An assessment of the Herpetofaunal biological diversity of the Hydrological Reserve on Isla Del Rey, Las Perlas Archipelago, Panama.

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Abstract

As part of the 2007 Darwin initiative project in Las Perlas archipelago, Panama, a terrestrial herpetological inventory and ecological survey of the moist forest within the newly designated Hydrological Reserve on Isla Del Rey aimed to identify a species list, knowledge of herptile species diversity (and related ecological characteristics) and any management issues or evidence of negative human impact on the quality of forest habitat.
18 belt transects (200m by 4m) were lined along the main trail from San Miguel to the interior of the reserve (further test transects near La Guinea in the mangroves and 3 nocturnal transects were used as test data).
Transects were walked and individuals/species encountered noted. GPS points were taken every 50m of each transect, including elevation readings and vegetation environmental variables. Data was analysed through species richness and diversity indices (Simpson, Berger-Parker, Margalef D and Chao 1) and density and abundance measures. The environmentals of vegetation cover and height, elevation and direct distance to the nearest town were combined with species data in multivariate analysis. Ordination using DCA, PCA, CA and CCA were plotted and the log output assessed.
The results showed a total of 15 species were identified on the island (33 confirmed within Las Perlas), of which 8 were found within the reserve boundaries on the main trail of transects. High levels of beta-diversity (6.5) were found to potentially occur along this assemblage and so, along with the vegetation and habitat changes, inferred an ecotone of agriculture to disturbed scrub to forest-edge to a gradient of progressively more mature and less intervened moist tropical habitat. Human disturbance was high, but the potential with local knowledge to form a highly successful partnership approach of integrated conservation and potentially ecotourism is also high; this is an excellent opportunity for the Panamanian government to prove their desire to follow Costa Rica in leading the way in tropical conservation and management.

1. INTRODUCTION

1.1. Biological diversity

The terms ‘ecological diversity’, ‘biological diversity’ and ‘biodiversity’ can and generally are used interchangeably (Magurran, 2004). The latter two terms will be used in this study, particularly the preferred ‘Biological diversity’.

The United Nation Environment Program (UNEP) uses the apparently much cited definition: “ ‘Biological diversity’ means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic systems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems” (Heywood, 1995, p8; cited in Magurran, 2004, p6).

1.2. Herpetofauna and biodiversity- diversity, species richness, density, abundance, evenness and dominance

Much research has been undertaken in terms of the biodiversity of the world’s herpetofauna (the umbrella term for reptile and amphibian species, which may often be abbreviated to ‘herptile’); the majority of which until relatively recently, has been either taxonomic or single species research. The recent change from research for research sake to research related to human needs has meant that biodiversity in herptiles now occurs through research in species richness to diversity (alpha, beta, gamma), through to community-ecosystem diversity and most recently genetic diversity (Zug et al., 2001). This puts larger volumes of herptile research into the increasingly relevant field of conservation biology (Zug et al., 2001). Despite 449 new reptiles and 493 new amphibian species being discovered 1991-7 (Bauer, 1999; cited in Zug et al., 2001), anthropogenic influenced extinction rates are more rapid now than the natural background rates; naturally loss of species tends to be slightly less or equal to the number of new species, allowing increases therefore in diversity (Zug et al., 2001).

Conservation biology has meant that research is now contributing to conservation management as well as diversity assessment, going from single species to habitat conservation. This study emphasizes how one can use analysis of such biological characteristics of herptile communities and assemblages in conservation management.

1.21. Distribution, dispersal and home ranges

The distribution and spatial pattern of individuals is based on their interactions with the local environment and the individual's physiological requirements and the locations of others (Zug et al., 2001). Home ranges of species are defined by their resources (shelter, mates, food, thermoregulation sites, escape routes and so on); the area of the home range that is "actively defended against intruders" is known as the 'territory' (Zug et al., 2001). The factors that influence movement in herpetofauna are summarized in table 1.1 below.

Table 1.1: cited in Zug et al., 2001.
Factors that influence movements of individual amphibians and reptiles

Environmental	Population	Individual
Daily temperature patterns	Density	Sex
Seasonal temperature patterns	Sex ratio	Body size
Humidity/rainfall	Age structure	Age
Habitat type or condition	Size structure	Physiological condition
Catastrophic events	Disease/parasitism	Reproductive state Recent experience

1.22. Community structure:

Community can be defined as: “an assemblage of species populations which occur together in space and time” (Akani, 1999, p630). Species richness (number of species), species diversity (number of species combined with relative densities or other components of diversity), predation and competition are characteristics that species and populations do not have (Zug et al., 2001). Within a community there are often sets of species that tend to use congregate, due to using particular resources in similar manners, these are known as ‘guilds’ (Zug et al., 2001). Community structure is therefore the species abundance, composition, and interactions; various abiotic (environmental) and biotic (relations with other species/individuals and those factors derivated from local vegetation, such as shade and humidity) factors may affect this structure (Zug et al., 2001)

1.23. Density and abundance

Density is particularly important for herpetofaunal communities within the herein studied Neotropics. Herpetofauna can occur at particularly high densities and therefore play an important role as either primary, mid or top level consumers (Bell and Donnelly, 2006). There is often a confusion on the definition or at least the calculation of both density and abundance (particularly the latter), some authors have clear distinctions and others prefer to class both as one of the same; the variation in equations depends very much on your methodology, faunal group/species and environmental conditions, as it does on theory. The most common difference is that density relies upon a measure of area, for example the number of Iguana per metre squared; whereas abundance is more likely to rely on a measure of effort (such as person-hours). Density is much more confined than abundance, and therefore measures within a specific survey or sample area, whereas abundance may be simply a measure of the number of individuals seen during an hour visual encounter survey (VES) walk; both are descriptions of the distribution of <u>individuals</u>, however.

There has been a plethora of studies on density or more specifically species-area relationships, this mainly within the context of comparing species numbers with island size or with mainland populations. Anole population density, for example, is 2 to 4 times larger on West Indian islands than mainland Central America; these densities get larger with larger island size, often due to concentration of resources (Zug et al., 2001), these resources seeming to be a limiting factor giving lower growth rates on island Anole species, but not mainland species (Andrews, 1976). Population densities can change annually, this maybe dependent on availability of these resources; however long-term studies of *Anolis limifrons* in Panama suggest the length of the dry season and the relative rainfall in the wet season determine anole population density (Zug et al., 2001 and Andrews, 1991).

Higher densities of anole on islands than mainland is not by any means an uncommon situation, many studies over different locations in the tropics have shown that densities of herpetofauna are generally greater on islands; but species richness is generally lower when compared to same size areas on the mainland (Zug et al., 2001). Buckley and Jetz (2007) recently demonstrated this "dramatic effect of insularity" on the abiotic and biotic controls of abundance and community sensitivity to species gain and loss. Looking at 643 lizard populations from around the world, island abundances were one order of magnitude higher than mainland ones (even if controlled by resource availability); Buckley and Jetz (2007) suggested that vastly reduced predator/competitor richness was driving lizard abundances.

MacArthur and Wilson (1967) gave the now famous 'island biogeography theory' or 'equilibrium theory of island species diversity' to explain the above phenomenon; this theory is summarized particularly well by Zug et al. (2001, p336): they explain that the theory "proposes that a balance exists between the number of species colonizing an island and the number of species going extinct. The colonization or immigration rate is a function of the island distance from a source area, and the extinction rate a function of island size. Since immigration and extinction are assumed to be continuous processes, species number reaches an equilibrium value and remains constant even though the composition of the species assemblages changes continually". This was backed up by many later studies such as that of MacArthur et al. (1972; 1973) on bird densities of the archipelago that located the study area for this thesis, the Las Perlas Islands (Panama).

1.24. Diversity: diversity, dominance and evenness and species diversity indices

Species richness (SR) and diversity are discussed in detail later in the methods section, SR generally a simple count of the number of species and diversity taking into account an evenness component. These are extremely common ways of discussing herptile ecological data and are largely based on statistical indices (details also in methods section). SR and diversity is the cornerstone of assessing biological diversity and can be influenced by a myriad of biotic and abiotic variables, several of which investigated here. At a basic level Araujo (2004) show that there is a positive relationship between species and habitat diversity, they inferred that increased numbers of habitats in conservation reserves or protected areas (PAs) would lead to increased species numbers; this is a particularly important, yet simple, idea for managing or creating PAs for conservation. They do point out that this relationship is to some extent of the aforementioned species-area relation (Araujo, 2004).

There are many relationship studies on the different variables that may affect herptile diversity at a given location, generally attempting to identify how much that variable accounts for the variation in diversity, SR and density (as described earlier). These include vegetation structure, type and cover, distance from forest fragments or urban areas, aspect, slope and degree of habitat quality/maturity or disturbance. One of the most common variables studied is that of elevation.

1.241. Elevation

One of the most widely-cited patterns for herptile abundance in the tropics is that of increases in density with elevation (e.g. Scott, 1976). A similar liner relation has been found for SR against elevation (Naniwadekar and Vasudeven, 2007). A substantial collection of studies show that increases in SR seem to peak at mid or intermediate-elevations in much research (e.g. Fu et al., 2006) and therefore tend to show a humped-back unimodal relationship when plotted (Fisher and Lindenmayer, 2005; Fu et al., 2006). Fisher and Lindenmayer (2005) claimed that elevation changes of 50m may be

related to species composition or richness changes. Several studies have however failed to find evidence for these relations, and in fact Fauth et al. (1989) found the opposite relation for density through mid-elevation sites; although they did find a positive relation with evenness (component of diversity), but this was not significantly correlated.

1.3. Threats to conservation and biodiversity

1.31. Habitat fragmentation

SR can be effected by habitat loss, fragmentation and modification; such practices as selective logging have been known to cause edge effects, complete removal such as 'slash and burn' farming techniques in the Neotropics removes the entire habitat and all the species within (Zug et al., 2001).

Selective logging potentially alters community-structure creating hotter forest openings than from natural tree-falls; canopy gaps attract heliothermic (gaining heat from the sun for thermoregulation) lizards, such as *Ameiva*, and these can reduce the populations of smaller frogs and lizards by predation or outcompeting for prey (Zug et al., 2001). Despite this herptiles have small home ranges, lower energy requirements and higher densities; therefore the maintenance in small patches or fragments of viable populations is very possible; they are certainly less affected by fragmentation than birds and there has even been some cases (admittedly with certain forest-edge, disturbance-philic species) where SR has increased (Bell and Donnelly, 2006).

1.32. Invasive or alien species

Invasive species cause massive threats to all types of ecosystem and habitat, no matter the levels of SR, diversity or endemism; such successful invaders are *Bufo marinus* and *Hemidactylus frenatus*, both now naturalised in huge parts of the world. Often naturalisation occurs when there is minimal competition, however success over so many continents and distances for the *B.marinus* is down to its quality as a generalist at high densities, its close association with habitats modified by humans, intentional introduction as a pest control (Zug et al., 2001) and its poison glands (defence mechanism). The principle of competitive exclusion means "two or more species with identical ecological requirements cannot coexist in a stable environment unless there is a superabundance of their various needs" (Lever, 2003, p3); hence the often better adapted invasive species will out-compete the native. Oceanic islands are especially sensitive to alien species population explosions, this is due to isolation leaving them without the chance to develop defences against competitors or predators (Lever, 2003); this is most significant on small, extremely isolated islands with little or no predators for herptile species.

Approximately 10% of alien species become naturalised and 10% of those obtain pest status (Lever, 2003).

1.33. Disease and climate change

There is now an immense collection of research on the effects of climate change, causing, especially in cloud forest ecotones, loss or movement of habitat up the altitudinal gradient; this leaves moisture dependent anurans to die out through desiccation. In conjunction with this work, and possibly related (as habitat dehydration could facilitate spread of disease), is the huge spread of fungal diseases in neotropical anurans. Whitfield et al. (2007) andYoung et al (2001) are good examples of this vast research area.

1.34. Hunting

Harvesting of herptiles through illegal trade and unsustainable consumption is probably the biggest threat other than habitat destruction/alteration (Zug et al., 2001). Typically Iguanas are hunted for local consumption, especially in central America; sharp declines in populations due to overhunting have been observed, despite the recent community-based Iguana farms development in Nicaragua, Costa Rica and Panama (Eilers et al., 2002) for reintroduction to the wild and providing meat for sale or consumption (Zug et al., 2001).

1.4. Herpetofauna research in Central America

Central America has been used as a taxonomic haven for hundreds of years, with many of the early discoveries of new species found here. Up until and including the 1960s and 1970s this taxonomic research, mainly from North America and Europe, had concentrated on species specific surveying. To gain an overview of the herpetofaunal work, distinguished authors such as Duellman (1966) produced several papers on the herptiles of Central America. Duellman (1966) detailed the following observations:

- Temperature and moisture were the chief environmental factors affecting distributions of herptiles in Central America.
- Shade and suitable breeding locations were significant factors for determining species distribution.
- He defined five major ecological assemblages, their characteristic species and geographical distribution.
- The humid tropical and arid tropical assemblages are widespread in lowlands and contain the largest numbers of species.
- The humid montane assemblage and its vast cloud forests show high degrees of endemism.

Duellman (1966)

An ecological transect in Costa Rica's Cordillera de Tilarin identified four such assemblages, these showing 13 key distribution patterns and being closely correlated with the transect vegetation zones (Heyer, 1967).

More recently much work has been more conservation and conservation management related; however there have still been many purely ecology based papers, specifically related to charismatic species such as the green Iguana (*Iguana iguana*). There still remain many general descriptions of specific area or country herpetofauna; these are still very important as many regions are still untouched and, excluding Costa Rica, very little in terms of field guides or identification books are available. Wilson and Townsend (2006) is a good example of such work and is the general description of herpetofauna of the rainforest of Honduras.
Recent work has particularly been extensive in the internationally important research reserve of La Selva, Costa Rica; much work by Savage, Guyer, and Donnelly has been done on this rare 'pristine' forest habitat. Important work by particularly Ibanez (amphibians), Rand (mainly Iguana), Sexton (general herpetofaunas) and Wright (lizards and avifauna) has been important for progress in Panamanian herpetology.

1.5. Herpetofauna research in Panama

Many herptiles dispersed between North and South America through the Panama Isthmus during what is known as the "Great American Biotic Interchange" (after the Pliocene closure of the gap) (Auth, 1994). Distributional continuities with South, North and Middle America have allowed a significant number of endemics, 14% of all amphibian and 7% of reptiles being endemic; there is roughly 2.8 times more native herptiles than in Florida, despite being about half the area in size (Auth, 1994).

Despite several published partial lists and notes on the herpetofauna of Panama, such as Swanson (1945) and Evans (1947), there was no published checklist and bibliography until Auth (1994); this extremely useful and well researched document identified 395 native species and 8 introduced (170 amphibia and 225 reptilia that are native).

Similar figures (228 reptiles and 170 amphibians) were summarised in the report on San Lorenzo PA in Panama (Weaver and Bauer, 2004).
There is an absence of any herpetofaunal field guide, so one has to use the limited selection of Central America guides or those from the much published Costa Rica; despite this there is a very meticulous and comprehensive book on the amphibia of Barro Colorado Nature Monument (run as a research station by the Smithsonian Tropical Research Institute – STRI) and surrounding area by Ibanez et al. (1999)

1.51. Specific case study STRI at Barro Colorado Island (BCI)

Most of the work on herpetofauna in Panama has been undertaken at BCI, this is a research facility in the Gatun Lake in the Panama Canal run by STRI. Work such as the intensive 19 year census at BCI, and 4 years in 20 other sites in central Panama, on the lizard *Anolis limifrons*, showed patterns of yearly changes in density (Andrews, 1991). Other important research is that of Rand and Myers (1990), their ecological summary of BCI précised many decades of herpetological research.

1.6. Herpetofauna research in Las Perlas

The study area for this thesis was based in the Las Perlas archipelago in the Pacific Ocean. Apart from several recent private ecological surveys for environmental impact assessments, the only species lists and indeed published research on the herpetofauna of the islands is that of the Barbour (1906) and Cochran (1946). Cochran (1946) has recent enough taxonomy for use in the identification of species and seems to be a detailed enough survey; Roberto Ibanez (pers. comm.) clarified that it seems a relatively conclusive list.

1.7. CONSERVATION IN PANAMA - Protected Areas

Boza's (1993) account of Costa Rica's National Parks and how they stand as a model for conservation of biological diversity in the tropics and the efforts of start-up is in stark comparison to nature conservation and especially management within Central America. If there are PAs and National Parks in central America, then they are often 'Paper Parks' or are mainly managed for tourism; 30 % of all PAs have not advanced beyond legal establishment and over 60% have not solved land tenure issues (UICN/BID, 1993; cited in Guevara, 2005). Costa Rica has 12.2% of the country set aside as preserves (PAs); and as most of the country's tourism is based within National Parks, the tourist industry is asked to support and encourage conservation within them (Boza, 1993).

Much important research has gone towards the partly theoretical Mesoamerican Biological Corridor (MBC), which uses the corridor and island biogeography theories (and many more recent study on the idea of megareserves and such like) of conservation to connect North and South America through connecting patches of habitat and PAs (Naranjo, 2001). This multilateral and multisectoral effort started through a meeting of the minsters of the environment of the 7 central American countries, the aim was to broaden biodiversity conservation and address sustainable development (including agriculture and poverty issues) (Guzman et al., 2003).

In Panama a PA is defined as: "geographical area, terrestrial, coastal, marine or lacustrine, legally declared to satisfy the conservation, recreation, education or research objectives of the natural and cultural resources" (ANAM, 1998; cited in Guevara, 2005). Panama's 63 PAs will be administered by ANAM's National System of Protected Areas (SINAP), PAs represent 32.6% of the country (Amend, 2004; ANAM, 2004; cited in Guevara, 2005).

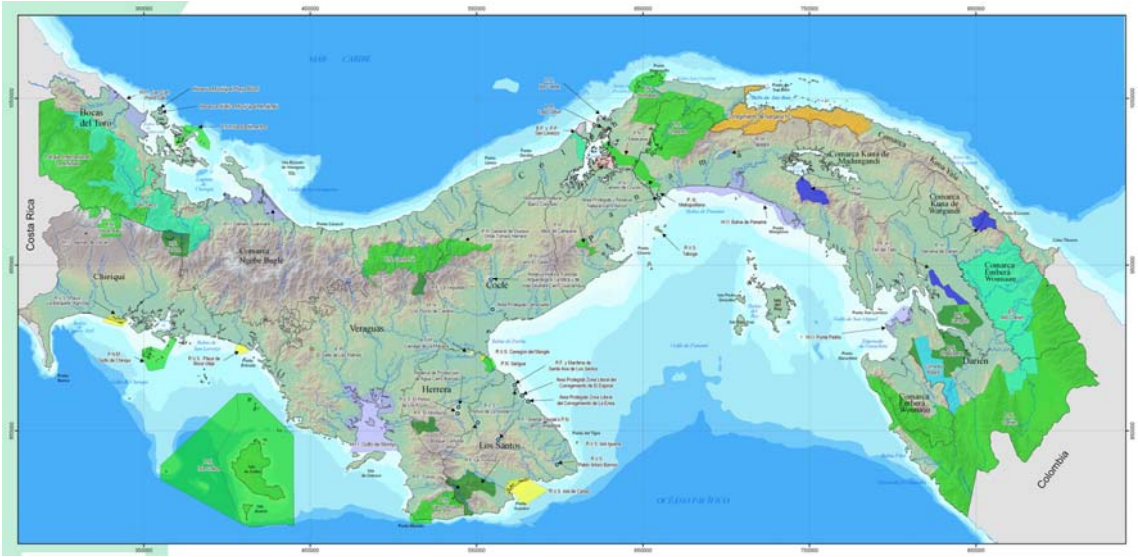


Fig. 1.1. Map showing the protected areas of Panama (coloured areas), (A.N.A.M, 2007).

1.8. DARWIN INTIATIVE

The work undertaken in this study is based on the research aims and requirement of the Las Perlas archipelago (Panama) Darwin Initiative project; this is project run through a joint venture between STRI and Herriot-Watt University (HWU) in Edinburgh (Scotland). The initiative is a small grants program aiming to promote biological diversity conservation and sustainable resources use around the world; it is funded and administered by the UK Department for Environment, Food and Rural Affairs (DEFRA) (STRI, 2007).

1.81. Project overview and history

PHASE I:
MARINE BIODIVERSITY ASSESSMENT AND DEVELOPMENT IN LAS PERLAS ARCHIPELAGO, PANAMA (DEFRA 162/12/02).

The project commenced in April 2003 for an initial 3 years aiming to provide the basis for a conservation strategy for the marine environment around the Las Perlas Archipelago. The biological diversity of key marine habitats was mapped and assessed to enable the establishment of the archipelago within the ANAM (Panamanian national authority) Panamanian PA system.
[STRI, 2007]

PHASE II:
CONSERVATION MANAGEMENT ZONING IMPLEMENTATION AND FACILITATION IN PERLAS ARCHIPELAGO, PANAMA (DEFRA EDPO 17)

The main purpose was making sure the conservation management structure of the “Las Perlas Special Management Zone” (detailed below) is implemented properly and in a sustainable manner. The project has an important role in shaping the start-up management plans for operating the zoning of the area and communicating this process with all stakeholders and local communities.
For over 5 years, staff scientists and collaborators have worked intensively to support the protection of the archipelago marine resources.
[STRI, 2007]

1.82. Project achievements

1.821. Hydrological reserve

The first major achievement of the project was that of the creation of Isla Del Rey (largest island in the archipelago) hydrological reserve (Fig. 1.2), Panama's Gaceta Oficial announced its creation on December 5th 2005.

The reserve limits (represented by a polygon) contains great diversity and endemism (15 bird endemic species), the protection of hydric resources (11 of the 15 watersheds), habitats, ecosystems, and associated species over an area of 9,822 hectares. An initial budget of $50,000 for the Management Plan of the Reserve is pending approval with, support from UNEP and the Global Environmental Facility (GEF).

[STRI news, 2006]

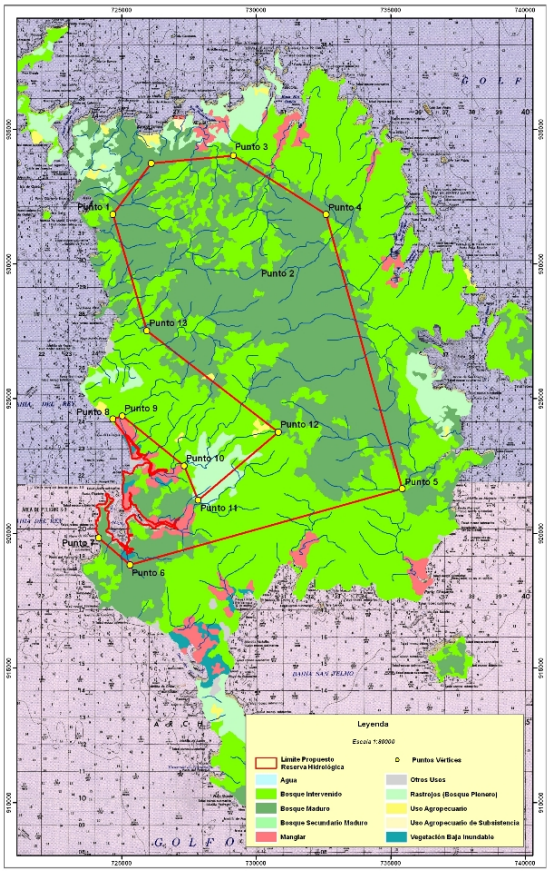


Fig 1.2. Hydrological reserve on El Rey, Las Perlas (shown by the polygon). Courtesy of Dr H. Guzman.

