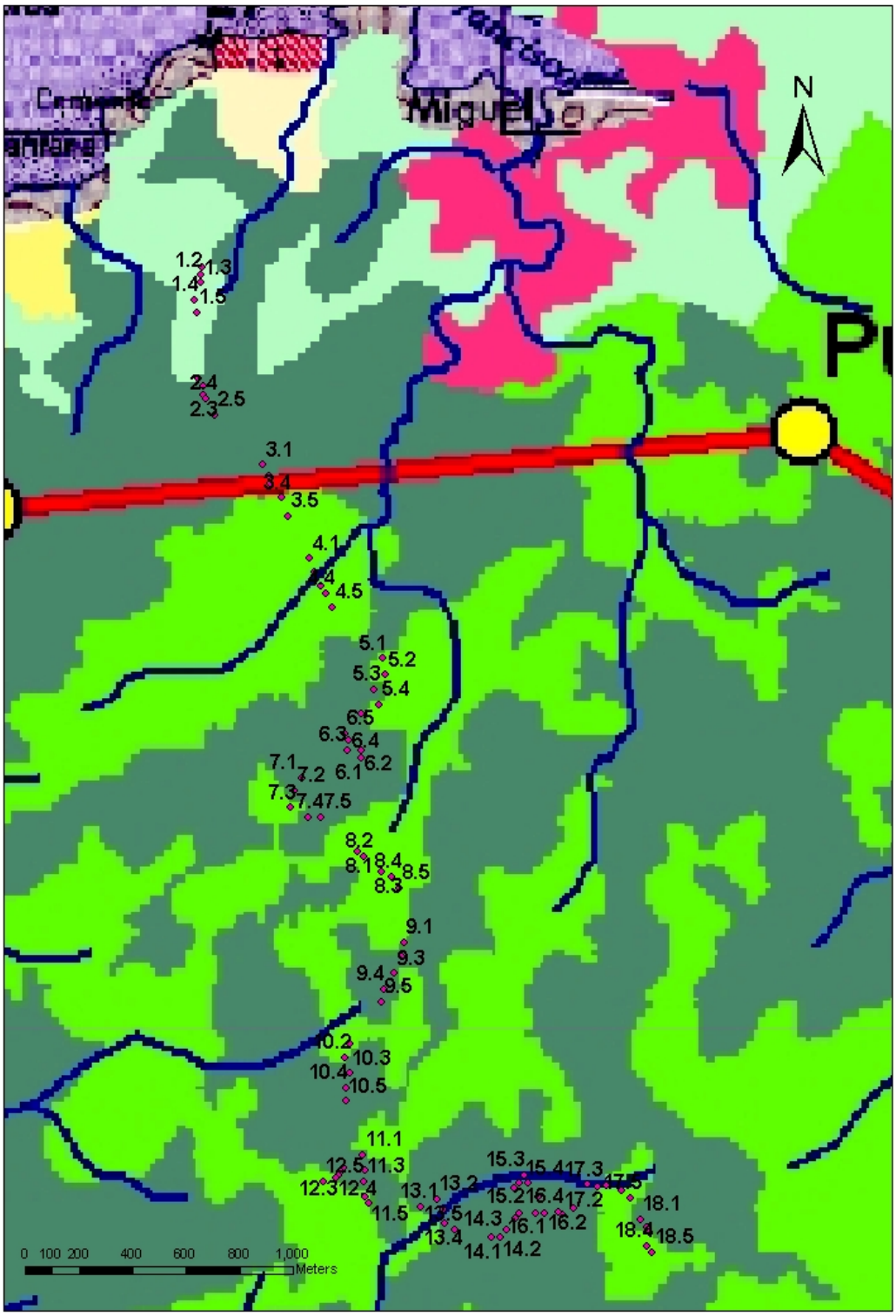
Isla del Rey, found in the south-eastern reaches of the archipelago has an area of 24,113 ha and a population of just under 1,500, found mainly in the fishing port of San Miguel (Campell, 2005). It is roughly rectangular, extending 19km from north to south and 14 km from east to west. Pedro Gonzalez and San Jose Islands are 12-13km to the west and Cangrejo, San Telmo, Monte and Camote Islands are immediately offshore (Angehr, 2003). The coast comprises rocky bays, sandy beaches and mangrove, whilst inland the vegetation is a mix of scrub and secondary forest. There is no primary forest but the oldest lowland semi-deciduous forest is found on the rougher terrain, towards the centre of the island. The habitat types of the island were classified by Guevara in 2005 using remote sensing techniques, and this study will adopt those classifications, primarily because the same map is to be used for drafting the management plan of the hydrological reserve (figure 1.4).

2.1.2 Recording location and target species

Due to the high levels of inaccessibility in the hydrological reserve, recording of birds had to be conducted primarily along existing paths and trails. Towards the end of the study period additional trails were cut to gain access to the forest. Consequently recording was conducted in a linear fashion from the boundary edge nearest to San Miguel in the north, heading in a south-southeasterly direction, ensuring both intervened and non-intervened forest habitat types were surveyed. Over 4500m of trail was subdivided into transects and buffer zones, covering a quarter of the islands length (figure 2.2). The original intention was for all survey work to be carried out inside the reserve but technical and logistical difficulties did not allow for this.

All survey work was terrestrial based, and restricted to land birds. Any marine, shoreline or mangrove birds detected in flight were omitted from data collection and subsequent analysis. Survey work was diurnal as night transect work was considered too treacherous in the terrain, so nocturnal species are also excluded from the study. A list of all species known to inhabit or visit El Rey, totaling 123 can be found in appendix 1. Many are migratory, aquatic, shorebirds or nocturnal, and once these are excluded there are 58 species remaining that fit the ‘terrestrial breeding resident’ criteria of this study.

Figure 2.2: GIS map of the study region showing the location of the transects.



Source: Dr Hector Guzman©, STRI.

2.1.3 Method justification

Although sampling along linear features such as rivers and trails can cause over representation of edge species in the data, under some field conditions there are no alternatives; this study was one such scenario. Sampling using both the linear transect method and point count method was conducted (Bibby *et al.,* 2004). The linear transect method is appropriate to quantify birds in open, scrubby habitats, whilst point counts are more appropriate in closed forest habitats (Gibbons *et al.,* 1996). As the microhabitats within the 4.5 km stretch were highly variable and each method has different strengths (see table 2.1), both methods were employed (Malizia *et al*., 2005). Neither technique requires complex equipment or expertise to practice, which conforms to the fundamental simplicity and repeatability requisites needed to promote long term-monitoring in such environments.

Table 2.1 Contrasting advantages of the point count and line transect methods (adapted from Bibby 2004).

Point Counts	**Line Transects**
Concentrate fully on bird observation	Cover more area quickly
More time to identify contacts	Less chance of recording same bird
Good for detecting cryptic species	Good for detecting sp. which 'flush' easily
Easier for distance estimation	Can relate occurrence to habitat features

Mist nets were not used as they do not complement the simplicity of the rapid assessment technique being explored. Firstly a license is required which relatively few people have, especially in developing tropical countries. In addition mist-netting is labour intensive, time inefficient, and a comparatively small proportion of the bird community is sampled, with a strong bias towards understorey species (Herzog *et al*., 2002). It has also been shown that point counts and line transects can be much more effective at sampling whole communities than mist net trapping (Estades *et al.,* 2006).

Recordings of vocalizations were taken because audio contacts are usually much more frequent than visuals, especially in forest where visibility may be only a few metres (Rosenstock, 1996). Recordings did not commence before 05.30 as sampling accuracy is lessened by the intensity of different bird song (Bibby *et al.,* 1985). A simplified version of distance sampling was used rather than the full method which involves the observer estimating the distance to each bird that is detected (perpendicular distance x for line transects, or radial distance r for point transects) (Rosenstock, 2002). Instead a binomial method that places detections into one of two distance categories was used (Buckland 1987).

For the purpose of the rapid assessment and in consideration of the scale of the study and the resources available a descriptive vegetation survey was selected. It requires no previous botanical knowledge of an area and is a simplified type of physiognomic and structural description, which are most valuable in the tropics

where floristic data is hard to obtain and analyse (Kent and Coker, 1992). The observation that birds choose their habitat primarily on vegetation rather than floristic composition has been documented numerous times in the literature as far back as 1933 (Lack, 1993; Fuller and Henderson, 1992; Bersier and Meyer 1994). The approach used in this study is based on the assumption that the two main forest types will exhibit different structural profiles which can be described and used in subsequent analysis.

2.1.4 Line transects and point counts

Prior to sampling, 4 km of existing trail was divided up and marked into a series of 18 transects. A further 0.5 km of trail was cut during the surveying when the trail came to an end. Each transect was 200m in length with an effective width of 50 m (25 m per side). This width is within the threshold of effective distance of detection according to Emlen (1971), and research by Diefenbach *et al.* (2003), shows that detection probabilities are <1.0 at distances >25 m for most observers and species. A 200 metre 'buffer' zone between adjacent transects was allowed as recommended by Gibbons *et al.* (1996). Within each transect markers were placed every 50m, GPS coordinates taken, and environmental descriptions noted. GPS was not used to measure transect or buffer zone length due to a consistently weak signal. These measurements were instead paced out by one individual with a stride of roughly 1m.

During 16 days in May (totalling approximately 160 hours), 1 work team consisting of 3 people (1 note taker and 2 observers) sampled the transects on the island from first light (approximately 0530) to 1100, although exact timing depended on bird activity. There was only time to sample each 200m transect once, but those sampled in the rain were repeated in fair weather. Transects and counts undertaken when the second observer was not present were also resurveyed with the second observer (a local trained by the Panamanian Centre for Research and Social Action (CEASPA) in basic ornithological identification).

For line transects, observers walked at a steady pace, recording for each contact; species, number of individuals, time of sighting, whether it was audio or visual and whether it was in the inner or outer 'belt'. The inner belt was given as 15 metres either side of the transect, and the outer belt up to 25m either side of the transect. Observations outside of the 25m were disregarded as identification accuracy beyond this point is low. The two counting bands are applied in order that through the calculation of relative species densities, the variation in the detectability of conspicuous species versus shy species can be corrected for (Bibby *et al.,* 1992).

Point counts were undertaken at 0, 100 and 200m along each transect. Point counts were located 100m apart instead of the recommended 250m (Hamel *et al*.,1996) to maximize coverage along the same area covered by the line transects (Wilson *et al*., 2000). Point count duration was ten minutes at each site, as recommended by Fuller and Langslow (1984), commencing after a five minute waiting period on arrival at each point to allow birds to 'settle'. Following the line transect method records of species, number of individuals, time of contact, audio or visual, inner or outer belt (radial) was noted.

2.1.5 Audio and visual recordings

All bird contacts encountered on line transects and during point counts were noted as either visual or audio identifications, or both. In the field, identification was based on standard field guides (Ridgely and Gwynne, 1989), and visual identifications were made using binoculars (Olympus 8x25 WP 1) and supported by field notes and photographic evidence (Canon Powershot S3IS). Audio recording was achieved through use of a digital hand held Dictaphone (Sony ICD P320) and a unidirectional microphone (Sony F-V120).

Both visual and audio identifications were confirmed by the second observer. On return from the field, an extensive collection of additional ornithological reference works (books, journals, CD-ROM, CANARY software[1]) were available to decipher difficult visual or audio identifications. This collection of references is held in the STRI (STRI) in Panama City. An interview with Dr George Angehr, head of the Panamanian Audubon society was also held in which some distorted vocal recordings were identified.

2.1.6 Vegetation description

At 0, 50, 100, 150 and 200m along each transect some basic environmental descriptors were noted, taken by the same observer in all instances to avoid inter-observer bias. Percentage cover of three different height classes were taken (understorey, midstorey and the canopy), along with the estimated maximum height of the canopy. Estimates were taken within a 5m radius of the observer, and for understorey included all vegetation less than 1m, for midstorey all vegetation between 1-5m and for canopy all vegetation greater than 5m in height. Elevation and location was recorded using handheld GPS (Garmin e Trex), which would allow a later calculation of which transects were in which of the two main forest type. On a number of occasions there was no GPS signal at a location and a reading would instead have to be taken a few metres away, usually in the nearest tree fall gap. Notes and photographs on predominant plant species, and any evidence of recent human activity such as burning was also recorded. Environmental parameters recorded can be found in appendix 3.

[1] Soundfiles can be uploaded to produce a sonogram which is distinct for each species and can be compared against a reference database (Baker and Logue, 2003).

2.2 Analytical Methodology

2.2.1 Species richness, composition and distribution

From here on 'transects' refers to the combination of the line transect with its associated point counts. The number of species observed for each transect was summed to give an empirical species richness value (*S*) for each. *S* was also calculated for the two main habitat types by grouping the species observations of transects found in each of the two habitats. Although the *S* value has little statistical value in itself it is an important element of many other analyses. There are a whole suite of species richness estimators available (Chao2 is considered the most robust (Chazdon *et al*., 1998)), but their accuracy is known to be very inconsistent and dependent on sample size and coverage (Brose *et al*., 2003), so they were not used in analysis.

To determine which transects were located in which of the two forest types, GPS points taken in the field were plotted on a habitat map. This allowed clarification that transects 1, 4, 5, 8, 17 and 18 were in the intervened habitat, and the remaining twelve transects (2, 3, 6, 7, 9, 1, 11, 12, 13, 14, 15 and 16) in the non-intervened habitat (figure 2.2). Transect 1 was actually located in 'pioneer' forest, although this is structurally and floristically similar enough to be grouped with the intervened secondary forest. This is acceptable for a rapid assessment ornithological study but would not be appropriate for a detailed vegetation survey.

The numbers of individuals of each species were plotted on bar charts for each transect, and on pie charts for each of the two habitats, with endemics shown in colour or bold (respectively). This allowed easy visual comparison of species composition between transects and habitats. Information on endemics was extracted from Angehr (2003), the most comprehensive and current source of information on the status of Panamanian birds. For each species a scatter graph was generated, plotting the observations for that species (number of individuals per transect) against the distance from San Miguel (from the innermost edge of the town to the mid-transect point). Distances from San Miguel were calculated in ArcGIS using GPS coordinates taken in the field. Again this allowed easy visual comparison between species, with regard to their distribution across the 4.5 km surveyed.

2.2.2 Species diversity

Investigations aiming to assess the conservation importance of an area often do so by determining the diversity of species present, allowing comparisons between habitats, and identifying possible 'hotspots' (Robertson and Liley, 1998). Assessing diversity was therefore a very important element of this study so analysis had to be thorough. There are numerous species diversity indices available and each is calculated using slightly different parameters, often resulting in different outcomes for the same set of data (Beaugrand and Edwards, 2001).

In view of this four indices were selected for analysis, ranging slightly in their treatment of richness, evenness and rarity in the data. These were Simpson's diversity index, the Berger-Parker index, Chao1 and Fisher's alpha, calculated using either Excel (2003) or EstimateS (version 7.0). The values calculated by these

indices were then used to perform t-tests (95% confidence) comparing diversity between the two habitat types. Linear regression was also used to test for any relationship between diversity and distance from San Miguel.

2.2.3 Bird density

There was too little data to calculate density for each species, so individual observations were just divided into inner or outer band recordings for each point count. Data from line transects were not included as one of the fundamental assumptions of the equation used is that birds do not move much during counts, and there were a lot of in-flight contacts during line transects. Data from counts of the same habitat type were combined and bird density for each of the two habitats was then calculated.

The probability of detecting a bird, if present at range x will decline according to the equation $p=exp(-(x/a)^2)$ where x is the distance from the observer and a is an unknown constant. Therefore, from knowledge of the number of birds recorded in the inner and outer bands and an estimation of a, density for a habitat can be calculated using the following equation (Bibby *et al.,*1992).

$$Density = ln\ (n/y) \times n/m\pi r^2$$

Where:

n is the total number of birds recorded
y is the total number of birds recorded beyond the 15m inner belt
m is the total number of counts
r is the fixed with/radius of the inner 15m

2.2.4 Species relative abundance

The Mackinnon Lists technique (Mackinnon and Phillips, 1993) provides a means of calculating species relative abundance. The method relates species richness to the number of observations rather than time or area therefore allowing comparisons of data obtained by different observers, using different methods under varying field conditions (Herzog *et al.,* 2002). The observer generates a list by noting each new species until a predetermined number of species is recorded. Each species is recorded just once in each list but may be recorded in subsequent lists (Bibby, 2004). The relative abundance of each species at each site is equivalent to the fraction of lists in which a species occurs. It is therefore calculated by counting the number of species list samples in which a species occurs and dividing this by the total number of samples collected for that group of sites.

Trainor (2002) determined that a species list number of 10 generated the most accurate species richness estimations in a species poor environment (less than 100 species). However, data collected was very sparse and from a target group of approximately 50 species. Following the recommendations of MacLeod (pers. comm; MacLeod *et al*., 2005) 5 species lists were used and data for transects in the same habitat were combined. The order of encounter (used to generate the 5 species lists)

was calculated from the original contact times noted in the field. This resulted in the generation of 18 sample lists for the intervened habitat and 26 sample lists for the non-intervened habitat (appendix 4).

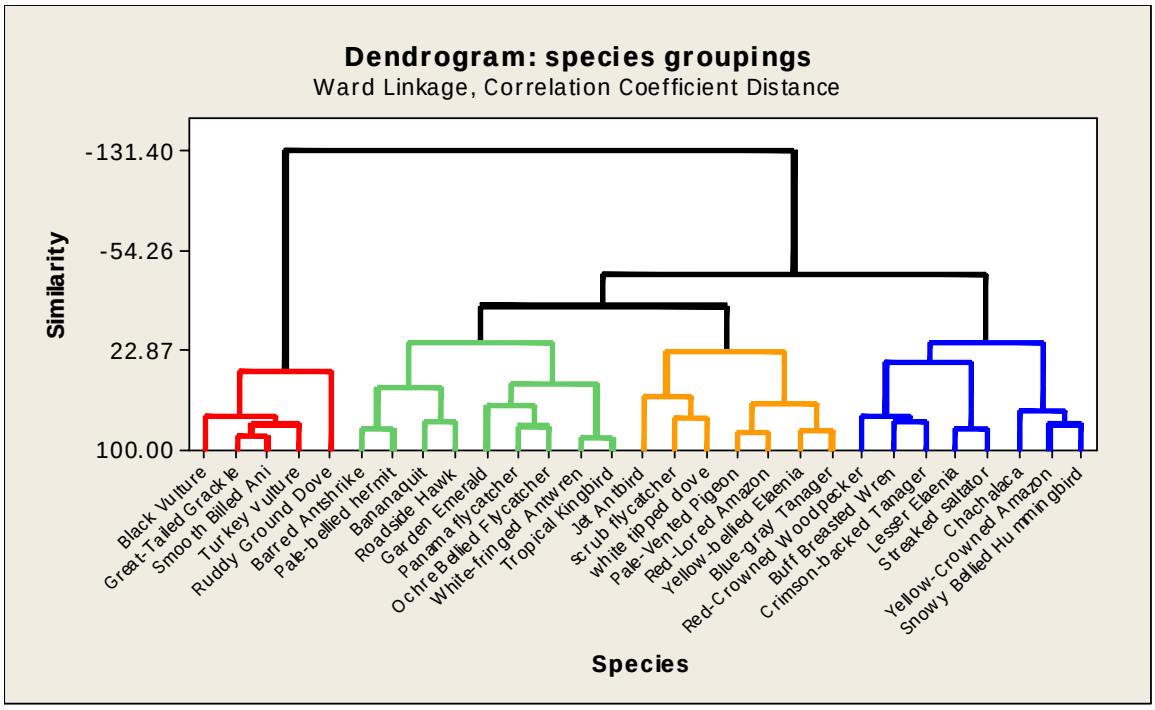
2.2.5 Multivariate analysis

Multivariate analysis was used to investigate the relationships between species, samples and environmental variables. Correspondence analysis ordinates individual samples or species on a plot in which each ordination axis represents a gradient along which the centroids of species and/or samples are distributed to maximize the distances between them. The first axis represents the gradient explaining most of the variability, the second axis explains most of the variability not accounted for by the first axis and so on (Storch *et al*., 2003).

First, a DCA (detrended correspondence analysis) was run on the data. The gradient of the axis was greater than 4, indicating that the data was unimodal i.e. high beta diversity. Therefore a correspondence analysis (CA) was conducted using CANOCO 4.5 (ter Braak and Smilauer 2002) to display the relationship of the sites in terms of their bird species composition. Bird species data was not transformed, detrended by segments to correct for the arch effect, and rare species were down-weighted to reduce the effect of outliers. To add another dimension and identify patterns of bird community variation across transects in relation to habitat variability, canonical correspondence analysis (CCA) was also used. By using this method the ordination axes demonstrate the maximum variability attributable to each of the environmental factors. Relative influence of each parameter is visualized by the length of the vectors in the ordination plot (Marsden *et al.,* 2006).

However, because individual variables are often strongly intercorrelated it is often not easy to decide which factors are actually responsible for the patterns. A solution to this problem is to test the significance of the effects of individual environmental parameters and eliminate those of less than a chosen significance from the correspondence analysis (Storch *et al.,* 2003). The CCA was therefore re-run with the Monte Carlo test, using manual selection and a significance level of < 0.05. Both the CA and CCA were also re-run with some species excluded from the analysis. This was performed because despite down-weighting of rare species there were clearly five species ‘pulling’ the distribution of all others on the plot. These species were confirmed to be outliers by a cluster analysis in Minitab 15 using Ward Linkage and correlation coefficient distance (recommended for species data by Romesburg, 2004), which grouped them separately to all the other 24 species (figure 2.3)

Figure 2.3: Dendrogram from cluster analysis showing five species separately grouped from the other 24 species.



2.2.6 Additional tests on environmental data

The environmental variables were also explored through One Way Analysis of variance (ANOVA). This test was used to determine if vegetation data along transects (percentage cover for three different height classes and estimated maximum canopy height) differed significantly between the two habitat types of interest; intervened forest, and non-intervened forest. Percentage data was arcsine transformed before analysis and a 95% confidence level was applied.

