The Problem with Parrots: Investigating Effective Sampling Techniques for *Amazona barbadensis* on Bonaire

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"Nature is wont to hide herself"

Heraclitus (540 BC - 480 BC), from *On the Universe*

The yellow-shouldered amazon parrot (*Amazona barbadensis*)

<u>Declaration of own work</u>

I declare that this thesis:

'The Problem with Parrots: Investigating Effective Sampling Techniques for Amazona barbadensis on Bonaire"

is entirely my own work and that where material could be construed as the work of others, it is fully cited and referenced, and/or with appropriate acknowledgement given.

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Acronyms

AIC:	Akaike's Information Criterion
BOPEC:	Bonaire Petroleum Exporting Company
CBD:	Convention on Biological Diversity
CDS:	Conventional Distance Sampling
DCNA:	Dutch Caribbean Nature Alliance
EDR:	Effective Detection Radius
GIS:	Geographic Information System
GPS:	Global Positioning System
HR:	Hazard Rate
IUCN:	International Union for Conservation of Nature
NGO:	Non-Governmental Organisation
WSNP:	Washington-Slagbaai National Park
YSA:	Yellow-shouldered amazon

Abstract

The identification of survey methods capable of producing robust density and population estimates are crucial to the effective monitoring of population trends in threatened taxa. On the Caribbean island of Bonaire, monitoring of the vulnerable yellow-shouldered amazon parrot (*Amazona barbadensis*) population has historically been undertaken using roost count methods. The 2010 roost count survey produced a minimum population of 800 birds. This compares to an estimated population of 2,829 birds generated using distance sampling methods in the same year.

In order to investigate the causes of such disparity, distance sampling surveys were undertaken on Bonaire in spring 2011. These utilised both standard and 'snapshot' data collection methods, resulting in the production of two separate density and population estimates. These were compared with the latest roost count result, with an analysis of the influence of bias within each dataset also undertaken.

The standard 6 minute distance sampling period produced average density and population estimates of 0.01 birds/ha and 2,169 parrots, respectively. The 'snapshot' sampling period produced corresponding values of 0.14 birds/ha and 3,127 parrots. This compares with a minimum roost count of 550 birds in January 2011. The effect of bias was observed in all three datasets. It is recommended that the 'snapshot' distance sampling method is used for future population surveys undertaken on Bonaire, following the institution of bias-reducing methods detailed in this thesis. The value of roost counts in raising public awareness and providing detailed demographic data is also acknowledged.

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1. Introduction

1.1. Study species

The yellow-shouldered amazon parrot (*Amazona barbadensis*) (henceforth YSA) exhibits a restricted and fragmented range along the northern coast of Venezuela and on a small number of satellite islands, historically including both of the Dutch Caribbean islands of Aruba and Bonaire (Figure 1.1). However, the species has undergone a marked decline over the last century, with populations extirpated from many sites, including Aruba (Voous, 1983).

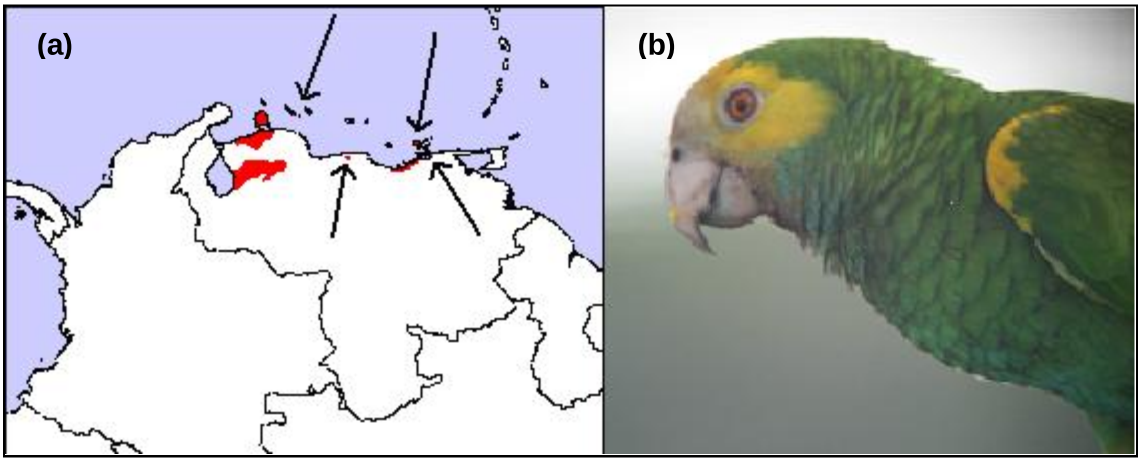

Figure 1.1: Geographic range (a) and photographic image (b) of the yellow-shouldered amazon (map courtesy of Birdlife International)