1.822. Special management zone [*Zona de Manejo Especial* (ZME)]

Law No.18 was published in the Gaceta Oficial on May 31st, 2007; this being the designation of the Las Perlas archipelago as a ZME (Fig 2.3). The ZME will become part of the Integrated coastal management of the local district of Balboa to protect its coastal and marine resources, to maintain the biological diversity of its ecosystems, to increase its productivity and to improve quality of life in the local fishing communities that depend upon these resources.
[STRI news 2007]

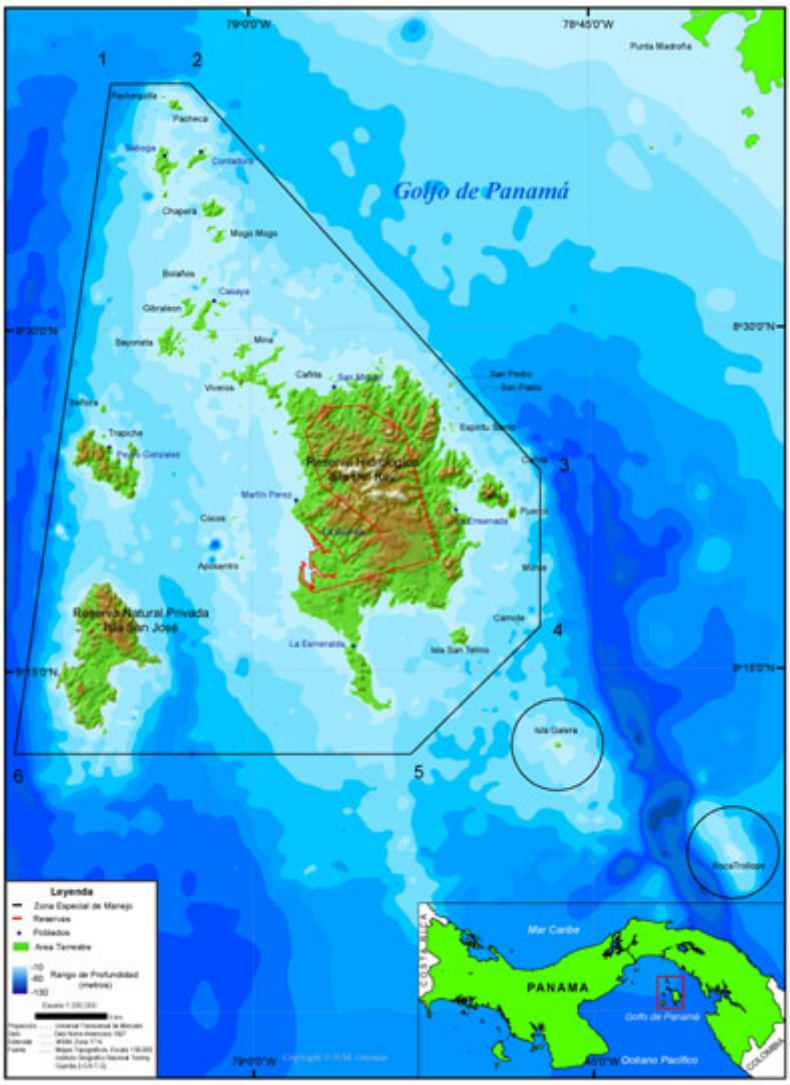


Fig. 2.3. The ZME shown as a black polygon and two isolated locations to the south-east; the Hydrological reserve on El Rey marked as a red polygon (courtesy of Dr H. Guzman, STRI).

1.83. Current research and the need for terrestrial research

The main current and previous research undertaken by the Las Perlas Darwin project can be broken down as follows (courtesy of STRI, 2007: the project website):

- Reef fish survey.
- Survey of the conservation status, diversity and distribution of coral reefs and coral communities.
- Reef fishes and mangrove connectivity.
- Dynamic of mangrove forests.
- Snapper stock assessment.
- Humpback Whale survey and protection.
- Species exploitation and disappearance.
- Biological oceanography (primary productivity, zooplankton, ictioplankton, El Nino)
- Metal tracing
- Habitat mapping using Remote Sensing and GIS
- Survey and habitat mapping
- Socio-ecological survey.
- Production of educational material

The majority of the project research has therefore evidently been based on marine ecological studies, surveys and research. Due to the designation of the Hydrological reserve on Isla Del Rey (El Rey), there has been a great need for general scientific research on the island's ecosystems and ecology. The most important ecosystems and habitats on El Rey are those of the supposed Primary or mature forests within the centre of the reserve, which are home to several species of endemic avifauna; mangrove swamps that encircle the island, especially important for shellfish such as Concha Negra; and finally the 11 watersheds designated within the hydrological reserve are extremely important habitats for many animals and birds. Most of the above marine research has simply looked at the reefs, the overfishing situation and the aforementioned mangrove communities; however the vast majority of the reserve is some distance from the marine environment. The aim of the Darwin projects is to

undertake research that will ultimately aid the management plan and therefore the overall conservation of the reserve. There is therefore the need for terrestrial or riverine based research in the heart of the island, within the reserve boundaries. This study was part of the 2007 project aims of producing as much terrestrial ecological knowledge of the reserve as possible; this study highlighting the herptile situation and another studying the avifauna. The little terrestrial research that has been undertaken on El Rey was mainly based on studies of the bird populations; as previously mentioned the knowledge of the archipelago's herpetofauna is largely based on studies from over 50 years previous, which themselves were chiefly based on other much smaller islands such as San Jose, Pedro Gonzalez and Saboga, rather than El Rey. This is therefore a significant gap in our knowledge, especially as this relatively large island has vast areas of uninhabited habitat that is ideally suited to herpetofauna; the numerous rivers and streams that dissect the island, along with a immensely undulating topography covered in moist rainforest, is likely to contain an abundance of suitable niches within an array of habitats ideal for many neotropic herptiles.

The problem is simply the lack of knowledge and the need for guidance within the management plan; the requirements for the project were at the most basic level an updated species list for herptiles on the island and above this a survey of the herptile ecology, and the threats and interactions with the local human population.

1.9. Aims and Objectives of thesis

- To devise an inventory of reptile and amphibian species on El Rey and within the hydrological reserve.
- To determine the herptile ecology and diversity of the habitats with the reserve boundary and identify any relationships with environmental variables such as elevation, distance to town (human habitation) and vegetation cover/structure and the significance of these relationship for conservation.
- To provide at least a preliminary study of the herpetofauna that will lead to further more in-depth studies or long-term monitoring programs.
- To investigate whether there are differences in the above between habitat types; particularly between the GIS identified 'non-intervened' and 'intervened' forest habitats.
- To investigate the impact of human disturbance on the reserve ecology and the potential for local people to interact with the development of the management plan.

ADDITIONAL BACKGROUND INFORMATION:

1.10. SOCIO-ECONOMIC BACKGROUND: local knowledge and PAs conservation

Previously PA conservation was based on the idea that people are bad for natural resources; therefore policies and practice have excluded people and hence local participation from conservation (Pimbert and Pretty, 1995). This has neglected local and indigenous knowledge and has caused much tension and conflict; this has been detrimental to conservation, especially as much evidence shows that local people have improved biological diversity through influencing the natural systems around them

(Pimbert and Pretty, 1995). A new type of conservation that interacts as much with local people as it does with professionals, scientists and other experts, is a challenging future that is necessary for conservation, particularly in the tropics.
Becker and Ghimire (2003) studied how ecological local knowledge and interactions with foreign Non-Governmental Organisations (NGOs) helped an indigenous people in Ecuadorian moist forest to change their management practices to improve water supply that had been lost due to forest clearing. The case "demonstrates that synergy between traditional knowledge and western knowledge can result in sustaining both ecosystem services and biodiversity in a forest commons" (Becker and Ghimire, 2003, p1).

1.101. Iguana farms and nurseries: an example of local knowledge and external expertise for PA conservation

Due to deforestation (half the forest lost in the last 40 years in Panama; Cohn, 1989) and degradation across Panama and neighbouring countries, the green Iguana (*Iguana iguana*) is now considered to be in danger and is hence protected under Panamanian law (Weaver and Bauer, 2004). The Iguana is also greatly affected by ongoing hunting for food and export through the pet trade; it is therefore also listed under CITES appendix II, giving much greater restrictions on trade (Weaver and Bauer, 2004; Eilers et al., 2002). Aiming to halt this problem NGOs and Central American governments have proposed farming iguanas; the idea being to provide extra income to small farmers, educate and stimulate local knowledge and attitudes on nature conservation and to produce food/protein for local people (Eilers et al., 2002). Despite the problems of poorly educated farmers struggling with paperwork for permission to farm a trade-restricted species, amongst other things, there has been great success in Panama (and Costa Rica and Nicaragua), with 11 farms by 2002, 3 of which are research farms; many entire villages have been educated about the farming, its goals and the importance of conservation (Eilers et al., 2002). Long-term projects such as that of

Werner, whose 5-year project had combined captive breeding, reintroduction and research (initially funded by STRI), has also been a viable success; importantly the work has shown that in some places 1 hectare of forest that is now pasture can yield 33 pounds of beef per year, but can yield 10 times this if restored to forest for iguana farming (Cohn, 1989).

1.11. Tourism and Conservation

Panama's tourism plan (1993-2003) divided the country into 9 tourist destination areas; the Las Perlas archipelago was 'Area 8', due to its huge potential for development of resorts and tourism (Casado, 2001); it currently has 2 large hotels and 200 private residences on the small Isla Contadora and 1 hotel on San Jose, nearest to El Rey (Raab and Roche, 2005). The Panamanian government produced the "Action Plan for Development of the Tourism-Conservation- Research strategic Alliance (TCR Action plan)" (Casado, 2001, p92), aiming to integrate tourism and conservation; this integrated ecotourism approach has been seen to be particularly successful in the Gamboa Tropical Forest Resort (Casado, 2001), but has caused many issues and opposition to tourism and hotel development in the internationally important Coiba island National Park (Steinitz et al., 2003).

Tourism and conservation in Las Perlas is at the earliest of stages and many contradictions are causing this integrated approach to ecotourism to look currently a very distant prospect. In late 2006 a municipal decree announced the hydrological reserve on El Rey and almost simultaneously central government announced a decree for large-scale tourism development on the islands, one could say "the left hand protects the ecology, the right hand builds on it" (Mair, 2006).

2. MATERIALS AND METHODS

2.1. Introduction to study area

The study was conducted on the Pacific island of Isla Del Rey, Las Perlas Archipelago, Panama.

Las Perlas Archipelago is a collection of approximately 255 islands and islets (Guevara, 2005) located in the Gulf of Panama (Pacific Ocean), approximately 60 km to the southeast of the capital Panama City, within the Balboa District of Panama (province of Panama), Panama [8º11'31.47" and 8º 40'16.33" North Latitude and 78º 46'21.95" and 79º 08'39.72" West Longitude (Guevara, 2005)]. The Archipelago has a population of 2,336 within the island communities of Contadora, Saboga, Casaya and Pedro González, along with the villages of San Miguel, La Ensenada, La Esmeralda, La Guinea and Martin Perez on Isla Del Rey (Guevara, 2005).

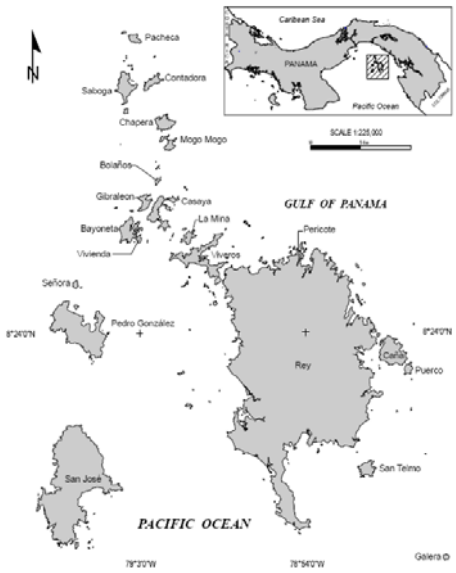


Fig. 2.1. Geographical location of Isla Del Rey within Las Perlas archipelago, Panama (Guevara, 2005).

2.11. PHYSICAL CHARACTERISTICS

2.111. Climate

Panama shows a distinct seasonal variation in climate related to the position of the Intertropical Convergence Zone (ITCZ), the area where the trade winds of the northern and southern hemisphere meet (Mcniven, 2003). The dry season (due to the south migration of the ITCZ) is generally from January to April and is characterised by predominant northeast trade winds and little rain/clear skies; the rainy season, habitually starts in May and extends through to November and is characterised by heavy rainfall and light variable winds. A phenomenon of "upwelling" occurs in the dry season in the Gulf of Panama; strong southmoving currents bring cold nutrient rich water to the surface, resulting in phytoplankton blooms, hence reducing light penetration and therefore causing high levels of zooplankton. These high levels of zooplankton forms the basis of rich fisheries of Las Perlas, hence the high numbers of marine birds and other predators feeding on baitfish (Baxter, 2004).

The Las Perlas Archipelago has a tropical moist climate with annual rainfall between 2,500 and 3,000 millimetres per year (Guevara, 2005), hence the vegetation is tropical moist forest.

2.112. Geology and soils

The majority of the Geology of the western side of the archipelago is of sedimentary rock of the Cenozoic Era. The remainder of the archipelago (East of Isla El Rey, South of the Archipelago) is formed of igneous rocks (lavas and pyroclastics, andesitic-basaltic) of the same Era (Guevara, 2005).
Las Perlas has only 36% of land considered as soils with appropriate agricultural production, the majority therefore is restricted to forests, pasture and reserve land (Guevara, 2005).

2.113. Ecology

The ecology of the islands is both little known and complex; the largest islands (del Rey, San Jose and Pedro Gonzales) are important places for threatened understorey species at national level, including the Yellow-crowned Amazon (*Amazona ochrocephala*) and White-fringed Antwren (*Formicivora grises*); along with 16 endemic subspecies (Angher, 2003; cited in Guevara, 2005); there are islands important for marine bird [such as the Blue-footed Booby (*Sula nebouxii*) and Magnificent Frigatebird (*Fregata magnificens*)] and sea turtle [Olive Ridley (*Lepydochelys olivacea*) and the Green Turtle (*Chelonia mydas*)] nesting sites (Guevara, 2005). There has been very limited study of the mammals and reptiles/amphibians; as such reports of pockets of Brown Brocket Deer (*Mazama gouazoubira*) and various wild pig and limited non-marine herpetological evidence other than the prominent Green Iguana (*Iguana iguana*).

2.12. TOURISM AND ECONOMIC ACTIVITY

The archipelago (especially the northern islands, such as Contadora) has become an important tourist destination, particularly second-home real estate for the wealthy. The designation as a special tourism development area for Panama (Tourism Zone 8 - Law 8, June 14, 1994 – Guevara, 2005), will inevitably lead to improvements in the currently poor infrastructure, but mass real estate and mariners/hotel complexes (such as planned for San Jose and Isla Del Rey) are causing great concern for conservationists (Guzman, pers. Comm).

Other than tourism, the main economic income for the inhabitants comes from the vast fishing resources that surround the islands, although overfishing of especially the lobster populations has lead to much research and concern particularly from the STRI itself (Guzman, pers comm). Environmental impacts in the Archipelago are not solely concentrated on overfishing; pollution such as that of the remnants of the Chemical weaponry testing by the US Government on San Jose during the Second World War and cold war, and boat motor oil/human or animal effluent release, are other major impacts. Agriculture, hunting and wood extraction are the main causes of the majority of degradation, particularly on the larger inhabited islands.

2.13. EL REY AND THE STUDY SITE

Isla del Rey is significantly the largest island within Las Perlas at over 23,900ha (Guevara, 2005) and resides within the southern extent of the archipelago. The island is covered by tropical moist forest; in 2000 this amounted to 70% of the land surface, a loss of 23% since 1974 due to deforestation, hunting and other activities (Guevara, 2005). The majority of the land use is therefore made up of forest or agricultural usage, 32% humid forest with little intervention and an equal percentage of intervened or secondary forest, 22% brushwood, 7% farming related lands, 6% mangroves and under 1% populated areas and beaches (Guevara, 2005)

Data collection surveys were undertaken during two fieldwork periods of 5-13th and 20th-26th May 2007; all day surveys conducted from 09.00 – 16.00 hours and night surveys 18.00 – 23.00 hours. The climate on El Rey during this time was of long periods of heavy rain and tropical storms, separated by days of dry and usually very hot days or part-days, this being characteristic of the start of the wet season; daily air temperatures ranged from 27.15 to 30.26°C and rainfall from 0 to 115.3mm, the average values for the fieldwork period (see table 2.1) were not particularly dissimilar to those for the entire month of May (28.59°C and 18.14mm of rainfall) and hence representative. (Data courtesy of STRI meterological station on Isla San Jose).

Table 2.1. Weather data for Las Perlas during fieldwork period.

Year	Month	Day	Air Temp (°C)	Rainfall (mm)
PHASE 1:				
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
		average	28.94	17.04
PHASE 2:				
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
		average	28.21	18.56
average for total fieldwork period			28.62	17.70

The vast majority of the land surface of El Rey has been designated as a Hydrological reserve. This reserve was the location of the required terrestrial work for the 2007 Darwin project. Therefore all transects, observations and other data collected, aimed to be undertaken within the theoretical confines of the reserve boundaries. After preliminary work it was identified that all herpetofaunal transects would be formed along the only already well established path (the only access into the dense forest other than by riverboat) that leads from the main settlement of San Miguel on the northern coast of El Rey, almost directly south into the interior of the reserve; the aim being to produce an almost single line of transects north to south, covering the changes from secondary and pioneer forest through to more mature/minimal-intervened forest. The location of the boundary of the reserve was estimated using point 2 (punto 2) of the reserve polygon, this point known to be Cerro Congo (a high point or hill) was corresponded between detailed paper maps, Global Positioning System (GPS) and local knowledge of its location. Once this point was located along the access path, transects were started from this point; however after plotting the GPS locations of the transects in GIS post-fieldwork, it was identified that infact transects 1 and 2 were located outside

the reserve boundaries; a confusion between local knowledge and GPS and map coordinates is the likely reason for this error. See map (plate 3.3) for locations of transects. In an attempt to survey a different part of the reserve and differing habitat, one days surveying in Phase 1 involved three transects in and around the mangroves of the tidal estuary of La Guinea that lead to the settlement of La Guinea in the western side of El Rey (see map for locations); access in this case was by riverboat.

2.2. METHODS

2.21. Preliminary investigations

Due to the lack of easy access into the reserve, the little previously known about the forest interior of El Rey and, as previously mentioned, minimal amounts of ecological research (particularly that of its herpetology) that had been carried out, it was vital for a thorough day of investigations to take place. During this day important logistical links were established with the local politician whom provided a knowledgeable local guide Carlos and two other men experienced in forest navigation; these (especially Carlos) would help with identifying the access path to the interior, that became our transect line, clearing the path and forming a continuation of the path when we indeed ran out of viable path. The day also was useful in terms of gaining local knowledge of herpetofaunal species that had been seen and there behaviour; other useful points of information on other species, particularly avian and feral pigs and other introduced mammals. The day was spent getting to know the forest and the particular species that seemed present and identifying the potential length of the access path, which seemed the most sensible location to form the length of a line of transect, as forming new paths would have been extremely time consuming (no other option being viable due to the dense nature of the vegetation).

2.22. Sampling strategy/design

The difficulty in collecting data on herpetofaunal communities is well documented, due to the mobility of species, their low density and ability to camouflage and seeking refuge due to human presence or changes in climatic conditions. Therefore the researcher needs to be flexible in the sampling design and the possibility of local condition required changes.

The aim of sampling is to gain a representation of the population under study, as one cannot produce a complete enumeration of the population (Krebs, 1999). It depends hugely on the type of data required and the environmental conditions of the study area

when deciding on the methods for sampling. In the case of the study area on El Rey, the restrictions formed by dense forests and therefore limited access, meant that random sampling generally was unviable; lack of prior knowledge of the different habitats and/or other distinct variations, meant that stratified sampling was also unviable. A systematic sampling procedure was therefore put in place; this involves the sampling points being placed at regular intervals, the sampling interval being fixed (Kent and Coker, 1992). As with all methods of sampling, there are advantages and disadvantages. Systematic transect sampling was decided on as the most practicable method, both for producing the data required and doing so within restricted field conditions and timeframe. Many other methods were considered, but were eliminated for the following reasons: expected field conditions, prior experience of various techniques in obtaining herpetological data, actual field conditions found during preliminary investigations, previous related studies and advice and knowledge of Panama based Herpetologist (with previous experience of working in Las Perlas and numerous locations within Panama) Dr Roberto Ibanez of STRI.

2.221. Transect design

The aforementioned preliminary work identified that the most feasible technique for using transects to systematically sample the herpetofaunal community would be to use the pre-existing access path to form a line of transects going near as possible to a north-south direction as possible; this preliminary work identified, using a 'Garmin eTrex' GPS, that the path indeed generally took this direction. The path itself became the central axis of a belt transect, each transect being 200m long and 4m wide (i.e. width of 2m each side of the central axis). Studies show that the minimum required length of a transect is 50m (Andrews, 1991; Bell and Donnelly, 2006); due to this study coinciding with other terrestrial research, a compromise of 200m was agreed, this also seemed sensible due to the relative scarcity of individuals. A belt transect design was formed, as line transects give minimal search area if just walking the line, or cause confusion on what individuals can acceptably be included within the data count (i.e. what distance from the line); a 2m distance from the line was chosen, as this gives a reasonable search area and hence an acceptable search time (Bell and Donnelly, 2006).

Transects were measured out into 50m sections and the GPS coordinates and local environmental conditions were noted at each point (each point marked clearly by flagging tape), GPS coordinates being used for navigation of the route also. The 50m points were measured by standardised metre-long pacing to check the movement of 50m by the GPS unit; the nearest location to the 50m point with a respectable satellite signal and accuracy was used to produce the GPS points. More often than not, despite the dense forest and often signal blackspots, the GPS points were located at the 50m points or within a couple of metres; the accuracy of the GPS points was never more than 25m and was generally a few metres higher or lower than 10m. A relative elevation was also taken at each GPS point (Buckley and Roughgarden, 2006), the elevation is relative as the accuracy of the 0m point is often unreliable on GPS. Starting from the assumed reserve boundary, 18 transects were formed into the interior of the reserve, each with a gap or buffer of 200m between each transect, to stop potential duplication of data. Three sections of river perpendicular to the path/line of transects, were used for 50m long night transects; due to being likely areas for particularly amphibian life. Three 100m transects were formed in the mangrove bordered estuary (in the west of the island), 2 from the banks of the river (beyond the mangroves) and one along a dry tributary bed.

2.23. Data acquisition

Data was collected at the very least an hour after transects were marked out, allowing the return of potentially scared off individuals. Either one or two persons would walk each 50m by 4m section and note the number of individuals seen, the species they belong too and if possible the weight, total length (TL) and Snout-Vent Length (SVL) of individuals. The search effort was also noted in person hours; the number of minutes that it took for the researcher/s to complete a thorough search of the 50x4m section, including all trees, bushes, dead wood and leaf litter.

Any notes of interest were also made, including the position and height of individuals on a tree trunk for example. Further notes of as many individuals seen as possible within the buffer sections and at times of no data collection were noted.
All species identified were confirmed or corrected by local herpetologist Dr Roberto Ibanez at the STRI in Panama City, during and post fieldwork.

The environmental data collected at each 50m point was an estimation of the maximum height of the canopy, the percentage cover of the canopy layer, mid-storey (between 1 and 5m from ground surface) and understorey (from ground to 1m); these measurements were formed by eye (consistently the same person) (Benedick et al., 2006), therefore were relative measurements.

2.24. Secondary evidence

Herpetofaunal species seen by locals within the forests near San Miguel were noted, along with other related information and socio-economic points; this local knowledge helped the sampling design and the final collected data.

A report by the Panamanian centre for research and social action (CEASPA) was obtained; this report contained information on in particular Iguana (Iguana iguana) nurseries (CEASPA, 2007), as well as other useful socio-economic information; this was obtained through conversations with project leader Dr Hector Guzman, along with other useful insights into the local people of San Miguel and Las Perlas.

Climate data for the fieldwork period were obtained from Karl Kaufman, via Dr Guzman, from the meteorological station on the island of San Miguel. The average air temperature and rainfall total for each day were recorded, only one days data was missing due to lightning striking the station.

2.3. ANALYSIS

2.31. GPS/GIS

The locations of all the transect 50m points, buffer points and other relevant GPS points (such as river locations and the presumed Cerro Congo point) were converted from degrees/minutes/seconds format to decimal degrees and were added to a GIS compatible spreadsheet [Comma Separated Values or csv (comma delimited)] Excel document, which contained all species and environmental variables, allowing for plotting of the transect locations and various graphical representations of all species and environmental data. The GPS (transects) points were displayed as a layer in ArcMap (version 9.1; ESRI, 2005) GIS as X and Y coordinate data on a previously georeferenced and rectified base map layer (tif file) of Isla Del Rey, making sure that all layers were accurately spatially referenced to the correct coordinate system (WGS_1984_UTM_Zone_17N).