3 Results

3.1 Species richness, composition and distribution

A total of 552 individuals representing 29 species of 13 families were recorded during the study period. Ten of these species are endemic subspecies (to the whole archipelago), one is biome restricted, one is nationally endangered, and one is nationally vulnerable (appendix 5 and 6).This represents 24% of the total species known to be present on the island (the remaining 76% are primarily water-based, nocturnal or migratory) (appendix 7). The three most commonly observed species were *Thamnophilus doliatus nesiotes* (Barred Antshrike), *Thryothorus leucotis conditus* (Buff-breasted Wren), and *Columba cayennensis* (Pale Vented Pigeon). In terms of the number of individuals recorded the three most common were *Thamnophilus doliatus nesiotes* (Barred Antshrike), *Ortalis cinereiceps* (Chachalaca), and *Amazona ochrocephala* (Yellow-crowned Amazon). *Tyrannidae* (flycatchers) was the best represented family with six species; high diversity in this family has been reported in a other Neotropical studies (Karr *et al.,* 1990).

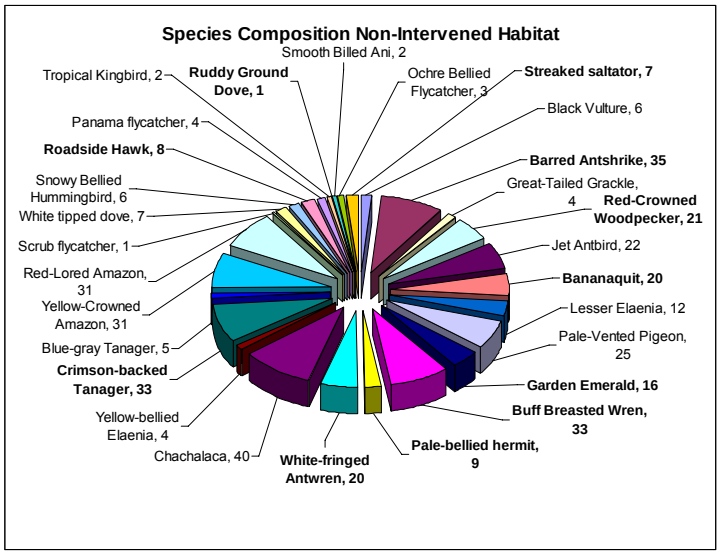


Figure 3.1 (a) The number of individuals (not observations) of each species recorded in the non-intervened habitat. Endemics or biome-restricted species are shown in bold.

Eight species, including the nationally endangered *Formicivora grisea alticincta* (White-fringed Antwren) and two other endemic subspecies were only recorded in the non-intervened forest. However, only one species, *Cathartes aura* (Turkey Vulture), was recorded in the intervened forest and not in the non-intervened (fig 3.1 (a) and (b)). The most commonly observed species in the non-intervened forest were *Thamnophilus doliatus nesiotes* (Barred Antshrike), *Thryothorus leucotis conditus* (Buff-breasted Wren) and *Columba cayennensis* (Pale Vented Pigeon). The most commonly observed species in the intervened forest were *Thamnophilus doliatus nesiotes* (Barred Antshrike), *Coereba flaveola cerinoclunis* (Bananaquit) and the *Centurus rubricapillus seductus* (Red-crowned Woodpecker).

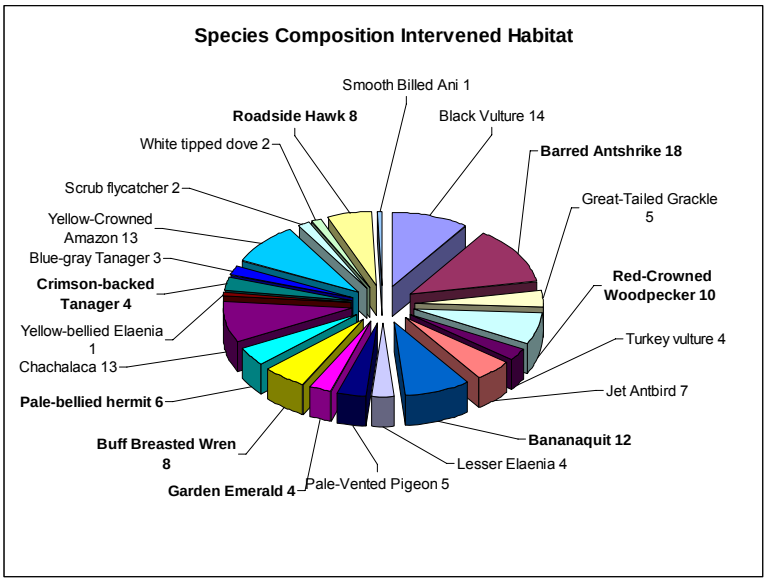


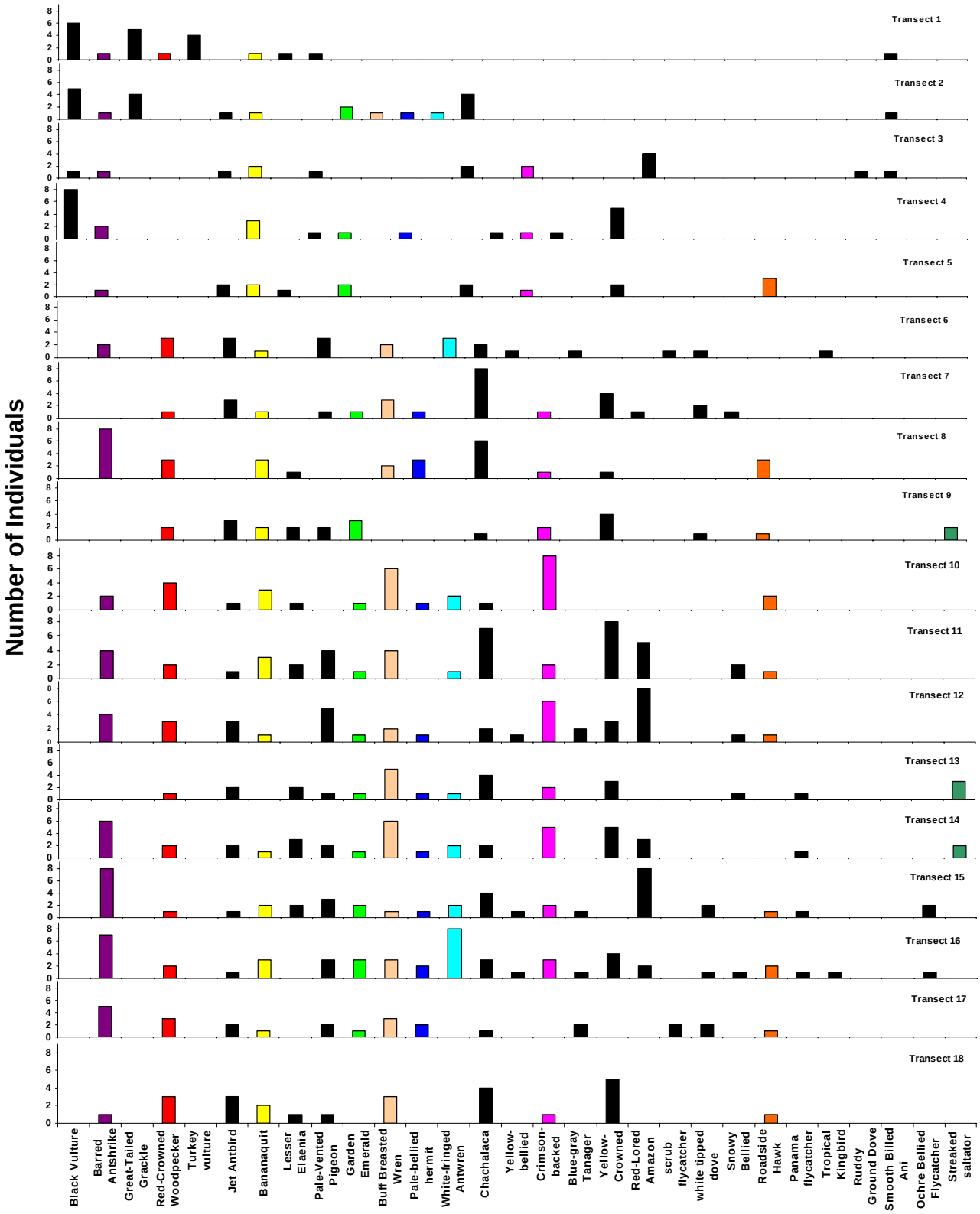
Figure 3.1 (b) The number of individuals (not observations) of each species recorded in the intervened habitat. Endemics or biome restricted species are shown in bold.

The 18 transects surveyed varied in the number of species observed, with the least recorded in transect 1 (9) and the most in transect 16 (21). Endemic subspecies were recorded in all transects, the least in transect 1 (3) and the most in transects 14, 15 and 16 (9 each) (figure 3.2). *Coereba flaveola cerinoclunis* (Bananaquit), one of the ten endemic subspecies, was recorded in all transects but one (transect 13), and *Thamnophilus doliatus nesiotes* (Barred Antshrike), another endemic subspecies was found in all but two (transect 13 and 9). Conversely another endemic subspecies, *Saltator albicollis speratus* (Streaked Saltator), was restricted to only three transects (9, 13, 14). The majority of species were recoded frequently, with only four species having fewer than four observations, and 48% of species having 20 or more observations. Seventy percent of all recordings were audio rather than visual and over 80% were recorded during point counts, rather than line transects. A breakdown of how many recordings were made by each method for each species is given in table 3.1, clearly showing certain methodologies can be more productive per unit effort under certain conditions.

Table 3.1: Number of recordings using each methodology for each species.

Species	Audio	Visual	Line	Point	Species	Audio	Visual	Line	Point
Black Vulture	2	5	1	6	Yellow-bellied Elaenia	4	1	1	4
Barred Antshrike	30	9	9	30	Crimson-backed Tanager	17	4	3	18
Great-Tailed Grackle	1	0	0	1	Blue-gray Tanager	3	3	0	6
Red-Crowned Woodpecker	18	10	5	23	Yellow-Crowned Amazon	10	5	4	11
Turkey vulture	1	2	0	3	Red-Lored Amazon	10	4	3	11
Jet Antbird	23	5	1	27	scrub flycatcher	3	1	2	2
Bananaquit	25	5	1	29	white tipped dove	4	2	2	4
Lesser Elaenia	10	7	3	14	Snowy Bellied Hummingbird	0	3	1	2
Pale-Vented Pigeon	21	8	7	22	Roadside Hawk	10	5	1	14
Garden Emerald	7	10	4	13	Panama flycatcher	1	3	0	4
Buff Breasted Wren	26	3	7	30	Tropical Kingbird	0	2	0	1
Pale-bellied hermit	5	6	3	8	Ruddy Ground Dove	1	0	0	1
White-fringed Antwren	14	4	5	13	Smooth Billed Ani	2	1	0	3
Chachalaca	23	4	4	22	Ochre Bellied Flycatcher	1	1	0	2
					Streaked saltator	2	3	1	4
Totals	**206**	**78**	**50**	**241**		**68**	**38**	**18**	**87**

Figure 3.2: Histograms presenting species composition of each transect. Transects are ordered with progressive distance from San Miguel. Endemics are shown in colour.



The distribution of endemic subspecies across a gradient of distance from the town of San Miguel into the forest is shown in figure 3.3 (scatter plots for all species can be found in appendix 8). The vast majority of species tend to have increased levels of abundance at an increasing distance from the town. The inverse is true for the five species already identified by cluster analysis (figure 2.3) as outliers.

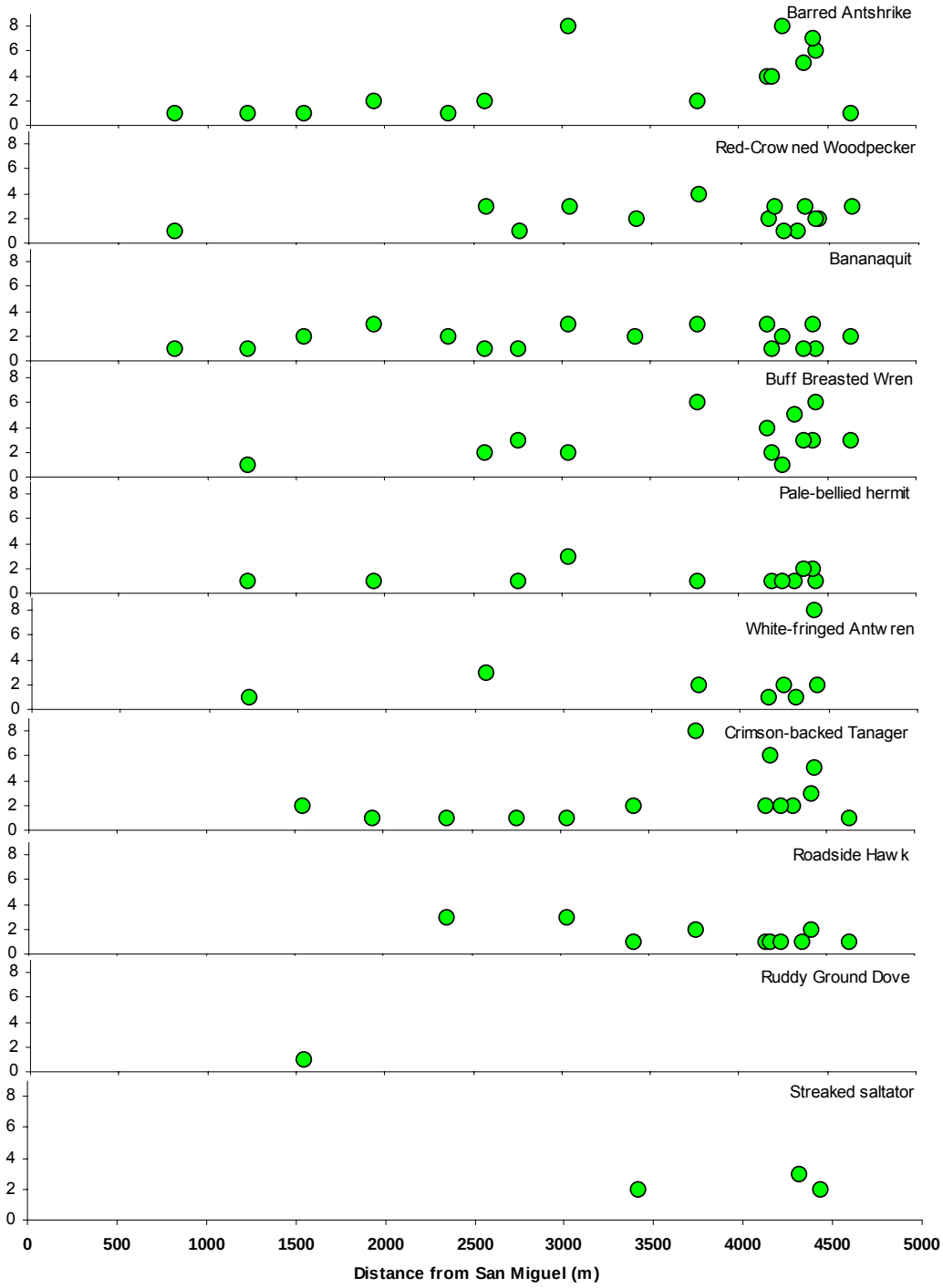


Figure 3.3: Scatter plots showing distribution and abundance of endemic subspecies with increasing distance from San Miguel.

Regression analysis shows that total bird abundance increases significantly (P=0.002) with increasing distance from San Miguel (figure 3.4).

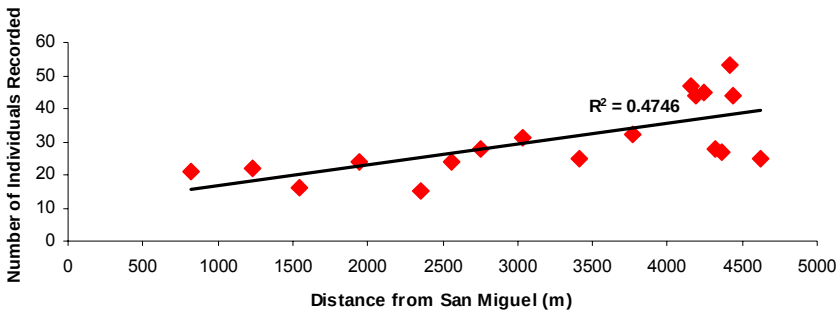


Figure 3.4: Spatial trend in bird abundance with increasing distance from San Miguel.

3.2 Species diversity

Regression analysis was also used to investigate the relationship between species diversity and distance from San Miguel (appendix 9). Diversity significantly increased with distance from the settlement using values generated by two out of the four indices; Simpsons (p=0.001) and Berger-Parker (p=0.023).Tests were performed at a 95% confidence level.

The extent of variation in index values calculated for transects differed between the four indices used, although standard deviation was never greater than 6 and generally below 3, indicating values are robust (appendix 10). Using values calculated by the Simpson's diversity index, diversity is found to be greater in the non-intervened than in the intervened habitat (p=0.026). For Fishers alpha diversity is also significantly greater (p=0.017), but the Berger-Parker and Chao1 diversity values were not significantly different between habitat types (appendix 11). All t-tests were run at a 95% confidence level.

The Fisher's alpha has been criticised for giving a high value to sites showing greater dominance, and poorly accounting for species evenness, which is a valuable measure of diversity. However, the Simpson's Diversity Index takes both richness and the proportional abundances of species into account, so the two significant results of the indices compliment each other well (Magurran, 1998). In consideration of this it can be concluded that the non-intervened habitat is more 'even' than the intervened habitat which is dominated by a few common species.

3.3 Density and relative abundance

The density of birds in the intervened habitat was calculated as 57.57 birds per/ha, and for the non-intervened habitat as 74.97 birds per/ha. The density of endemics for the intervened habitat was 24.41 and 42.39 for the non-intervened.
Using the Mackinnon list technique percent relative abundance was calculated for each species in both the intervened and non-intervened habitat. A number of species had a high index value in both of the habitat types (example shown in yellow), whilst others had quite different values in the different habitats (example shown in green) (see table 3.2).

Table 3.2: The relative abundance index for each species in the two forest types.

Species	Relative Abundance Index (Intervened)	Relative Abundance Index (non-intervened)
Black Vulture	11.11	3.85
Barred Antshrike	38.89	30.77
Great-Tailed Grackle	5.56	3.85
Red-Crowned Woodpecker	27.78	30.77
Turkey vulture	5.56	0.00
Jet Antbird	22.22	38.46
Bananaquit	38.89	34.62
Lesser Elaenia	16.67	7.69
Pale-Vented Pigeon	27.78	34.62
Garden Emerald	22.22	30.77
Buff Breasted Wren	22.22	30.77
Pale-bellied hermit	27.78	26.92
White-fringed Antwren	5.56	34.62
Chachalaca	33.33	30.77
Yellow-bellied Elaenia	16.67	7.69
Crimson-backed Tanager	16.67	26.92
Blue-gray Tanager	22.22	11.54
Yellow-Crowned Amazon	27.78	19.23
Red-Lored Amazon	0.00	26.92
scrub flycatcher	5.56	0.00
white tipped dove	16.67	11.54
Snowy Bellied Hummingbird	5.56	11.54
Roadside Hawk	33.33	19.23
Panama flycatcher	11.11	7.69
Tropical Kingbird	5.56	3.85
Ruddy Ground Dove	0.00	3.85
Smooth Billed Ani	5.56	3.85
Ochre Bellied Flycatcher	5.56	0.00
Streaked saltator	0.00	11.54

3.4 Exploring associations between variables

A correspondence analysis on the data (appendix 12) showed transects 1, 2, 3 and 4 (nearest the village of San Miguel) to have an association with the outlier species; *Coragyps atratus* (Black Vulture), *Crotophaga ani* (Smooth Billed Ani), *Columbina talpacoti nesophila (*Ruddy Ground Dove), *Cassidix mexicanus* (Great-tailed Grackle) and C*athartes aura* (Turkey Vulture).

These species were not recorded beyond transect 4 and are likely to be anthropophillic. There are a number of studies reporting similar patterns and one study which refers to such species as 'urbanisation-enhanced' (Crooks *et al.,* 2004:451).

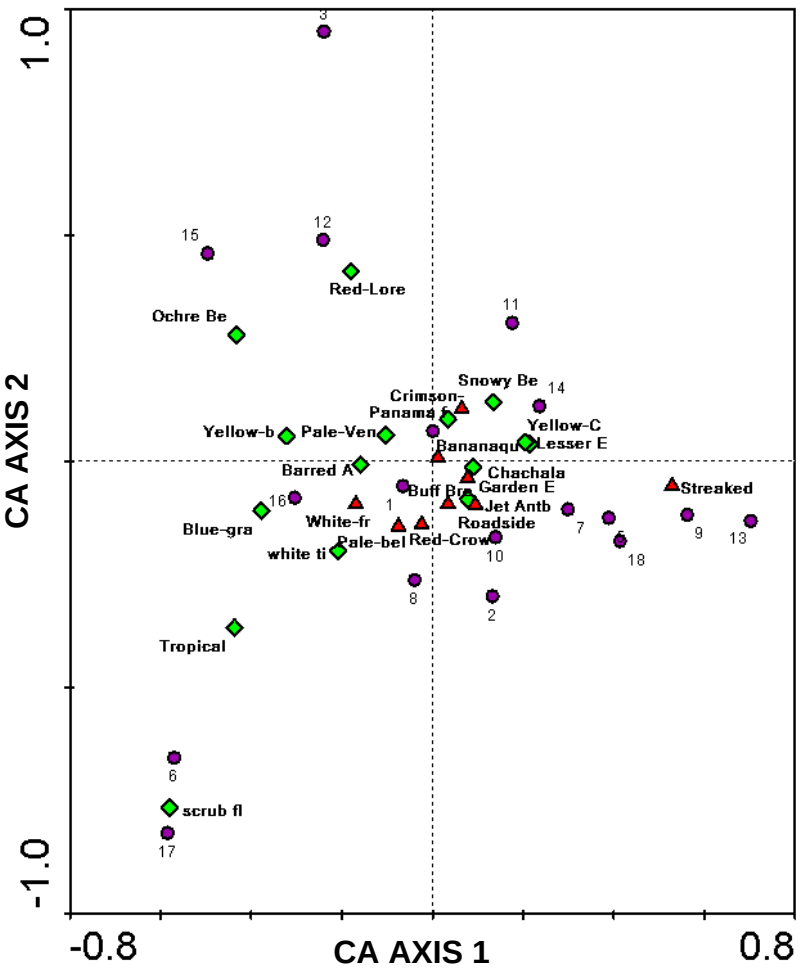


Figure 3.5: CA biplot showing associations between transects and species.