This decline has been primarily driven by continuing, excessive, levels of poaching fuelling a largely internal trade in wild-caught parrots (Rodríguez & Rojas-Suárez 1995; Birdlife International, 2011). Further drivers of population decline include habitat destruction and degradation and, in certain areas, issues arising from conflict between agriculturalists and foraging parrots (Parks, 2010). In addition, island taxa are often considered more vulnerable to extinction than their mainland relatives due to the greater potential impact of stochastic events upon island populations (MacArthur & Wilson, 1967, Soulé 1987, Whittaker, 1998).

The species is listed by the International Union for Conservation of Nature (IUCN) as Vulnerable due to the varied threats facing its declining and fragmented population, in addition to being cited as a key species of conservation concern in the IUCN Parrot Action Plan (Snyder *et al*, 2000).

The population of YSA on Bonaire has however benefited in recent years from the instigation of several conservation programmes. Schemes aimed at raising awareness and decreasing the incidence of poaching at nests have been initiated by local NGOs (Montanus, 2003), and trial removals of introduced ungulates and habitat recreation have been undertaken by STINAPA Bonaire within Washington-Slagbaai National Park (henceforth WSNP) (Birdlife international, 2011). As such, the Bonairean population of YSA exhibits potential to act as a 'lifeboat' for the species, *in lieu* of similar conservation initiatives in mainland Venezuela (where poaching pressure is still high) (Birdlife International, 2011; Williams, 2009).

1.2. Problem statement

In order to assess the impact of any conservation programme on Bonaire, it is imperative that an accurate, precise and cost-effective monitoring method is utilised to assess trends in the YSA population (Casagrande & Beissinger, 1997). Valid inferences regarding conservation management can only be made following the provision of reliable information about population density and trends (Greene, *et al*. 2010).

Historically, an annual island-wide survey of traditional roost sites has been undertaken to provide a population estimate for the species. The roost count survey undertaken on Bonaire in 2011 generated an estimated minimum population of 550 individual YSA (Montanus, 2011). By contrast, a population estimate generated in the previous year via the use of distance sampling techniques (Buckland *et al*, 1993) suggested a population of 2,829 parrots (Rivera-Milán & Simal, 2011b).

The use of distance sampling to estimate population sizes of rare, cryptic, or low density bird species has historically proved problematic due to the nature of species rarity and their uneven distribution across the landscape (Bibby, Jones & Marsden, 1998). These problems are compounded by behavioural traits in many such species, including communal roosting, foraging in flocks, and large peaks in daily movement patterns.

These issues may be further compounded by the use of variable length sampling periods during independent distance sampling studies. When applied to parrot species, distance sampling surveys have historically utilised a 6 to 10 minute cumulative sampling period at each survey location (Marsden, 1999). This extended sampling period length is however today losing ground to the use of a 'snapshot' survey period, whereby the location of all birds is first noted and then an instantaneous measurement to their positions taken (Buckland, 2006). A comparison of the efficacy of these two sampling periods during parrot surveys has not been previously investigated on Bonaire.

Bonaire presents ideal conditions to investigate the cause of any disparity between roost count and distance sampling methods due to the availability of roost count data going back to 1998 (with sporadic count data available from 1980 onwards) (Montanus, 2011). Furthermore, the YSA is an ideal study species, as it uses both traditional roost sites and is particularly vocal. During the breeding season on Bonaire (occurring between May and July, approximately (S.Williams, 2009)), YSA pairs are territorial around their nest site (and therefore theoretically more evenly spread across suitable habitat) making the application of distance sampling techniques particularly suitable (Buckland, 2006).

1.3. Aims and objectives

The overarching aim of my research is to investigate why disparities exist between the YSA population estimates previously produced using roost count and distance sampling methodologies. As a corollary to this, I will attempt to identify how the existing methods can be tempered to improve both their efficiency and robustness. Finally, I will attempt to identify which of the methods are the most practicable for use in any ongoing parrot monitoring scheme undertaken on Bonaire.

1.4. Focus research questions

In order to refine the research process, the following focal questions will be addressed during my analysis:

1. Is there evidence of bias in any of the YSA population survey methods used on Bonaire?

2. Does the use of the ‘snapshot’ data collection method improve the robustness of population estimates generated via distance sampling?