The following procedure was used for georeferencing: 8 randomly chosen control point locations and their link table were used to establish the exact decimal degree extent and spatial of the Hydrological reserve map from the original reserve designation [itself an image produced through scanning an original 1:50,000 I.G.N.A (Instituto Geografico Nacional Tommy Guardia) topographical map of Isla Del Rey and overlaying land use/cover types].

GIS was also used to produce the environmental variable of 'Distance from town' used later in the analysis; this is a measure of how far each 50m GPS transect point is from urban settlement, the method being the use of the measurement tool in ArcMap, measuring from the GPS point to the outermost edge of San Miguel town (same location used for each measurement).

2.32. Species richness and alpha-diversity

The herpetofaunal transect species data was analysed for its ecological characteristics; the community structure, distribution and overall biodiversity quality on Isla Del Rey were assessed firstly by measures of species richness and diversity. There is much confusion over the meaning, measurement and interpretation of diversity (Kent and Coker, 1992). Species richness itself is often confused with diversity; however it is essentially a simple count of the number of species within the area/assemblage sampled (Kent and Coker, 1992; Magurran, 2004). This number of species is purely a measure of the richness within the sampled assemblage and should be used with care; it is not a total number of species present, which apart from very small or sparsely populated locations (such as islands and desert habitats) is near impossible for researchers to obtain. The number of species within the assemblage of belt transects on El Rey was totalled and classed as the species richness (SR) of each transect of the assemblage surveyed only. Density is another basic estimate of richness; here density was calculated for total number of individuals rather than number of species, due to the low number of species found, density of each transect calculated simply by:

$$sD = N/A$$

{Where sD is density in number of individuals per metre squared; N is the number of individuals in each transect; A is the total area of each transect, as the majority of transects (especially those on the main trail) were 200x4m, A was generally 800m²)}.

To show the distribution of individuals within the sampled community, the density in terms of area (m²) occupied per individual was calculated as the reciprocal of the above density (1/sD).

Scatterplots of density against two important environmental variables, 'elevation' and 'distance to town' were then constructed to see changes in density over distance from urban settlement and along an altitudinal gradient. The same plots were constructed to compare a measure of relative abundance of individuals [number of individuals seen per hour per person (Munoz et al., 2003)] against these two variables.

As species richness estimates depend on sampling effort (as above) (Gaston, 1996), a limited number of species richness indices have been devised (including Margalef index, discussed later); however the sampling effort is still highly influencing. Further to this there has been much work on estimating actual species richness through extrapolation of accumulation curves (Magurran, 2004); the accumulation curves of cumulative relative abundance, survey effort, number of individuals and number of transect and distance to town against cumulative number of species were plotted, although a good visual interpretation the plots were not extrapolated to estimate total species richness.

Diversity is defined as either alpha-, beta- or gamma-; only the first two are discussed/used within this thesis, gamma-diversity being a comparison of diversity between different areas or regions. Alpha-diversity is the diversity within a community (number and abundance patterns); whereas beta-diversity is the between community diversity (changes in the composition of species along an environmental gradient). Diversity measures generally combine the above species richness with evenness components to form a measure of heterogeneity that are usually combined as an index (Magurran, 2004). There is no single index of diversity, one should identify which component of diversity one wishes to measure and then select the index that performs this the most effectively (Magurran, 2004). Although there are many indices/statistical approaches that use logarithmic series and lognormal distribution, their complexity and poor theoretical validation means that non-parametric measures are more commonly used, these make no assumptions about the species-abundance curve shape (model) (Krebs, 1999). It must however be mentioned that the performance of these non-parametric measures is frequently governed by species abundance distribution (Magurran, 2004).

Analysis using four non-parametric alpha-diversity indices were performed on the transect data. Various indices were rejected, either through their complexity to calculate, measurement of unrelated diversity components or their documented disadvantages. The main index to be rejected was the Shannon-Weiner index; despite its huge popularity, mainly due to its use in many long-term projects, there are fundamental problems and many authors “go out of their way to underline the disadvantages” (Magurran, 2004, p106).

The first index used in the analysis was one of the first measures proposed, the **Simpson index**. This index describes the probability that two individuals drawn from the same population are the same species, where equal distribution is shown by the highest values (Krebs, 1999; Magurran, 2004). Essentially it determines the "variance of the species abundance distribution" (Magurran, 2004, p115). The formula used here is the reciprocal of the original; this is now the commonly used definition of the Simpson index:

$$D_{sm} = 1 / (\sum p_i^2)$$

{Where D_{sm} = Simpson index; p_i = proportion of individuals in the ith species.}

Advantages of Simpson index are that it is widely used in the literature and that it works particularly well with small sample sizes, as found in this study (Magurran, 2004). The disadvantages are that it is influenced by the abundance distribution pattern (Magurran, 2004).

The **Margalef D index** is technically a species richness index that attempts to compensate for the sampling effects such as sample size (Magurran, 2004):

$$D_{mg} = (S-1)/\ln N$$

{Where D_{mg} = Margalef D index; S = number of species; ln = lognormal; N = total number of individuals}.

The advantages are its ease of calculation and its suitability; the disadvantages being that it remains heavily influenced by the sampling effort (Magurran, 2004).

The **Berger-Parker index** is a simple dominance measure, expressing the proportional abundance of the species that are the most abundant (Magurran, 2004):

$$D_{bp} = 1/(N_{max}/N)$$

{Where D_{bp} = Berger-Parker index; N_{max} = number of individuals of most common species; N = total number of individuals}.

This index has advantages of being easy to calculate and interpret, but disadvantages of strong influence of most dominant species and the neglecting of rare species.

Chao 1 index is also technically a species richness measure; it is a simple nonparametric estimator of the absolute number of species within the assemblage based on the rare species number within the sample (Magurran, 2004):

$$S_{chao\ 1} = S_{obs} + (S_1^2/2S_2)$$

{Where $S_{chao\ 1}$ = Chao 1 index, the estimated no of species; S_{obs} = observed number of species; S_1 = number of singletons, the number of species observed represented by one individual; S_2 = number of doubletons, the number of species observed represented by two individuals}.

The advantages are that it is easy to calculate and is particularly robust, however it relies on abundance data rather than presence-absence data; for presence-absence data one can use Chao 2 instead (Magurran, 2004).

The above indices were calculated for each transect as a whole, rather than every 50m section of each transect, this was due to the low numbers of individuals seen; this also made the comparison of change along the transect line (gradient) much simpler and

between transects. The index values were plotted against the environmental variables of 'Elevation' and Distance to town' in Excel scatterplots.

T-Test using 't-Test: Two-Sample Assuming Equal Variances' in Excel were used to compare the difference between transects that were located within the Non-intervened and the Intervened forest; the GIS map of the Hydrological Reserve was used to identify these two habitat groupings, it was based on which habitat the majority of the GPS points for each transect fell (i.e. three or more). The only exceptions were transect 1 (T1), which was placed in the intervened group as it was classified as in scrub habitat; and transect 20 (T20), which although classed as non-intervened, had been noted in the fieldnotes as being particularly disturbed.
According to Magurran (2004), techniques such as t-tests and ANOVA can viably be used to compare assemblages/samples, due to the generally normal distribution of widely used diversity measures (such as Simpson index).

Other tests of comparison, clustering and classification such as ANOVA (above), MINITAB dendrograms of clustering and TWINSPAN, were not performed in this study due to the small number of individuals recorded.

2.321. Beta-diversity.

Although analysed further using multivariate statistics, a single measure of beta-diversity was undertaken here to see the overall turnover diversity along the transect assemblage of the main trail from San Miguel. The Whittaker measure β_w was used on the transect data; it is one of the most simple, easy to calculate and effective measures of beta-diversity (Magurran, 2004). For an overall beta-diversity of the whole transect assemblage the equation used was:

$$\beta_w = S/\alpha$$

{Where β_w = Whittaker's measure of overall beta-diversity along assemblage; S = total number of species (richness); α = mean richness}.
It has been suggested that the result of this index represents the "number of distinct communities" (McCane and Grace, 2002 cited in Sasseen and Debacker, 2006 p4) encountered along the assemblage.

The above equation was also used to compare the beta-diversity from intervened to non-intervened forest transects (therefore the beta-diversity between the two habitats), 1 was subtracted from the answer to give a scale of beta-diversity between 0 (minimum diversity or similar species composition) and 1 (maximum diversity).

2.33. Multivariate analysis

Multivariate analysis helps discover structure in data and provides an objective summarisation of the data; it aids comprehension of the data and a method of effectively communicating the results (Gauch, 1982). Multivariate analysis is required, as in this study, where a number of individuals have had more than one characteristic measured on them, the relationships among what are in this case environmental variables, means there is a requirement for all to be studied simultaneously (Krzanowski, 1972; cited in Gauch, 1982). There are indirect and direct ordination techniques which can define major patterns or gradients and the relationships within; it is often used for data reduction, however not in this case (there are sufficient variables here to make it viable: Gauch, 1982 suggested a minimum of 5)(Kent and Coker, 1992). The variation within the data that cannot be explained or that has no ecological significance is commonly known as noise (Kent and Coker, 1992). Here we use the computer software package 'CANOCO 4.5 for Windows' for all multivariate analysis described below and their various output data.
Despite the difference between methods as being direct against indirect the most important choice to make is what type of method to use in terms of the way it treats your data and the assumptions presumed; the choice is between linear and unimodal

ordination. Here a Detrended Correspondence Analysis (DCA) was used to determine whether the data followed a linear or unimodal distribution; Leps and Smilauer (2003, p169) suggested that "it is good to estimate the heterogeneity in the species data, using the length of the community composition gradients in species turnover units, as calculated by DCA". The DCA is performed and the length of the gradient in standard deviation units (SD) of the first axis determines whether the data is linear or unimodal. If the axis is shorter than 3.0 then it is linear and linear methods should be used; if longer than 4.0 it is unimodel, showing high beta-diversity and therefore unimodel methods should be used, (Leps and Smilauer, 2003). When using DCA in this study, detrending segments and biplot scaling were selected; the length of the longest axis therefore provides an estimate of the beta diversity in the data set (Leps and Smilauer, 2003).

If the result of DCA is between 3.0 and 4.0, then both ordination methods work reasonably well. In this study this was found to be the case, although closer to unimodal (and more emphasis was put on this), all major ordination methods were used to compare their results.

The method used for a linear result of the DCA is the Principal Component Analysis (PCA); this indirect method identifies the underlying environmental gradients and explores the basics of the data often before more complicated analyses are undertaken. PCA takes a cloud of data points and identifies the most important gradients by rotating this cloud so that the maximum variability is seen; here the option for 'Centre and Standardise' was used in CANOCO, this produces an eigenanalysis of the correlation matrix, axis 1 goes through the maximum variation in the data, axis 2 does the same but at a right angle (i.e. completely uncorrelated) (Palmer, 2007).

Species rarely respond to the environment in a linear fashion, they are most likely to exhibit unimodal or responses found where there is a high beta-diversity in the data. The remaining methods are based on this unimodal response:

The CA was performed on both the species data (individuals counted in transects) and the environmental data (environmental variables: elevation, distance to town, percentage cover of understorey, mid-storey and canopy and the maximum height of the canopy) separately, as was performed with DCA. The DCA is a detrended and ad hoc adjustment of the CA, it removes the 'arch' effect distortion (Kent and Coker, 1992), if there is no arch then the CA should be the preferred method of analysis. It

should be noted that a so called horse-shoe distortion effect can be seen in PCA outputs, this is a similar problem to that seen in the above CA (Gauch, 1982).

Canonical Correspondence Analysis (CCA) is a direct gradient analysis (where you know the underlying environmental factors) of species and environment data (log transformed for normality here), where the species data are constrained as functions of the measured environmental data (Kent and Coker, 1992); it finds the best dispersion of species scores (Palmer, 2007). CCA is a combination of CA and multiple regression; CA maximises correlation between the sample and the species scores, whereas CCA the sample scores are linear combinations of the explanatory/environmental variables (Palmer, 2007). The resultant graph produced here (as with DCA, PCA and CA using CANOCO DRAW) was plotted as a tri-plot (species, samples and environmental variables), this resulting ordination is a product of variability of environmental and species data (Kent and Coker, 1992).

The log file of the CCA was inspected for any variables with an inflation factor over 20; this means the variable is almost perfectly correlated with other variables, and so becomes unstable; any variables over 20 are removed and the CCA rerun (Urbina-Carbona, 2006).

A reduced model of the CCA was attempted using forward selection via the 'monte carlo' test to highlight only the variables that are significant in independently explaining variation in the dataset.

A log file of the full CCA analysis performed was produced, containing the eigenvalues (showing the importance of axes gradients) and percentage variance in the data accounted for by each variable.

All the variables were run individually using CCA and the monte-carlo test, the resultant logs were use to produce a table of the percentage variance of the first axis each variable alone accounted for in the dataset and whether it was significant (P value).

3. RESULTS

3.1. Mapping of GPS coordinates in GIS

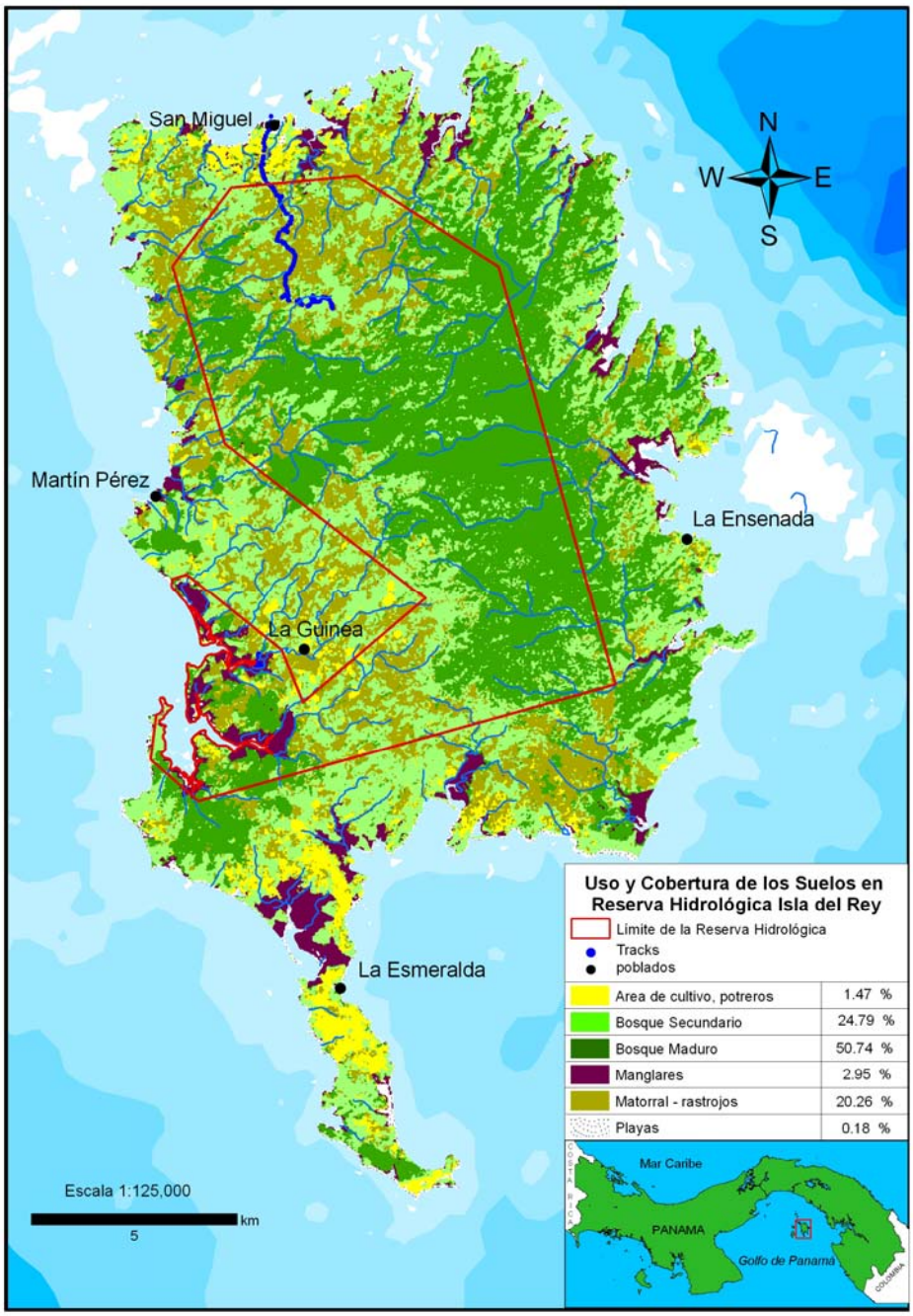


Plate 3.1. GIS map of El Rey showing the location of our transect assemblage within the reserve boundary. This map is different to the original hydrological reserve map used for the original designation of the reserve and the data analysis here. The cover types/classes used here show some different patterns of habitat to the original map.

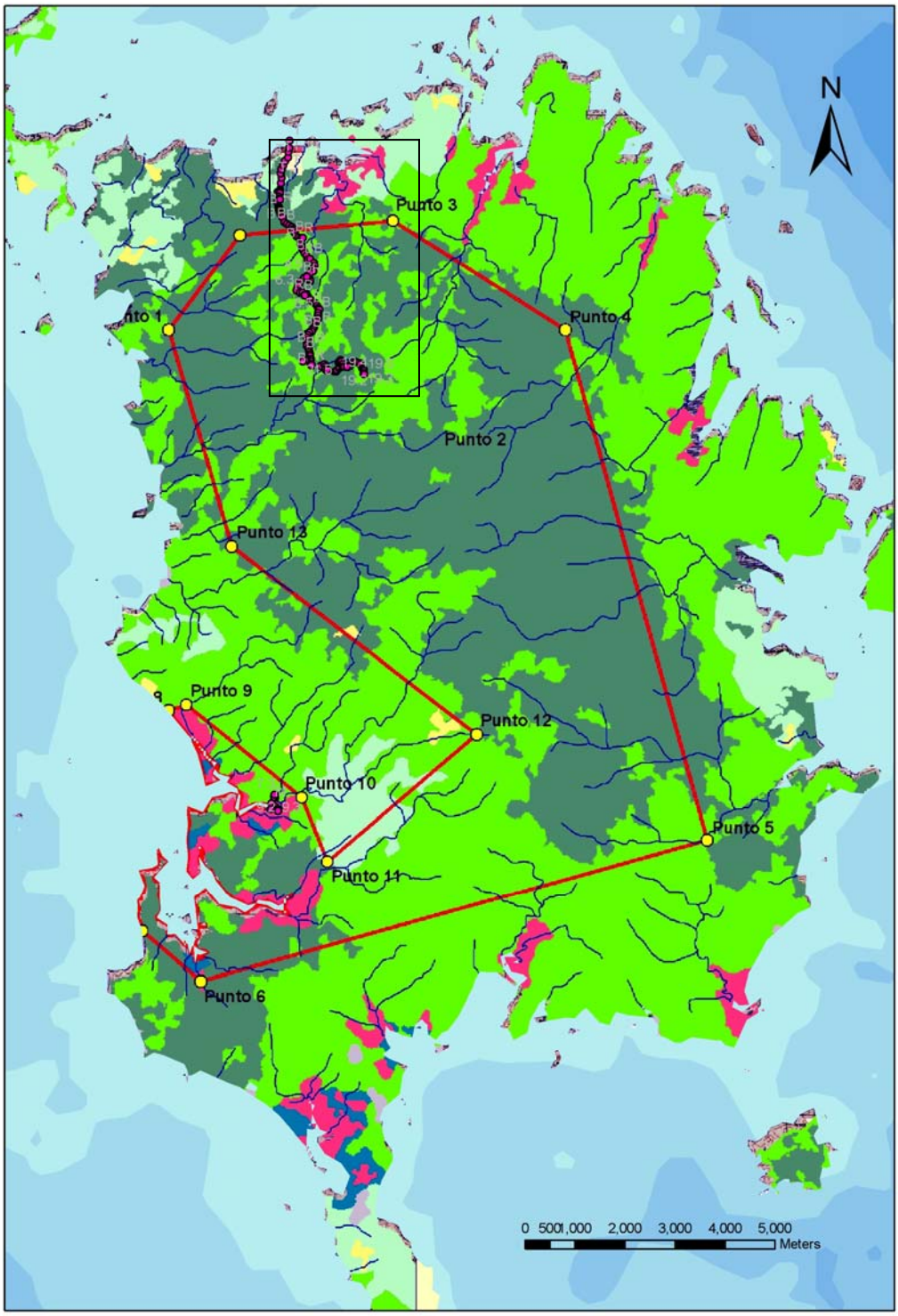


Plate 3.2. . GIS map of El Rey showing the locations of the transect GPS points using the original reserve map (as previously shown in Introduction). The black box indicates the area shown in Plate 3.3.

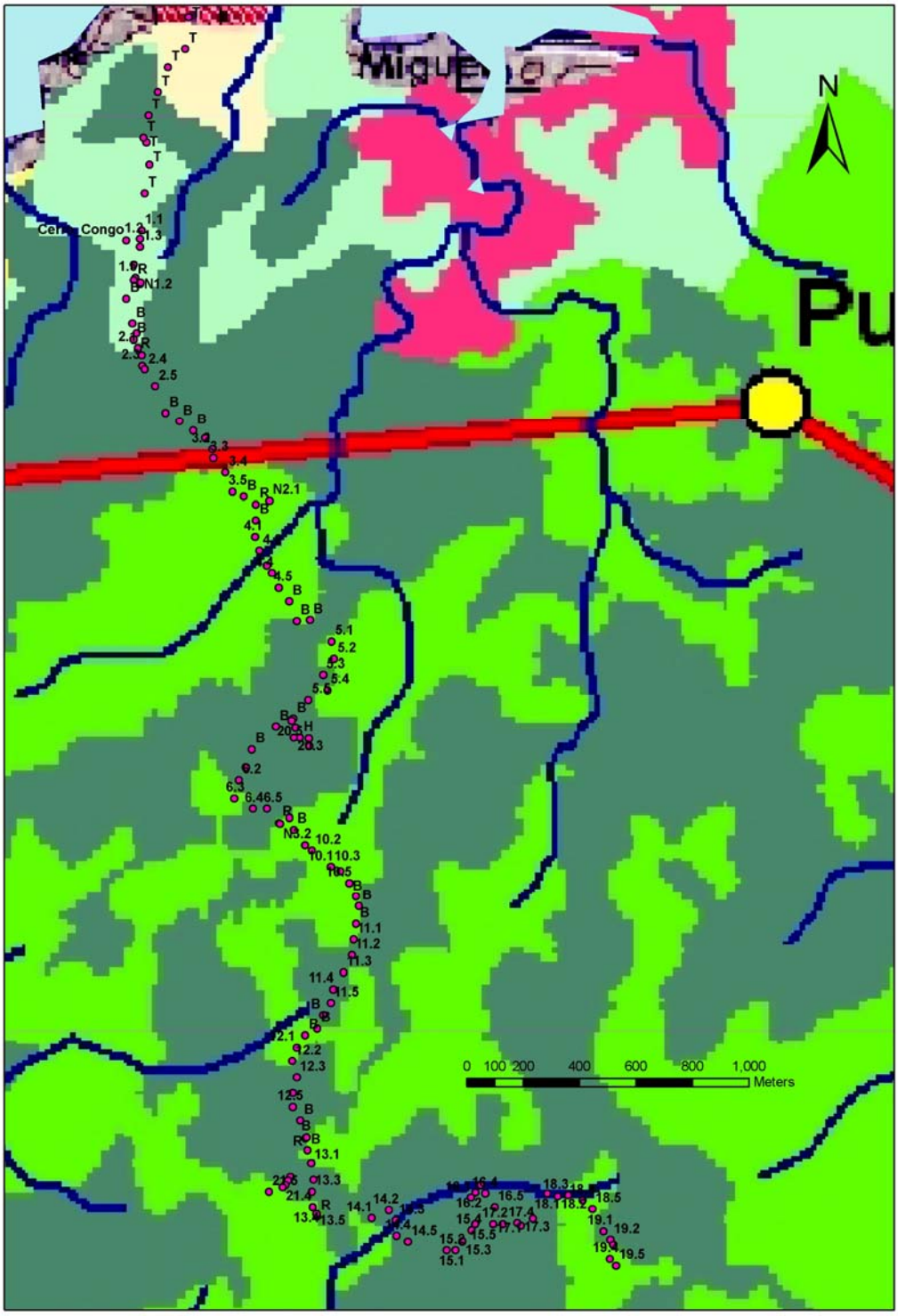


Plate 3.3. GIS map of the main trail transect assemblage from San Miguel; this is a larger scale version of the area within the black box in Plate 3.2. T= GPS points along the trail from San Miguel to transect 1; R= GPS point on a river; B = GPS buffer points, i.e. points along the 200m buffer gap between transects; 1.1 = GPS point for transect 1, 0m (5.4 = transect 5, 150m and so on). N1.2 = night transect 1.2.