A CA with those species removed (figure 3.5) shows the endemics (represented by red triangles) and the majority of other species (green diamonds) are loosely associated with the majority of transects (purple circles). This is unsurprising as we can see from figure 3.2 that most species are found in most transects. There are however a couple of species not confined to the central cluster that are worth mentioning. *Amazona autumnalis* (Red-lored Amazon) and *Mionectes oleaginea* (Ochre-Bellied Flycatcher) are closely associated with transect 12 and 15 respectively. Interestingly these are two of only three birds recorded during the survey that are defined by Angehr (2006) as a 'forest' species, see appendix 6. This means these species prefer older more mature forest to the secondary, open intervened habitat. Transects 12 and 15 were both located in the non-intervened forest and have notably high canopy cover and maximum canopy height an indication that the forest is older at that site (appendix 3).

The species *Sublegatus arenarum* (Scrub Flycatcher), as its name implies, is usually found in scrubbier habitat, so it is unsurprising that it is found associated with transect 6 which has a vegetation profile of dense understorey and sparse canopy. The vegetation profile of transect 17, which this species also seems to be associated with changes drastically within a short distance, with environmental observations at 200m giving high canopy cover and low understorey measurements. However, cross

referencing with the original field observations confirms that the recording of *Sublegatus arenarum* (Scrub Flycatcher) was at the beginning of transect 17 were the vegetation profile was similar to that if 6. The species *Saltator albicollis speratus* (Streaked Saltator) is found at the distal end of the gradient from *Sublegatus arenarum* (Scrub Flycatcher) which might imply these birds have very different ecologies or habitat requirements, but there is nothing in the literature to support this.

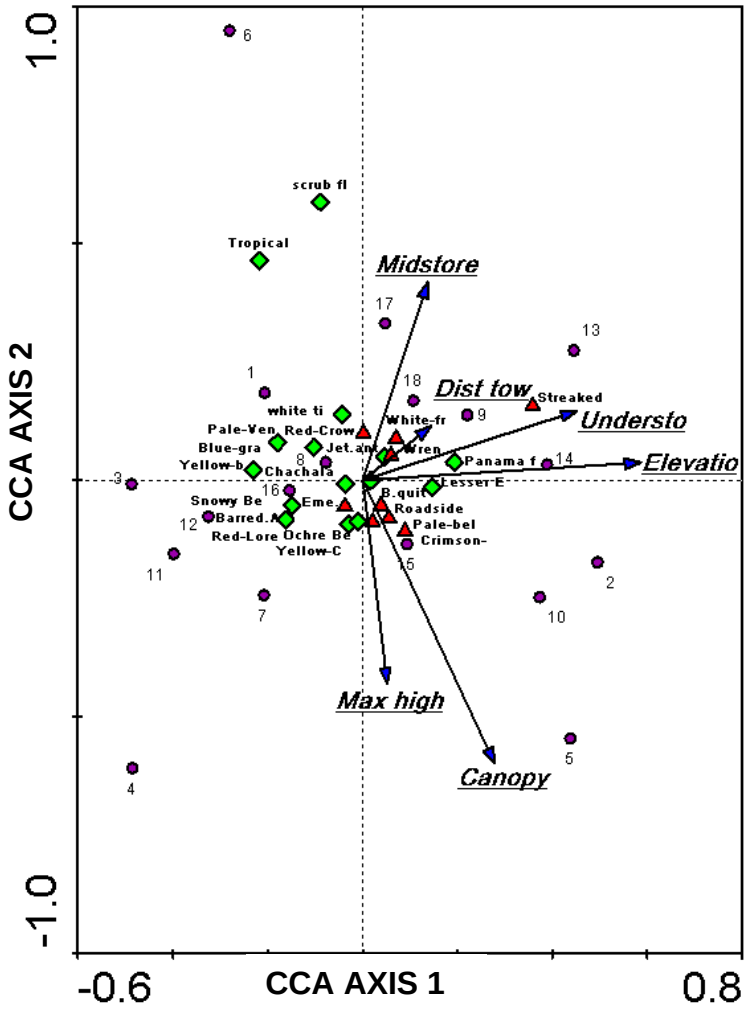


Figure 3.6: CCA triplot showing environmental parameters (midstorey, distance from town, understorey, elevation and maximum height of the canopy), species and transects. Percentage of variance explained by individual canonical axes is given in parentheses.

Indeed, according to Angehr (2006), both species are commonly associated with scrubland and open habitat. However, *Saltator albicollis speratus* (Streaked Saltator) is known to travel between many habitats searching for fruiting trees (Seutin *et al*, 1993). This may define therefore where it is observed, rather than within a recognised habitat association, because it is more conspicuous whilst foraging. A CCA (with outliers removed) (figure 3.6) confirms the negative association between canopy cover and *Sublegatus arenarum* (Scrub Flycather), although all other species and transects remain centrally clustered. The first axis is strongly related to elevation and accounts for 33.3 % of the total variation in the data. Axis two however accounts for almost 30% of variation also and is most strongly related to canopy cover and maximum height. Midstorey is inversely proportional to canopy cover.

Removal of the insignificant environmental variables (determined by the Monte Carlo permutation test) left only the maximum canopy height (P = 0.04). The resultant ordination plot (figure 3.7) however, shows very little spread of the species along the gradient. There also appears to be little relationship between transects and maximum height, although an ANOVA found both maximum height (P=0.002) and canopy cover (p=0.01) to be significantly greater in the non-intervened transects than intervened (appendix 13). To discern any distinct correlative relationships, and then determine which represent real biologically meaningful relationships is clearly not possible on the basis of these ordination plots.

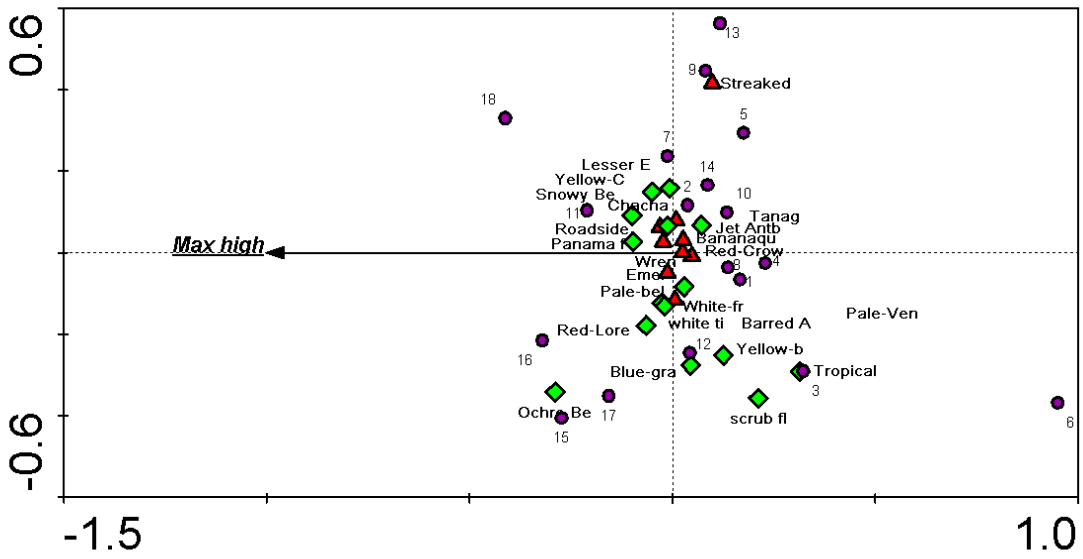


Figure 3.7: CCA after Monte Carlo permutation test was run, showing maximum height of the canopy (the only variable determined significant), species and transects.

4 Discussion

4.1 Ecology

4.1.1 Density compensation on El Rey

12,000 years ago sea level was about 100m below its present level and the Pearl Island Archipelago was joined to the Panamanian mainland, supporting most of the rich mainland avifauna (Flint, 1957). Many of these species arrived on the island when there was still a connection with the mainland whilst others colonized over water after the submergence of the land bridge by sea level rise. Today however, El Rey has only a fraction of these bird species, and although some have continued to exist as relicts of the land bridge, most have become extinct in the last 12,000 years (MacArthur *et al.,* 1973). El Rey is therefore relatively species poor and the birds that persist there are a very nonrandom sample of the mainland avifauna.

The species that survived were those capable of persisting as isolated populations or colonising over water. This includes species that can find sufficient food within a foraging area small enough to defend as an exclusive territory. Interestingly, two families that fit this criterion are the Antbirds (*Formicariidae*) and the Flycatchers (*Tyrannidae*), both of which were well represented in the data, together accounting for over 25% of all individuals recorded. Another example from Rey is the case of the Buff Breasted Wren (*Thryothorus leucotis conditus),* which is the only, but highly abundant (one of the three most observed species) Wren on the whole island. Indeed all the islands of the Las Perlas Archipelago have just one Wren species, and in each case the locally successful colonist (by fortune of some slight adaptive difference) has made it impossible for other similar immigrant species to establish on the island (MacArthur *et al.,* 1973).

This phenomenon where species richness of an island is very low, but those species found are found in abundance is known as density compensation and is an ecological process very apparent on El Rey. Studies of the island of Puercos, (Las Perlas Archipelago) by MacArthur *et al.* (1972), found the combined densities of its 18 bird species to be greater than the combined densities of 60 species in comparable habitats on the mainland. This scenario has been reported in a number of island studies (Grant, 1966; Keast, 1970; Yeaton, 1974), and is thought to be due the reduced levels of competitors and predators on islands compared to the mainland.

4.1.2 Habitat preferences of the avifauna of El Rey

Density compensation may occur with or without a niche shift. Individuals may persist by foraging in the same location and extracting more food, or they may exploit more space, through utilising a broader range of altitudes, habitats, or vertical vegetation strata. In the case of the avifauna of El Rey it apears to be the latter as the majority of species were found in both forest types and did not follow the textbook classification of their habitat preference. For example *Centurus rubricapillus seductus* (Red-crowned Woodpecker), normally associated with grassland and open

woodland, was common in the dense non-intervened forest. This generalist behaviour exhibited by insular passerines has been reported by many ornithologists studying island populations (Alerstam *et al*., 1974; Lack, 1976; Diamond and Marshall, 1977). It is worth noting however, that not all species appear to exploit both habitats; eight species, including the nationally endangered *Formicivora grisea alticincta* (White-fringed Antwren) and two other endemic subspecies were recorded only in the non-intervened habitat. This observation must be taken into due consideration with regard to forest management in the hydrological reserve.

It is unclear whether niche expansion or 'ecological release' is due to increased genotypic variability, a behavioural response to reduced competition, or both (Diamond, 1970); clearly more research is needed on this. The Pearl Islands may be an excellent candidate as a location for such research, particularly as morphological changes (one adaptation to facilitate niche expansion) have been observed in some species. For example, on the mainland *Thamnophilus doliatus nesiotes* (Barred Antshrike) is associated with forest edge habitat, but on El Rey it was recorded in nine of the non-intervened forest transects. The light is much reduced in the forest interior compared to the edge, and it is fascinating to note that *Thamnophilus doliatus nesiotes* (Barred Antshrike) on El Rey are considerably darker in colour than their mainland counterparts (pers. com. Angehr). According to Robinson-Wolrath and Owen (2003:1106), morphological differences between island and mainland forms play an 'important role in stimulating evolutionary and ecological hypotheses'. In this respect some knowledge other than for conservation purposes can be gained through the observation and recording of the avifauna of Isla Del Rey and other islands of the archipelago.

4.1.3 Endemism on El Rey

Another ecological trait typical of many oceanic islands is high levels of endemism. This is certainly demonstrated on El Rey, with 15 endemic subspecies known to be present. Populations of the 10 endemic subspecies recorded appear to be healthy in terms of relative abundance, density, distribution and habitat utilisation. The only endemic subspecies that might give cause for concern is *Columbina talpacoti nesophila* (Ruddy Ground Dove), which was recorded only once during surveying. It should be noted however, that considerably more were seen outside the survey area foraging in the fields adjacent to San Miguel.

Around the world, a network of areas accorded priority for avian conservation based on their high levels of endemism has been identified. Stattersfield *et al.* (1998), has termed these locations 'Endemic Bird Areas', and the Las Perlas archipelago is one such listed 'hotspot'. However, the validity of this approach to prioritise areas for conservation has been questioned (Peterson and Navarro-Sigüenza, 1999), along with the significance of endemic subspecies. The processes and patterns that initiate variety at a sub-species level are almost as hard to comprehend as inter-species behaviour at community level, and as a result there has been a tendency within conservation to view it as less significant (Norris, 2002).

Nevertheless, there remains a need to identify diversity at the sub-species level so that legislative protection can ensue. In accordance with this many ornithological

conservationists (Ryder, 1986; Moritz, 1994; Vogler and DeSalle, 1994; Pennock and Dimmick, 1997; Waples, 1998) are increasingly using phylogenetic definitions. Although there is ongoing disagreement as to whether more emphasis should be placed on conserving taxonomic genetic diversity (Vane-Wright *et al.,* 1991), or alternatively evolutionary fronts (Erwin, 1991) (lineages which are currently evolving), the actively diversifying endemic subspecies of El Rey satisfy both these criteria and should therefore receive conservation priority.

4.1.4 Human activity and the avifauna of El Rey

The distribution of species diversity is the result of ecological, physical and historical factors across time and space (Hill and Hill, 2001). Although biogeographical history greatly influences the species assemblages of a geographical region, particularly so for islands, local community composition is also strongly determined by abiotic and biotic conditions (Wiens and Donoghue, 2004). A number of explanations for diversity gradients have been proposed, including species–energy relationships, habitat structural complexity, and historical factors (Rompré *et al.,* 2007).

In the case of Isla Del Rey, the diversity gradient away from the main human settlement towards the island's interior is undeniable. However, whether this is as a direct result of human activity or a more subtle interplay of both biotic and abiotic factors is difficult to determine. A number of transects in close proximity to the village contained non-intervened forest, but bird abundance and species diversity is found to be much diminished there compared to transects further into the island with the same habitat type. This 'site-effect' (Jones *et al.,* 2003) leads to the tentative suggestion that human disturbance has a greater influence on the patterns of avian diversity seen on Isla Del Rey than habitat type. Although habitat type is undoubtedly also an important factor, as shown by the results of the diversity indices, the true extent of its significance would require comparative measurements of species fitness, not just species occurrence within each habitat (Renner *et al.,* 2006).

The types of disturbance that may be affecting the bird community of the island include burning and hunting activities, evidence for which was found within the boundary of the reserve (figure 4.1 (a) and (b)). The two are interlinked as 'controlled' burning is used to clear areas in order for the quarry (mainly giant jumping rat and iguana) to be easily seen (pers. comm. Mendieta.) It is unclear whether the birds are hunted directly. Both types of habitat had burnt regions within them, although this is not immediately apparent from satellite images as patches may only be 10m². As a result, classification of the island's land-use by remote sensing led to two forest type categories (intervened and non-intervened) when a third may actually be present. This third category would be the more mature forests of the interior, which because they are too far for villagers to venture from their settlements, are genuinely non-intervened. Indeed, the frequency of burnt patches diminished noticeably (along with a distinct trail) past 3 km from the town.

Figure 4.1 (a) Discarded cartridges show clear evidence of hunting.

Figure 4.1 (b) An extensive burnt area where fire has become uncontrolled.
Source; Researchers own.

Other studies that have shown evidence of anthropogenic burning as disruptive to forest birds, primarily through fragmentation, include Shankar-Raman (2001), Blankespoor (1991), Bowman *et al.* (1990), and Johns (1992). However, it is worth noting that results from island communities don't necessarily follow the general rule between disturbance and bird communities, as island species often undergo niche expansion, increasing their resilience to habitat perturbations (Lack 1969; Cox and Ricklefs, 1977). Interestingly, Jones *et al.* (2001), demonstrated that endemic species and sub-species tend to be best able to utilise disturbed habitat, and the three most commonly observed species in the intervened habitat on El Rey were all endemic subspecies.

4.2 Rapid assessment

4.2.1 The need for rapid assessment

The way in which the diversity of bird species is described, measured, and accorded conservation priorities will be a pivotal factor in determining the quantity, conditions, and populations which survive the 21st century. In order to conserve both current bio-diversity and the processes of future evolution, preserving as many diverse habitats as possible is a top priority. Subsequently the communities of birds inhabiting them should be enabled to fulfil their part in maintaining ecosystem health (and therefore resilience to change), as they have for some 100 million years (Bruford, 2002). Of key importance will be deciding exactly which places are given conservation priority. This decision may be founded on the number of endemics, biome restricted, nationally endangered, or globally vulnerable species a site boasts, but in every case the decision must be based on scientific data sources.

This is more challenging than it may initially appear however, as many areas of the world have high levels of biodiversity that is understudied, or in many places completely undocumented. This is not just a 'taxonomic impediment' but a great hindrance to designating and managing protected areas and the fauna within their boundaries. Protected areas are clearly not the only form of conservation management, and their value in our rapidly changing climate is open to debate (Araujo *et al.,* 2004). However, their mention is relevant to this study, and many of the issues arising, such as a need for simple ecological data, are common themes found in other approaches to conservation.

The urgency to collect and present data in order to catalyse much needed conservation initiatives is greatest in the tropics, where diversity is immense, vastly unexplored, and sadly under threat (Norris, 2002). Limitations imposed by the political, economic, and indeed physical environment of tropical countries have resulted in some researchers using methods of rapid assessment (O'Dea *et al.,* 2004). It must be emphasised that rapid assessment is not a substitute for in-depth studies, simply a preliminary investigation to begin to fill the knowledge gap that is only too apparent for many areas. It should also be stressed that rapid assessment is not a standardised methodology. Only a handful of researchers have used it, but those that have, have modified, substituted, augmented and supplemented from a pool of varied methodologies.

Some studies have focused more on the auditory aspects of rapid assessment (Macleod *et al.,* 2005), others have placed great emphasis on the use of MacKinnon lists (O'Dea *et al.,* 2004), whilst others have integrated more traditional methodologies such as point counts (Poulsen and Krabbe, 1998). This lack of standardisation is an all too common problem with many methodologies, and needs to be addressed if rapid assessment is to have any chance of becoming a popular, useful and comparable technique. This study explored as many of the rapid assessment methodologies as possible, with varying degrees of ease and productivity, and the various merits of each approach are examined here.

4.2.2 Strengths and weaknesses of the rapid assessment technique

4.2.2.1 Line transects

If the purpose of the research is to survey the diversity of avian life in relation to factors such as habitat type, or the influence of people on them, then it is necessary to adopt a method which is sufficient to encompass the whole variety of circumstances. This inevitably means covering as much ground as possible, both horizontally and vertically. In the tropics this is no easy feat as researchers have to contend with densely vegetated, steep and often unmapped terrain. Line transects are therefore an obvious survey choice allowing sampling along current linear features such as trails and riverbeds.

The use of line transects in this study certainly allowed more ground to be covered than would have been possible with any other methodology of the same simplicity. It enabled a range of vegetation types and altitudes to be covered, both considered important environmental determinants of bird distribution (Norris and Pain, 2002). There are however, some obvious disadvantages to the line transect approach, mainly, that edge species are going to be over-represented in the sample, which is true for vegetation as well as fauna. Some of the more abundant plant species recorded along transects are commonly associated with forest edge habitats, for example *Heliconia platystachys, Dicranopteris pectinata* and *Aechmea magdalenae* (pers. comm. Galdemes). This is undoubtedly an artifact of the methodology in which the surveyor described vegetation within a five metre radius. Unfortunately the vegetation was so dense, and therefore highly inaccessible in most areas that taking a reading 10m perpendicular to the transect would have probably doubled surveying time.

4.2.2.2 Vegetation description

The methodology to survey vegetation in this study was highly simplistic and merely based on percentage cover estimates. It was useful in the context of this study because patterns of bird abundance and diversity are more closely related to structural elements of habitat than detailed aspects such as tree species (Lack, 1993; Fuller and Henderson, 1992; Bersier and Meyer, 1994). However, the method could not be repeated or compared to other studies as it involved highly subjective estimates by one individual. Unfortunately detailed vegetation surveys using quantative methods require large amounts of time and expertise (Kent and Coker 1992) and do not complement the rapid assessment technique. Additional constraints

arise in the tropics where plant species are inadequately described (Greig-Smith, 1983).

Clearly what is needed then is a balance between a too simplistic and a too complex approach. One suggestion would be to use the vegetation classification system proposed by Elton and Miller (1954). This was originally devised as a quick method of describing habitats for zoologists but has proved to be a useful technique for general surveys of ecosystems (see Kent and Coker (1992) for a full description). More detailed observations should not be dismissed however, as they may prove valuable in time. For example, the endemic subspecies *Phaethornis anthophilus hyalinus* (Pale Bellied Hermit), on each occasion it was observed was either foraging in, or in very close proximity to a patch of *Allamanda cathartica,* (figure 4.2) known by the locals as Cat Killer for its unpleasant odour. This descriptive type of information can seem irrelevant for quantative analysis that aims to establish baseline data. However, knowledge of such relationships may prove valuable in future management decisions, most particularly if the populations of this species were noticeably declining.