3. Are either roost counts or distance sampling survey methods more applicable to the production of YSA population estimates on Bonaire?

1.5. Importance and relevance of research

The production of robust annual population estimates for the YSA on Bonaire will prove invaluable, allowing the monitoring of population trends to be undertaken in parallel with ongoing habitat restoration and control of introduced ungulates. A paucity of suitable breeding locations (primarily mature, hollow, trees) has been identified as a limiting factor in the recovery of the Bonairean YSA population (Williams, 2009). Any increase in the extent and maturity of native habitats on the island should therefore be reflected in the YSA population. Results from an accurate assessment of the YSA population size could therefore prove an important indicator of the effectiveness of wider conservation interventions undertaken on Bonaire.

When contemplating the international value and relevance of the research, it is important to remember that all of the endemic, or near endemic, *Amazona* taxa found within the Caribbean are listed as threatened by the IUCN (www.iucnredlist.org). Additionally, a large proportion of other species within the genus, found only on mainland South America, are similarly categorised. As such the identification of a robust and replicable population monitoring method for *Amazona* species is of great importance for the conservation and management of these threatened populations.

In terms of policy and compliance, the initiation of an effective and respected monitoring programme on Bonaire will assist the Dutch Caribbean Government in achieving their objectives under the Convention on Biological Diversity (CBD) (www.cbd.int). Articles 7 and 8 of the Convention (‘Identification and Monitoring’ and ‘*In-situ* conservation’, respectively) will be directly addressed. Recommendations within the CBD Thematic Programme ‘Island Biodiversity’ will also be addressed, as will those comprising the CBD cross-cutting issue ‘Identification, Monitoring, Indicators and Assessment’.

1.6. Overview of structure

This thesis will now provide a literature review of the primary methods used to monitor wild parrot populations. The primary focus of the review will be roost count and distance sampling methodologies, with a critical analysis undertaken of their respective strengths and weaknesses. This will include examples from previous studies undertaken and explore the central themes of the issue. Following this, the methods used and data collected during my research will be detailed, with the latter explored with reference to any wider conservation implications of the study.

2. Background

2.1. The problem with parrots…

Parrots exhibit a range of behavioural and ecological traits which make the estimation of population sizes difficult. Many species are cryptically coloured and secretive in their behaviour, inhabiting darkened forest understoreys where location of individuals may prove difficult (Casagrande & Beissinger, 1997). Many parrots will also form mixed-species flocks, potentially confounding individual species identification when the species concerned are similarly coloured (especially when moving in large groups). Additionally, many species fly long distances (often on a daily basis) between feeding, roosting and nesting areas (Chapman *et al*. 1989).

This indicates that the application of any particular survey method within a distinct geographic location at differing temporal or seasonal points may produce significantly different population estimates. As such, the identification of a robust method to provide a measure of parrot population size has proved problematic. The following sections identify and critically analyse two of the main methods used to date.

2.2. Roost counts

The propensity for many low density parrot species to roost communally, often in traditional locations (Wright, 1996), lends itself to roost count survey methods. The method comprises the identification of communal roost sites and the attempted undertaking of absolute parrot counts by a varying number of surveyors (dependent upon roost size and accessibility) as birds fly to or from the roost (Cougill & Marsden, 2004). This method has not been widely used to estimate parrot populations in the Neotropics (Matuzak & Brightsmith, 2007). Intensive roost count monitoring has however been undertaken for a number of species, including the yellow-naped amazon (*A.auropalliata auropalliata*) in Costa Rica (Matuzak & Brightsmith, 2007), the red-tailed amazon (*A.brasiliensis*) in Brazil (Cougill & Marsden, 2004), and the red-lored amazon (*A.autumnalis*) in Ecuador (Berg & Angel, 2006).

The accurate identification of roost site locations is critical to the method, and is often based upon extensive fieldwork, in addition to interviews with local people (Cockle, et al. 2007). Nevertheless, several studies have identified the difficulties associated with the accurate location of all active roosts as a key constraint when producing population indices based upon roost count data (Casagrande & Beissinger 1997; Cougill & Marsden, 2004; Rodriguez-Ferrara & Sanz, 2007).