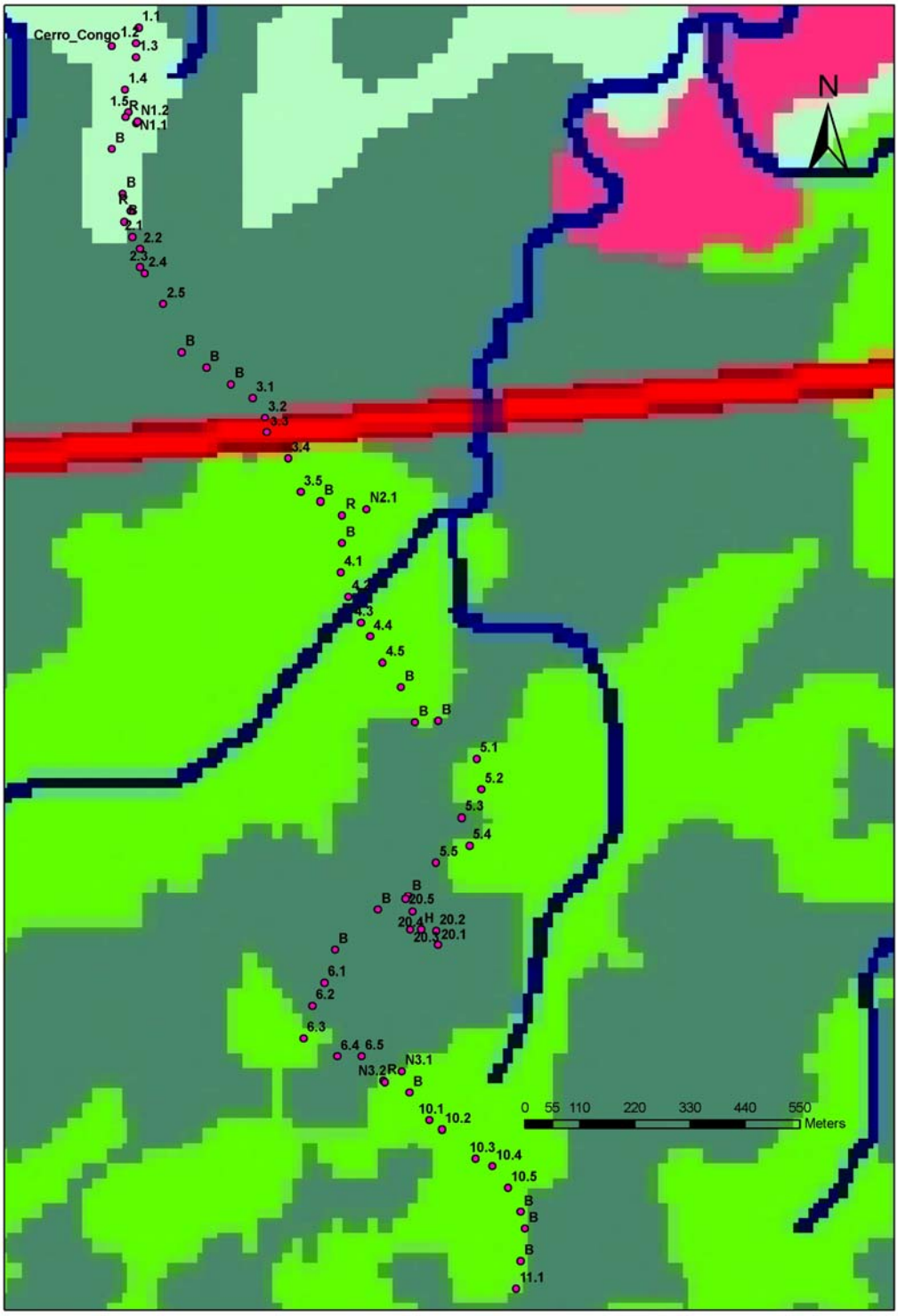


Plate 3.4: Further improved scale map, showing transects 1 (T1) to start of T11.

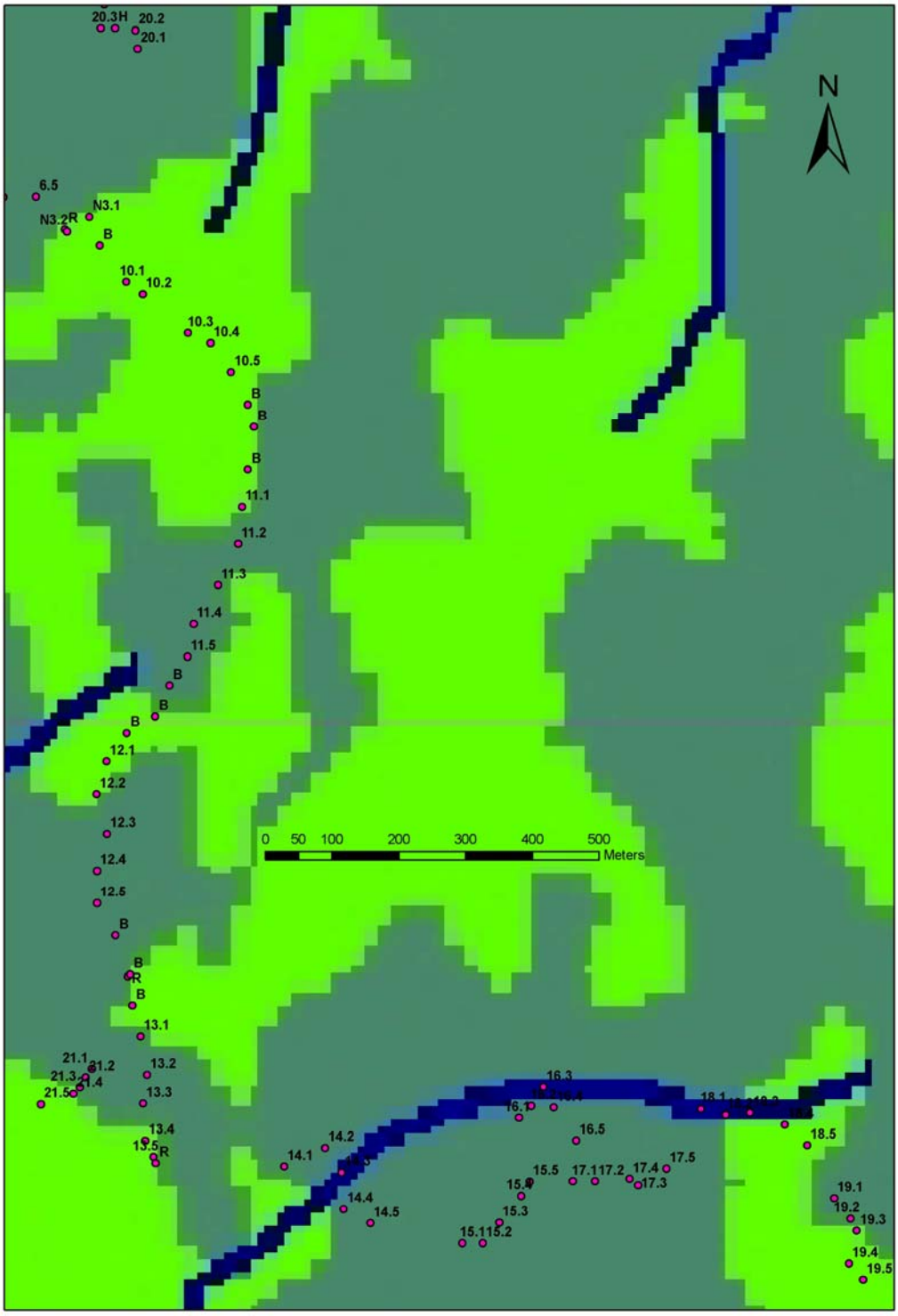


Plate 3.5: GIS map at larger scale of T6/20 to T19 (the end of the main trail assemblage).

3.2. Observation and local knowledge

There is much that could be taken from both the transect data, observations and sightings of herpetofauna in non-transect areas or times and from general aesthetic observation and further information from local knowledge, mainly through the project guide Carlos.

The following series of graphs and table show the basics of what can be gleaned from the raw data collected in the field.

Fig 3.1. Shows the elevation profile of all the 50m GPS points along the main trail. The main trail is used in this study to mean the assemblage of transects that line the trail from San Miguel to the reserve interior; this assemblage is the main focus of this study, due to the environmental gradient it covers it is therefore the subject of the majority of the analysis. The order of the main trail transects can be seen in the GIS images above (plates 3.1 to 3.5) and is also shown as the x-axis to fig 3.3.

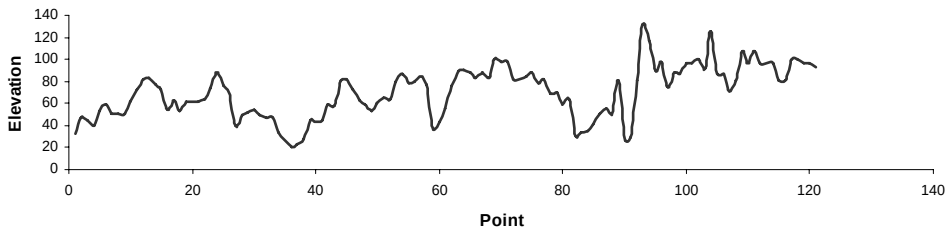


Fig. 3.1. Elevation (m) profile of the main trail from beach/coast level in San Miguel (point 0) to the end of T19.

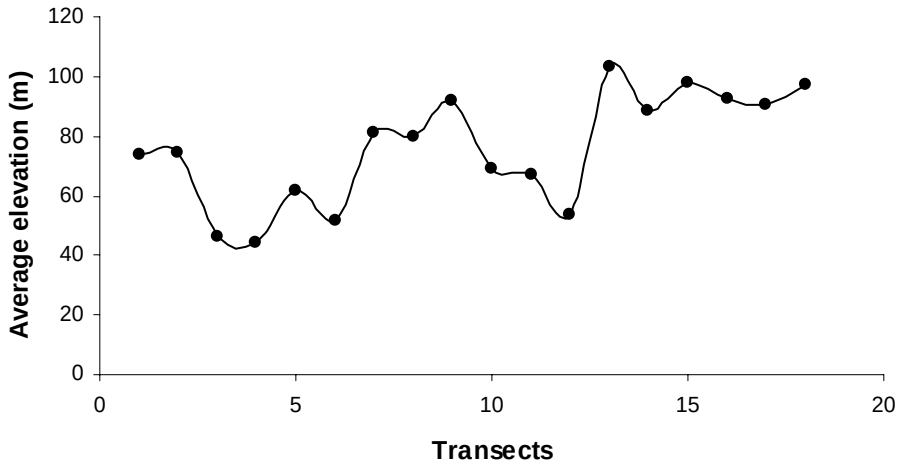


Fig. 3.2. Profile of average elevation for each transect from T1 to end of main trail.

Fig. 3.2. shows the average elevation (from GPS) of each transect along the main trail. These values are those use used as the environmental variable 'elevation' used in the following analysis. Both Fig. 3.1 and 3.2 show the dramatically undulating topography of a north-south trail through the interior of the reserve and therefore El Rey.

Fig. 3.3. shows the changes in the remaining environmental variables of vegetation cover and maximum height of the canopy layer. The maximum canopy height steadily increases as one gets further into the interior of the reserve and hence with increasing maturity of the forest trees; there is a small decrease at T20 due to this area being a recent regrowth area after previous farming. The low canopy cover and high mid-storey and understorey at T20 also confirm this vegetation structure. Generally mid-storey and understorey show similar patterns along the gradient, the more open areas tending to show higher value, due to reduced canopy competition. Canopy cover is rarely similar to understorey. T6-T12 shows a unique vegetation structure, where there is an almost simultaneous rise of all three cover types at similar values; this corresponds with the elevation rise between these points (see fig. 3.1) and shows how rises in elevation seem to coincide with increases in vegetation cover of presumably less disturbed or degraded forest.

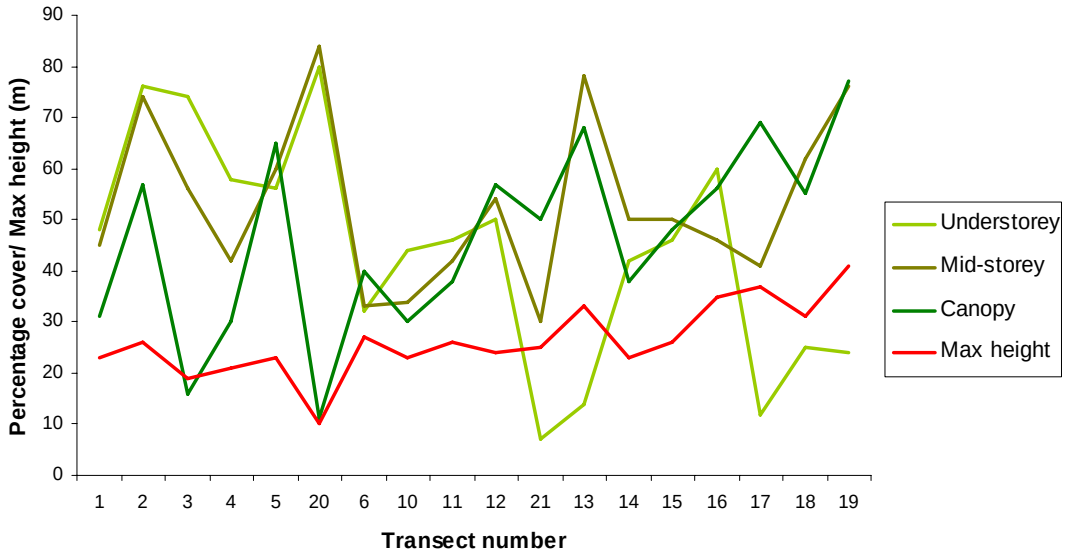


Fig.3.3. Change in average vegetation cover for each transect along main trail and change in Maximum height of canopy (in metres).

A total of 33 species (and 2 possible ones) are shown in the species list (appendix 3.10), this shows all species known to be in Las Perlas (Cochran, 1946 and Barbour, 1909 papers and authors fieldwork). Species x is an unknown species found in T5, as this was not properly identified it is excluded from these lists. During this study a total of 15 species (and 2 possibles) were identified in the inventory for Isla Del Rey; 14 of which were found within the reserve (the other being the urban settling house gecko - *Hemidactaylus frenatus*); 10 species (and species x) were found on the total of all transects; 8 (and Species x) were recorded on the main trail transect assemblage. Table 3.1 shows a selection of the herpetofaunal observation recorded during non-transect times and areas; all the snakes seen were during these observations, including at least one solid red snake that would be a new species record for the islands (but not identified conclusively), the table also shows some weights and total lengths of individuals (some after capture and others by trained estimates by eye). The table of local knowledge observations (appendix 3.1) helped to clarify the above species list and the potential species that have yet to be recorded.

Fig. 3.4. Shows the species composition of the individuals recorded on the transects. The species majority of the main trail species are species that are forest edge species (*Norops tropidogaster*) or those indicative of open areas and or disturbed habitat (either naturally or by human presence or disturbance) (*Gonatodes albogularis, Mabuya*

unimarginata and Ameiva Ameiva). T5 shows the highest species richness and the Mangrove (M1-3) transects show a different species composition centred around *C.similis*. The night transects display the expected results of three night-time transects along rivers, this being *Bufo marinus* and *Basilicus basilicus*. The surprisingly low count of *Iguana iguana* is due to their elusive behaviour high up in the canopy of the mature trees; many were heard or briefly seen, but not conclusive visuals to record. The sexual dimorphism of *G. albogularis* (males with orange-yellow head and black body; females with a speckled mottled olive-yellow and black head and body) made it possible to identify the sex of most of the individuals of this species; 11 males to 9 females, and 2 juveniles were found in the transect data.

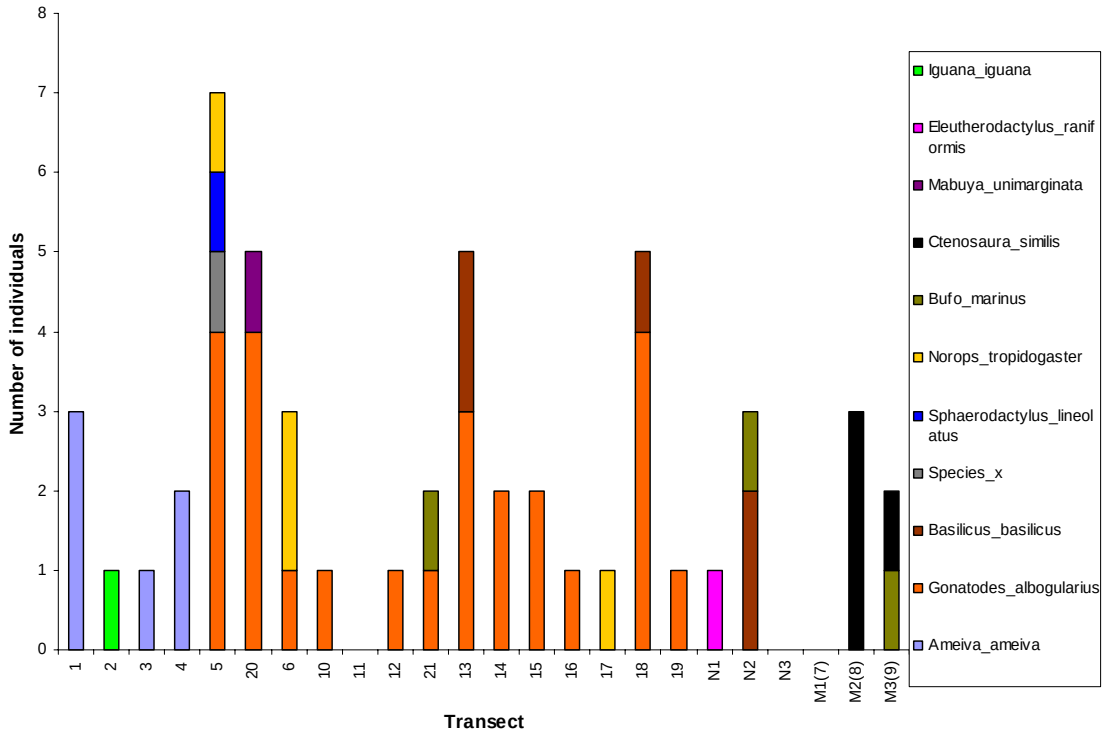


Fig. 3.4. Species composition of each transect; night and mangrove transects placed separately at the right end of the graph.

The table (appendix 3.2) of summary of vegetation notes, shows a plant composition typical of disturbed habitats; the most disturbed transects (one containing the most burnt or open areas), such as T1 in particular, are in the first half of the environmental gradient of the main trail. These disturbed areas are commonly associated with Bromelia and Heliconia presence and show the majority of the disturbance tolerant

herptiles species and are significantly the closest transects to the San Miguel urban/ human settlement area and its sphere of influence on the surrounding forest habitat.

Table 3.1. Herpetofaunal observations in non-transect location or during non-transect times [Total Length (TL) and weight of those captured also stated].

Species (common)	Species (Scientific)	captured?	TL (cm)	Weight (g)
Boa constrictor	Boa constrictor	yes	208	5300
4 x whiptail	Ameiva ameiva	no	30	?
Brown vine snake	Oxybelis aeneus	yes	150	130
Green vine snake	Oxybelis fulgidus	no	100?	?
juv Green Iguana	Iguana iguana	no	?	?
juv Jesus Christ Lizard	Basilicus basilicus	no	7	?
3 x House Gecko	Hemidactaylus frenatus	no	10?	?
Yellow-headed lizard	Gonatodes albogularius	no	5.-7	?
2x Jesus christ lizard	Basilicus basilicus	no	?	?
6 x Yellow-headed lizard	Gonatodes albogularius	no	5.-7	?
3 x House Gecko	Hemidactaylus Frenatus	no	10?	?
2 x Whiptail	Ameiva ameiva	no	30	?
Jesus christ lizard	Basilicus basilicus	no	?	?
clay/black Iguana	Ctenosaura similis	no	50+	?
2 x Whiptail	Ameiva ameiva	no	20 & 30	?
2x Jesus christ lizard	Basilicus basilicus	no	30-40	?
1 black snake - unknown species	possibly Clelia clelia (or Spilotes pullatus)	no	150-200?	?
1 rat catcher snake	possible juvenile Clelia clelia or Pseudoboa neuwiedii	no	under 100	?
3x Jesus christ lizard	Basilicus basilicus	no	largest 30+	?
2 Yellow-headed lizard male	Gonatodes albogularius	no	?	?
2 Yellow-headed lizard female	Gonatodes albogularius	no	?	?
Anole	Norops tripidogaster	yes	13	?
Boa constrictor	Boa constrictor	no	150-250	?
unknown red snake	possible juvenile Clelia clelia or Pseudoboa neuwiedii			

3.3. Analysis of ecological data

3.31. Species Richness, abundance, density and species diversity indices

The relationship shown by all the scatterplots within Fig 3.5 and 3.7 are all insignificant to the standard significance level used in this study of $P<0.05$ (see table 3.2) and have extremely poor linear relationships; for example one of the most significant and correlated relationships is for Chao 1 index against elevation variable ($r^2_{17} = 0.10$, $P = 0.19$). The relationship and correlation is indicative of the non-linear relationship present, applying a linear regression and significance level here should be accepted with caution as the true relation and significance level maybe well be high and significant respectively. Due to this polynomial or non-linear relationship transformations of the data using the commonly used standard Log, exponential and square-root transformations were performed on the data to approach it to linearity; however this did not yield more highly significant results, therefore the original relationship was kept.

Apart from slight differences with density and relative abundance, all the diversity indices and SR showed the same almost bimodal response to distance from town variable, this double hump-backed relationship shows a high peak at what seems to be the most species rich transect of T5, the second smaller hump is likely to represent T13 and T18. This bi-modal or polynomial relationship may indicate several communities or guilds present in this assemblage.

Elevation displays the highest diversity, SR and densities/abundance at mid-elevation of 60-70m; a pseudo-unimodal relationship is shown for all diversity indices and SR, this pyramid cloud of data shows a steep rise from low elevations and decline to high elevations in diversity and SR. The relationship is however concentrated within a small range of elevations, from 40 to 110m.

Fig. 3.6. all show very similar typical species-cumulation curves; the relationships are highly correlated and extremely significant as one might expect (values not included for this reason). These curves are particularly common in ecology, especially when attempting to estimate a total potential number of species for an area. These stepped curves show that as more individuals are found, as the relative abundance increases, as

the number of transects surveyed increases, as effort increases and as one surveys further from human habitation; the number of species steadily increases to a slowing down or plateau effect.

When using the data from the 3 mangrove transects and 3 night transect undertaken and adding this to the scatterplots for the 4 diversity indices (appendix 3.4), the relationship is consolidated and is little improvement on the original plots.