4.2.2.3 Point counts and density calculations

Although the use of line transects allowed a lot of ground to be covered, and therefore the exploration of a number of different habitats and their vegetation, in terms of birds observed the method accounted for only less than 20% of records. This may be more to do with the conditions under which the methods were used rather than their innate effectiveness, as a forest study by Wilson *et al.* (2000), found the exact opposite. Reynolds *et al.* (1980) proposed that line transects result in fewer bird detections as observers spend less time actively looking for birds due to difficulties in following transect lines. This physical distraction certainly goes part way to explaining why records for line transects were so poor in this particular study. As well as accounting for the vast majority of observations, point counts also allowed recording of bird vocalizations (figure 4.3) with much greater ease than line transects, simply because there was less background noise from rustling vegetation. Clear vocalizations are critical, because they allow computer programs such as CANARY to generate distinctive sonograms.

According to Buckland *et al.* 2001, point counts combined with distance estimation provide a reliable means of estimating bird population densities. This was certainly found to be the case in this study, as distance estimation data recorded during the point counts allowed bird densities for the two habitat types to be calculated. This produced a simple but valuable result; bird densities are higher in the non-intervened forest than intervened. Data collected from line transects simply wouldn't have been sufficient to calculate bird densities, although an equation for this application can be found in Bibby *et al.* (1992). It is not uncommon for studies to struggle to calculate density estimates following standard distance sampling, usually because low relative abundances mean the assumptions of the method cannot be met (Ordano 1996; Buckland *et al.*, 2001). In such cases it is recommended that the example of this study is followed in combining species data from sites of the same habitat type, rather than trying to calculate a density estimate for each transect or species.

Figure 4.2: *Allamanda cathartica* (Cat Killer) on which the endemic subspecies *Phaethornis anthophilus hyalinus* (Pale Bellied Hermit) was frequently observed feeding.

Figure 4.3: Recording bird vocalizations during a point count.
Source: Both photographers own.

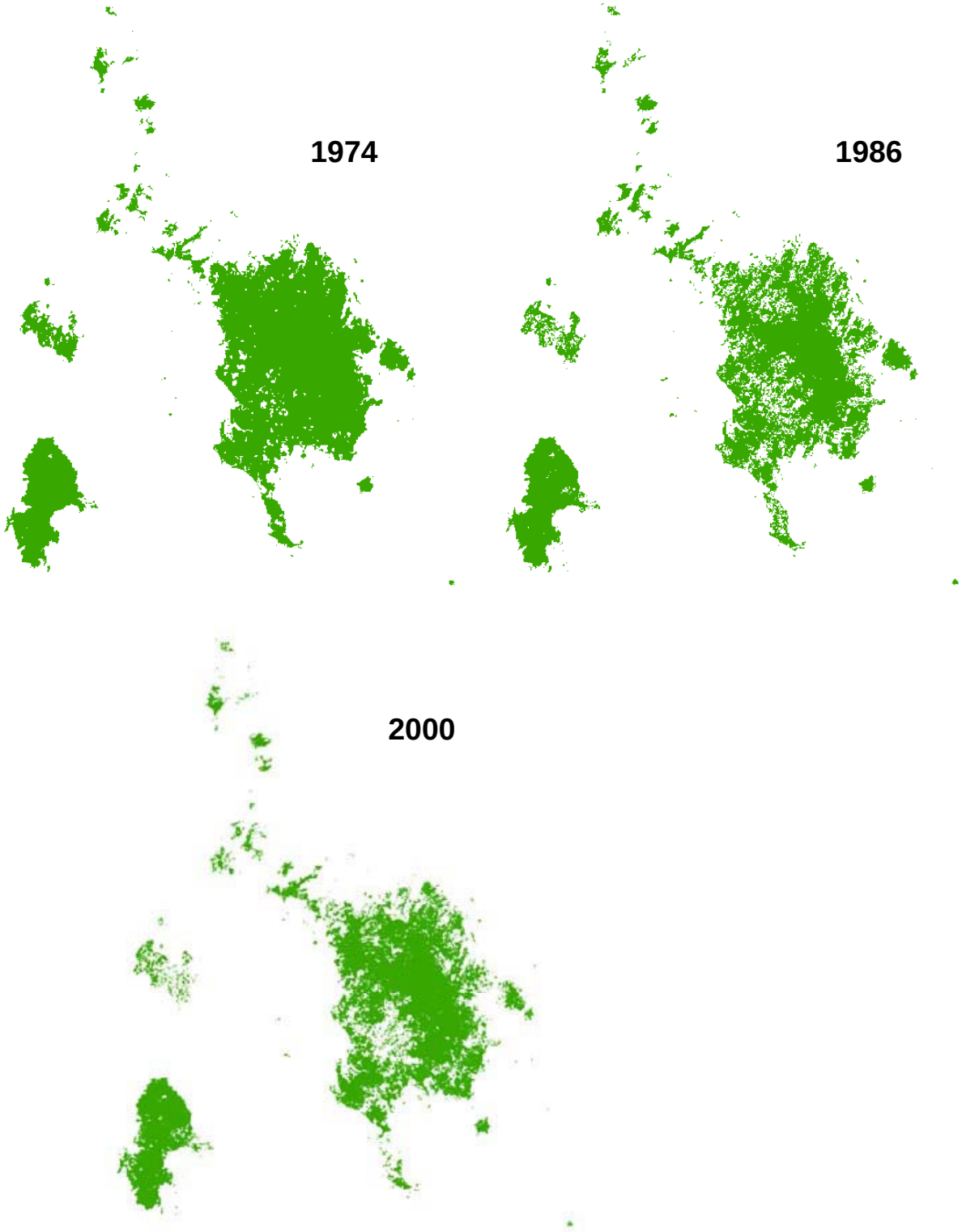
Another way of streamlining and simplifying distance sampling is to use the two belted approach (Bibby *et al.,* 1992). The full version of distance sampling involves the observer estimating the distance to each bird that is detected (perpendicular distance x for line transects, or radial distance r for point transects) (Rosenstock, 2002). However, this method does not lend itself well to rapid assessment, in terms of the assumptions that must be met, and lack of flexibility in application to a range of habitats. The observer has to be relatively experienced to judge distances accurately, especially as birds may be moving at the time of observation. In addition such an approach can only really be applied in open habitats, as estimating an accurate distance to an audio identification is near impossible. Instead a binomial method that places detections into one of two distance categories is recommended as it has proved an easy and efficient technique.

4.2.2.4 Audio and visual identification

During the study period much time was spent rummaging through the identification guide in the pouring rain, trying to locate one species out of the 900 listed. This is not a common problem with most studies as ornithologists tend to be familiar with their quarry. However, most countries are poorly lacking in trained ornithologists and the use of semi-amateurs or locals is of increasing necessity. In such cases it would be better to compile a list of species liable to be seen extracted from field identification manuals or existing studies of local birds, accompanied by laminated photo cards. This document should also list species of particular interest such as endemics of restricted range or threatened species (BirdLife International 2000). The use of a digital camera with a reasonable zoom proved more valuable than binoculars, as an immediate visual record was generated, allowing accurate identification at a later date.

Visual identifications however, accounted for only 30% of all recordings, and whilst surveyors should make every effort to familiarise themselves with the visual attributes of species, audio identification, in this study at least, proved far more valuable. Parker (1991:443) advocates the use of vocalisation recordings as an alternative to specimen collection for building a ‘reference library of song’, but few researchers have actually used sound recording to survey birds (Foster *et al.,* 1994). This is surprising as the method was not only productive, but required little expertise. As each vocalisation was archived on tape there was no immediacy to identify species in the field and although analysing calls using CANARY was time consuming it meant accuracy was high. Analysing recorded calls, which allows all species to be identified, has even led to the discovery of taxa new to science (Parker and O’Neil, 1985). Some authors have even suggested that an automated sound recording system could be established so that very intensive or extensive surveys could be undertaken without the need to have an expert in the field at all (Haselmayer and Quinn, 2000).

Figure 4.4: Changes in forest cover on El Rey during the period 1974-2000.



4.2.2.5 MacKinnon Lists

The MacKinnon List approach allowed reliable, comparable, species relative abundance information to be produced very rapidly and efficiently. It required very little effort in the field (simply noting the time of each contact) and was easy to calculate post-expedition. It has the potential to be applied to a variety of existing data collection methods, as a sort of 'add-on'. For example a simple census that notes presence and abundance could be slightly embellished so that species are ranked in order of observation. The methodology can also stand alone as a time and space independent sampling method. This kind of methodological flexibility that retains comparability is ideal, and is highly recommended. For other examples of where this method has been successfully employed see MacKinnon and Phillips, 1993; Trainor, 2002; Fjeldsa, 1999; and Poulsen *et al.,* 1997

4.2.3 General comments

Rapid assessment is about utilising a plethora of census procedures to produce a comprehensive data set under various constraints. Selecting which version and combination of methodologies to use is inevitably dependent on the resources available, objectives of the study and conditions in which the investigation will be undertaken. The use of MacKinnon lists and sound recording are greatly encouraged in tropical avian surveys. However, based on the findings of this survey it is not possible to comment on the use of these methodologies for other taxa and ecosystems. Although there are examples in the literature of where rapid assessments have been used for other organisms ranging from butterflies (Simonson *et al.,* 2001) to plants (Stohlgren *et al.,*1997) to primates (Buija *et al*., 2003) the methodologies employed are not comparable to those used here.

4.3 Recommendations for management

4.3.1 Current threats to the avifauna of El Rey

Although a certain level of disturbance has been shown to be beneficial to some communities (Petraitis *et al.,* 1989) too much can tip the balance and result in diversity loss (Veach *et al.,* 2003; Thiollay, 1997). Human disturbance on El Rey, mainly as a result of slash and burn, may pose a problem for forest bird communities in the future. The slash and burn activities on the island have resulted in an increasing loss of forest since 1974 (figure 4.4) and continue despite the recent designation of the hydrological reserve (researchers own observations). With a considerable rise in the population of San Miguel expected over the coming decade (Campbell, 2005) this trend is unlikely to halt. In fact it is set to increase, not just as the population of the islands inhabitants expands, but as development grows to meet the demands of the much anticipated rise in tourism.

Increased human activity will inevitably result in further fragmentation of the forest, undoubtedly to the detriment of bird populations (Manu *et al.,* 2007), Blankespoor (1991), Bowman *et al.* (1990), and Johns (1992). Due to the fact that there is no previous monitoring data it is impossible to know how close any of the bird species on El Rey might already be to population decline. Pursuing remedial action once a population is recognised as declining is not an option, particularly for birds as decline can be very fast once an initial threshold has been passed (Sutherland *et al.,* 2004).

It is highly recommended therefore that a precautionary principle is adopted and policies put in place which can decelerate the pace of forest fragmentation. This may include such measures as employing wardens for the reserve so illegal fires and hunting no longer go unchecked. It is important however, not to generate hostility between the local community and the authorities. One way to avoid this would be to train and employ wardens from within the local population. Educational workshops could also be held on the value of an in-tact forest, with emphasis on the functions it can provide for the community and future generations. These wardens could also be trained in the rapid assessment methodology. An annual survey of the islands avifauna following the recommendations of this study would allow an archive of ecological data to accumulate that could be consulted for management decisions or as persuasive material in funding applications.

4.3.2 Future threats to the avifauna of El Rey

The foreseeable intensification of land use for economic productivity and urban dwellings will result in smaller more dispersed habitats within the landscape matrix, which then becomes increasingly impermeable for dispersing organisms (Opdam and Wascher, 2004). This is currently the greatest threat perceived to the avifauna of El Rey, as is the case with many locations in the tropics. However, the true scale of the issue that conservation managers face can only be appreciated when habitat fragmentation is considered in the context of our rapidly changing climate. In synergy with climate change, habitat fragmentation can create isolated pockets of species populations, impeding gene flow, and eventually resulting in the loss of genetic diversity (Davis and Shaw, 2001).

In order to ensure that future evolutionary adaptability is maintained, the careful stewardship of intraspecific parts of genetic diversity will become a pivotal factor in programmes for conservation (Bruford, 2002). This recognition has created the ‘evolutionarily significant unit’, a concept being used more and more as the basic unit for prioritisation in conservation, substituting for the traditionally employed units of species and subspecies (Tarr and Fleischer 1999; Zink *et al.* 2000). It is evident that an understanding of these terms and their relevance for conserving biodiversity will become increasingly important for managers of protected areas in the future. For the hydrological reserve on El Rey, in which 15 endemic subspecies are found, the concept of the ‘evolutionarily significant unit’, if it continues to grow in popularity, may result in increased support and funding for protection, and future managers should be aware of the potential to exploit this.

It is apparent then, that managers need to be aware of the potential for rapid loss of genetic diversity in populations which are isolated and/or small, such as those on oceanic islands. Current practical management of avian populations on Las Perlas

should concentrate on maintaining genetic diversity, primarily through ensuring the health of the populations of endemic subspecies. An annual census of species using rapid assessment can indicate whether there are any general trends in the population. Based on the outcomes of this more detailed study investigating clutch size, generation time and mortality rates can be carried out if deemed necessary. Sometimes it may not be necessary to wait for a 'sign' in a population trend via rapid assessment to warrant further investigation. For example anecdotal information may provide a way to acquire information on historical species losses or population trends from an area where there has previously been little or no biological recording.

4.3.3 Utilising local knowledge and involving the community

This potential for traditional and local ecological knowledge to provide a source of information to complement "western scientific approaches" to conservation and resource management is slowly being recognised (Berkes *et al*., 2000). Anecdotal evidence has been used in a number of studies, probably most famously to piece together the ecology of the now extinct Great Auk *(Pinguinus impennis) (*Bengtson, 1984). In an interview with a member of the Panama Audubon Society, two inhabitants of San Miguel described how Dicksissels (*Spiza Americana*) were once so abundant on the island one had to "work out how much rice to sow because the Dicksissels would eat two armfuls of it" (Delgado, 2006). This bird was not observed during the study period but the men interviewed gave their ages as less than 30, indicating a worrying trend in this species in recent years.

When people local to an area are shown field guide images of its bird life, they can assist field surveyors to a great extent. In Las Perlas the use of a local who had received some training from the Audubon society was invaluable in species identification (see figure 4.5 (a) and (b)). However, it's important to be alert to their natural tendency to want to please researchers, which may result in optimistic or mistaken evidence of occurrence (Bibby, 2004). Although the reliability of such knowledge is much debated and received with skepticism by the scientific community, it may play an important role in remote areas where standard scientific approaches are impractical and previous survey data is limited or non-existent.

A standardized approach to collection of such knowledge, for example holding interviews with several interviewees separately to quantify variability among individuals would help reduce this element of unreliability. Depending on the time and financial constraints of the study, a selection of the individuals could actually be trained in basic ornithology. On the Island of El Rey the Panamanian Centre for Research and Social Action (CEASPA) did exactly this with 19 people from five villages in 2006. A follow up report from the training includes records of two new bird sightings for El Rey; the Crowned Woodnymph (*Thalurania colombica*), and the Cattle Tyrant (*Machetornis rixosus*) (Wilson, 2007). Although these records need to be properly confirmed before being accepted into the literature, this type of information is not to be dismissed. In the follow up report many of the participants commented on a change in the other villager's behaviour towards birds and fauna in general on the island. A small amount of education and training has allowed them to see the value of organisms other than as a hunting target or a nuisance to their crops. This shift in perspective is undoubtedly heavily influenced by the future prospect of ecotourism and awareness of the revenue it brings.

Figure 4.5: (a) Carlos Mendieta, an inhabitant of San Miguel who received some training from the Panama Audubon Society imparts his knowledge to an STRI researcher.

Figure 4.5: (b) The endemic subspecies the Ruddy Ground Dove (*Columbina talpacoti*) which likes to roost in huts and as a result is all too easily caught.
Source: Researchers own.

4.3.4 Ecotourism on El Rey

In late 2006 the Las Perlas Archipelago Municipality announced the designation of the hydrological reserve, inside the boundaries of which forest and riparian habitats, and the wealth of species they support would be protected. Currently there is little or no tourism traffic within the reserve because tourists like having proximity to established facilities and tend to stay on the coast (Priskin, 2003). The result of this is that tourism is much localised and habitats and species in the interior of the island remain relatively undisturbed. This scenario is likely to be challenged in the near future however, and the management paradigm will have to shift. On a global scale the number of 'ecotourists' is set to double by 2020 (Christ *et al.,* 2003), and on a local scale El Rey faces its own ecotourism onslaught. As the designation of the reserve was formalised, central government simultaneously promulgated another decree announcing major large-scale tourist development plans for the archipelago (Mair, 2006).

Ecotourism may not always have a detrimental impact, and in some developing countries has energised local economies and even generated revenue for the conservation of protected areas (Sekercioglu 2002). However, conservationists' concerns regarding the ecological impacts of recreational activities, development of infrastructure, disease transmission, invasion by alien species and reduced habitat quality are well founded (Heil, *et al.,* 2007). Studies examining the effects of tourism on avifaunal communities have reported reduced breeding performance (Beale and Monaghan, 2004), changes in habitat preference (Gill *et al.,* 1996), changes in population abundance (Miller *et al.,* 1998), and modification of community structure (Skagen *et al.,* 1991). The management of Isla Del Rey might be best able to deal with the inevitable changes that ecotourism will bring by first running small-scale manipulative studies to determine sustainable levels of visitation, as recommended Rodriguez-Prieto and Fernández-Juricic, 2005). In addition, tourist traffic within the reserve should be limited to few trails rather than expanding the area visitors can access, to minimise fragmentation and direct disturbance to wildlife.

5 Conclusion

According to Birdlife International (2000), almost 75% of threatened species of bird are accommodated on less than 5% of the planet's land surface. Important strides have been made by conservationists in locating, and supporting the safeguarding of, the most significant sites for avifauna conservation, whether at regional, national or continental scales (Stattersfield *et al*., 1998; Heath and Evans, 2000). Yet essential monitoring of these sites is lacking, mainly because the majority of species live in sub-tropical and tropical countries where practical measures are thwarted by shortages of monetary and technical resources.

Programmes such as the Darwin Initiative go some way to alleviating this problem by providing funding and academic expertise for the less developed tropical regions of the world. However, without simple methodologies to generate a solid base of information which can underpin public consciousness, training and education, and ultimately conservation management, projects in these countries are liable to be unsuccessful.

The rapid assessment methodology is one such methodology and produced a sizeable amount of valuable data during a short trial period in the Las Perlas Islands. Although rapid assessment proved to be well suited to a study focusing on forest passerines over a large area of varying habitats, it would not be applicable to all fauna and all regions. With some refinement and standardization of the methodologies used it has the potential to provide an effective, time efficient tool for avifaunal surveys. For 'hyperdiverse' groups of organisms however, such as arthropods, nematodes, fungi, and microorganisms, an entirely different set of methodologies is required.

Genetic diversity, behavioural flexibility and a generalist disposition make the avifauna of El Rey, like many insular communities self-regulating assemblages of species that are relatively resistant to the risks of spontaneous extinction and invasion. However, insular communities are among the most vulnerable biota on Earth in the face of fragmentation and climate change. The conservation of non-intervened habitat and avian endemism should govern the priorities for conservation management on Isla Del Rey. Management should incorporate a monitoring scheme for the avian communities as well as encouraging more in depth research on the evolutionary and genetic changes underway in some species populations. Policies to buffer against the impacts of future tourism should also be incorporated into plans for the reserve, and where possible involve community participation.

References

Personal Communication

Galdames, C. Research botanist, Smithsonian Tropical Research Institute, 17/10/08.

Guzmán, H. M. Senior researcher, Smithsonian Tropical Research Institute, 10/05/07.

MacLeod, R. Lecturer, Glasgow University, 18/08/07.

Mendieta, C. Inhabitant of San Miguel and trained guide, 12/05/08

Bibliography

Abate, T (1992) 'Environmental rapid-assessment programs have appeal and critics', *Bioscience*, 42, 7, 488-489.

Adler, G.H. (1992) 'Endemism in birds of tropical pacific islands' *Evolutionary Ecology,* 6, 296-306.

Alerstam, T., S. G. Nilsson, and S. Ulfstrand (1974), 'Niche differentiation during winter in woodland birds in southern Sweden and the island of Gotland', *Oikos* 25, 321–330.

Angehr, G. (2003) *Directory of Important Bird Areas in Panama*, Netherlands: Sociedad Audubon de Panama, Birdlife/Vogelbescherming.

Angehr, G. (2006) *Annotated Checklist of the Birds of Panama*, Panama: Panama Audubon Society.

Araujo, M.B., W.Z. Mar Cabeza, T. Wilfried, H. Lee and P.H. Williams (2004) 'Would climate change drive species out of reserves? An assessment of existing reserve methods', *Global Change Biology*, 10, 1618-1626.

Baker, Myron C., and David M. Logue (2003), 'Population differentiation in a complex bird sound: A comparison of three bioacoustical analysis procedures' *Ethology* 109, 223—242.

Bangs, Outram, and W.W. Brown (1901), 'The Mammals Collected in San Miguel Island, Panama', *The American Naturalist*, 35, 416, 631-644

Beale, C.M., and P. Monaghan (2004), 'Behavioural responses to human disturbance: a matter of choice?', *Animal Behaviour* 68, 1065–1069.

Beaugrand, G., and M.Edwards (2001), 'Differences in performance among four indices used to evaluate diversity in planktonic ecosystems', *Oceanologica Acta* 24, 5, 467-477.

Bengston, S.A. (1984), ‘Breeding ecology and extinction of the great auk (*Pinguinus impennis*): Anecdotal evidence and conjectures‘, *Auk* 101, 1,
1-12.