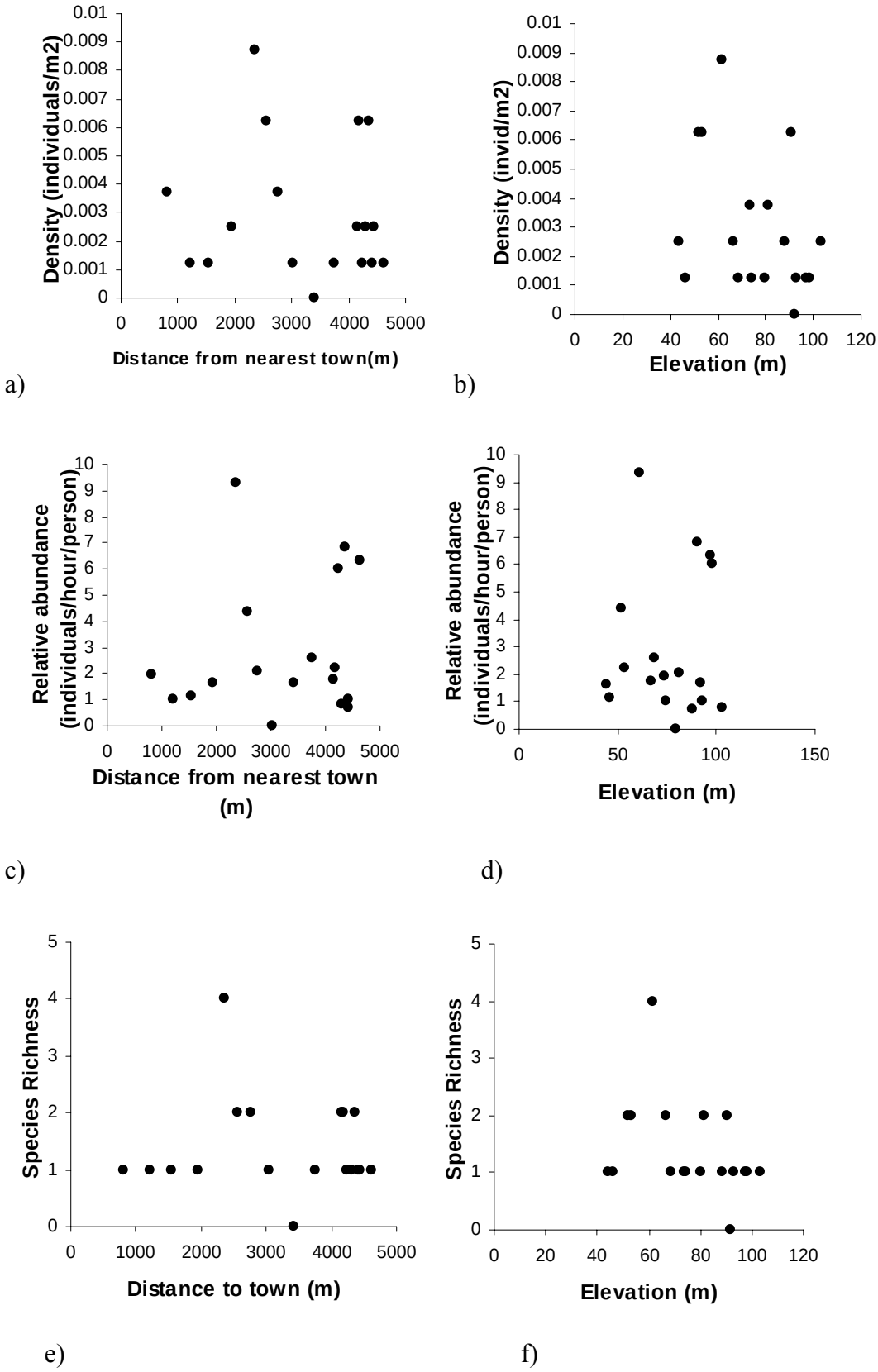


Fig.3.5. Scatterplots showing the relationship between Density, Relative abundance, SR against Distance to town (a, c and e respectively) and against Elevation (b, d and f respectively).

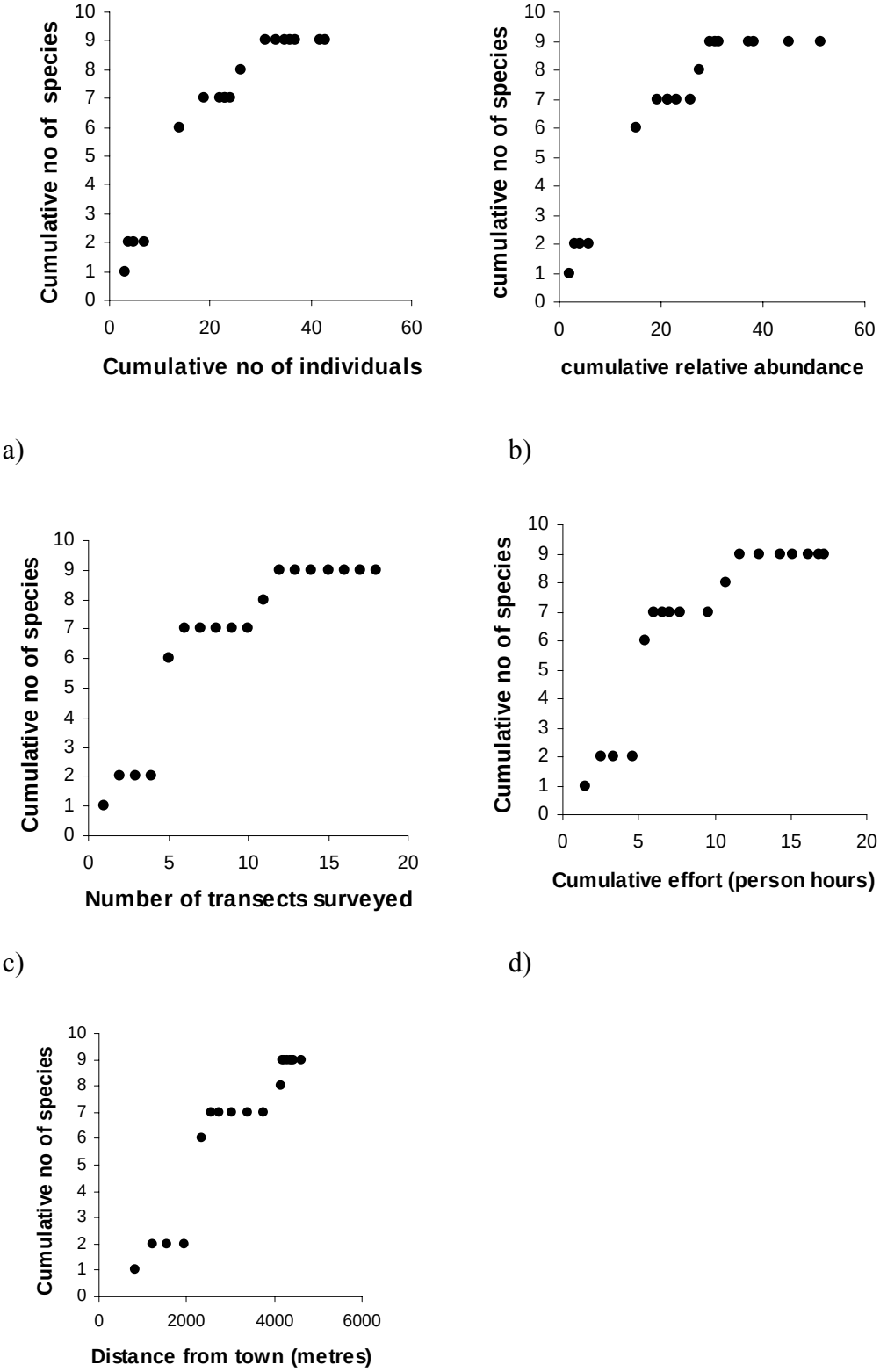
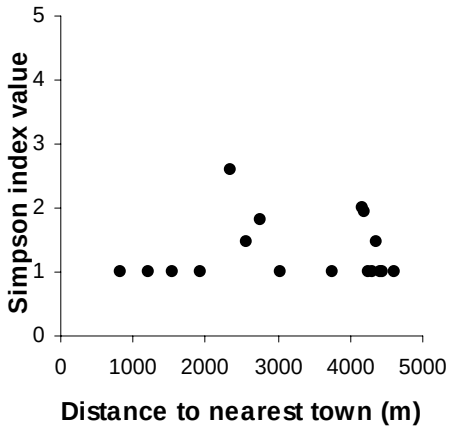
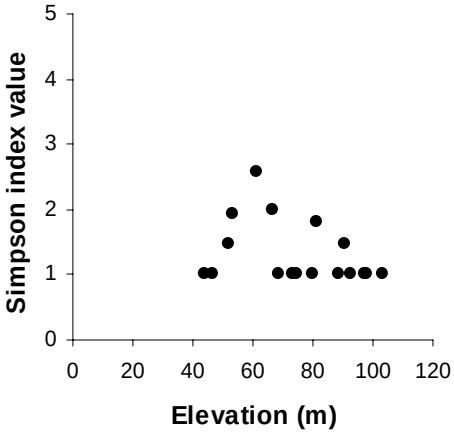


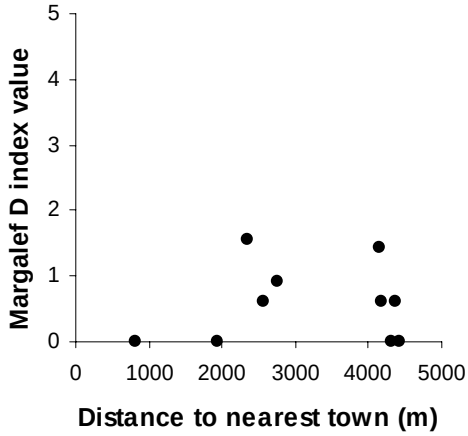
Fig.3.6. Scatterplots showing species accumulation graphs for the relationship between Cumulative number of species and a) cumulative number of individuals, b) Cumulative relative abundance, c) Number of transects surveyed, d) Cumulative effort, e) Distance to town.


Simpson index value
Distance to nearest town (m)

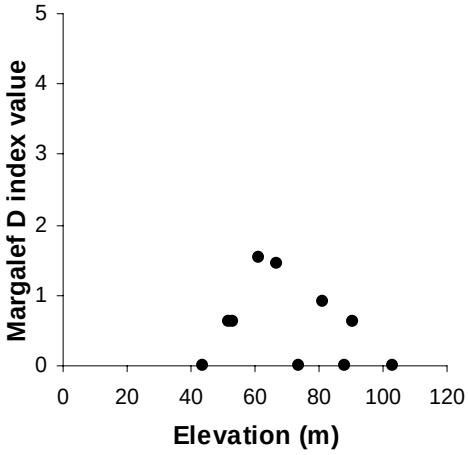
a)


Simpson index value
Elevation (m)

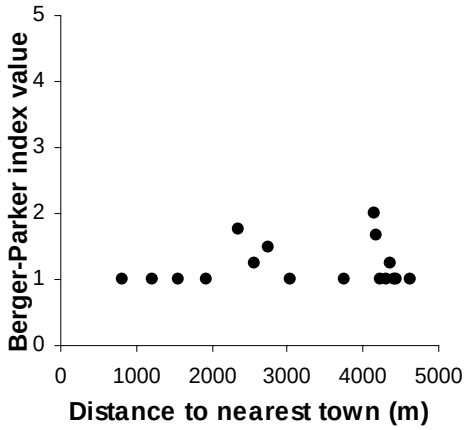
b)


Margalef D index value
Distance to nearest town (m)

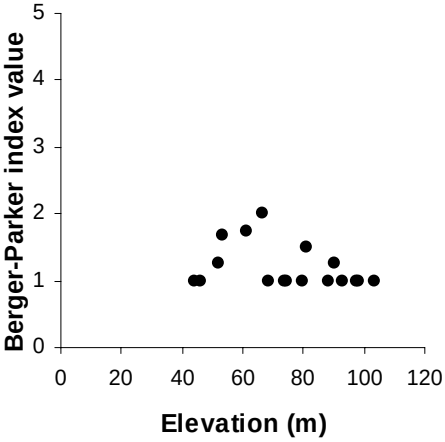
c)


Margalef D index value
Elevation (m)

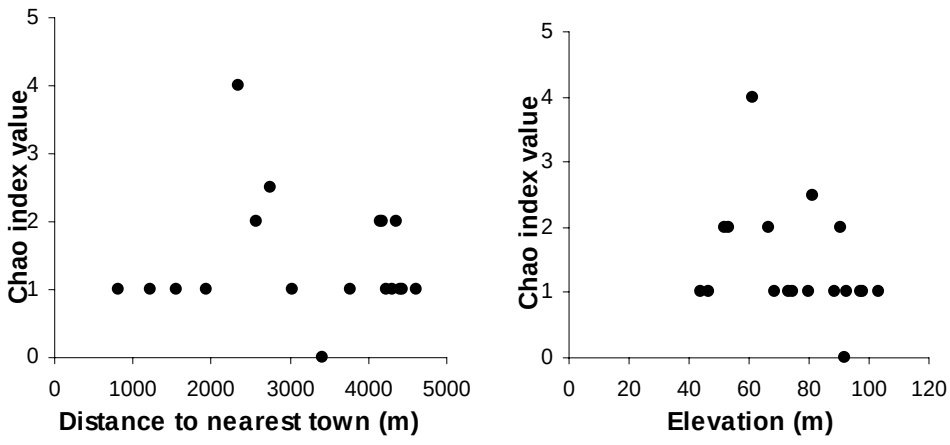
d)


Berger-Parker index value
Distance to nearest town (m)

e)


Berger-Parker index value
Elevation (m)

f)



g) h)

Fig.3.7. Scatterplots showing the relationship between Simpson, Margalef D, Berger-Parker and Chao 1 species diversity indices against Distance to town (a, c, e and g respectively) and against Elevation (b, d, f and h respectively).

Table 3.2. Regression correlation (R-squared) and significance (p-value) of diversity index and environmental variable (elevation and distance to town) relationships.

Relationship	R - squared	P -value	Degrees of freedom
Simpson v elevation	0.10	0.21	16
Simpson v distance to town	0.00	0.90	16
Margalef D v elevation	0.06	0.50	9
Margalef D v distance to town	0.01	0.78	9
Chao 1 v elevation	0.10	0.19	17
Chao 1 v distance to town	0.00	0.80	17
Berger-Parker v elevation	0.10	0.22	16
Berger-Parker v distance to town	0.02	0.64	16
Density v elevation	0.13	0.14	17
Density v distance to town	0.01	0.73	17
Richness v elevation	0.12	0.16	17
Richness v distance to town	0.00	0.84	17

T-tests

The t-test to compare intervened (T1,4,5,10,18,19,20) and non-intervened (T2,3,6,11,12,13,14,15,16,17,21) habitats is displayed in appendix 3.5. The results show no significant differences (using the 2-tail p value) between habitats for SR and the 4 diversity indices.

Beta-diversity

Whittaker β_w overall beta-diversity of the assemblage (main trail) = 6.48.
This indicates a high beta-diversity, that could be assumed to show roughly 6.5 (6-7) distinct communities along the assemblage/gradient (Mccane and Grace, 2002; cited in Sassen and Debacker, 2006).
Whittaker β_w between sample pairs: Intervened against Non-Intervened = 0.38 (out of 1). This shows a low diversity, therefore the two habitats are not that dissimilar (corroborating the t-test results).

3.32. Multivariate analysis

As detailed in the material and methods section, the DCA (fig.3.8 a) shows medium to high beta-diversity (species turnover) of 3.5 SD units. Therefore both linear and unimodal methods were used in the analysis (PCA, CA and CCA). The DCA also shows an unusually long gradient in the second axis is 12 SD long, but it is difficult to suggest much from the second axis as it may mainly be noise (Gauch, 1982).
The DCA show three distinct community clusters along the first axis, the species and sample plot shows *I.iguana* and *A.ameiva* as two distinct communities separated from the remaining species by 3 SD units. Looking at the CANOCO log file 57.2% of variation in the data is explained by axis 1 and 2 (28.6% and 28.6% respectively).

The linear relationship of the PCA (Fig. 3.8.b) has identified *A.ameiva* and *I.iguana* as highly correlated to each other and samples (transects) 1 to 4. *G. albogularis* is highly negatively correlated to the above species and the importance of this variable is high due to a very long vector (length of the arrow); *M.unimarginata* and *Basilicus basilicus* are also both negatively correlated to the same species. Looking at the CANOCO log file 47.4% of variation in the data is explained by axis 1 and 2 (28.6% and 18.8% respectively).

There is a similar community clustering with the CA (Fig 3.8 (c)) of the species data compared to the DCA. This time the three clusters are slightly different in their composition. *A.ameiva* and *I.iguana* are now associated together and with transects 1-4, as with the PCA; Leps and Smilauer, (2003, p4) confirm that this proximity of species symbols to sample symbols in feature space indicates that these species are likely to occur more often or with higher abundance than those with symbols from further away, this is true for all the ordination plots. Looking at the CANOCO log file 45.5% of variation in the data is explained by axis 1 and 2 (28.6% and 16.9% respectively).

The ordination plot of DCA, PCA and CA for the environmental variable data are displayed in appendix 3.6. The PCA shows that canopy cover, maximum height of canopy, distance and elevation as well correlated together; understorey seemingly is

highly negatively correlated to elevation and midstore is at a right-angle to all other variables, indicating no relationship present. The PCA shows indications of a horse-shoe artefact in the data. DCA and CA show little useful information; the CA is highly affected by an arch effect and all the samples are clustered in the centre of the graph for the DCA. Looking at the CANOCO log files 76.1% of variation in the data is explained by axis 1 and 2 (56% and 20.1% respectively) for the PCA; for DCA 78.5% of variation in the data is explained by axis 1 and 2 (71.1% and 7.4% respectively); finally the CA log file shows that 88.8% of variation in the data is explained by axis 1 and 2 (73.5% and 15.3% respectively).

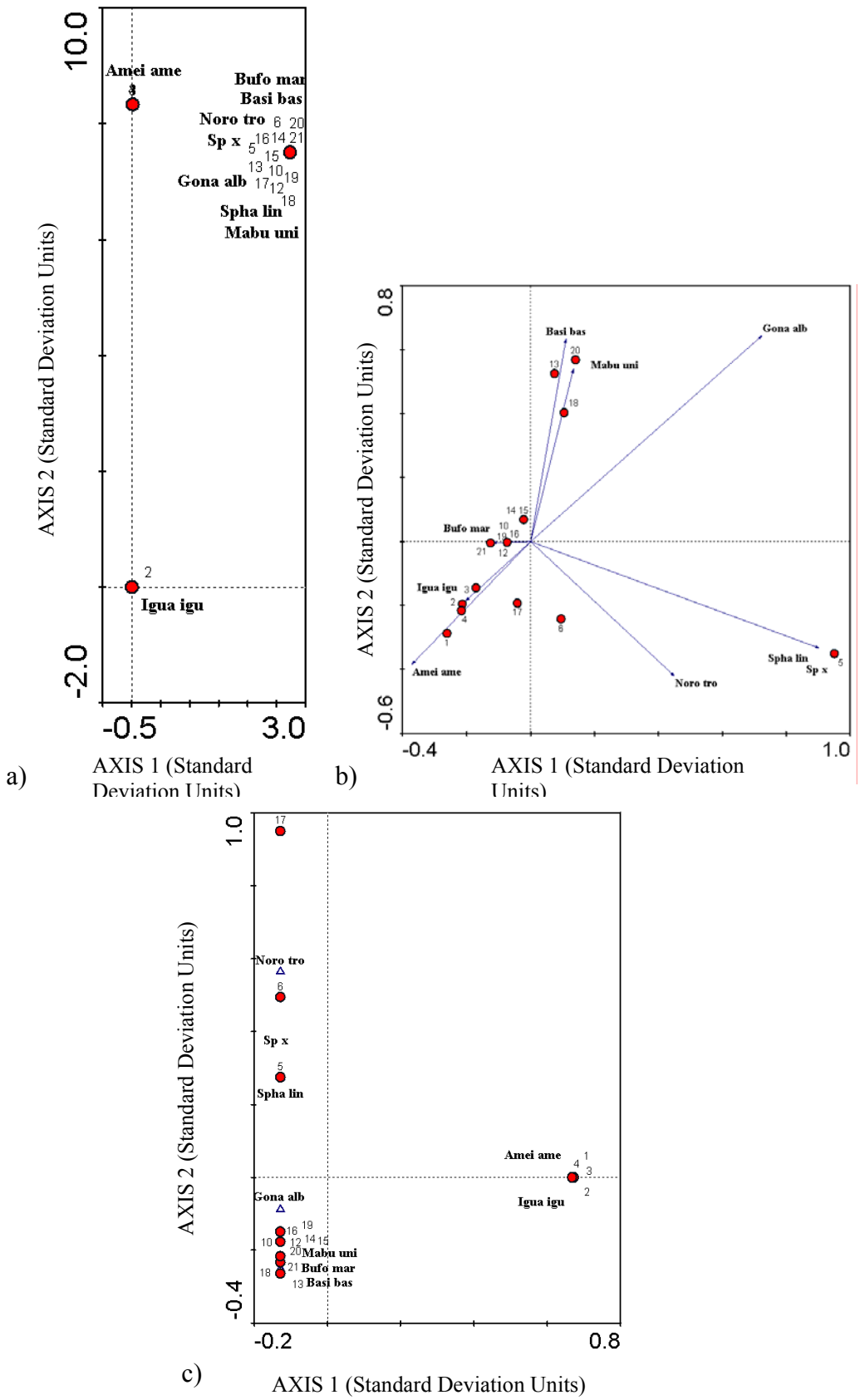


Fig. 3.8. Ordination plots for species and sample data: a) DCA, b) PCA and c) CA.

As with the PCA the most important variable for the CCA (fig 3.9.) is 'distance to town', as it is the most closely correlated (negatively) with the primary axis; *A.ameiva* is extremely negatively correlated to this variable, indicating that the further you go from human habitation, the lower the abundance there is of this species. Midstorey cover is the most correlated to the secondary axis (negatively) and is therefore particularly unrelated to distance from town. *M.unimarginata* is well correlated to transects 19 and 20 and to strong arrow of midstorey variable. *I. iguana* is strongly correlated with transect 2 and the understorey variable. There seem to be 6 distinct species communities shown by the CCA; these being the three mentioned above, a *N. tropidogaste*r community, a *B. marinus* community and a community containing the remaining species which seems equally correlated to distance to town as midstorey (although closer to distance to town).

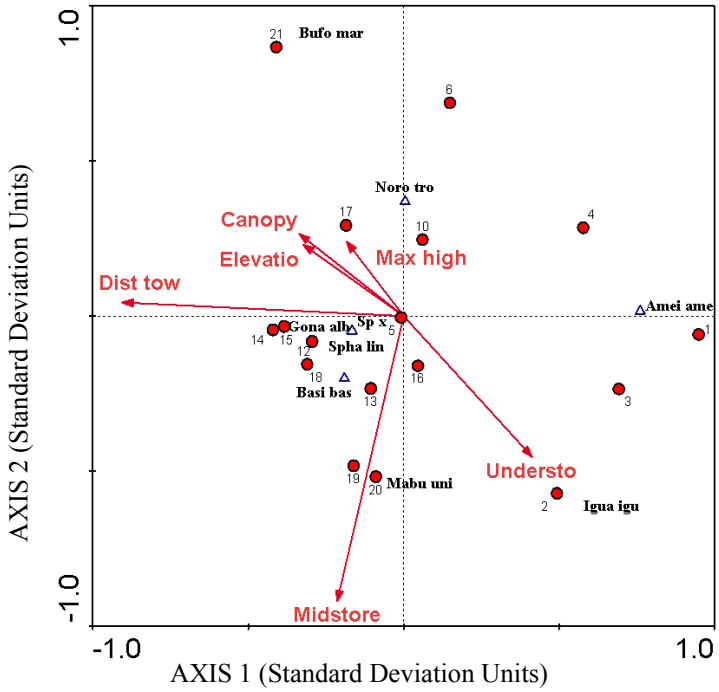


Fig. 3.9. Ordination tri-plot (species, samples and environmental data) of CCA.

Looking at the results of the monte carlo test in Table 3.3, it shows that all variables are not significant to the P<0.05 level except distance to town (P=0.006). All the variables explain similar percentages of the variation (inertia) in the data accounted by the first axis (from 5-10%), except that of 'distance to town' which explains or accounts for almost 20% of the variation in the data.

A reduced CCA using forward selection also identified 'distance to town' as the only significant variable (at P<0.05 level).

Table 3.3. Table of percentage variation accounted for in the first axis and significance thereof (using monte carlo test).

Environmental Variable	Percentage (%) variation accounted for by axis 1	P- value
Understorey	9.9	0.124
Mid-storey	9.1	0.182
Canopy	8.6	0.196
Max height	6.3	0.402
Elevation	5.3	0.568
Distance to town	19.8	0.006

The output log of the original CCA (appendix 3.8) shows the weight correlation matrix, those figures that show high correlation (generally over 0.6) are highlighted in red. Distance to town and Midstorey are strongly negatively correlated to axis 1 and 2 respectively (as seen through the locations of the arrows in the CCA plot). It seems that the fourth axis is the most important (for the remainder of the variables) after the first 2; the graph as shown in appendix 3.7 displays a strong positive correlation for canopy cover and max height with axis 4 and a strong negative correlation with understorey.

The summary table at the end of appendix 3.8 gives us much information regarding the variation or inertia in the data. The important values are also highlighted in red here. Eigenvalues show the importance of axes gradients; the eigenvalue for axis 1 is 0.808, this is a fairly high value representing a fairly strong gradient; the second, third and fourth axes are progressively weaker gradients (Palmer, 2007). The table shows that axis 1 and 2 explain 32% of the variation or inertia in the data (23.1% and 8.9%); axis 1 shows by far the most inertia in the data, however with all four axes explaining only 46.7% of the variation in the data there is over half the variation explained by other factors (potentially other variables not measured). To measure how well the variables explain the observed species composition we can devise an analogue to r^2; this can be

done by dividing the amount of variation explained by environmental variation (sum of all canonical eigenvalues) by the overall inertia: therefore $r^2 = 0.514$ (1.799/3.498).

4. DISCUSSION OF RESULTS

4.1. GIS, Observations and local knowledge

In attempting to achieve the aims of this study, the initial idea was for a single trail or gradient of transects to go from the reserve boundary to as far into the centre of the reserve as possible. It is commonly appreciated that when using GPS there is some error involved, that one must accept this as limitation of the equipment; the techniques to reduce this error (described in the methodology) were employed, however it seems that the start point near to the location 'Cerro Congo' (Plate 3.3) is some distance from the reserve boundary and its actual location on the base map. It is unlikely that the GPS is that inaccurate and it therefore seems that the calculation of the reserve boundary, Cerro Congo (both from map coordinated to GPS coordinates in the field) and the local people's definition of which high point is Cerro Congo are more probable sources of error. The GPS points show a trail to just off the coast at San Miguel, this is the beach at San Miguel and therefore shows that the GPS trail seems to fit the base map. At many of the GPS points where a river is indicated, there is not a river marked on the map (Plate 3.3) and vice versa. This could be due to only the major rivers being located on the map or slight inaccuracies with the GPS; the constant crossing of the river by T14-19, was as experienced in the field, many of which were not made as GPS points.

The observations gained from the transect data collection and general visual encounters showed a distinct pattern of vegetation and herptile species composition. Although much of what was observed needs to be statistically verified and analysed using the techniques already described and to be discussed later in this section, there is much that one can elucidate from visual observation and experience of the habitat to be studied. This may sound antiquated, but much of what one observes in herpetofaunal ecology and behaviour is through visual encounters and study; this is especially important due to the low relative density and abundance of most herptiles (compared to other groups

such as birds), their cryptic nature, response to danger/predators and weather conditions and their extreme mobility.

The surprising observation was that of how much the forest habitat on the edge of the reserve has been disturbed or degraded; the local hunting and agriculture were evident in these areas. Many of the areas that were burnt or had large cleared areas (appendix 3.2) were firstly near the human habitation of San Miguel (mainly transects 1-6 and 20) and its agricultural land, and secondly seemed void of any agricultural activity (despite the convincing language of our local guides); with evidence of gun cartridges and open areas being surrounded by large trees, it looked suspiciously like these areas we used to hunt Iguana or feral pigs that have been forced into the clearing (Guzman, pers. comm). The evidence shown in appendix 3.2 table of no burnt patches or cleared areas (not to be confused with natural clearings) after T11 and the steady increase in canopy height (Fig 3.3) and the apparent increases in forest density (convergence of under-, mid- and canopy cover values seen in fig 3.3), shows that there is a definite change in habitat quality and age as one goes further from habitation. Despite the GIS classification of the land cover types, there seems to be a three way distinction between a scrub/agricultural zone of influence close to San Miguel, the secondary/intervened/regrowth habitat that is T1-6, T20 (especially, with many banana palms this is one of the few areas that shows some evidence of agriculture) and T10 and T11, and finally a less intervened/more mature forest as one enters further into the interior (T12-19 and T21).

The theories of equilibrium and island biogeography (MacArthur and Wilson, 1967) seems to be important for the herpetofauna of El Rey; these along with species-area relationships (Zug et al., 2001; Buckley and Jetz, 2007) essentially describe islands as having higher abundances of individuals and therefore higher density levels than the mainland, but have lower SR and in theory diversity than the mainland. The lack of predators seems to be one main reason for this.

The species list (inventory) for Las Perlas (appendix 3.10) shows a total of 33 species, with 2 possibles; this is not even 10% of the total 395+ species identified in the whole of Panama (the majority of which being mainland habitat) (Appendix 3.9). There are no endemics, apart from possible sub-species *Boa constrictor sabogae*, on the islands; hence there is a poor SR and lack of endemism, but a high abundance of the species that are present. Included in those present are several species listed under the CITES convention (*Crocodylus acutus, I. Iguana* and *B. constrictor*); the latter two and

C.similis are protected by Panamanian law (appendix 3.10). The number of species seen during fieldwork was almost half the total species count for the islands (15), however only 8 species were seen (plus Species x) on the main trail transects; this is a particularly low number, hence why many common analysis techniques were not used (such as ANOVA and TWINSPAN).

Although the emphasis of the study was on the transects in the main trail, there were three transects in the mangrove swamps on the west coast of the island and three night transects that were undertaken; these were mainly intended as test data to assess the habitat and type of species found for future research. The mangrove transects showed a much different vegetation that, other than the mangroves species on the edge of the land, were much denser and mature habitats/forests; the species found were the coastal and riverine loving species of *C.similis* and *B.marinus* . There was no evidence of any of the species that are indicative of forest edge or disturbed habitat, found in the main trail transects; evidence, no doubt, of the impact human disturbance has on habitat quality.

This therefore leads on to a quick assessment of the species composition of the main trail. As mentioned earlier (above and chapter 3.2) the majority of the species were forest edge or indicative of human settlement/disturbance. Forest clearance for whatever reason leaves canopy gaps that attract heliothermic lizards such as *A.Ameiva*, this species must have these areas to thermoregulate; Sartorius et al. (1999) showed this requirement for tests they performed in open disturbed habitat (caused by anthropogenic change) and forest habitat (with high shade/canopy cover) in Brazil, the species requires a certain amount of sunlight and habitat, whenever this species was observed in fieldwork it was always in open areas or moving between open areas. Boyden (1976, p75) described *A.Ameiva* as: “ground dwelling, prefer open country and generally forage in areas where cover is nearby. Most individuals forage actively when the sun is shining but disappear with cloudy or rainy weather (lower temperatures)”; the last part of the statement was clearly seen in the many rain storms or within hours of storms during fieldwork, where no individuals were seen, as they were hiding in their burrows/holes. Many of these thermophilic or heliothermic lizards have restricted home ranges (Boyden, 1976); their lower energy requirements means that they can viably live in small fragmented habitats at high densities (Bell and Donnelly, 2006); the heliothermic *B. basilicus* was mainly seen very close to rivers or streams, this is confirmed by Aucoin et al. (2000) statement that they are not found more than 5m from

the riverbank. *A. tropidogaster* is similar in its characteristic, but is more intermediate in its thermoregulatory requirements as it is occurs in the ecotone between grassland and forest (i.e. forest edge) (Ballinger et al., 1970).
The distribution and abundance of *G. albogularis* is influenced more by structural configuration of its environment than by the microclimatic conditions, densities are closely related to densities of scaly barked trees (Heatwole and Sexton, 1966); this species was one of the most commonly seen in the transects and did indeed show this preference along with aggressive defending of its territory (Ellingson et al., 1995).

4.2. Analysis of ecological data

4.21 Species Richness, abundance, density and species diversity indices

Density and abundance seem to be intrinsically linked to species-area and island biogeography research or discussion, this has already been discussed with this chapter and in previous ones (sections). The simple fact that El Rey is an island in the pacific, isolated from the mainland and within a closely connected archipelago system, is therefore likely to lead to such discussions or research, and indeed should be an important theme for future research. The work in this project was aimed purely on the ecology and diversity of those species of herpetofauna (and their associated habitats) residing within the hydrological reserve boundaries and there was no comparison with other islands; therefore limited thought was driven to the above issues.
Despite this there are things that one can glean from the density data collected here. Firstly, even the highest value in T5 shows an extremely low density, the density being 0.009 individuals per metre^2 or 114 metre^2 of area per individual herptile (this the reciprocal of 0.009); this is a rather large area covered only by one individual. Despite these values it is more important to look at the relative changes from transect to transect, rather than an estimate of density that is highly restricted by the method of fieldwork employed and the clear knowledge that individuals are not equally spaced out over the entire area of the island; densities will vary depending on the number of niches available, the resource availability and home range extent (to name a few). The

plots of density against elevation and distance to town show similar relationships to those of the species diversity indices (discussed later), both show a probable polynomial relationship, with distance to town showing a distinct bimodal or polynomial shape that is common for relative abundance, SR and species diversity; a crude representation of this is shown in Fig 4.1.

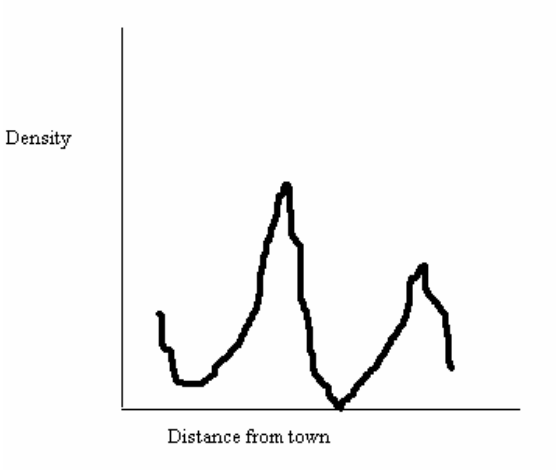


Fig. 4.1. The basic shape of the relationship of distance from human habitation against density (similar shape seen for relative abundance, SR, and the four species diversity indices).

The changes in habitat and species composition along the main trail are evident within this above shape; the shape in Fig 4.1 is the same as with abundance (as abundance is intrinsically related to density). If one looks at Fig 3.2 (T20 and 6 are the 6th and 7th transects in this graph, respectively) and 3.4, the first peak above seems to represent T5, T20 and T6 which is in the mid-elevation range; as previously discussed (and further later), this is a very commonly seen trait of highest densities, SR or diversity at mid-altitudinal ranges (Gaston, 1996). The second peak seems to represent the high numbers found in T13 and T18, T13 has a particularly low elevation and T18 a particularly high one. The high numbers in these two transects is therefore not potentially associated with the elevation variable; but pure observations that both areas were near or directly next to rivers or streams and contained the perfect moist habitat requirements for many herptile species, particularly *B. basilicus* that was found at both sites, seem to give reason to the second peak. The high mid- and canopy cover values for both T13 and T18 and the low understore cover (fig. 3.3) are also ideal conditions for the usually arboreal species seen in these transects (*G. albogularis* and *B. basilicus)*;

the vast number of scaly trees prevalent within both transects is also ideal for the dominant *G. albogularis* species (Heatwole and Sexton, 1966).
The humped-back shape seen in the form of the unimodal relationship, which is often an assumed close projection of many ecological systems and processes, was found to associate density and SR as a function of island area (Buckley and Roughgarden, 2006). The relation has been described as a significant and robust finding (Buckley and Roughgarden, 2006); this goes someway to dispel the problems of poor linear regression and significance that was found in the plots in fig 3.5 and 3.7. The biomodal (polynomial) relationship could be the influence of two or several unimodal community or guild species responses along the transect gradient.
Other influences, such as that of avian predation, have been known to affect the density of lizards (Anoles in particular) on islands (Buckley and Roughgarden, 2006; Poulin et al, 2001). Populations of Anoles especially show instability, which has been reflected in year on year fluctuations of *A. limifrons* density in Barro Colarado,central Panama (in a 19 year census); an assumption that high species diversity is associated with population stability, is therefore erroneous (Andrews, 1991).

Species richness and diversity

The majority of the analysis in fig 3.5 and 3.7 focused on species diversity indices and SR (a measure of diversity); the relationships and lack of high correlation or significance were similar to the above in shape; showing that there are distinct patterns in the data that are expressed in similar forms with differing methods. As with density and abundance the same two environmental variables of elevation and distance to town were used. Graphs using the vegetation cover variables showed no relevant information or relationships to warrant a discussion; this is backed up by Duellman (1966) and other authors showing that herptile distribution and vegetation seem to be independent of one another, and that habitat is much more important.

Conroy (1999) found a similar changeable SR/diversity curve as the distance to town plots in Fig 3.5 and 3.7. Conroy (1999) showed the changes were over an ecotone, this resembles the probable ecotone change between disturbed and less disturbed/more

mature habitats that seem to evolve along the main trail assemblage in this study; this explanation would explicate the non-linear relationship and the increasing evidence of multiple communities or guilds across the assemblage. The Whittaker's beta-diversity measure for the whole transect gave a value of 6.5, therefore a possibility of 6-7 distinct communities (McCane and Grace, 2002; cited in Sasseen and Debacker, 2006); other evidence in the form of the DCA and CA biplots [Fig. 3.8. a) and c)] produced in the multivariate analysis, show very distinct communities (3 and 4 communities respectively) along a reasonably high beta-diversity of 3.5. This other evidence gives weight to the idea of high species turnover and hence diversity across the assemblage, which is aided by many different changes in elevation and habitat type or condition.
The values of SR and diversity are very low for all the diversity indices, with the possible exception of T5, this shows that there is low or weak alpha-diversity and hence as already described, there is a high beta-diversity or heterogeneity. This high beta-diversity is very important as an ecological trait and has great value, despite the low number of species identified within the reserve (although possibly not that low for an island) and the seemingly disappointing density and abundance levels; the beta-diversity is extremely important for conservation and the management of the reserve. The conservation importance is in the number of distinct communities and the variety of niches and habitats changes (particularly in the more mature forest transects); the management issues are in the comparison of habitat quality from the intervened or disturbed to the non-intervened and more mature forest, the effects that disturbance and degradation has had on habitat quality and the type of species that resides. Evidently managers would aim to restore this quality and aim to prevent the entire reserve being dominated by a species poor distribution of forest edge and disturbance adapted guilds (Bell and Donnelly, 2006).
The ecotone results (fig 4.2) found by Conroy (1999) showed similar SR and diversity results, in that they did not differ significantly between positions or locations within the ecotone.

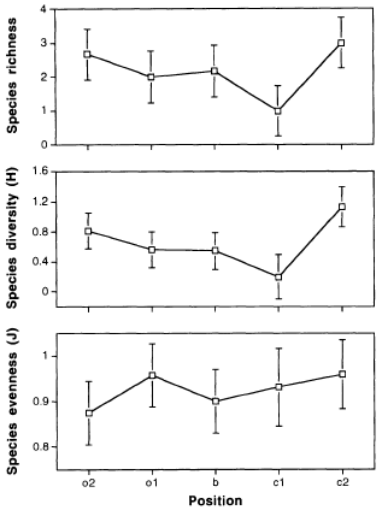


FIG. 4. Change in mean lizard species richness, species diversity, and species evenness across positions. Error bars are 95% least significant differences.

Fig 4.2. Change in mean lizard SR, diversity and evenness across ecotone positions (Conroy, 1999).

The distance to town plots have similar traits within the SR and diversity indices, as with density. There is little further to mention other than these plots showing a flat start to the plot and a small step change on the declining side of the first hump; the number of species, compared with individuals in each transect is therefore not necessarily associated. The Chao 1 index seems to show the most change in the data, in the clearest way; after assessing the indices it seems to give more information in a better way than the other indices, this robust quality of biodiversity estimation has been championed by Peterson and Slade (1988) and Naniwadekar and Vasudeven (2007). Chao 1 was the only index that did not have missing points on the plot due to 'error' values on calculation of the index on some of the transects; the most unsuccessful in these terms and hence plotting the least amount of useful information, was the Margalef D index. Simpson index was robust and successful as many believe it to be in showing evenness qualities of diversity, Magurran (2004) having much evidence of its support within the literature. The Berger-parker index is an index of dominance, and hence shows a flatter plot, where the dominant species influence the diversity values and hence the relationship; the scatterplot does emphasise that indeed the number of individuals counted in the data were dominated by, in particular, three species: *G.albogularis*, *B. basilicus* and *A. ameiva*, evidently seen in Fig 3.4 and 3.7(e).
There is little research of the change in SR or diversity with distance to urban areas or human habitation to associate with the data collected here, however much work on the

similar idea of isolation (minimum distance to intact forest) is accessible within the literature, such as Benedick et al. (2006).

Contrary to the limited state of the literature on the above environmental variable, there is a reasonable depth of work on the relationship of elevation with SR and diversity. The affects of El Nino and climate change causing the upward movement of species ranges to avoid desiccation and the concern over ever increasing fungal diseases among amphibians in particular (such as Young et al, 2001) may add a little conservational background to the need for increases in this research area.
The elevation pyramid shape distributions shown by all the SR and diversity indices indicate a very poor linear distribution, unlike such work as Naniwadekar and Vasudeven (2007) and Scott (1976; with density not SR/diversity), but do clearly show that the highest values are within the mid-elevations (around 60-70m). As already stated T5 is an excellent example of relatively high species diversity at mid-elevations. The shape of the plots or cloud of data points is not too dissimilar to that of a typical unimodal distribution, found commonly in nature and in many papers on the subject, such as Fu et al (2006) and Fisher and Lindenmayer (2005; Fig 4.3 below); this non-linear relation may have polynomial tendencies within this complicated distribution.

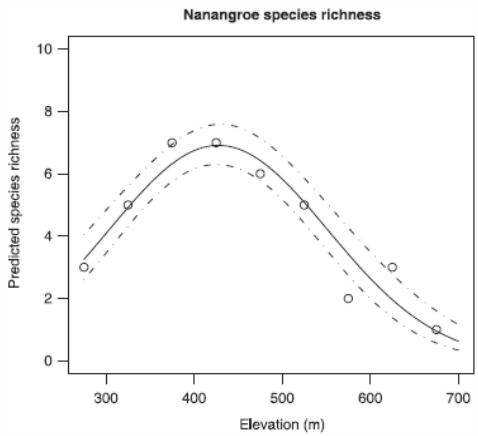


Figure 3 The relationship between elevation and species richness at Nanangroe. Dotted lines show 95% confidence intervals around the predicted relationship ($P < 0.001$).

Fig. 4.3. Humped relationship between elevation and species richness. (Fisher and Lindenmayer, 2005).

The mid-elevation phenomenon leaves Fisher and Lindenmayer (2005, p225) to conclude that lizards are “highly sensitive to elevation”; it seems to a certain extent this is true of the Sauria species in the assemblage surveyed in this study, especially with the dramatically undulating landscape the island contains (a feature noted by the above authors in their study also). One would not go as far as to say that this is a controlling factor, especially as one could say that almost all transects were in mid-elevations and ask the question of what indeed constitutes a ‘mid-elevation’ on an island the size of El Rey in the neotropics, especially as high altitude mountain ranges in the central spine of central America can class mid-altitude or elevation to values such as 1000-1500m.
Fu et al (2006, p919) suggest that area, geometric constraints and climate have been the most commonly cited explanation for the humped and linear relationships between elevation and SR. Naniwadekar and Vasudeven (2007) detail that multi-modal (as potentially the case here) patterns of SR is due to overlapping of species range boundaries; this adds weight to the assumption that the data in this study is showing a high beta-diversity. They also reiterate the complex nature of the explanations for these elevational patterns and suggest competition, resource diversity, stress, habitat complexity and the presence of ecotones and disturbance as the main causal factors (p843). The latter two causes being the two main reasons that have come out of the diversity data here for El Rey, by the evidence of different high species turnover and disturbance-adapted species respectively.

There has been a mental distinguishing between potential habitat types in the data down to intervened or disturbed forest and non-intervened or more mature forest; the attempt at this separation through GIS gave a selection of transects in two classes, at least one transect (T20) was miss-classified by GIS when comparing to fieldwork observations; the map used to produce this data was the original that went with the reserve designation, there is further more up-to-date and possibly more accurate data now available that would be advisable to be analysed in the future. The t-test comparison between the intervened and non-intervened forests assigned gave a not significant two-tail p-value; this either shows the classification of habitat/land cover types was incorrect or erroneous or the differences between habitats are not that vast and the possibility that the assemblage conveys a gradual ecotone change gradient from San Miguel to the interior.

As a final note to the discussion the species diversity index and SR data must be taken as only one aspect of many factors to investigate the ecology of the herptile communities on El Rey; each one comes with many assumptions, inconsistencies and bias. Akani (1999, p639) summarise these issues with the assessment that species diversity indices "cannot provide a wholly adequate description of the biological diversity of a natural community, at least if we do not consider their conceptual limitations….biodiversity should be characterised by different levels of understanding, including composition, structure, and function…".

4.22. Multivariate analysis

The performance of the DCA analysis has already been discussed in relation to the beta-diversity described. The DCA shows the species composition of the main trail assemblage in the clearest and most simply of formats. Conroy (1999) used DCA as their preferred solution for two reasons that are indeed self-evident in the El Rey data: the first couple of axes nearly at all times have some ecological basis, this even the case when they only account for a small percentage of the variance, which is not a problem in the El Rey data with 57% accounted for by axis 1 and 2; the second reason is mainly down to the ease of use and the functionality of the DCA where a concurrent ordination of attributes (species) in object space and vice versa occur (Conroy, 1999,p415 and Gauch, 1982). The first axis shows beta-diversity of 3.5 SD units, this is closest to the 4.0 suggested barrier for using unimodal methods, the analysis of which seemed more useful; a combination of all methods was however taken into account due to this intermediate position within the DCA gradient. The long second gradient is an indication of noise (Gauch, 1982), but taking a purely visual assessment, this helps visualise the three key communities that are represented in the feature space.
The beta-diversity gradient on the axis 1 of DCA (3.5) corroborates the previous discussion that there seems to be a high and distinct beta-diversity within the assemblage. The three clear clusters and their well-separated positions are evidence of the distinct attributes of those communities; all species are in the cluster in the far right corner except *A.ameiva* and *Iguana iguana*, which are separated by 3.0 SD units.

Although this distribution seems to show a clear community separation, which does coincide with these observations in the field, there is a great concern with all the multivariate analysis techniques that the lack of species data in particular is potentially forcing a distribution that may not be wholly a true reflection of the ecological characteristics of El Rey. There are many sources of error in this type of analysis which have already been taken into account and raised previously; there is always going to be concerns and reasons for non-acceptance of the results obtained, but the observations in the field, along with the use of more than one analysis method, means that the inferences discussed here are based on a variety of reasoning and the use of common sense. This said, despite the differences seen in the CA analysis biplot (fig. 3.8 c), the distinction between the two most populous species (*G.albogularis* and *A.ameiva)* is evident and is even shown on the CCA (fig. 3.9); this is an important trait, as it shows that despite both species being indicative of disturbance by human activity *A.ameiva* prefers more open habitat in the first few transects (as seen in fig. 3.4), whereas *G.albogularis* prefers the scaly bark of the denser and more closed habitat in the transects further into the reserve interior. The presence of the latter species in what is classified as mature or non-intervened habitat by the GIS map used in this study, reiterates the findings that it is indeed disturbed, only has minimal numbers of mature trees (certainly not a mature 'habitat') and has been subject to hunting and human presence consistently, and therefore the GIS has miss-classified. It is suggested here that the use of the more recent GIS data would be invaluable in the future. This species was mentioned in Bell and Donnelly (2006) as being part of a disturbance-adapted, non-forest guild that includes *B. marinus* and *Hemidactylus frenatus*; their research on the influence of forest fragmentation on the lizard community showed that the above guild was not present in the disturbed fragments, but around the human habitation; this either worryingly suggests the extent of disturbance to the El Rey habitat to allow this species to be dominant several kilometres (5-6) from settlement or that the extremely high quality habitat of their site in La Selva, Costa Rica, has only allowed the most extremely disturbed areas to contain this guild of species. The above *H. frenatus* was only seen within buildings in San Miguel (on El Rey), there is at least some evidence that even the transects closest to the town are not of sufficiently poor quality as to allow their establishment; one can therefore assume that *G.albogularis* is not indicative of such disturbed habitat as the above species, and hence there needs to not be the level of concern that potentially could have been inferred from the above 'worrying' suggestion;

it still however indicates a level of disturbance within the habitat represented by the majority of the transects surveyed.