Berkes, Fikret, Johan Colding, and Carl Folke (2000) ’Rediscovery of traditional ecological knowledge as adaptive management’, *Ecological Applications*, 10, 5, 1251-1262.

Bersier, L. and D.R. Meyer (1994) ‘Bird assemblages in mosaic forests: the relative importance of vegetation and floristic composition along the successional gradient*,’ Acta Ecologica*, 15, 5, 561-576.

Bibby, C.J. (2004) ‘Bird diversity survey methods’, in Sutherland, W.J., I. Newton and R.E. Green (eds.) *Bird ecology and conservation,* New York: Oxford University Press, 1-11.

Bibby, C.J., D.A. Hill, N.D. Burgess and S. Mustoe (1992) *Bird Census Techniques*, second edition, London: Academic Press.

Bibby, C.J., B.N. Phillips and A.J.E. Seddon (1985) ‘Birds of restocked conifer plantations in Wales’, *Journal of Applied Ecology*, 22, 619-633.

Blankespoor, G.W. (1991), ‘Slash-and-burn shifting agriculture and bird communities in Liberia, West Africa‘, *Biological Conservation* 57, 1, 41-71.

Blondel, J. ‘Evolution and ecology of birds on islands: Trends and prospects’ (2000), *Vie et Milieu (Life and Environment)* 50, 4, 205-220.

Bowman, D. M. J. S., J. C. Z. Woinarski, D. P. A. Sands, A. Wells, and V. J. McShane (1990), ‘Slash-and-burn agriculture in the wet coastal lowlands of Papua New Guinea: Response of birds, butterflies and reptiles’, *Journal of Biogeography*, 17, 3, 227-239.

Brose, U., N.D. Martinez, and R.J. Williams (2003), ’Estimating species richness: sensitivity to sample coverage and insensitivity to spatial patterns’, *Ecology,* 84, 2364–2377.

Bruford, Michael W. (2002), ‘Biodiversity - evolution, species, genes’, in Norris, Ken and Deborah J. Pain (eds) *Conserving Bird Biodiversity,* Cambridge: Cambridge University Press 1-19.

Bruntland, *G.* H., (1988) *Our common future (Report of the world commission on environment and development)*, New York: Oxford University Press.

Brussard, P.F. and P.R. Ehrlich (1992) ‘The challenges of conservation biology’ *Ecological Applications*, 2, 1. 1-2.

Buckland, S. T. (1987) ‘On the variable circular plot method of estimating animal density’, *Biometrics*, 43:363–384.

Buckland S.T., D.R. Anderson, K.P. Burnham, J.L. Laake, D.L. Borchers, and L. Thomas (2001), *Introduction to distance sampling: estimating abundance of biological populations,* Oxford: Oxford University Press.

Buija, R., I. Singleton, E. Krakauerc, and C.P. van Schaik (2003), 'Rapid assessment of orangutan density' R. Buija, I. Singletonb, *Biological Conservation* 114, 103–113.

Campbell, I (2005) 'The role of local communities in the designation of a protected area in Las Perlas archipelago, Panama', Thesis (MSc) Heriot-Watt University, Edinburgh, United Kingdom, 98pp, mimeo.

Chazdon, R.L., R.K. Colwell, J.S. Denslow, and M.R. Guariguata (1998), 'Statistical methods for estimating species richness of woody regeneration in primary and secondary rain forests of NE Costa Rica' in Dallmeier F. and J.A. Comiskey (eds), *Forest Biodiversity Research, Monitoring and Modeling: Conceptual Background and Old World Case Studies*, Paris: Parthenon Publishing, 285-309.

Chek, A.A., S. C. Lougheed,J. P. Bogart and P. T. Boag (2001) 'Perception and history: molecular phylogeny of a diverse group of neotropical frogs' *Molecular Phylogenetics and Evolution* 18, 3, 370–385.

Christ, C., O. Hillel, S. Matus, J. Sweeting (2003) *Tourism and biodiversity: mapping tourism's global footprint.* Washington DC: Conservation International.

Crooks, K. R., A.V. Suarez, and D.T. Bolger (2004) 'Avian assemblages along a gradient of urbanization in a highly fragmented landscape' *Biological Conservation* 115, 3, 451-462.

Conroy, M.J., J.D. Nichols and E.R. Asanza (1990) 'Contemporary quantitative methods to understand and manage animal populations and communities', *Interciencia*, 22, 5, 247-249.

Cox, G.W., and R.E. Rickets (1977), 'Species diversity and ecological release in Caribbean land bird faunas', *Oikos*, 28, 1, 113-122.

Davis, M.B., and R.G. Shaw (2001), 'Range shifts and adaptive responses to quaternary climate change' *Science,* 292, 673–679.

Delgado, J.P. (2006) 'Archaeological reconnaissance of the 1865 American built submarine Explorer at Isla San Telmo, Archipielago de las Perlas, Panama' *The International Journal of Nautical Archaeology*, 35, 2, 230-252.

Diamond, J.M. (1970) 'Ecological consequences of island colonization by southwest Pacific birds, II. The effect of species diversity on total population density', *Proceedings of the National Academy of Sciences,* 67, 1715–1721.

Diamond, J. M., and A. G. Marshall (1977), ‘Niche shifts in New Hebridean birds’, *Emu,* 77, 61–72.

Diefenbach DR, Brauning DW, Mattice JA (2003) ‘Variability in grassland bird counts related to observer differences and species detection rates’ *AUK,*120 (4): 1168-1179.

Dubois, A (2003) ‘The relationships between taxonomy and conservation biology in the century of extinctions’ *C. R. Biologies*, 326, 9–21.

Ehrlich, P. R. (2001) ‘Intervening in evolution: ethics and actions‘ *Proceedings of the National Academy of Sciences,* 98: 5477–5480.

Elton, Charles S. and Richard S. Miller (1954), ‘The ecological survey of animal communities: With a practical system of classifying habitats by structural characters’, *The Journal of Ecology*, 42, 2, 460-496.

Emlen, J. T. (1971) ’Population densities of birds derived from transect counts‘, *AUK,* 88:323–342.

Environment Australia (1998) *The Darwin Declaration,* Canberra: Australian Biological Resources Study, Department of the Environment and Heritage.

Erwin, T.L. (1991), ’An evolutionary basis for conservation strategies’, *Science* 253, 750-752.

Estades C.F., M.A.H. Escobar, J.A. Tomasevic M.A. Vukasovic, M. Paez, (2006) ‘Mist nets versus point counts in the estimation of forest bird abundances in south-central Chile‘ *Ornitologica Neotropical,* 17, 2, 203-212

Fjeldsa, J. (1999), ’The impact of human forest disturbance on the endemic avifauna of the Udzungwa Mountains, Tanzania‘, *Bird Conservation International*, 9, 47–62.

Flint, R.F. (1957), *Glacial and Pleistocene geology,* New York: Wiley.

Freeman, M.A. (1998) ‘The economic value of biodiversity‘ *Bioscience* 48, 5, 339.

Forsbergh, E.D. (1969) ‘On the climatology, oceanography and fisheries of thePanama Bight‘ *Bulletin of the Inter-American Tropical Tuna Commission,* 14,49-259.

Foster, R.B. *et. Al.* (1994), *The Tambopata-Candamo Reserved Zone of south-eastern Peru: A biological assessment,* Washington DC: Conservation International.

Fuller R.J. and A.C.B. Henderson (1992) ‘Distribution of breeding songbirds in Bradfield Woods, Suffolk, in relation to vegetation and coppice management’, *Bird Study*, 39, 73-88.

Fuller, R.J. and D.R. Langslow (1984) 'Estimating numbers of birds by point counts: how long should counts last?' *Bird Study,* 31, 195-202.

Furness R.W. and J.J.D. Greenwood (eds.) (1993) *Birds as monitors of environmental change,* London: Chapman and Hall.

Gibbons, D.W., Hill, D.A. & Sutherland, W.J. (1996) 'Birds' in Sutherland (ed.) *Ecological Census Techniques: a Handbook*, Cambridge: W.J.University Press, 227-258.

Gill, J.A., W.J. Sutherland, and A.R. Watkinson (1996), 'A method to quantify the effects of human disturbance on animal populations', *Journal of Applied Ecology* 33, 786–792.

Glynn, P.W. Robert H. Stewart (1973), 'Distribution of coral reefs in the Pearl Islands (Gulf of Panama) in relation to thermal conditions', *Limnology and Oceanography*, 18, 3, 367-379.

Grant, P.R. (1966), 'The density of land birds on Tres Marias Island in Mexico', *Canadian Journal of Zoology*, 44, 805-815.

Gregory, R.D., A. Strien, and P. Vorisek (2006), 'Using birds as indicators of environmental change in Europe', *Journal of Ornithology,* 147, 5, 16.

Greig-Smith, P. (1983), *Quantitative plant ecology.* 3rd. ed. Oxford: Blackwell Scientific.

Guevara, J.M. (2005) 'Changes in Land Use and cover in Archipelago Las Perlas: A proprosal for a Protected Area'. Thesis (MSc) Heriot-Watt University, Edinburgh, United Kingdom. 88pp, mimeo.

Hamel, P.B., W.P. Smith and D.J. Twedt, J.R. Woehr, E. and r. J. Cooper R. J. (1996) 'A land manager's guide to point counts of birds in the southeast', Technical Report, SO-120. New Orleans, Louisiana:USDA Forest Service.

Haselmayer, J., and James S. Quinn (2000), 'A comparison of point counts and sound recording as bird survey methods in Amazonian south-east Peru', *The Condor,* 102, 887-893.

Haub, C.M. and Y. Yanagashita (1990), *1990 world population data sheet*, Washington: Population Reference Bureau.

Heil, Lisandro, Esteban Ferna´ndez-Juricic, Daniel Renison, Ana M. Cingolani, and Daniel T. Blumstein (2007), 'Avian responses to tourism in the biogeographically isolated high Co´ rdoba Mountains, Argentina', (2007), *Biodiversity Conservation,* 16, 1009–1026.

Herzog, S.K., M. Kessler and T. M. Cahill (2002) Estimating species richness of tropical bird communities from rapid assessment data, The Auk, 119, 3, 749-769.

Hickman, Karen R., Greg H. Farley, Rob Channell, and Jan E. Steier (2006), 'Effects of old world bluestem (*bothriochloa ischaemum*) on food availability and avian community composition within the mixed grass prairie', *The Southwestern Naturalist,* 51, 4, 524-530.

Hill, J.L. and R.A. Hill (2001), 'Why are tropical rain forests so species rich? Classifying, reviewing and evaluating theories', *Progress in Physical Geography,* 25, 3, 326-354.

Holdren, J. C. (1990) 'Energy in transition', *Scientific American*, 263, 156-163.

Karr, J.R., J. D. Nichols, M. K.Klimkiewicz and J. D. Brawn, 'Survival Rates of Birds of Tropical and Temperate Forests: Will the Dogma Survive?' *The American Naturalist*, Vol. 136, No. 3 (Sep., 1990), pp. 277-291

Keast, A. (1970), 'Adaptive evolution and shifts in niche occupation in island birds', *Biotropica* 2, 61-75.

Kent, M. and P. Coker (1992), *Vegetation description and analysis: A practical approach,* Chichester: John Wiley and Sons.

Krabbe, N. and B.O. Poulsen (1998) 'Avifaunal diversity of five high-altitude cloud forests on the Andean western slope of Ecuador: testing a rapid assessment method', Jounal of Biogeography, 25, 83-93.

Lack, D. (1933) 'Habitat selection in birds', *Journal of Animal Ecology* 2, 239-262.

Lack, D. (1969) 'Population changes in the land birds of a small island', *Journal of Animal Ecology,* 38: 211-218.

Lack, D. (1976), *Island biology, illustrated by the land birds of Jamaica,* Oxford: Blackwell Scientific.

Levings, S.C. Stephen D. Garrity; Linda R. Ashkenas (1986) 'Feeding rates and prey selection of oystercatchers in the Pearl Islands of Panama', *Biotropica*, 18, 1, 62-71.

Lisandro H., E. Fernandez-Juricic, D. Renison, A. M. Cingolani, D.T. Blumstein (2007) 'Avian responses to tourism in the biogeographically isolated High Cordoba Mountains Argentina', *Biodiversity Conservation,*16, 1009–1026.

MacArthur, R.H. (1972) *Geographical Ecology*, New York: Harper and Row.

MacArthur R.H., J.M. Diamond, and J.R. Karr (1972) 'Density compensation in island faunas', *Ecology,* 53, 330-342.

MacArthur, R.H., J. MacArthur, D. MacArthur, and A. Macarthur (1973), 'The effect of island area on population densities', *Ecology* 54, 657–658.

MacKinnon, S., and K. Phillipps (1993), *A Field Guide to the Birds of Borneo, Sumatra, Java and Bali,* Oxford: Oxford University Press.

MacLeod, R., S.K. Ewing, S.K. Herzog, R. Bryce, K.L. Evans and A. MacCormick (2005) 'First ornithological inventory and conservation assessment for the yungas forests of the Cordilleras Cocapata and Mosetenes, Cochabamba, Bolivia', *Bird Conservation International*, 15:361–382.

Magurran, A.E. (1998) Ecological diversity and its measurement, London: Chapman and Hall.

Malizia LR, Blendinger PG, Alvarez ME, Rivera LO, Politi N, Nicolossi G (2005) 'Bird communities in Andean premontane forests of northwestern Argentina', *Ornitologia Neotropical,* 16, 2, 231-251.

Manu, S., W. Peach and W. Creswell (2006), 'The effects of edge, fragment size and degree of isolation on avian species richness in highly fragmented forest in West Africa', *Ibis* 149, 287–297.

Marsden, Stuart J., Craig T. Symes, and Andrew L. Mack (2006), 'The response of a New Guinean avifauna to conversion of forest to small-scale agriculture' *Ibis* 148, 629–640.

Mayr, E. (1965) 'Avifauna: turnover on islands', *Science* 150, 1587-8.

McNeely, J. (1999) 'The Convention on Biological Diversity: a solid foundation for effective action', *Environmental Conservation,* 26, 4, 250–251.

Meine, C. M. Soule and R.F. Noss (2006) 'A mission driven discipline: the growth of conservation biology', *Conservation Biology,* 20, 3, 631–651.

Miller, S. G., R.L. Knight, and C.K. Miller (1998), 'Influence of recreational trails on breeding bird communities' *Ecology Applied* 8, 162–169.

Mitchell, T. P., and J. M. Wallace, (1992), 'The annual cycle in equatorial convection and sea surface temperature' *Climate*, 5, 1140–1156.

Naggs, F., D. Raheem, K. Ranawana and Y. Mapatuna (2005) 'The Darwin initiative project on Sri Lankan land snails: patterns of diversity in Sri Lankan forests', *The Raffles bulletin of zoology,* 12, 23-29.

Norris, K and D.J. Pain (2002) *Conserving bird biodiversity,* Cambridge: University press.

Noss, R.F. (2007) 'Values are a good thing in conservation biology', *Conservation Biology,* 21,1, 18–20.

O'Dea, Niall, and Robert J. Whittaker (2007), 'How resilient are Andean montane forest bird communities to habitat degradation?', *Biodiversity Conservation* 16, 1131–1159 .

Opdam, Paul, (2004), ‘Climate change meets habitat fragmentation: linking landscape and biogeographical scale levels in research and conservation’, *Biological Conservation,* 117, 285–297.

Parker, T. A., and J. P. O’Neill (1985), ’A new species and a new subspecies of wrens, with comments on the taxonomy of the *Thryothorus euophrys* Complex‘ *Ornithological Monographs* 36, 9–15.

Parker, T.A. and B. Bailey (1991) ‘A biological assessment of the Alto Madidi region and adjacent areas of northwest Bolivia’, *Conservation International, RAP Working Papers,*1.

Parker, T. A. (1991), ‘On the use of tape recorders in avifaunal surveys‘, *Auk,* 108, 443–444.

Pennock D.S. and W.W. Dimmick (1997) ‘Critique of the evolutionary significant unit as a definition for “distinct population segments” under the U.S. Endangered Species Act‘. *Conservation Biology*, 11, 611– 619.

Pereira, Henrique M., and H. David Cooper (2006), ‘Towards the global monitoring of biodiversity change’, *Trends in Ecology and Evolution,* 21, 123-129.

Perrings C (1995), ‘The economic value of biodiversity‘, in Heywood V.H. *Global Biodiversity Assessment,* Cambridge (UK):Cambridge University Press, 823-914.

Petraitis, Peter S., Roger Earl Latham, and Richard A. Kirshenbaum (1989), ‘The maintenance of species diversity by disturbance’, *The Quarterly Review of Biology*, 64, 4, 393-418.

Poulsen, B.O., N. Krabbe, A. Frlander, M. Hinojosa and C. Quiroga (1997) ‘A rapid assessment of Bolivian and Ecuadorianmontane avifaunas using 20-species lists: efficiency, biases and data gathered’, *Bird Conservation International*, 7, 53–67.

Priskin, J. (2003) ‘Tourist perceptions of degradation caused by coastal nature-based recreation‘, *Environmental Management* 32, 189–204.

Raab, D. and D. Roche, (2005) ‘A preliminary assessment of the artisanal fishery in the town of Pedro Gonzalez, Archipielago of Las Perlas, Panama‘, Dept. of Biology, McGill University, Canada, mimeo.

Raven, P.H. (Chairman) and Committee, (1980), *Research Priorities in Tropical Biology,* Washington: National Academy of Sciences.

Rendhal, H. (1920) ‘A list of birds of the Pearl Islands, Bay of Panama‘, *Arkiv för. Zoologi,* 13, 1-56.

Renner, S.C., M. Walter and M. Hlenberg (2006) 'Comparison of bird communities in primary vs. young secondary tropical montane cloud forest in Guatemala', *Biodiversity and Conservation,* 15:1545–1575.

Reynolds, R. T., J. M. Scott, and R. A. Nussbaum (1980), 'A variable circular-plot method for estimating bird numbers', *Condor* 82, 309-313.

Ridgely, R.S. and J.A. Gwynne (1989) *A Guide to the Birds of Panama*, second edition, Princeton: University Press.

Robertson, P.A. and D. Liley (1998) 'Assessment of sites: measurement of species richness and diversity', in Bibby, C., M. Jones and S. Marsden, (eds) *Expedition field techniques: Bird surveys,* London: Royal Geographical Society, 80-101.

Robinson-Wolrath, S.I., and I.P.F.Owens (2003), 'Large size in an island-dwelling bird: intraspecific competition and the Dominance Hypothesis', *Journal of Evolutionary Biology,* 16, 1106–1114.

Rodriguez-Prieto, I., and E. Fernández-Juricic (2005), 'Effects of direct human disturbance on the endemic Iberian frog (*Rana iberica*) at individual and population levels', *Biological Conservation* 123, 1–9.

Romesburg, C.H. (2004) Cluster analysis for researchers, Carolina: Lulu press.

Rosendal, G.K. (2000) *The convention on Biological Diversity and Developing Countries,* Norwell, USA: Kluwer Academic Publishers, pp1-316.

Rosenstock, A.A., D.R. Anderson, K.M. Giesen, T. Leukering and M.F. Carter (2002) 'landbird counting techniques: current practices and an alternative', *Auk,* 119, 1, 46-53.

Rosenstock, S. S. (1996) 'Habitat relationships of breeding birds in northern Arizona ponderosa pine and ponderosa pine-Gambel oak forests', Arizona: Game and Fish Department Research Branch, Technical Report 23.

Ryder, (1986) 'Individual DNA fingerprints from Galapagos tortoises, International Zoo Yearbook, 28, 84-87.

Sekercioglu, C.H. (2002), 'Impacts of birdwatching on human and avian communities', *Environmental Conservation* 29, 282–289.

Seutin, G., J. Brawn, R.E. Ricklefs and E. Bermingham (1993) 'Genetic divergence among populations of a tropical passerine, the streaked saltator (Saltator albicollis)', *Auk,* 110, 117-126

Shankar-Raman T. (2001) 'Effect of slash-and-burn shifting cultivation on rainforest birds in Miozoram, north-east India', *Conservation Biology,* 15: 685–698.

Simonson, Sara E., Paul A. Opler, Thomas J. Stohlgren, and Geneva W. Chong, (2001), 'Rapid assessment of butterfly diversity in a montane landscape', *Biodiversity and Conservation* 10, 1369–1386.

Skagen, S.K., R.L. Knight and G.H. Orians (1991), 'Human disturbance of an avian scavenging guild', *Ecology Applied* 1, 215–225.

Soulé, M.E. and K.A Kohm (1989) *Research Priorities for Conservation Biology*, Washington: Island Press.

Stattersfield, A. J., M. J. Crosby, A. J. .Long, and D.C. Wege (1998), *Endemic bird areas of the world. Priorities for biodiversity conservation,* Cambridge: Birdlife International.

Stohlgren, Thomas J., Geneva W. Chong, Mohammed A. Kalkhan, and Lisa D. Schell (1997), 'Rapid assessment of plant diversity patterns: a methodology for landscapes', *Environmental Monitoring and Assessment,* 48, 25–43.

Storch, David, Martin Konvicka, Jiri Benes, Jana Martinkova and Kevin J. Gaston (2003), 'Distribution patterns in butterflies and birds of the Czech Republic: separating effects of habitat and geographical position', *Journal of Biogeography,* 30, 1195–1205.

STRI (2006) '*Gaceta Oficial* announces creation of Isla del Rey hydrological reserve' STRI News.

Sutherland, W.J., I. Newton. R.E. Green (2004) *Bird ecology and conservation: a handbook of techniques,* New York: Oxford University Press.

Tarr, C. L. and R.C. Fleischer (1999) Mitochondrial-DNA variation and evolutionary relationships in the Amakihi complex', *Auk,* 110, 825-831.