The information gleaned from the PCA (fig. 3.8 b) was similar as with the DCA and CA above. PCA gives the *G.albogularis* and *A.ameiva* distinction even more credit, the vectors show they are extremely negatively correlated to each other; the strength of the eigenvalues gives the *G.albogularis* vector arrow a great length and hence great importance. Transect 1-4 are highly associated with *A.ameiva* here, a situation noticed in the field; this species was clearly present in high numbers within and between transects 1-4, but its absence was noticeably evident after this and generally replaced by *G.albogularis*. These two species seem to show such high levels of difference within all analysis undertaken in this study that one can comfortably suggest they either outcompete each other or are adapted to distinctly different niches and or habitats, therefore solely between the two species one can infer that at the most simplest level there can be a separation of habitat types as 1-4 and 5 to T19.

CCA (fig 3.9) evidence is important in establishing the above inferences and the isolation of potentially 6 distinct species communities is twice that of DCA; although DCA is crucial due to its robust nature and previously discussed author led credibility, the inclusion of vegetation data in the CCA allows for further discovery of the species distribution. The 6 species clusters also coincide with the evidence from Whittaker's beta-diversity equation of 6.5 communities; with both lines of evidence, the possibility of a very high turnover of species is feasible. Despite this evidence, the data is not of sufficient quantity and has not been repeated over enough transects and different weather conditions to allow one to assume this as conclusive.
CCA also brings up the importance of the 'distance to town' variable again. The evidence of alpha-diversity correlation to this measure previously showed a bimodal or polynomial response across the assemblage; the validity of the influence of this variable is also significant ($p= 0.006$) within the CCA plot, the highly negatively correlated response of this variable to the first CCA axis and the fact that 19.8% (table 3.3) of the variation within this axis is explained by this variable (Palmer, 2007), gives backing to this suggestion. All remaining variables showed much less variations and all were insignificant on the first axis, however midstore was highly correlated to the

second axis and the other variables to axis 4. Midstore explains the *Mabuya* community, Understorey the *Iguana* community; *B.marinus* is associated with several relatively weak variables (small arrows, therefore not particularly important).
Araujo (2004, p1041) highlighted that the low cumulative percentage variation shown by the first three axes (7.4-21%) in their data, was a common outcome of ordinations which summarise many "complex patterns of compositional variation for many species over large geographical areas"; therefore the 32% shown by axis 1 and 2 in the data from El Rey is very acceptable. The clustering of species around the CCA origin is an indication of weak species-environment relations (Hirst and Jackson, 2007); as many species and samples (transects) are located in this region makes those species at the limits of the plot, such as *A.ameiva,* or at least the difference in distance between them and the origin all the more important.

4.3. The socio-economic point of view: integrated conservation and reserve management

The information gained so far is extremely useful background information for the management of the hydrological reserve. The ecology of the herpetofauna is information that was previously missing. The distinction between communities and habitats from the evidence above is much needed in knowing how to manage the reserve as it is, with the potential for the advent of tourism and the local human impacts.
A suggestion would be for using the main trail as the only access to the reserve and maintaining or improving the habitat surrounding it. In terms of tourism, the species of disturbance-adapted guilds could be a useful form of education for an ecotourism venture; the species themselves are so common and striking in their colouration that the visual impact would be strong and allow people to interact at close proximity and to then see the difference as they move towards the interior of the reserve. The changes in species and habitat quality are then self-evident for tourists, learning that human impact

can drastically influence the species composition of a neotropical ecotone within very short distances.

The potential for tourism has already been realised in the northern islands of the archipelago. Ecotourism issues of more planned tourist expansion and construction and the implementation of conservation areas and laws (Mair, 2006; Casado, 2001), is allowing huge human impacts to coexist with newly implemented reserves such as the hydrological reserve on El Rey. There are currently plans for a 500 room hotel on the island along one of the rivers (pers. Comm Dr Guzman) that is part of the 11 watershed reserve; most of the herpetofauna on El Rey rely on rivers or water to survive, hence why the designation is so important and why the hotel could give a huge environmental impact issue for the island. On the other hand a Columbian enthusiast is far down the route of developing an eco-lodge on the island, using only material from the island and allowing minimal impact in a sustainable format (pers. Comm Dr Guzman and direct conversations with unnamed enthusiast). Hopefully there will be more influence and support for the latter project in reducing the all too prevalent thinking for tourism on the islands. There is a massive push for more tourist activities from developers and prospective tourists themselves; little action is taken by the government despite the TCR action plan and the implementation of PAs seems to be merely a consolation.

In terms of the local population, their impacts are self-evident; however much previous research has showed that local knowledge is very important in aiding conservation (Becker and Ghimirem, 2003; Eilers et al, 2002; Pimbert and Pretty, 1995 etc).

Work by CEASPA (panamanian NGO for social improvements) reported on the measures that had already been implemented in Las Perlas (CEASPS, 2007). The program for Iguana nurseries, one of which is being carried out in one of the communities on El Rey has been very successful in teaching the local children and entire village about the Iguana's threatened status and the importance for conservation; the local people have been involved at a high level throughout the project.

As shown by Eilers et al (2002) Iguana nurseries or farms have been ultimately one of the most successful forms of integrated conservation and use of local knowledge; the aim in El Rey is similar in educating the locals, but also forming a centre for breeding Iguanas to release into the wild to reduce the impact of previous hunting for food by locals. Breeding to give a sizeable contribution (protein) to the diets of the local

community is almost more important, as this would stop the need for hunting and therefore drastically reduce habitat fragmentation, disturbance, burnt areas, cleared areas and use of ammunition. The steps made by CEASPA as part of the connection for the management plan of the hydrological reserve and the $50,000 already made available for its implementation, will introduce a highly modern integrated method for conservation and indeed give a truly positive outlook for the future.

5. Conclusion

The below section lists the aims of the project and whether and to what extent they have been achieved:

- To devise an inventory of reptile and amphibian species on El Rey and within the hydrological reserve.

A list of 33 species presumed to exist on El Rey has been constructed, 15 of which were noted by this particular fieldwork.

- To determine the herptile ecology and diversity of the habitats with the reserve boundary and identify any relationships with environmental variable such as elevation, distance to town (human habitation) and vegetation cover/structure and the significance of these relationship for conservation.

Distance to San Miguel showed a bimodal or polynomial response to species diversity; elevation showed evidence of highest diversity and abundances at mid-elevations. A high beta-diversity and relatively low alpha-diversity was discovered, with potentially up to 6 distinct species communities or guilds; the species *G.albogularis* and *A.ameiva* were particularly different in their association and highly influenced the distribution. Through the evidence amassed this beta-diversity and other information regarding the assemblage shows that an ecotone change is prevalent along the transect assemblage, showing distinct changes in micro-habitat and habitat and their related species. The majority of species are members of a disturbance-adapted guild or indicative of degradation or disturbance, the above two species in particular. There is very little evidence of endemism being possible or there being species that are indicative of quality more mature tropical moist forest habitat. The habitat improved as one moved along the transect assemblage further into the interior of the reserve, if this continues, and the fact that from T13 until T19 no obvious trail was present (local guides having to make a trail for these remaining transects), then there is the potential for a more pristine habitat and species thereof to be found.

- To provide at least a preliminary study of the herpetofauna that will lead to further more in-depth studies or long-term monitoring programs.

Much ecological data has been collected that is very useful; there has been many problems with the difficulty of fieldwork and the need for much more further work, both repeating these transect surveys and further inventory work to build a better picture of how close to the total number of herptile species are indeed present in the reserve. Further work on different habitat types within the reserve from around the island will no doubt lead to different species being encountered and give a more holistic assessment to its ecology; a short three transect assessment of the mangrove areas near La Guinea yielded results in this study that indicated this could be the case.

- To investigate whether there are differences in the above between habitat types; particularly between the GIS identified 'non-intervened' and 'intervened' forest habitats.

The aforementioned habitat classifications seemed to be inaccurate; further, more up-to-date data needs to be used in the future. The t-test results that compared these two habitats showed not significant results at P= 0.05 level. The above ecological traits identified that a possible habitat separation could be from San Miguel to T1 being agriculture/human disturbed scrub; T1-4 being disturbed/intervened secondary forest or scrub; and T5-19 being less disturbed secondary forest with isolated mature forest fragments, with quality of habitat improving with distance from San Miguel.

- To investigate the impact of human disturbance on the reserve ecology and the potential for local people to interact with the development of the management plan.

As mentioned above, the human disturbance is significant, but not irreversible. The interactions with local people and their knowledge, the implementation of more Iguana nurseries and advent of sustainable, well managed ecotourism could form a highly beneficial integrated management plan and form of conservation. The future has huge potential for massive steps in conservation; the hydrological reserve needs to move

forward from a 'paper park' to a truly modern and influential conservation landmark in at least Panama's perspective.

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7. APPENDICES

Local/spanish name	Common name	Scientific name	Notes
Iguana verde	Green or Common iguana	Iguana iguana	Hunted and eaten by locals
Iguana negro	Black iguana	Ctenasaura similis	
Bejuquilla café	Brown Vine snake	Oxybelis aeneus	
Bejuquilla verde	Green Vine snake	Oxybelis fulgidus	
Bejuquilla roja? (red)	? Vine snake	Maybe Imantodes cenchoa?	Red vine snake
Boa (yellow)	Boa constrictor	Boa constrictor sabogae?	Possibly the sub-species found on the Sabogae island. Or different age specimens of below species.
Boa (pink-black)	Boa constrictor	Boa constrictor	Probably normal Boa constrictor
Jabao	? (Black with white spots)	Clelia clelia? (or Spilotes pullatus)	Grabs you and whips you with its tail loads
			NO VENEMOUS SNAKES ON ISLAND!!!
Rat-catcher	?	juvenile Clelia clelia?	Solid red snake that feeds on mice and rats at night
Lisa	Parrot snake???	Leptophis ahaetulla???	Gray-green snake, feeds on lizards, frog, iguana eggs

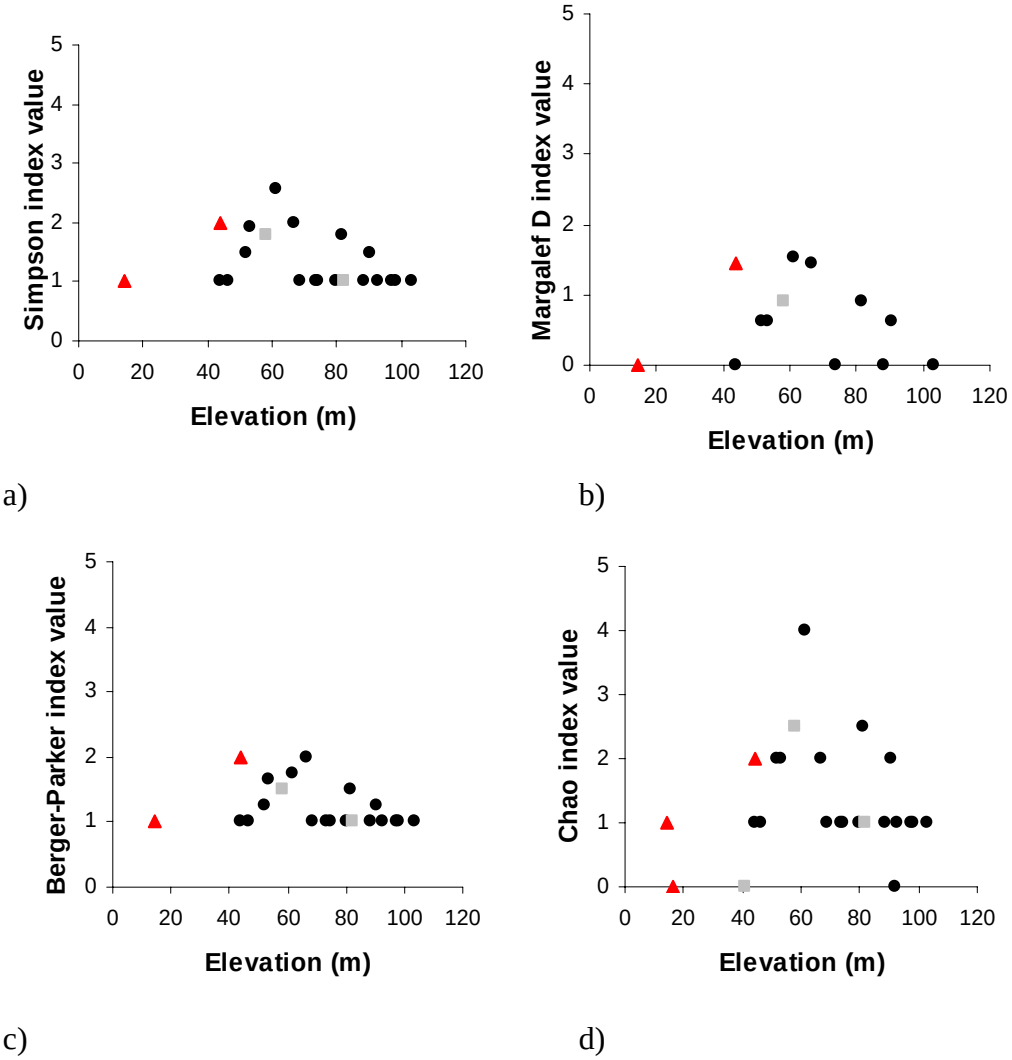
Appendix 3.1. Local knowledge of herptile species present on El Rey (mainly from local guide Carlos)

Appendix 3.2: Table of vegetation notes and disturbance within transects along main trail.

Transect	Number of 50m section containing burnt/open disturbed areas	Summary of vegetation notes
1	4	Vines, grasses (Cyperacea), ferns
2	0	Ferns, vines, orchids, Bromelia, Melastomomataceae (Mst) very abundant
3	1	Grass, thick understorey, Bromelia. Pioneer Cecropia (trumpet tree)
4	3	thick vegetation, palms, Bromelia, Heliconia, Mst, Piperaceae
5	2	Bromelia, dense shrub layer, vines. Heliconia dominant understorey in cleared area/burnt.
6	1	Significantly more mature than Transect 5
20	1	Heliconia and banana palm. Dense undergrowth, vines and creepers
10	0	Heliconia, Bromelia. Many arboreal Bromelia and Piperaceae
11	1	Heliconia and many Piperaceae
12	0	Palms, grass, Bromelia
21	0	Palms and dense forest
13	0	Large dense palm forest section, vines.
14	0	Reeds, grasses, ferns. Dense leaf litter
15	0	Grasses, ferns
16	0	Grasses, lots leaf litter
17	0	Lots leaf litter, damp area, ferns and dead wood
18	0	Reeds
19	0	Vines, very dense and large canopy trees.

Appendix 3.3: Results from the calculations of four species diversity indices and SR and density.

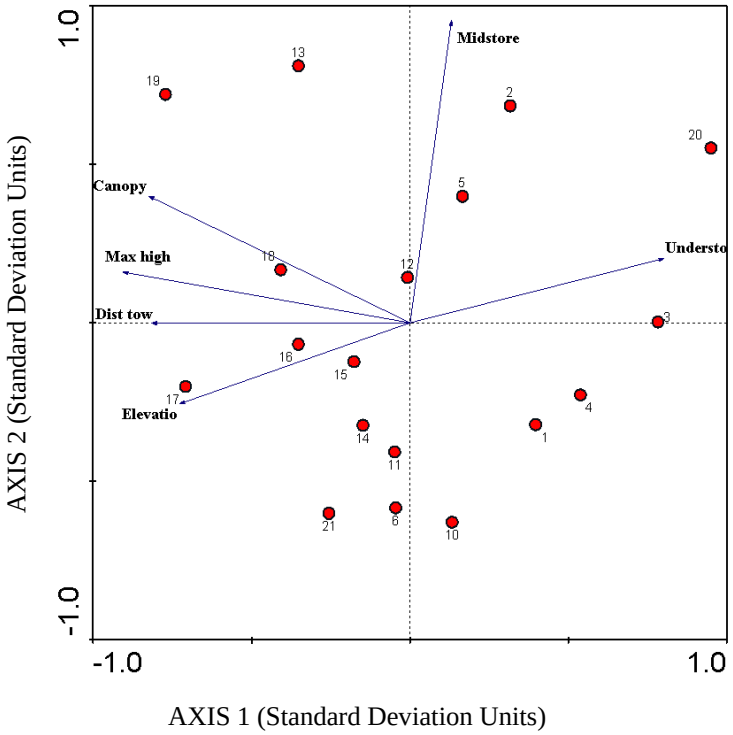
Transect	No individuals	Density (individual/m2)	Area per individual in m2	Richness	Simpson index	Margalef D	Berger-Parker	Chao 1
1	3	0.00375	266.6666667	1	1	0	1	1
2	1	0.00125	800	1	1	error	1	1
3	1	0.00125	800	1	1	error	1	1
4	2	0.0025	400	1	1	0	1	1
5	7	0.00875	114.2857143	4	2.578947368	1.541695027	1.75	4
6	3	0.00375	266.6666667	2	1.8	0.910239227	1.5	2.5
7	0	0	error	0	error	error	error	0
8	3	0.00375	266.6666667	1	1	0	1	1
9	2	0.0025	400	2	2	1.442695041	2	2
10	1	0.00125	800	1	1	error	1	1
11	0	0	error	0	error	error	error	0
12	1	0.00125	800	1	1	error	1	1
13	5	0.00625	160	2	1.923076923	0.621334935	1.666666667	2
14	2	0.0025	400	1	1	0	1	1
15	2	0.0025	400	1	1	0	1	1
16	1	0.00125	800	1	1	error	1	1
17	1	0.00125	800	1	1	error	1	1
18	5	0.00625	160	2	1.470588235	0.621334935	1.25	2
19	1	0.00125	800	1	1	error	1	1
20	5	0.00625	160	2	1.470588235	0.621334935	1.25	2
21	2	0.0025	400	2	2	1.442695041	2	2
N1	1	0.00125	800	1	1	error	1	1
N2	3	0.00375	266.6666667	2	1.8	0.910239227	1.5	2.5
N3	0	0	error	0	error	error	error	0



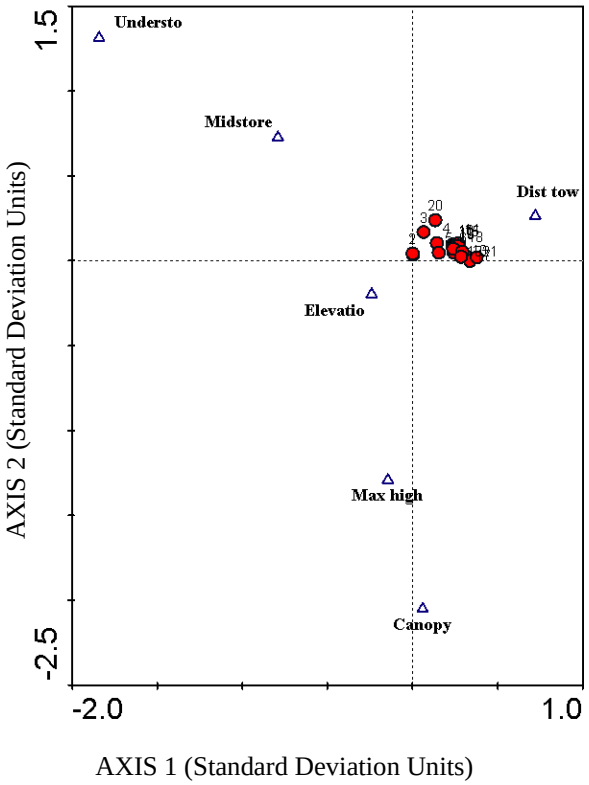
Appendix 3.4. Scatterplots of elevation against a) simpson index, b) Margalef D, c) Berger-Parker and d) Chao 1. The grey data series is that of the night transects and the red data series is that of the three mangrove transects (near La Guinea).

t-Test: Two-Sample Assuming Equal Variances	Species Richness		Simpson index		Margalef D index		Berger-Parker index		Chao 1 index	
	Variable 1	*Variable 2*	*Variable 1*	*Variable 2*	*Variable 1*	*Variable 2*	*Variable 1*	*Variable 2*	*Variable 1*	*Variable 2*
Mean	1.181818182	1.714285714	1.272308	1.360018	0.594854	0.556873	1.216667	1.178571	1.227273	1.714286
Variance	0.363636364	1.238095238	0.194506	0.338115	0.381677	0.3996	0.136111	0.077381	0.468182	1.238095
Observations	11	7	10	7	5	5	10	7	11	7
Pooled Variance	0.691558442		0.25195		0.390638		0.112619		0.756899	
Hypothesized Mean Difference	0		0		0		0		0	
df	16		15		8		15		16	
t Stat	-1.324304327		-0.35458		0.096083		0.230351		-1.15779	
P(T<=t) one-tail	0.102004524		0.363919		0.462909		0.410466		0.13197	
t Critical one-tail	1.745883669		1.75305		1.859548		1.75305		1.745884	
P(T<=t) two-tail	**0.204009048**		**0.727839**		**0.925818**		**0.820931**		**0.263941**	
t Critical two-tail	2.119905285		2.13145		2.306004		2.13145		2.119905	

Appendix 3.5: T-test output for Intervened against non-intervened forest. Two-tail P-value of the significance of dissimilarity are in bold. The t-stat and degrees of freedom values are also displayed above.