Ter Braak, C.J.F. and P. Smilauer P (2002), *Canoco for Windows,* Wageningen: Biometris – Plant Research International.

Thayer, J.E. and O.Bangs (1908)The present state of the ornis of Guadalupe island, Condor 10, 101-116.

Thiollay, J.M., (1997), 'Disturbance, selective logging and bird diversity: A Neotropical forest study', *Biodiversity and Conservation* 6, 8, 1155-1173.

Trainor, C.R. (2002), 'Status and habitat associations of birds on Lembata Island, Wallacea, Indonesia, with reference to a simple technique for avifauna survey on small islands', *Bird Conservation International,* 12, 365–381.

United Nations (1993) *Convention on biological diversity (with annexes)*, United Nations Treaty Series, No. 30619, 83pp.

Vane-Wright R.I., C.J. Humphries and P.H. Williams (1991) 'What to protect?- Systematics and the agony of choice', *Biological Conservation.*, 55, 235–254.

Veach, R., D. Lee, and T. Philippi (2003), 'Human disturbance and forest diversity in the Tansa Valley, India', *Biodiversity and Conservation,* 12, 5, 1051-1072.

Venier, L.A. and J.L. Pearce (2004), 'Birds as indicators of sustainable forest management', *Forestry Chronicle,* 80, 1, 61-66.

Vogler A.P., and A.P. DeSalle (1994) 'Diagnosing units of conservation Management', *Conservation Biology*, 8, 354–363.

Waples R.S. (1998) 'Evolutionarily significant units, distinct population segments, and the Endangered Species Act: reply to Pennock and Dimmick.', *Conservation Biology*, 12, 718–721.

Ward, D.F. and M.C. Lariviere (2004), 'Terrestrial invertebrate surveys and rapid biodiversity assessment in New Zealand: lessons from Australia', *New Zealand Journal of Ecology,* 28, 1, 151-159.

Wetmore, A (1947) 'The birds of San Jose and Pedro Gonzalez Islands, Rebublic of Panama', *Smithsonian Miscellaneous Collection*, 106, 1-60.

Wetmore, A (1974) 'The birds of the republic of Panama', *Smithsonian Miscellaneous Collection*, 150, 1-3.

Wiens, J.J. and M.J. Donoghue (2004) 'Historical biogeography, ecology and species richness', *Trends in Ecology and Evolution*, 19, 639–644.

Wilson, R. Randy, Daniel J. Twedt, and A. Blaine Elliott (2000), 'Comparison of line transects and point counts for monitoring spring migration in forested wetlands', *Journal of Field Ornithology,* 71, 2, 345–355.

Wilson, R.R., D.J. Twedt and A. B. Elliott (2006) 'Comparison of line transects and point counts for monitoring spring migration in forested wetlands', *Journal of Field Ornithology,* 71, 2, 345-355.

Wortley, A.H. and Wilkie, P. (2005) *Thematic Review of Darwin Initiative's Contribution to the Global Taxonomy Initiative*, London, DEFRA, ECTF

Wright, S.J., J. Faaborg and C. J. Campbell (1985) 'Birds form tightly structured communities in the Pearl archipelago, Panama' in Buckley, P.A., M.S. Foster, R.A. Ridgely and F.G. Buckley (eds.) *Neotropical Ornithology, Ornithological Monographs No.36,* Washington, American Ornithologists Union, 719-812.

Yeaton, R.I. (1974), 'An ecological analysis of chaparral and pine forest bird communities on Santa Cruz island and mainland California', *Ecology* 55, 959-973.

Zink, R. M. A.V. Andreev and J.B. Slowinski (1995) 'Evidence from molecular

systematics for decreased avian diversication in the Pleistocene Epoch', Proceedings of the National Academy of Sience, USA 92, 5832-5835.

Websites

Mair, J (2006) 'Eco-tourism: a sustainable trade?'
http://news.bbc.co.uk/go/pr/fr/-/2/hi/science/nature/6179901.stm

STRI (2007) http://striweb.si.edu/darwin_initiative/ 'Darwin Initiative; about the project'. 04/08/07.

Appendix 1. The birds of the Las Perlas Archipelago.

Common Name	Scientific name	Common Name	Scientific Name
Little Tinamou	*Crypturellus soui*	Bat Falcon	*Falco rufigularis*
Least Grebe	*Tachybaptus dominicus*	Merlin	*Falco columbarius*
Waved Albatross	*Phoebastria irrorata*	American Kestrel	*Falco sparverius*
Galapagos Petrel	*Pterodroma phaeopygia*	Peregrine Falcon	*Falco peregrinus*
Sooty Shearwater	*Puffinus griseus*	Gray-headed Chachalaca	*Ortalis cinereiceps*
Black Storm-Petrel	*Oceanodroma melania*	Uniform Crake	*Amaurolimnas concolor*
Wedge-rumped Storm-Petrel	*Oceanodroma tethys*	American Oystercatcher	*Haematopus palliatus*
Least Storm-Petrel	*Oceanodroma microsoma*	Black-bellied Plover	*Pluvialis squatarola*
White-vented Storm-Petrel	*Oceanites gracilis*	Wilson's Plover	*Charadrius wilsonia*
Nazca Booby	*Sula granti*	Semipalmated Plover	*Charadrius semipalmatus*
Blue-footed Booby	*Sula nebouxii*	Killdeer	*Charadrius vociferus*
Peruvian Booby	*Sula variegata*	Ruddy Turnstone	*Arenaria interpres*
Brown Booby	*Sula leucogaster*	Whimbrel	*Numenius phaeopus*
Red-footed Booby	*Sula sula*	Willet	*Catoptrophorus semipalmatus*
Brown Pelican	*Pelecanus occidentalis*	Spotted Sandpiper	*Actitis macularius*
Neotropic Cormorant	*Phalacrocorax brasilianus*	Sanderling	*Calidris alba*
Guanay Cormorant	*Phalacrocorax bougainvillii*	Western Sandpiper	*Calidris mauri*
Magnificent Frigatebird	*Fregata magnificens*	Least Sandpiper	*Calidris minutilla*
Bare-throated Tiger-Heron	*Tigrisoma mexicanum*	Parasitic Jaeger	*Stercorarius parasiticus*
Great Blue Heron	*Ardea herodias*	South Polar Skua	*Stercorarius maccormicki*
Great Egret	*Ardea alba*	Laughing Gull	*Larus atricilla*
Snowy Egret	*Egretta thula*	Gull-billed Tern	*Sterna nilotica*
Tricolored Heron	*Egretta tricolor*	Royal Tern	*Sterna maxima*
Little Blue Heron	*Egretta caerulea*	Elegant Tern	*Sterna elegans*
Agami Heron	*Agamia agami*	Sooty Tern	*Sterna fuscata*
Cattle Egret	*Bubulcus ibis*	Bridled Tern	*Sterna anaethetus*
Black-crowned Night-Heron	*Nycticorax nycticorax*	Black Tern	*Chlidonias niger*
Yellow-crowned Night-Heron	*Nyctinassa violacea*	Pale-vented Pigeon	*Columba cayennensis*
White Ibis	*Eudocimus albus*	White-tipped Dove	*Leptotila verreauxi*
Black Vulture	*Coragyps atratus*	Western Wood-Pewee	*Contopus sordidulus*

Turkey Vulture	*Cathartes aura*	Tropical Kingbird	*Tyrannus melancholicus*
Hook-billed Kite	*Chondrohierax uncinatus*	Eastern Kingbird	*Tyrannus tyrannus*
Swallow-tailed Kite	*Elanoides forficatus*	Gray-breasted Martin	*Progne chalybea*
Plumbeous Kite	*Ictinia plumbea*	Sand Martin	*Riparia riparia*
Zone-tailed Hawk	*Buteo albonotatus*	Cliff Swallow	*Petrochelidon pyrrhonota*
Ruddy Quail Dove	*Geotryon Montana*	Barn Swallow	*Hirundo rustica*
Blue-headed Parrot	*Pionus menstruus*	House Wren	*Troglodytes aedon*
Red-lored Amazon	*Amazona autumnalis*	Swainson's Thrush	*Catharus ustulatus*
Yellow-crowned Amazon	*Amazona ochrocephala*	Tropical Gnatcatcher	*Polioptila plumbea*
Black-billed Cuckoo	*Coccyzus erythropthalmus*	Cedar Waxwing	*Bombycilla cedrorum*
Smooth-billed Ani	*Crotophaga ani*	Yellow-throated Vireo	*Vireo flavifrons*
Barn Owl	*Tyto alba*	Yellow-green Vireo	*Vireo flavoviridis*
Pauraque	*Nyctidromus albicollis*	Red-eyed Vireo	*Vireo olivaceus*
Lesser Nighthawk	*Chordeiles acutipennis*	Tennessee Warbler	*Vermivora peregrina*
Vaux's Swift	*Chaetura vauxi*	Yellow Warbler	*Dendroica petechia aestiva*
Garden Emerald	*Chlorostilbon assimilis*	Yellow (Mangrove) Warbler	*Dendroica petechia erithrachoides*
Snowy-bellied Hummingbird	*Amazilia edward*	Yellow-rumped Warbler	*Dendroica coronata*
Ringed Kingfisher	*Ceryle torquata*	Blackburnian Warbler	*Dendroica fusca*
Belted Kingfisher	*Ceryle alcyon*	Cerulean Warbler	*Dendroica cerulea*
Green-and-rufous Kingfisher	*Chloroceryle inda*	Bay-breasted Warbler	*Dendroica castanea*
Barred Antshrike	*Thamnophilus doliatus*	American Redstart	*Setophaga ruticilla*
Dusky Antbird	*Cercomacra nigricans*	Black-and-white Warbler	*Mniotilta varia*
Scrub Flycatcher	*Sublegatus arenarum*	Prothonotary Warbler	*Protonotaria citrea*
Greenish Elaenia	*Myiopagis viridicata*	Northern Waterthrush	*Seiurus noveboracensis*
Yellow-bellied Elaenia	*Elaenia flavogaster*	Louisiana Waterthrush	*Seiurus motacilla*
Lesser Elaenia	*Elaenia chiriquensis*	Canada Warbler	*Wilsonia canadensis*
Ochre-bellied Flycatcher	*Mionectes oleaginea*	Red-legged Honeycreeper	*Cyanerpes cyaneus*
Bran-colored Flycatcher	*Myiophobus fasciatus*	Blue-gray Tanager	*Thraupis episcopus*
Cattle Tyrant	*Machetornis rixosa*	Summer Tanager	*Piranga rubra*
Panama Flycatcher	*Myiarchus panamensis*	Scarlet Tanager	*Piranga olivacea*
Great Crested Flycatcher	*Myiarchus crinitus*	Indigo Bunting	*Passerina cyanea*
Streaked Flycatcher	*Myiodynastes maculatus*	Rose-breasted Grosbeak	*Pheucticus ludovicianus*
Piratic Flycatcher	*Legatus leucophaius*	Short-tailed Swift	*Chaetura brachyura*
Willow Flycatcher	*Empidonax traillii*	Variable Seedeater	*Sporophila americana*

Alder Flycatcher	*Empidonax alnorum*	Striped cuckoo	*Tapera naevia*
Acadian Flycatcher	*Empidonax virescens*	**Green Heron***	***Butorides striatus margaritophilus****
Eastern Wood-Pewee	*Contopus virens*	**Tropical Screech-Owl***	***Otus choliba crucigerus****
Blue-black Grassquit	*Volatinia jacarina*	**Roadside Hawk***	***Buteo magnirostris alius****
Yellow-bellied Seedeater	*Sporophila nigricollis*	**Gray-necked Wood-Rail****	***Aramides cajanea latens****
Lesser Seed-Finch	*Oryzoborus angolensis*	**Gray-necked Wood-Rail II ** **	***Aramides cajanea morrisoni **
Dickcissel	*Spiza americana*	**Ruddy Ground-Dove***	***Columbina talpacoti nesophila****
Orchard Oriole	*Icterus spurius*	**Pale-bellied Hermit***	***Phaethornis anthophilus hyalinus****
Baltimore Oriole	*Icterus galbula*	**Red-crowned Woodpecker***	***Centurus rubricapillus seductus****
Great-tailed Grackle	*Cassidix mexicanus*	**Bananaquit***	***Coereba flaveola cerinoclunis****
Mangrove Black-Hawk	*Buteogallus subtilis*	**Crimson-backed Tanager***	***Ramphocelus dimidiatus limatus****
Osprey	*Pandion haliaetus*	**Streaked Saltator***	***Saltator albicollis speratus****
Crested Caracara	*Caracara cheriway*	**White-fringed Antwren***	***Formicivora grisea alticincta****
Yellow-headed Caracara	*Milvago chimachima*	**Buff-breasted Wren***	***Thryothorus leucotis conditus****
		Southern Beardless Tyrannulet*	***Camptostoma obsoletum major****
		Barred Antshrike*	***Thamnophilus doliatus nesiotes****

Biome-restricted species
Nationally Endangered
Nationally Vulnerable
Endemic subspecies*
Found on Isla Del Rey

Appendix 2: Daily averages for rainfall and temperature in the Las Perlas Islands during the study period. Source: Smithsonian Tropical Research Centre.

Year	Month	Day	Air Temp °C	Rainfall (mm)
2007	5	5	29.29	0
2007	5	6	29.22	4.82
2007	5	7	27.15	115.3
2007	5	8	28.12	1
2007	5	9	29.49	0
2007	5	10	29.28	0.25
2007	5	11	30.26	0
2007	5	12	29.94	0.25
2007	5	13	27.74	31.73
2007	5	20	29.24	1.02
2007	5	21	26.81	81.98
2007	5	22	27.8	12.67
2007	5	23	28.58	0
2007	5	24	28.31	0
2007	5	25	28.47	19.28
2007	5	26	28.28	14.96

Appendix 3: Environmental parameters recorded in the field.

T	U	M	C	MHC	E	T	U	M	C	MHC	E	T	U	M	C	MHC	E
1.1	40	30	5	15	82	7.1	60	50	50	20	87	13.1	50	80	30	25	81
1.2	70	50	50	30	83	7.2	70	80	60	30	79	13.2	30	70	30	20	131
1.3	50	25	15	20	77	7.3	10	15	30	30	80	13.3	60	30	40	20	117
1.4	50	60	5	15	72	7.4	10	10	20	20	84	13.4	40	40	50	25	89
1.5	30	60	80	35	54	7.5	10	10	40	35	77	13.5	30	30	40	25	98
2.1	90	80	70	40	64	8.1	40	30	20	20	56	14.1	30	30	30	20	75
2.2	30	70	25	30	74	8.2	20	30	20	20	76	14.2	60	70	50	30	88
2.3	100	60	70	20	88	8.3	100	50	70	35	89	14.3	80	70	30	30	87
2.4	80	80	60	20	76	8.4	30	30	20	20	91	14.4	20	30	60	10	96
2.5	80	80	60	20	70	8.5	30	30	20	20	88	14.5	40	50	70	40	96
3.1	20	30	5	15	54	9.1	40	40	50	25	100	15.1	100	20	40	35	100
3.2	50	40	15	20	50	9.2	40	40	10	15	98	15.2	90	60	50	35	92
3.3	100	70	30	30	47	9.3	50	40	30	20	98	15.3	80	60	60	30	125
3.4	100	70	15	15	47	9.4	70	50	50	20	82	15.4	20	40	50	35	87
3.5	100	70	15	15	34	9.5	30	40	50	50	82	15.5	10	50	80	40	87
4.1	50	40	20	20	28	10.1	50	50	75	40	82	16.1	10	50	80	40	71
4.2	40	10	20	15	45	10.2	80	70	40	15	69	16.2	20	20	75	35	81
4.3	80	20	60	25	43	10.3	70	60	40	15	70	16.3	10	35	60	30	107
4.4	20	70	40	30	45	10.4	30	40	50	25	59	16.4	10	50	50	45	97
4.5	100	70	10	15	59	10.5	20	50	80	25	64	16.5	10	50	80	35	108
5.1	70	80	75	15	72	11.1	10	70	50	35	51	17.1	50	60	30	30	97
5.2	50	10	35	25	63	11.2	10	80	60	25	55	17.2	50	80	35	25	97
5.3	40	60	70	20	59	11.3	15	80	70	35	51	17.3	10	70	50	35	97
5.4	40	70	70	15	53	11.4	10	80	80	40	81	17.4	5	40	80	35	81
5.5	80	80	75	40	60	11.5	25	80	80	30	29	17.5	10	60	80	30	81
6.1	90	80	5	15	60	12.1	5	20	50	20	65	18.1	25	80	60	40	100
6.2	100	85	0	5	52	12.2	5	30	80	30	65	18.2	20	90	80	30	100
6.3	100	85	0	5	45	12.3	5	40	55	35	65	18.3	25	90	80	45	97
6.4	60	90	10	10	20	12.4	10	30	70	30	70	18.4	40	80	75	40	97
6.5	50	80	40	15	47	12.5	10	30	60	40	69	18.5	10	40	90	50	93

U = Understorey % cover
M = Midstorey % cover
C = Canopy % cover
MHC = Max. height Canopy (m)
E = Elevation (m)
T = Transect
.1 = 0m
.2 = 50m
.3 = 100m
.4 = 150m
.5 = 200m

Appendix 4: MacKinnon Lists for intervened and non-intervened habitat.

Habitat Type Non-Intervened Forest			
List 1	**List 2**	**List 12**	**List 13**
Black Vulture	Grackle	Buff Breasted Wren	Barred Antshrike
Garden Emerald	Barred Antshrike	Roadside Hawk	White Fringed Antwren
Buff Breasted Wren	Smmoth Billed Ani	Red Crowned Woodpecker	Garden Emerald
Jet Antbird	Pale-bellied hermit	Lesser Elaenia	Pale-Bellied Hermit
Bananaquit	White-fringed Antwren	Crimson-backed Tanager	Jet Antbird
List 3	**List 4**	**List 14**	**List 15**
Chachalaca	red crowned amazon	Barred Antshrike	Buff Breasted Wren
Bananaquit	Crimson-backed Tanager	Pale Vented Pigeon	Yellow-Crowned Amazon
Black Vulture	Jet Antbird	Red-Lored Amazon	Red Crowned Woodpecker
Ruddy ground dove	Chachalaca	Chachalaca	Lesser Elaenia
Barred Antshrike	Pale Vented Pigeon	Bananaquit	Garden Emerald
List 5	**List 6**	**List 16**	**List 17**
Smooth Billed Ani	Blue Gray Tanager	Snowy Bellied Hummingbird	Roadside Hawk
Barred Antshrike	Chachalaca	Roadside Hawk	Jet Antbird
Red Crowned Woodpecker	Bananaquit	Jet Antbird	Chachalaca
White Fringed Antwren	scrub flycatcher	White Fringed Antwren	Red-Lored Amazon
Pale Vented Pigeon	Buff Breasted Wren	Crimson-backed Tanager	Crimson-backed Tanager
List 7	**List 8**	**List 18**	**List 19**
jet antbird	Garden Emerald	Barred Antshrike	Pale Bellied Hermit
Yellow-bellied Elaenia	white tipped dove	Buff Breasted Wren	Pale Vented Pigeon
Tropical Kingbird	Snowy Bellied Hummingbird	Red Crowned Woodpecker	Bananquit
white tipped dove	Jet Antbird	Snowy Bellied Hummingbird	Yellow-bellied Elaenia
Buff Breasted Wren	Chachalaca	Blue Gray Tanager	Yellow-Crowned Amazon
List 9	**List 10**	**List 19**	**List 20**
Red-Lored Amazon	Crimson-backed Tanager	Garden Emerald	Snowy Bellied Hummingbird
Bananaquit	Yellow-Crowned Amazon	White Fringed Antwren	Buff Breasted Wren
Red Crowned Woodpecker	streaked saltator	Pale Vented Pigeon	Red Crowned Woodpecker
Pale-bellied hermit	Pale Vented Pigeon	yellow crowned amazon	Panama flycatcher
Pale Vented Pigeon	Garden Emerald	streaked saltator	Chachalaca
List 11	**List 12**	**List 21**	**List 22**
Jet Antbird	Crimson-backed Tanager	Jet Antbird	Crimson-backed Tanager
Red Crowned Woodpecker	White Tipped dove	Pale Bellied Hermit	Barred Antshrike
yellow crowned amazon	Roadside Hawk	Lesser Elaenia	Yellow-Crowned Amazon
Bananaquit	Chachalaca	Garden Emerald	Buff Breasted Wren
Lesser Elaenia	Bananaquit	Crimson-backed Tanager	streaked saltator
List 23	**List 24**	**List 25**	**List 26**
Garden Emerald	Pale Vented Pigeon	Pale Bellied Hermit	White Fringed Antwren
Red Crowned Woodpecker	Lesser Elaenia	Crimson-backed Tanager	Buff Breasted Wren
Panama flycatcher	Chachalaca	Lesser Elaenia	Red-Lored Amazon
Jet Antbird	Red-Lored Amazon	Pale Vented Pigeon	Garden Emerald
White Fringed Antwren	Bananaquit	Barred Antshrike	Chachalaca

Habitat Type Intervened Forest			
List 1	**List 2**	**List 3**	**List 4**
Black Vulture	Smooth Billed Ani	Barred Antshrike	Pale Vented Pigeon
Barred Antshrike	Bananaquit	bananaquit	Garden Emerald
Great-Tailed Grackle	Lesser Elaenia	yellow crowned amazon	Blue-gray Tanager
Red-Crowned Woodpecker	Pale-Vented Pigeon	Yellow-bellied Elaenia	Pale-bellied Hermit
Turkey vulture	Black Vulture	Crimson-backed Tanager	Barred Antshrike
List 5	**List 6**	**List 7**	**List 8**
Roadside Hawk	yellow crowned amazon	yellow crowned amazon	Buff Breasted Wren
Garden Emerald	Crimson-backed Tanager	Chachalaca	Roadside Hawk
Jet Antbird	Chachalaca	Red C. Woodpecker	Pale-Bellied Hermit
Lesser Elaenia	Lesser Elaenia	Pale Bellied Hermit	Red Crowned Woodpecker
Bananaquit	Barred Antshrike	Bananaquit	White Tipped Dove
List 9	**List 10**	**List 11**	**List 12**
Jet Antbird	scrub flycatcher	Jet Antbird	Buff Breasted Wren
Barred Antshrike	Blue Gray Tanager	Pale Vented Pigeon	Bananaquit
Bananaquit	Pale Vented Pigeon	Crimson-backed Tanager	Chachalaca
Chachalaca	Roadside Hawk	Yellow-Crowned Amazon	Lesser Elaenia
Garden Emerald	Barred Antshrike	Red C. Woodpecker	Roadside Hawk
List 13	**List 14**	**List 15**	**List 16**
ochre bellied flycatcher	Blue Gray Tanager	Buff Breasted Wren	Barred Antshrike
Chachalaca	Panama flycatcher	White Fringed Antwren	Pale Bellied Hermit
Crimson-backed Tanager	Tropical Kingbird	Garden Emerald	Red Crowned Woodpecker
Roadside Hawk	Yellow-Crowned Amazon	Bananaquit	Yellow-bellied Elaenia
Snowy B. Hummingbird	Chachalaca	Pale Vented Pigeon	White Tipped dove
List 17	**List 18**		
Jet Antbird	White Tipped dove		
Buff Breasted Wren	Pale Bellied Hermit		
Roadside Hawk	Blue Gray Tanager		
Panama flycatcher	Yellow-bellied Elaenia		
Bananaquit	Red C. Woodpecker		

Appendix 5: Number of individuals of each species recorded in each transect during the observation period.

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	Species Total
Black Vulture	6	5	1	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20
Barred Antshrike	1	1	1	2	1	2	0	8	0	2	4	4	0	6	8	7	5	1	53
Great-Tailed Grackle	5	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
Red-Crowned Woodpecker	1	0	0	0	0	3	1	3	2	4	2	3	1	2	1	2	3	3	31
Turkey vulture	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Jet Antbird	0	1	1	0	2	3	3	0	3	1	1	3	2	2	1	1	2	3	29
Bananaquit	1	1	2	3	2	1	1	3	2	3	3	1	0	1	2	3	1	2	32
Lesser Elaenia	1	0	0	0	1	0	0	1	2	1	2	0	2	3	2	0	0	1	16
Pale-Vented Pigeon	1	0	1	1	0	3	1	0	2	0	4	5	1	2	3	3	2	1	30
Garden Emerald	0	2	0	1	2	0	1	0	3	1	1	1	1	1	2	3	1	0	20
Buff Breasted Wren	0	1	0	0	0	2	3	2	0	6	4	2	5	6	1	3	3	3	41
Pale-bellied hermit	0	1	0	1	0	0	1	3	0	1	0	1	1	1	1	2	2	0	15
White-fringed Antwren	0	1	0	0	0	3	0	0	0	2	1	0	1	2	2	8	0	0	20
Chachalaca	0	4	2	0	2	2	8	6	1	1	7	2	4	2	4	3	1	4	53
Yellow-bellied Elaenia	0	0	0	1	0	1	0	0	0	0	0	1	0	0	1	1	0	0	5
Crimson-backed Tanager	0	0	2	1	1	0	1	1	2	8	2	6	2	5	2	3	0	1	37
Blue-gray Tanager	0	0	0	1	0	1	0	0	0	0	0	2	0	0	1	1	2	0	8
Yellow-Crowned Amazon	0	0	0	5	2	0	4	1	4	0	8	3	3	5	0	4	0	5	44
Red-Lored Amazon	0	0	4	0	0	0	1	0	0	0	5	8	0	3	8	2	0	0	31
scrub flycatcher	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	0	3
white tipped dove	0	0	0	0	0	1	2	0	1	0	0	0	0	0	2	1	2	0	9
Snowy Bellied Hummingbird	0	0	0	0	0	0	1	0	0	0	2	1	1	0	0	1	0	0	6
Roadside Hawk	0	0	0	0	3	0	0	3	1	2	1	1	0	0	1	2	1	1	16
Panama flycatcher	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	4
Tropical Kingbird	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	2
Ruddy Ground Dove	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Smooth Billed Ani	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Ochre Bellied Flycatcher	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	3
Streaked saltator	0	0	0	0	0	0	0	0	2	0	0	0	3	2	0	0	0	0	7
																			552

Appendix 6: Species and families recorded during the study period on Isla Del Rey.

Birds Observed on El Rey			
Common Name	**Status and Habitat**	**Scientific Name**	**Family Name**
Black Vulture	Ba	*Coragyps atratus*	*Cathartidae*
Barred Antshrike*	**SB s/e**	***Thamnophilus doliatus nesiotes****	***Formicariidae***
Great-Tailed Grackle	B g	*Cassidix mexicanus*	*Icterinae*
Red-Crowned Woodpecker*	**B o/s/g**	***Centurus rubricapillus seductus****	***Picidae***
Turkey vulture	Ba	*Cathartes aura*	*Cathartidae*
Jet Antbird	B e/s	*Cercomacra nigricans*	*Formicariidae*
Bananaquit*	**B e/s/o**	***Coereba flaveola cerinoclunis****	***Coerebinae***
Lesser Elaenia	B s/o/g	*Elaenia chiriquensis*	*Tyrannidae*
Pale-Vented Pigeon	B o/s	*Columba cayennensis*	*Columbidae*
Garden Emerald	B g	*Chlorostilbon assimilis*	*Trochilidae*
Buff Breasted Wren*	**B s**	***Thryothorus leucotis conditus****	***Troglodytidae***
Pale-bellied hermit*	**B o/s**	***Phaethornis anthophilus hyalinus****	***Trochilidae***
White-fringed Antwren*	**B f/o**	***Formicivora grisea alticincta****	***Formicariidae***
Chachalaca	Bs	*Ortalis cinereiceps*	*Cracidae*
Yellow-bellied Elaenia	B s/o/g	*Elaenia flavogaster*	*Tyrannidae*
Crimson-backed tanager*	**B s**	***Ramphocelus dimidiatus limatus****	***Thraupinae***
Blue-gray Tanager	B g/s/e	*Thraupis episcopus*	*Thraupinae*
Yellow-Crowned Amazon	B o/g	*Amazona ochrocephala*	*Psttacidae*
Red-Lored Amazon	B f/o	*Amazona autumnalis*	*Psittacidae*
Scrub flycatcher	B s/o	*Sublegatus arenarum*	*Tyrannidae*
White tipped dove	B o/s	*Leptotila verreauxi*	*Columbidae*
Snowy Bellied Hummingbird	B g/s/o	*Amazilia edward*	*Trochilidae*
Roadside Hawk*	**B o/s**	***Buteo magnirostris alius****	***Accipitridae***
Panama flycatcher	B o/s	*Myiarchus panamensis*	*Tyrannidae*
Tropical Kingbird	B g/s/e	*Tyrannus melancholicus*	*Tyrannidae*
Ruddy Ground Dove*	**B g/s**	***Columbina talpacoti nesophila****	***Columbidae***
Smooth Billed Ani	B g/s	*Crotophaga ani*	*Cuculidae*
Ochre Bellied Flycatcher	B f/o	*Mionectes oleaginea*	*Tyrannidae*
Streaked saltator*	**B s/o**	***Saltator albicollis speratus****	***Cardinalinae***

Biome-restricted species
Nationally Endangered
Nationally Vulnerable
Endemic subspecies*
B= breeding resident
a = aerial
s = second growth, scrub, shrubby areas
f = forest, inc. primary and tall second growth
e = forest edge
o = open woodland or disturbed forest
g = grassland, savannah, pastures

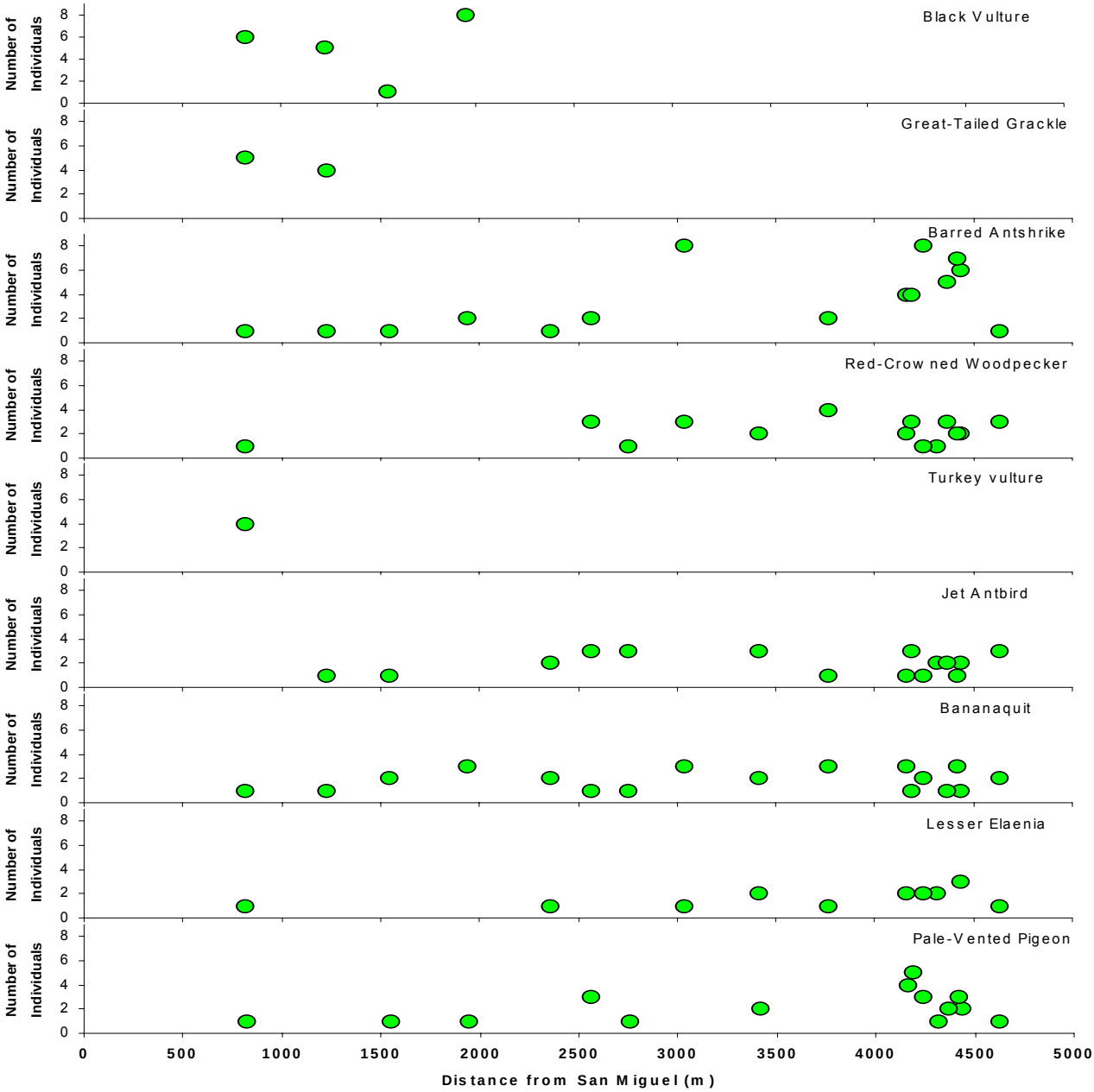
Appendix 7: Species of bird known to be in the Las Perlas Archipelago (pers. comm. Angehr).

Common Name	Scientific name	Common Name	Scientific Name
Little Tinamou	*Crypturellus soui*	Bat Falcon	*Falco rufigularis*
Least Grebe	*Tachybaptus dominicus*	Merlin	*Falco columbarius*
Waved Albatross	*Phoebastria irrorata*	American Kestrel	*Falco sparverius*
Galapagos Petrel	*Pterodroma phaeopygia*	Peregrine Falcon	*Falco peregrinus*
Sooty Shearwater	*Puffinus griseus*	Gray-headed Chachalaca	*Ortalis cinereiceps*
Black Storm-Petrel	*Oceanodroma melania*	Uniform Crake	*Amaurolimnas concolor*
Wedge-rumped Storm-Petrel	*Oceanodroma tethys*	American Oystercatcher	*Haematopus palliatus*
Least Storm-Petrel	*Oceanodroma microsoma*	Black-bellied Plover	*Pluvialis squatarola*
White-vented Storm-Petrel	*Oceanites gracilis*	Wilson's Plover	*Charadrius wilsonia*
Nazca Booby	*Sula granti*	Semipalmated Plover	*Charadrius semipalmatus*
Blue-footed Booby	*Sula nebouxii*	Killdeer	*Charadrius vociferus*
Peruvian Booby	*Sula variegata*	Ruddy Turnstone	*Arenaria interpres*
Brown Booby	*Sula leucogaster*	Whimbrel	*Numenius phaeopus*
Red-footed Booby	*Sula sula*	Willet	*Catoptrophorus semipalmatus*
Brown Pelican	*Pelecanus occidentalis*	Spotted Sandpiper	*Actitis macularius*
Neotropic Cormorant	*Phalacrocorax brasilianus*	Sanderling	*Calidris alba*
Guanay Cormorant	*Phalacrocorax bougainvillii*	Western Sandpiper	*Calidris mauri*
Magnificent Frigatebird	*Fregata magnificens*	Least Sandpiper	*Calidris minutilla*
Bare-throated Tiger-Heron	*Tigrisoma mexicanum*	Parasitic Jaeger	*Stercorarius parasiticus*
Great Blue Heron	*Ardea herodias*	South Polar Skua	*Stercorarius maccormicki*
Great Egret	*Ardea alba*	Laughing Gull	*Larus atricilla*
Snowy Egret	*Egretta thula*	Gull-billed Tern	*Sterna nilotica*
Tricolored Heron	*Egretta tricolor*	Royal Tern	*Sterna maxima*
Little Blue Heron	*Egretta caerulea*	Elegant Tern	*Sterna elegans*
Agami Heron	*Agamia agami*	Sooty Tern	*Sterna fuscata*
Cattle Egret	*Bubulcus ibis*	Bridled Tern	*Sterna anaethetus*
Black-crowned Night-Heron	*Nycticorax nycticorax*	Black Tern	*Chlidonias niger*
Yellow-crowned Night-Heron	*Nyctinassa violacea*	Pale-vented Pigeon	*Columba cayennensis*
White Ibis	*Eudocimus albus*	White-tipped Dove	*Leptotila verreauxi*
Black Vulture	*Coragyps atratus*	Western Wood-Pewee	*Contopus sordidulus*
Turkey Vulture	*Cathartes aura*	Tropical Kingbird	*Tyrannus melancholicus*
Hook-billed Kite	*Chondrohierax uncinatus*	Eastern Kingbird	*Tyrannus tyrannus*
Swallow-tailed Kite	*Elanoides forficatus*	Gray-breasted Martin	*Progne chalybea*
Plumbeous Kite	*Ictinia plumbea*	Sand Martin	*Riparia riparia*
Zone-tailed Hawk	*Buteo albonotatus*	Cliff Swallow	*Petrochelidon pyrrhonota*
Ruddy Quail Dove	*Geotryon Montana*	Barn Swallow	*Hirundo rustica*
Blue-headed Parrot	*Pionus menstruus*	House Wren	*Troglodytes aedon*

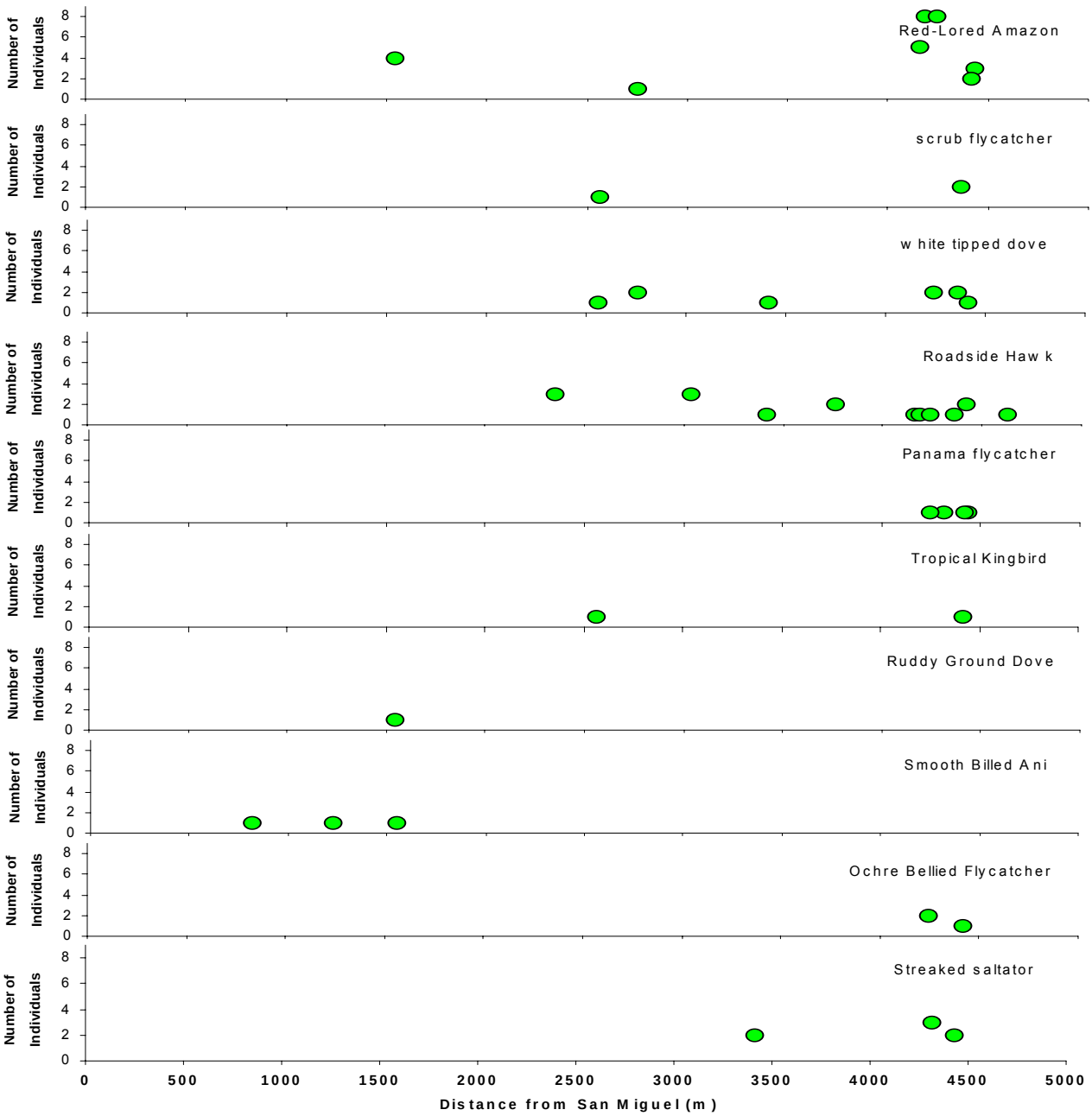
Common Name	Scientific name	Common Name	Scientific Name
Red-lored Amazon	*Amazona autumnalis*	Swainson's Thrush	*Catharus ustulatus*
Yellow-crowned Amazon	*Amazona ochrocephala*	Tropical Gnatcatcher	*Polioptila plumbea*
Black-billed Cuckoo	*Coccyzus erythropthalmus*	Cedar Waxwing	*Bombycilla cedrorum*
Smooth-billed Ani	*Crotophaga ani*	Yellow-throated Vireo	*Vireo flavifrons*
Barn Owl	*Tyto alba*	Yellow-green Vireo	*Vireo flavoviridis*
Pauraque	*Nyctidromus albicollis*	Red-eyed Vireo	*Vireo olivaceus*
Lesser Nighthawk	*Chordeiles acutipennis*	Tennessee Warbler	*Vermivora peregrina*
Vaux's Swift	*Chaetura vauxi*	Yellow Warbler	*Dendroica petechia aestiva*
Garden Emerald	*Chlorostilbon assimilis*	Yellow (Mangrove) Warbler	*Dendroica petechia erithrachoides*
Snowy-bellied Hummingbird	*Amazilia edward*	Yellow-rumped Warbler	*Dendroica coronata*
Ringed Kingfisher	*Ceryle torquata*	Blackburnian Warbler	*Dendroica fusca*
Belted Kingfisher	*Ceryle alcyon*	Cerulean Warbler	*Dendroica cerulea*
Green-and-rufous Kingfisher	*Chloroceryle inda*	Bay-breasted Warbler	*Dendroica castanea*
Barred Antshrike	*Thamnophilus doliatus*	American Redstart	*Setophaga ruticilla*
Dusky Antbird	*Cercomacra nigricans*	Black-and-white Warbler	*Mniotilta varia*
Scrub Flycatcher	*Sublegatus arenarum*	Prothonotary Warbler	*Protonotaria citrea*
Greenish Elaenia	*Myiopagis viridicata*	Northern Waterthrush	*Seiurus noveboracensis*
Yellow-bellied Elaenia	*Elaenia flavogaster*	Louisiana Waterthrush	*Seiurus motacilla*
Lesser Elaenia	*Elaenia chiriquensis*	Canada Warbler	*Wilsonia canadensis*
Ochre-bellied Flycatcher	*Mionectes oleaginea*	Red-legged Honeycreeper	*Cyanerpes cyaneus*
Bran-colored Flycatcher	*Myiophobus fasciatus*	Blue-gray Tanager	*Thraupis episcopus*
Cattle Tyrant	*Machetornis rixosa*	Summer Tanager	*Piranga rubra*
Panama Flycatcher	*Myiarchus panamensis*	Scarlet Tanager	*Piranga olivacea*
Great Crested Flycatcher	*Myiarchus crinitus*	Indigo Bunting	*Passerina cyanea*
Streaked Flycatcher	*Myiodynastes maculatus*	Rose-breasted Grosbeak	*Pheucticus ludovicianus*
Piratic Flycatcher	*Legatus leucophaius*	Short-tailed Swift	*Chaetura brachyura*
Willow Flycatcher	*Empidonax traillii*	Variable Seedeater	*Sporophila americana*
Alder Flycatcher	*Empidonax alnorum*	Striped cuckoo	*Tapera naevia*
Acadian Flycatcher	*Empidonax virescens*	**Green Heron***	***Butorides striatus margaritophilus****
Eastern Wood-Pewee	*Contopus virens*	**Tropical Screech-Owl***	***Otus choliba crucigerus****
Blue-black Grassquit	*Volatinia jacarina*	**Roadside Hawk***	***Buteo magnirostris alius****
Yellow-bellied Seedeater	*Sporophila nigricollis*	**Gray-necked Wood-Rail****	***Aramides cajanea latens****
Lesser Seed-Finch	*Oryzoborus angolensis*	**Gray-necked Wood-Rail II ** **	***Aramides cajanea morrisoni ** **
Dickcissel	*Spiza americana*	**Ruddy Ground-Dove***	***Columbina talpacoti nesophila****
Orchard Oriole	*Icterus spurius*	**Pale-bellied Hermit***	***Phaethornis anthophilus hyalinus****
Baltimore Oriole	*Icterus galbula*	**Red-crowned Woodpecker***	***Centurus rubricapillus seductus****
Great-tailed Grackle	*Cassidix mexicanus*	**Bananaquit***	***Coereba flaveola cerinoclunis****
Mangrove Black-Hawk	*Buteogallus subtilis*	**Crimson-backed Tanager***	***Ramphocelus dimidiatus limatus****
Osprey	*Pandion haliaetus*	**Streaked Saltator***	***Saltator albicollis speratus****
Crested Caracara	*Caracara cheriway*	**White-fringed Antwren***	***Formicivora grisea alticincta****
Yellow-headed Caracara	*Milvago chimachima*	**Buff-breasted Wren***	***Thryothorus leucotis conditus****
		Southern Beardless Tyrannulet*	***Camptostoma obsoletum major****
		Barred Antshrike*	***Thamnophilus doliatus nesiotes****