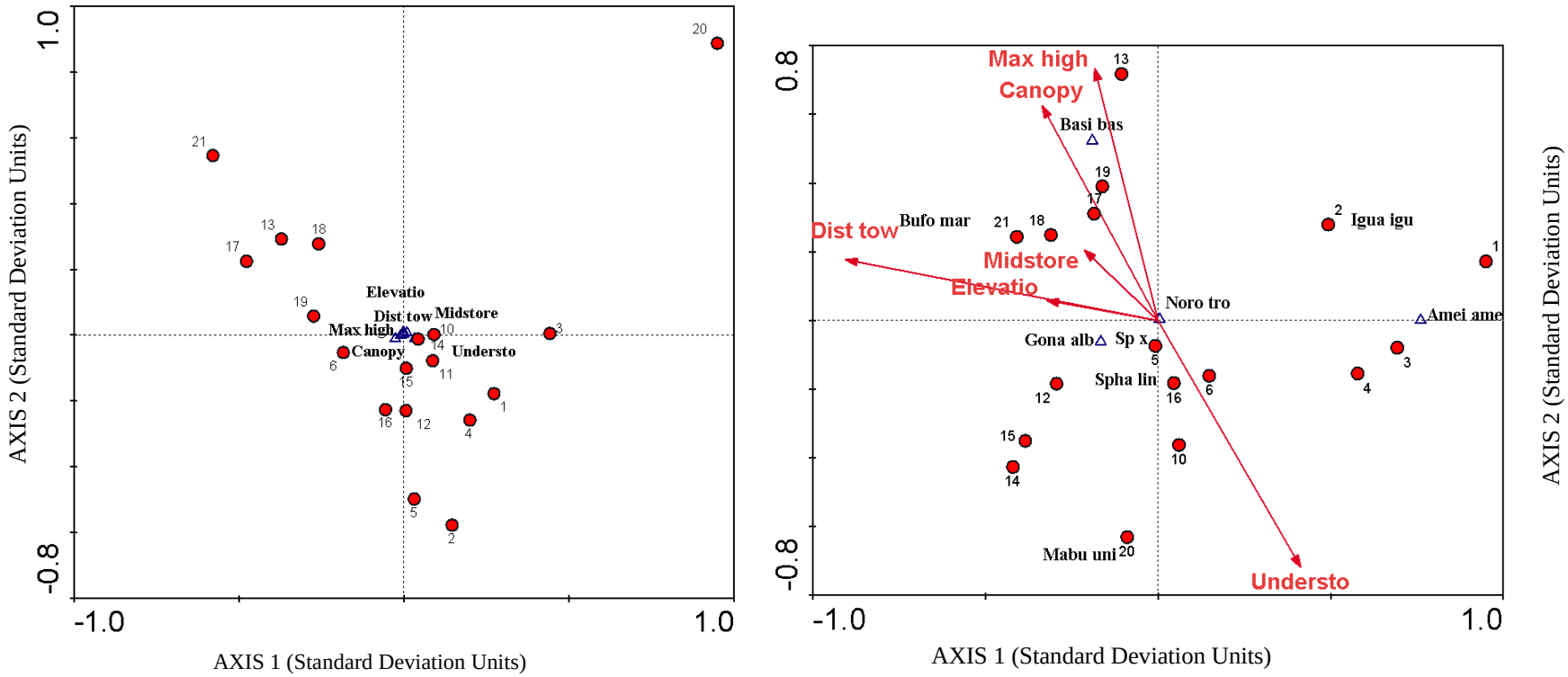


a)



b)

Appendix 3.6: a) is the PCA for the environmental variables; b) is the DCA of the same.



a) b)

Appendix 3.7: a) CA for the environmental variables and b) CCA triplot of species, samples and environmentals, displayed as axis 1 against axis 4

Appendix 3.8: Output log of CCA. (red highlights shows generally over 0.6 relationships between variables)

**** Weighted correlation matrix (weight = sample total) ****

SPEC AX1	1.0000							
SPEC AX2	-0.0032	1.0000						
SPEC AX3	-0.0550	-0.1204	1.0000					
SPEC AX4	0.0510	-0.2475	0.1260	1.0000				
ENVI AX1	0.9086	0.0000	0.0000	0.0000	1.0000			
ENVI AX2	0.0000	0.7877	0.0000	0.0000	0.0000	1.0000		
ENVI AX3	0.0000	0.0000	0.7178	0.0000	0.0000	0.0000	1.0000	
ENVI AX4	0.0000	0.0000	0.0000	0.8576	0.0000	0.0000	0.0000	1.0000
Understo	0.3752	-0.3572	0.2081	-0.6158	0.4130	-0.4534	0.2899	-0.7180
Midstore	-0.1945	-0.7242	-0.0688	0.1764	-0.2141	-0.9194	-0.0958	0.2057
Canopy	-0.3053	0.2086	0.3816	0.5359	-0.3360	0.2648	0.5316	0.6249
Max high	-0.1667	0.1885	0.1341	0.6290	-0.1834	0.2393	0.1869	0.7334
Elevatio	-0.2933	0.1810	0.2114	0.0507	-0.3228	0.2298	0.2944	0.0591
Dist tow	-0.8228	0.0347	-0.1367	0.1519	-0.9055	0.0440	-0.1905	0.1771
	SPEC AX1	SPEC AX2	SPEC AX3	SPEC AX4	ENVI AX1	ENVI AX2	ENVI AX3	ENVI AX4

Understo	1.0000					
Midstore	0.1728	1.0000				
Canopy	-0.5476	-0.1656	1.0000			
Max high	-0.6906	-0.1846	0.8772	1.0000		
Elevatio	-0.3106	-0.3435	0.5022	0.6137	1.0000	
Dist tow	-0.5678	0.1485	0.4512	0.4352	0.3617	1.0000

	Understo	Midstore	Canopy	Max high	Elevatio	Dist tow

N	name	(weighted) mean	stand. dev.	inflation factor
1	SPEC AX1	0.0000	1.1005	
2	SPEC AX2	0.0000	1.2695	
3	SPEC AX3	0.0000	1.3931	
4	SPEC AX4	0.0000	1.1661	
5	ENVI AX1	0.0000	1.0000	
6	ENVI AX2	0.0000	1.0000	
7	ENVI AX3	0.0000	1.0000	
8	ENVI AX4	0.0000	1.0000	
1	Understo	1.5051	0.2833	3.1975
2	Midstore	1.6962	0.1582	1.4774
3	Canopy	1.5720	0.3262	5.2448
4	Max high	1.3918	0.1459	8.9163
5	Elevatio	1.8387	0.1221	2.3458
6	Dist tow	3.4705	0.2006	2.2011

**** Summary ****

Axes	1	2	3	4	Total inertia
Eigenvalues :	0.808	0.311	0.280	0.232	3.498
Species-environment correlations :	0.909	0.788	0.718	0.858	
Cumulative percentage variance					
of species data :	23.1	32.0	40.0	46.7	
of species-environment relation:	44.9	62.2	77.8	90.7	

Sum of all eigenvalues	3.498
Sum of all canonical eigenvalues	1.799

[Fri Sep 07 04:12:42 2007] CANOCO call succeeded

Appendix 3.9. Full list of species of Herpetofauna in Panama (based on ITEC, 2007 website and Auth, 1994)

---------- = seen in Las Perlas in 1946 survey (Cochran, 1946).

Class Reptilia

Order Crocodylia (Crocodiles & Alligators)

Alligatoridae Family

- *Caiman crocodilus*†

Crocodylidae Family

- *Crocodylus acutus*†

Order Squamata

Suborder Amphisbaenia (Worm-Lizards)

Amphisbaenidae Family

- *Amphisbaenia alba*
- *Amphisbaenia fuliginosa*
- *Amphisbaenia spurrelli*

Suborder Sauria (Lacertilia)

Anguidae Family (Alligator Lizards)

- *Coloptychon rhombifer*
- *Diploglossus bilobatus*
- *Diploglossus monotropis*†
- *Diploglossus montisilvestris*

- *Mesaspis monticola*

Corytophanidae Family (Basilisks)

- *Basiliscus basiliscus*
- *Basiliscus galeritus*
- *Basiliscus plumifrons*†
- *Basiliscus vittatus*†
- *Corytophanes cristatus*†

Gekkonidae Family (Geckos)

- *Coleonyx mitratus*
- *Gonatodes albogularis*† (fuscus?)
- *Gonatodes annularis*
- *Hemidactylus brookii*
- *Hemidactylus frenatus*†
- *Hemidactylus mabouia*
- *Hemidactylus turcicus*
- *Lepidoblepharis sanctaemartae*
- *Lepidoblepharis xanthostigma*
- *Lepidodactylus lugubris*†
- *Sphaerodactylus argus*
- *Sphaerodactylus graptolaemus*
- *Sphaerodactylus homolepis*†
- *Sphaerodactylus lineolatus*
- *Thecadactylus rapicauda*†

Iguanidae Family (Iguanas)

- *Ctenosaura similis*
- *Dactyloa chloris*
- *Dactyloa chocorum*
- *Dactyloa frenata*
- *Dactyloa insignis*
- *Dactyloa latifrons*
- *Dactyloa microtus*
- *Enyalioides heterolepsis*
- *Iguana iguana*† c
- *Morunasaurus groi*

Phrynosomatidae Family (Spiny Lizards)

- *Sceloporus malachiticus*†

Polychrotidae Family (Anoles)

- *Norops altae*
- *Norops aquaticus*
- *Norops auratus*

- *Norops biporcatus*†
- *Norops capito*†
- *Norops carpenteri*
- *Norops casildae*
- *Norops fortunensis*
- *Norops fungosus*
- *Norops fuscoauratus*
- *Norops humilis*†
- *Norops intermedius*
- *Norops kemptoni*
- *Norops lemurinus*†
- *Norops latifrons*
- *Norops limifrons*†
- *Norops lionotus*†
- *Norops microtus*
- *Norops oxylophus*
- *Norops pachypus*
- *Norops pentaprion*†
- *Norops poecilopus*
- *Norops polylepis*
- *Norops procellaris*
- *Norops sulcifrons*
- *Norops tropidogaster*
- *Norops vociferans*
- *Norops woodi*
- *Polychrus gutturosus*

Scincidae Family (Skinks)

- *Mabuya unimarginata*†
- *Sphenomorphus cherriei*
- *Sphenomorphus rarus*

Teiidae Family (Whip-tailed Lizards)

- *Ameiva ameiva (46- subspecies A.A.praesisnis)*
- *Ameiva festiva*†
- *Ameiva leptophrys*
- *Ameiva quadrilineata*†
- *Anadia ocellata*
- *Anadia vittata*
- *Bachia blairi*
- *Bachia pallidiceps*
- *Cnemidophorus lemniscatus*
- *Cnemidophorus rodecki*
- *Echinosaura horrida*
- *Gymnophthalmus speciosus*
- *Leposoma rugiceps*
- *Leposoma southi*†
- *Prionodactylus vertebralis*
- *Ptychoglossus festae*
- *Ptychoglossus plicatus*

Xantusiidae Family
(Night Lizards)

- *Lepidophyma flavimaculatum*†

Suborder Serpentes
(Ophidia) (Snakes)

Anomalepididae Family
(Dawn Blind Snakes)

- *Anomalepis mexicanus*
- *Helminthophis frontalis*
- *Liotyphlops albirostris*

Boidae Family
(Boas)

- *Boa constrictor*†c
- *Corallus annulatus* c
- *Corallus hortulanus* c
- *Epicrates cenchria* c

Colubridae Family
(Harmless Snakes)

- *Amastridium veliferum*
- *Atractus clarki*
- *Atractus crassicaudatus*
- *Chironius carinatus*
- *Chironius exoletus*
- *Chironius grandisquamis*
- *Clelia clelia*
- *Clelia equatoriana*
- *Clelia scytalina*
- *Coniophanes bipunctatus*
- *Coniophanes fissidens*†
- *Coniphanes joanae*
- *Dendrophidion nuchalis*
- *Dendrophidion paucicarinatum*
- *Dendrophidion percarinatum*
- *Dendrophidion vinitor*
- *Diaphorolepis wagneri*
- *Dipsas articulata*
- *Dipsas temporalis*
- *Dipsas tenuissima*

- *Dipsas variegata*
- *Dipsas viguieri*
- *Dryadophis melanolomus* (46 – D.M. Alternatus)
- *Dryadophis pleei*
- *Drymarchon corais* (46 – melanuras??)
- *Drymobius margaritiferus*
- *Drymobius rhombifer*
- *Enulius flavitorques*
- *Enuliophis sclateri*
- *Erythrolamprus bizonus*
- *Erythrolamprus mimus*
- *Geophis brachycephalus*
- *Geophis championi*
- *Geophis godmani*
- *Geophis hoffmanni*
- *Hydromorphus concolor*
- *Hydromorphus dunni*
- *Imantodes cenchoa*†
- *Imantodes gemmistratus*
- *Imantodes inornatus*†
- *Imantodes phantasma*
- *Lampropeltis triangulum*
- *Leptodeira annulata*
- *Leptodeira septentrionalis*†
- *Leptophis ahaetulla*†
- *Leptophis depressirostris*
- *Leptophis riveti*
- *Liophis epinephalus*
- *Liophis lineatus*
- *Masticophis mentovarius*
- *Mastigodryas melanolomus*†
- *Ninia atrata*
- *Ninia maculata*
- *Ninia psephota*
- *Ninia sebae*
- *Nothopsis rugosus*
- *Oxybelis aeneus*†
- *Oxybelis brevirostris*
- *Oxybelis fulgidus*
- *Oxyrhopus petola*
- *Phimophis guianensis*
- *Pseudoboa neuwiedii*
- *Pseustes poecilonotus*†
- *Pseustes shropshirei*
- *Rhadinaea calligaster*
- *Rhadinaea decipiens*
- *Rhadinaea decorata*†
- *Rhadinaea fulviceps*
- *Rhadinaea godmani*
- *Rhadinaea guentheri*
- *Rhadinaea pachyura*
- *Rhadinaea pulveriventris*
- *Rhadinaea sargenti*
- *Rhadinaea vermiculaticeps*
- *Rhinobothryum bovallii*
- *Scaphiodontophis annulatus*
- *Sibon annulata*

- *Sibon argus*
- *Sibon longifrenis*
- *Sibon nebulatus*†
- *Siphlophis cervinus*
- *Siphlophis longicaudatus*
- *Spilotes pullatus*†
- *Stenorrhina degenhardtii*
- *Tantilla albiceps*
- *Tantilla alticola*
- *Tantilla melanocephala*
- *Tantilla reticulata*
- Tantilla rufileps?? (46)
- *Tantilla schistosa*
- *Tantilla supracincta*
- *Tretanorhinus mocquardi*
- *Tretanorhinus nigroluteus*†
- *Trimetopon barbouri*
- *Trimetopon pliolepis*
- *Trimetopon slevini*
- *Tripanurgos compressus*
- *Urotheca euryzona*†
- *Xenodon rhabdocephalus*

Elapidae Family (Coral Snakes)

- *Micrurus alleni*†
- *Micrurus ancoralis*
- *Micrurus clarki*
- *Micrurus dissoleucus*
- *Micrurus dumerilii*
- *Micrurus mipartitus*
- *Micrurus multifasciatus*
- *Micrurus nigrocinctus*†
- *Micrurus stewarti*

Hydrophiidae Family (Sea Snakes)

- *Pelamis platurus*

Leptotyphlopidae Family (Thread Snakes)

- *Leptotyphlops goudotti*
- *Leptotyphlops macrolepis*

Tropidophiidae Family (Trachyboas)

- *Trachyboa boulengeri* c

Ungaliophiidae Family (Dwarf Boas)

- *Ungaliophis panamensis* c

Viperidae Family (Vipers)

- *Atropoides nummifer*
- *Atropoides picadoi*
- *Bothriechis lateralis*
- *Bothriechis nigroviridis*
- *Bothriechis schlegelii*†
- *Bothriopsis punctata*
- *Bothrops asper*†
- *Cerrophidion godmani*
- *Lachesis muta*
- *Porthidium lansbergii*
- *Porthidium nasutum*
- *Porthidium ophryomegas*

Order Testudines (Chelonia) (Turtles and Tortoises)

Suborder Cryptodira

Cheloniidae Family (Sea Turtles)

- *Caretta caretta* *
- *Chelonia mydas* *
- *Eretmochelys imbricata* *
- *Lepidochelys kempii*
- *Lepidochelys olivacea*

Chelydridae Family (Snapping Turtles)

- *Chelydra serpentina* *

Deromchelyidae Family (Leatherback Sea Turtle)

- *Deromchelys coriacea* *

Emydidae Family
(Pond and River Turtles)

- *Rhinoclemmys annulata* *
- *Rhinoclemmys funerea* *
- *Rhinoclemmys melanosterna*
- *Trachemys scripta* *

Kinosternidae Family
(Mud and Musk Turtles)

- *Kinosternon angustipons*
- *Kinosternon leucostomum* *
- *Kinosternon scorpioides*

Testudinidae Family
(Tortoises)

- *Geochelone carbonaria* *

Class Amphibia

Order Anura
(*Salientia*)
Frogs and Toads
Bufonidae Family
(True Toads)

- *Atelopus certus*
- *Atelopus chiriquiensis*
- *Atelopus glyphus*
- *Atelopus limosus*
- *Atelopus varius*
- *Atelopus zeteki*
- *Bufo coccifer*
- *Bufo coniferus*†
- *Bufo fastidiosus*
- *Bufo granulosus*
- *Bufo haematiticus*†
- *Bufo margaritifer*
- *Bufo marinus*†
- *Bufo peripatetes*
- *Crepidophryne epiotica*
- *Rhamphophryne acrolopha*

Centrolenidae Family
(Glass Frogs)

- *Centrolene ilex*
- *Centrolene prosoblepon*
- *Cochranella albomaculata*
- *Cochranella granulosa*
- *Cochranella euknemos*
- *Cochranella spinosa*
- *Hyalinobatrachium chirripoi*
- *Hyalinobatrachium colymbiphyllum*
- *Hyalinobatrachium fleischmanni*
- *Hyalinobatrachium pulveratum*
- *Hyalinobatrachium valerioi*
- *Hyalinobatrachium vireovittatum*

Dendrobatidae Family
(Dart-Poison Frogs)

- *Colostethus chocoensis*
- *Colostethus flotator*
- *Colostethus inguinalis*
- *Colostethus latinasus*
- *Colostethus nubicola*
- *Colostethus pratti*
- *Colostethus talamancae*

- *Dendrobates arboreus*
- *Dendrobates auratus*†
- *Dendrobates pumilio*†
- *Dendrobates speciosus*
- *Dendrobates vicentei*
- *Epipedobates maculatus*
- *Minyobates fulguritus*
- *Minyobates minutus*†
- *Phyllobates lugubris*†

Hylidae Family (True Treefrogs)

- *Agalychnis calcarifer*
- *Agalychnis callidryas*†
- *Agalychnis litodryas*
- *Agalychnis spurrelli*
- *Anotheca spinosa*
- *Duellmanohyla lythrodes*
- *Duellmanohyla rufioculis*
- *Duellmanohyla uranochroa*
- *Gastrotheca nicefori*
- *Hemiphractus fasciatus*
- *Hyla boans*
- *Hyla calypsa*
- *Hyla colymba*
- *Hyla crepitans*
- *Hyla debilis*
- *Hyla ebraccata*†
- *Hyla graceae*
- *Hyla lancasteri*
- *Hyla microcephala*†
- *Hyla miliaria*
- *Hyla palmeri*
- *Hyla phlebodes*†
- *Hyla picadoi*
- *Hyla pseudopuma*
- *Hyla pugnax*
- *Hyla rivularis*
- *Hyla rosenbergi*
- *Hyla rufitela*
- *Hyla subocularis*
- *Hyla thysanota*
- *Hyla tica*
- *Hyla zeteki*
- *Phrynohyas venulosa*
- *Phyllomedusa lemur*
- *Phyllomedusa venusta*
- *Ptychohyla legleri*
- *Scinax boulengeri*
- *Scinax elaeochroa*†
- *Scinax rostrata*
- *Scinax ruber*
- *Scinax staufferi*
- *Smilisca phaeota*
- *Smilisca sila*

- *Smilisca sordida*

Leptodactylidae Family
(Rain Frogs & Leptodactylid Frogs)

- *Eleutherodactylus achatinus*
- *Eleutherodactylus andi*
- *Eleutherodactylus antillensis*
- *Eleutherodactylus azueroensis*
- *Eleutherodactylus biporcatus*
- *Eleutherodactylus bransfordi*
- *Eleutherodactylus bufoniformis*
- *Eleutherodactylus caryophyllaceus*
- *Eleutherodactylus cerasinus*
- *Eleutherodactylus crassidigitus*
- *Eleutherodactylus cruentus*
- *Eleutherodactylus diastema*
- *Eleutherodactylus emcelae*
- *Eleutherodactylus fitzingeri*
- *Eleutherodactylus fleischmanni*
- *Eleutherodactylus gaigeae*
- *Eleutherodactylus gollmeri*
- *Eleutherodactylus jota*
- *Eleutherodactylus laticorpus*
- *Eleutherodactylus longirostris*
- *Eleutherodactylus melanostictus*
- *Eleutherodactylus monnichorum*
- *Eleutherodactylus moro*
- *Eleutherodactylus museosus*
- *Eleutherodactylus noblei*
- *Eleutherodactylus pardalis*
- *Eleutherodactylus podicifer*
- *Eleutherodactylus punctariolus*
- *Eleutherodactylus raniformis*
- *Eleutherodactylus rayo*
- *Eleutherodactylus ridens*
- *Eleutherodactylus rugulosus*
- *Eleutherodactylus stejnegerianus*
- *Eleutherodactylus taeniatus*
- *Eleutherodactylus talamancae*
- *Eleutherodactylus taurus*
- *Eleutherodactylus vocator*
- *Leptodactylus bolivianus*
- *Leptodactylus fuscus*
- *Leptodactylus labialis*
- *Leptodactylus melanonotus*
- *Leptodactylus pentadactylus* †
- *Leptodactylus poecilochilus*
- *Physalaemus pustulosus*
- *Pleurodema brachyops*

Microhylidae Family
(Narrow-Mouthed Frogs)

- *Chiasmocleis panamensis*
- *Elachistocleis ovalis*

- *Nelsonophryne aterrima*
- *Relictivomer pearsei*

Pipidae Family
(Clawed Frogs and Surinam Toads)

- *Pipa myersi*

Ranidae Family
(True Frogs)

- *Rana vaillanti* †
- *Rana vibicaria*
- *Rana warszewitchii*

Order Gymnophiona (*Apoda*)

Caeciliidae Family (Caecilians)

- *Caecilia leucocephala*
- *Caecilia nigircans*
- *Caecilia tentaculata*
- *Caecilia volcani*
- *Dermophis mexicanus*
- *Dermophis parviceps*
- *Gymnopis multiplicata*
- *Oscaecilia elongata*
- *Oscaecilia ochrocephala*

Order Urodela
(*Caudata*)

Plethodontidae Family
(Lungless Salamanders)

- *Bolitoglossa biseriata*
- *Bolitoglossa colonnea*
- *Bolitoglossa compacta*
- *Bolitoglossa cuna*
- *Bolitoglossa lignicolor*
- *Bolitoglossa marmorea*
- *Bolitoglossa medemi*
- *Bolitoglossa minutula*
- *Bolitoglossa nigrescens*
- *Bolitoglossa phalarosoma*
- *Bolitoglossa robusta*
- *Bolitoglossa schizodactyla*
- *Bolitoglossa subpalmata*
- *Bolitoglossa taylori*
- *Oedipina alfaroi*

- *Oedipina collaris*
- *Oedipina complex*
- *Oedipina cyclocaudata*
- *Oedipina grandis*
- *Oedipina parvipes*
- *Oedipina uniformis*

Class	Order	Sub-order	Family (common name)	Species	CITES list	Protected by Panamanian law
Reptilia	Crocodylia	-	Crocodiles	Crocodylus acutus	appendix I	
Reptilia	Squamata	Sauria	Basilisks	Basilicus basilicus		
Reptilia	Squamata	Sauria	Geckos	Gonatodes albogularis		
Reptilia	Squamata	Sauria	Geckos	Hemidactylus frenatus		
Reptilia	Squamata	Sauria	Geckos	Sphaerodactylus lineolatus		
Reptilia	Squamata	Sauria	Iguanas	Ctenosaura similis		Yes
Reptilia	Squamata	Sauria	Iguanas	Iguana iguana	appendix II	Yes
Reptilia	Squamata	Sauria	Anoles	Norops auratus		
Reptilia	Squamata	Sauria	Anoles	Norops pentaprion		
Reptilia	Squamata	Sauria	Anoles	Norops tropidogaster		
Reptilia	Squamata	Sauria	Anoles	Polychrus gutturosus		
Reptilia	Squamata	Sauria	Skinks	Mabuya unimarginata		
Reptilia	Squamata	Sauria	Whiptail lizards	Ameiva ameiva		
Reptilia	Squamata	Serpentes	Dawn blind snakes	liotyphlops albirostris		
Reptilia	Squamata	Serpentes	Boa	Boa constrictor	appendix II	Yes
Reptilia	Squamata	Serpentes	Harmless snakes	Clelia clelia	appendix II	
Reptilia	Squamata	Serpentes	Harmless snakes	Dryadophis melanolomus		
Reptilia	Squamata	Serpentes	Harmless snakes	Drymarchon corais		
Reptilia	Squamata	Serpentes	Harmless snakes	Enulius flavitorques		
Reptilia	Squamata	Serpentes	Harmless snakes	Imantodes cenchoa		
Reptilia	Squamata	Serpentes	Harmless snakes	Leptodeira annulata		
Reptilia	Squamata	Serpentes	Harmless snakes	Leptophis ahaetulla		
Reptilia	Squamata	Serpentes	Harmless snakes	Oxybelis aeneus		
Reptilia	Squamata	Serpentes	Harmless snakes	Pseudoboa neuwiedii		
Reptilia	Squamata	Serpentes	Harmless snakes	Oxybelis fulgidus		
Reptilia	Squamata	Serpentes	Harmless snakes	Spillotes pullatus		

Reptilia	Squamata	Serpentes	Harmless snakes	Tantilla rufileps??? (1946)		
Reptilia	Squamata	Serpentes	Coral snakes	Micrurus nigrocintus		
Reptilia	Squamata	Serpentes	Sea snake	Pelamis platurus		
Amphibia	Anura	-	True toads	Bufo marinus		
Amphibia	Anura	-	Rain/Leptodactylid frogs	Eleutherodactylus fitzingeri		
Amphibia	Anura	-	Rain/Leptodactylid frogs	Eleutherodactylus raniformis		
Amphibia	Anura	-	Rain/Leptodactylid frogs	Leptodactylus bolivanius		
Amphibia	Anura	-	Rain/Leptodactylid frogs	Physalaemus pustulosus		
Amphibia	Gymnophiona (Apoda)	-	Caecilian	Oscaecilia ochrociphala		

Appendix 3.10 Full species list for Las Perlas islands and therefore in theory El Rey. All species, except those in pink and green from lists by Cochran (1946) and Barbour (1906). Species in gold and green rows are those observed during fieldwork on El Rey for this study, those in green are species not in the above original lists. Pink species are the highly probable 'unknown' (or that we were unable to ID) species seen during fieldwork). Species listed under CITES and those protected under Panamanian law were detailed by Weaver and Bauer (2004). Species x found in T5 is not included as this unknown gecko or lizard was not identified.