Biome-restricted species
Nationally Endangered
Nationally Vulnerable
Endemic subspecies*
Found on Isla Del Rey

Appendix 8: Scatter plots showing distribution and abundance of species with increasing distance from San Miguel



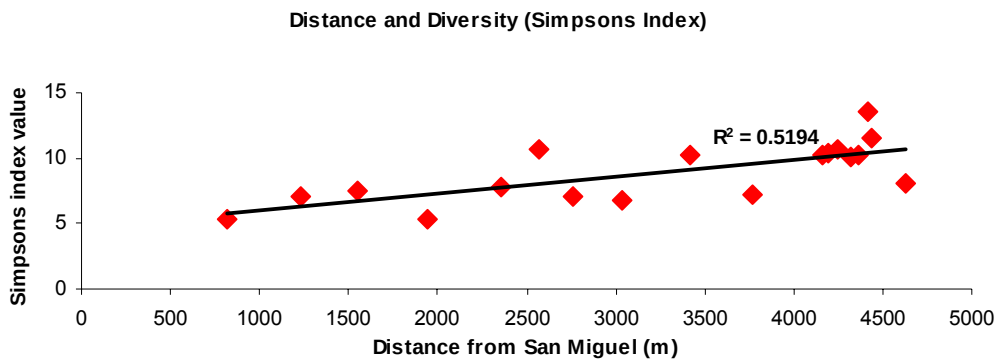
Garden Emerald
Buff Breasted Wren
Pale-bellied hermit
White-fringed Antwren
Chachalaca
Yellow-bellied Elaenia
Crimson-backed Tanager
Blue-gray Tanager
Yellow-Crowned Amazon
Number of Individuals
0
2
4
6
8
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Distance from San Miguel (m)


Red-Lored Amazon
scrub flycatcher
white tipped dove
Roadside Hawk
Panama flycatcher
Tropical Kingbird
Ruddy Ground Dove
Smooth Billed Ani
Ochre Bellied Flycatcher
Streaked saltator
Number of Individuals
0
2
4
6
8
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Distance from San Miguel (m)

Appendix 9: Regression outputs for distance from San Miguel and diversity.

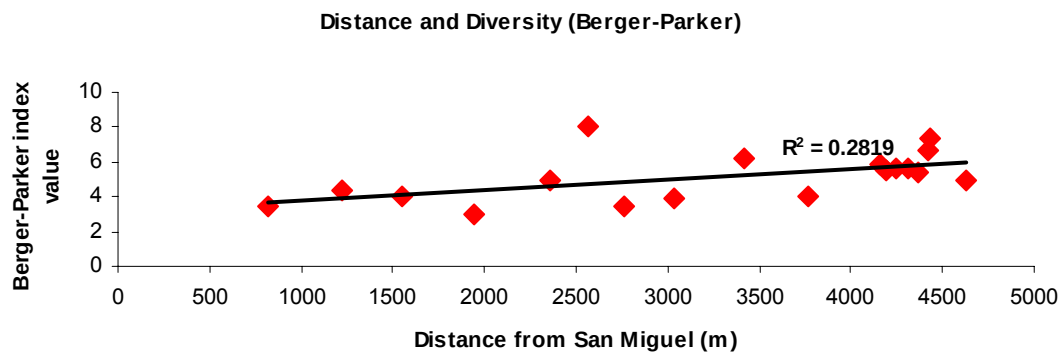
Regression Statistics Simpsons	
Multiple R	0.721
R Square	**0.519**
Adjusted R Square	0.489
Standard Error	886.852
Observations	18.000

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-269.900	867.625	-0.311	0.760	-2109.183	1569.383
X Variable 1	394.068	94.762	4.158	**0.001**	193.181	594.955



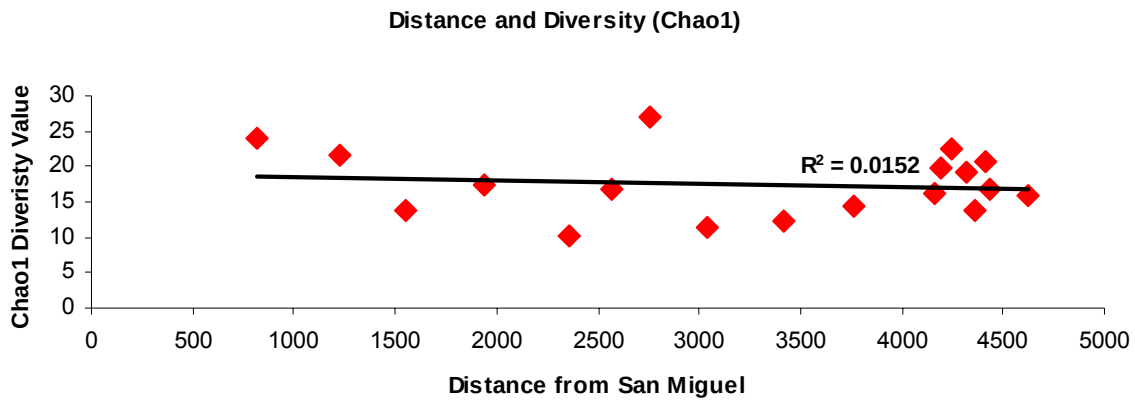
Regression Statistics Berger Parker	
Multiple R	0.531
R Square	**0.282**
Adjusted R Square	0.237
Standard Error	1084.054
Observations	18.000

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	777.158	1012.147	0.768	0.454	-1368.497	2922.813
X Variable 1	477.873	190.661	2.506	**0.023**	73.689	882.057



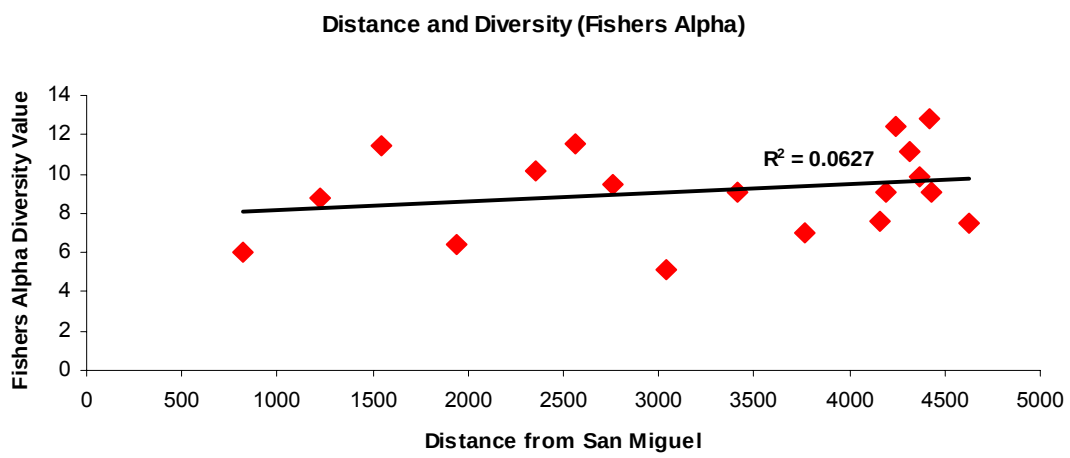
Regression Statistics Chao1	
Multiple R	0.123
R Square	**0.015**
Adjusted R Square	-0.046
Standard Error	1269.533
Observations	18.000

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	3822.411	1225.818	3.118	0.007	1223.793	6421.029
X Variable 1	-33.839	68.111	-0.497	**0.626**	-178.228	110.551



Regression Statistics Fishers alpha	
Multiple R	0.250
R Square	**0.063**
Adjusted R Square	0.004
Standard Error	1238.507
Observations	18.000

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	1959.437	1263.661	1.551	0.141	-719.405	4638.279
X Variable 1	139.322	134.623	1.035	**0.316**	-146.066	424.710



Appendix 10: Outputs of the four diversity indices run on the data.

Transect 1	
Individuals (computed)	21.00
Chao 1 Mean	**24.00**
Chao 1 SD (analytical)	5.89
Alpha Mean	**5.97**
Alpha SD (analytical)	2.13
Simpsons	**5.31**
Berger-Parker	**3.50**

Transect 2	
Individuals (computed)	22.00
Chao 1 Mean	**21.50**
Chao 1 SD (analytical)	3.98
Alpha Mean	**8.75**
Alpha SD (analytical)	3.17
Simpsons	**7.12**
Berger-Parker	**4.40**

Transect 3	
Individuals (computed)	16.00
Chao 1 Mean	**13.75**
Chao 1 SD (analytical)	4.21
Alpha Mean	**11.41**
Alpha SD (analytical)	5.38
Simpsons	**7.53**
Berger-Parker	**4.00**

Transect 4	
Individuals (computed)	24.00
Chao 1 Mean	**17.50**
Chao 1 SD (analytical)	5.18
Alpha Mean	**6.44**
Alpha SD (analytical)	2.13
Simpsons	**5.33**
Berger-Parker	**3.00**

Transect 5	
Individuals (computed)	15.00
Chao 1 Mean	**10.20**
Chao 1 SD (analytical)	1.84
Alpha Mean	**9.50**
Alpha SD (analytical)	4.51
Simpsons	**7.76**
Berger-Parker	**5.00**

Transect 6	
Individuals (computed)	24.00
Chao 1 Mean	**16.75**
Chao 1 SD (analytical)	4.21
Alpha Mean	**11.58**
Alpha SD (analytical)	4.13
Simpsons	**10.67**
Berger-Parker	**8.00**

Transect 7	
Individuals (computed)	28.00
Chao 1 Mean	**27.00**
Chao 1 SD (analytical)	4.78
Alpha Mean	**9.43**
Alpha SD (analytical)	2.96
Simpsons	**7.13**
Berger-Parker	**3.50**

Transect 8	
Individuals (computed)	31.00
Chao 1 Mean	11.50
Chao 1 SD (analytical)	2.60
Alpha Mean	**5.12**
Alpha SD (analytical)	1.46
Simpsons	**6.72**
Berger-Parker	**3.87**

Transect 9	
Individuals (computed)	25.00
Chao 1 Mean	**12.43**
Chao 1 SD (analytical)	0.91
Alpha Mean	**9.06**
Alpha SD (analytical)	3.04
Simpsons	**10.25**
Berger-Parker	**6.25**

Transect 10	
Individuals (computed)	32.00
Chao 1 Mean	**14.50**
Chao 1 SD (analytical)	3.16
Alpha Mean	**6.97**
Alpha SD (analytical)	1.97
Simpsons	**7.21**
Berger-Parker	**4.00**

Transect 11	
Individuals (computed)	47.00
Chao 1 Mean	**16.20**
Chao 1 SD (analytical)	1.84
Alpha Mean	**7.61**
Alpha SD (analytical)	1.76
Simpsons	**10.27**
Berger-Parker	**5.87**

Transect 12	
Individuals (computed)	44.00
Chao 1 Mean	**19.75**
Chao 1 SD (analytical)	4.21
Alpha Mean	**9.05**
Alpha SD (analytical)	2.18
Simpsons	**10.41**
Berger-Parker	**5.50**

Transect 13	
Individuals (computed)	28.00
Chao 1 Mean	**19.25**
Chao 1 SD (analytical)	5.38
Alpha Mean	**11.14**
Alpha SD (analytical)	3.58
Simpsons	**10.05**
Berger-Parker	**5.60**

Transect 14	
Individuals (computed)	44.00
Chao 1 Mean	**16.86**
Chao 1 SD (analytical)	1.40
Alpha Mean	**9.05**
Alpha SD (analytical)	2.18
Simpsons	**11.52**
Berger-Parker	**7.33**

Transect 15	
Individuals (computed)	45.00
Chao 1 Mean	**22.50**
Chao 1 SD (analytical)	3.45
Alpha Mean	**12.40**
Alpha SD (analytical)	3.01
Simpsons	**10.71**
Berger-Parker	**5.62**

Transect 16	
Individuals (computed)	53.00
Chao 1 Mean	**26.60**
Chao 1 SD (analytical)	5.35
Alpha Mean	**12.85**
Alpha SD (analytical)	2.85
Simpsons	**13.57**
Berger-Parker	**6.62**

Transect 17	
Individuals (computed)	27.00
Chao 1 Mean	**13.86**
Chao 1 SD (analytical)	1.40
Alpha Mean	**9.86**
Alpha SD (analytical)	3.18
Simpsons	**10.27**
Berger-Parker	**5.40**

Transect 18	
Individuals (computed)	25.00
Chao 1 Mean	**16.00**
Chao 1 SD (analytical)	6.05
Alpha Mean	**7.50**
Alpha SD (analytical)	2.46
Simpsons	**8.12**
Berger-Parker	**5.00**

Appendix 11 : Outputs of t-test used to test diversity between habitats.

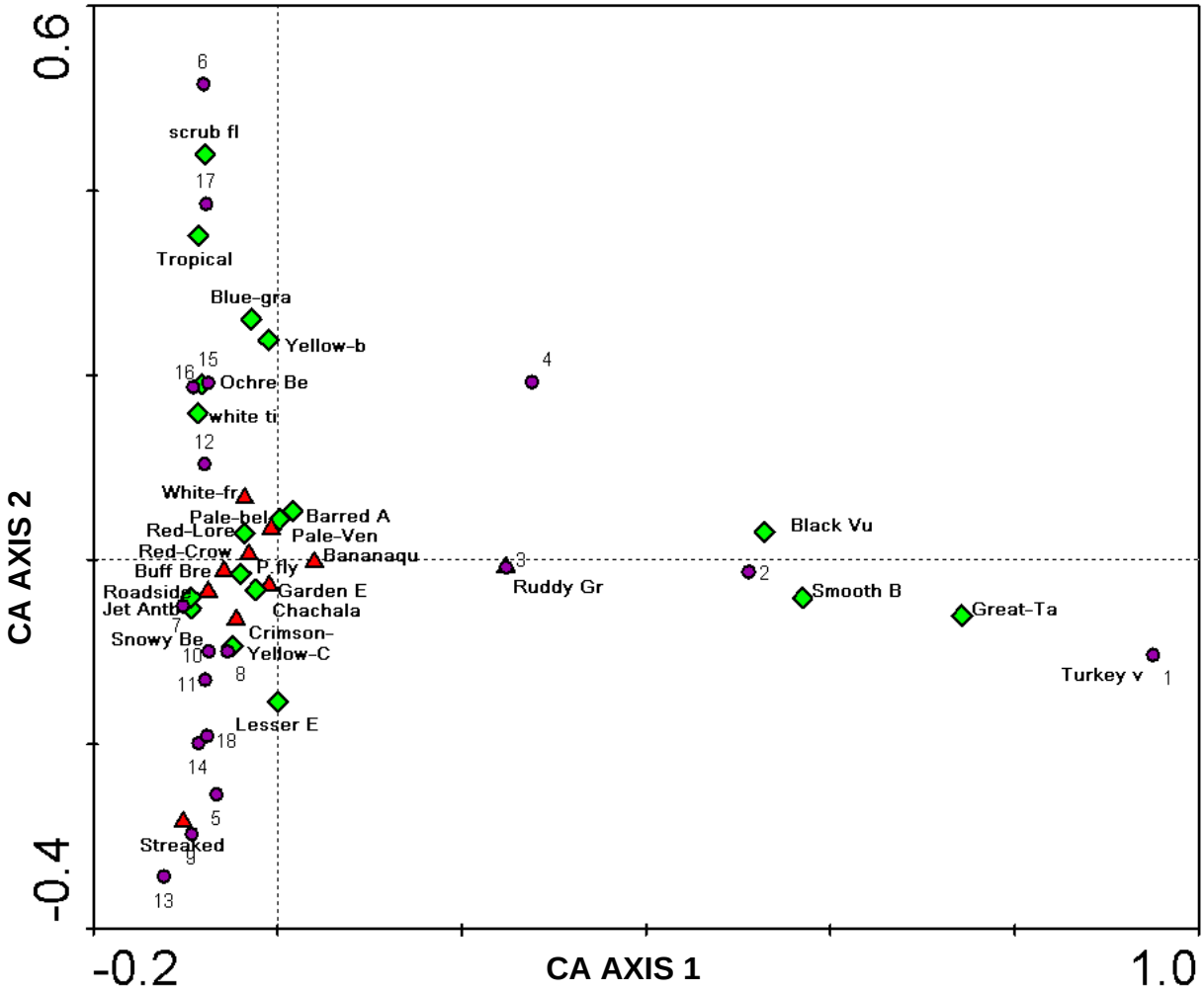
Simpson's diversity	*Variable 1*	*Variable 2*
Mean	7.252	9.703
Variance	3.574	4.152
Observations	6.000	12.000
Pooled Variance	3.971	
df	16.000	
t Stat	-2.460	
P(T<=t) one-tail	0.013	
t Critical one-tail	1.746	
P(T<=t) two-tail	**0.026**	
t Critical two-tail	2.120	

Fishers alpha	*Variable 1*	*Variable 2*
Mean	7.398	9.942
Variance	3.727	3.554
Observations	6.000	12.000
Pooled Variance	3.608	
df	16.000	
t Stat	-2.678	
P(T<=t) one-tail	0.008	
t Critical one-tail	1.746	
P(T<=t) two-tail	**0.017**	
t Critical two-tail	2.120	

Berger-Parker	*Variable 1*	*Variable 2*
Mean	4.295	5.558
Variance	0.941	1.932
Observations	6.000	12.000
Pooled Variance	1.622	
df	16.000	
t Stat	-1.983	
P(T<=t) one-tail	0.032	
t Critical one-tail	1.746	
P(T<=t) two-tail	**0.065**	
t Critical two-tail	2.120	

Chao1	*Variable 1*	*Variable 2*
Mean	15.510	18.424
Variance	24.656	17.288
Observations	6.000	12.000
Pooled Variance	19.590	
df	16.000	
t Stat	-1.317	
P(T<=t) one-tail	0.103	
t Critical one-tail	1.746	
P(T<=t) two-tail	**0.206**	
t Critical two-tail	2.120	

Appendix 12: CA with full suite of species. Ordination plot generated by CANOCO 4.5.



Appendix 13 : ARCSIN-transformed values for environmental recordings and outputs given by one-way ANOVA.

	Understorey	Midstorey	Canopy	Max high
T2	0.86	0.83	0.61	26.00
T3	0.83	0.59	0.16	19.00
T6	0.93	1.00	0.11	18.00
T7	0.33	0.34	0.41	27.00
T9	0.48	0.43	0.39	26.00
T10	0.52	0.57	0.61	24.00
T11	0.14	0.89	0.75	33.00
T12	0.07	0.30	0.52	25.00
T13	0.43	0.52	0.39	29.00
T14	0.48	0.52	0.50	36.00
T15	0.64	0.48	0.59	42.00
T16	0.12	0.42	0.76	37.00
T1	0.50	0.47	0.32	16.00
T4	0.33	0.55	0.23	10.00
T5	0.49	0.62	0.12	14.00
T8	0.59	0.41	0.10	5.00
T17	0.25	0.67	0.24	15.00
T18	0.24	0.50	0.37	22.00

ANOVA Max height between NI and I

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	880.11	1.00	880.11	18.92	**0.002**	4.49
Within Groups	744.33	16.00	46.52			

ANOVA Understorey between NI and I

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.03	1.00	0.03	0.45	**0.51**	4.49
Within Groups	1.05	16.00	0.07			

ANOVA Midstorey between NI and I

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.01	1.00	0.01	0.18	**0.68**	4.49
Within Groups	0.58	16.00	0.04			

ANOVA Canopy between NI and I

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.26	1.00	0.26	8.03	**0.01**	4.49
Within Groups	0.51	16.00	0.03			