Although no standardised roost count method is cited within the scientific literature, most studies undertaken have consisted of a variable number of surveyors stationed at strategic vantage points in proximity to active roosts (Casagrande & Beissinger 1997; Cougill & Marsden, 2004; Cockle, *et al*. 2007). Most have utilised both evening and morning survey periods in order to identify any difference in the timing and number of birds observed entering or leaving the roost. Evening counts have been highlighted as the more effective of the two, as the movement of birds into the roost is less concentrated, allowing a more accurate count to be made (Cougill & Marsden, 2004; Berg & Angel, 2006; Matuzak & Brightsmith, 2007). However, one issue associated with the use of evening roost data especially, is that parrots will move around within the roost and often repeatedly enter and leave (Snyder *et al*. 1987), thus increasing the risk of both under and double-counting of individuals occurring.

One benefit of the roost count method is that changes in weather conditions do not affect the number of parrots observed flying in (Matuzak & Brightsmith, 2007). However, Cougill & Marsden (2004) did note that birds generally arrived later in the afternoons on warm, sunny, days, than on cooler, sunless, days and that surveys should not be attempted during periods of poor visibility, such a mist or torrential rainfall.

The real benefit of undertaking roost count surveys is that they allow demographic, in addition to population, data to be collected. *Amazona* parrot species form stable family groups, with adult pairs usually readily separable from any associated young birds by obvious plumage differences (Gilardi & Munn, 1998). This allows the estimation of both recruitment and fledging rates, and an assessment of the size of the effective breeding population at the roost (Matuzak & Brightsmith, 2007). It is potentially possible to gather such demographic data using other methods, such as distance sampling, although the under-recording of family groups is more likely using this method, due to the imperfect detectability associated with its undertaking.

One potential key constraint to consider when using roost count data is the availability of birds for detection. Studies have shown that attendance at communal roost locations by a variety of parrot species drops off as the breeding season approaches and females spend more time isolated within the nest cavity (Cougill & Marsden, 2004; Berg & Angel, 2006; Rodriguez-Ferrara & Sanz, 2007). In addition to this marked seasonality in roost attendance, daily variation in the numbers of parrots visiting individual roosts can be extreme, with Cougill & Marsden (2004) noting the average difference between roost counts undertaken on consecutive nights being almost 25%, with a 60% difference noted on one occasion during the same study. Discrepancies such as these may be exacerbated via observer bias, making individual counts unreliable. Such daily and seasonal variability in roost attendance means that caution should be applied during the interpretation of any roost counts undertaking over just one or a few nights (Cougill & Marsden, 2004).

Overall, roost count surveys can potentially provide useful information on changes in the roosting populations of threatened *Amazona* taxa (Pitter & Christiansen, 1995). However, the key requirements of the method (comprising the accurate location of all roost sites and the undertaking of extended survey periods) are often impracticable. Therefore, it is unlikely that the method will ever be able to produce a robust density or population estimate of use to conservation managers.

2.3. Distance sampling

Distance sampling is a well-recognised method of generating population estimates. The method requires that the surveyor either travels along a transect, or surveys a point location, recording the perpendicular distance between all target organisms sighted and the line/point (Buckland, 2006). The surveyor is unlikely to detect all of the target organisms present within the immediate vicinity, although a fundamental assumption of the method is that all organisms located on the line or point are detected.

Intuitively, detection rates should decline at increasing distance from the surveyor. This decline in detection rates allows the calculation of a detection function, from which the surveyor can then calculate the proportion of the target organism's population which was not detected during the survey. Theoretically unbiased density and population estimates can then be extrapolated from the fitted function (Buckland, et al. 2001). Distance sampling methods are of particular use in ornithological survey work, although they have also been applied to many other animal groups.

The effectiveness of distance sampling is reliant upon the fulfilment of three key assumptions when undertaking data collection: (1) all organisms on the line or point (referred to as *g*(0)) are identified; (2) all distance measurements taken refer to the original location of the organism concerned, and; (3) all distance measurements taken are accurately recorded (Buckland, 2006). However, meeting these assumptions is often fraught with difficulty in the field.

2.3.1. Recording of all targets at *g*(0)

Dependent upon the type and structure of the habitat being surveyed, the identification of all birds at *g*(0) will often prove problematic (Cahill, Walker & Marsden, 2006). Many bird surveys undertaken in densely vegetated habitats will fail to locate cryptic or shy species within dense layers of foliage (Marsden, 1999). A study undertaken by Bächler & Liechti (2007) on nine radio-tagged orphean warblers (*Sylvia hortensis*) indicated that visual detection at *g*(0) was only 58% after a five minute search, even when the location of birds within individual bushes was known.

One way of minimising this effect (in the case of point counts at least) is to spend a short period of time at the end of each sampling period moving around/beneath the *g*(0) location to try and identify any hidden individuals which were initially missed (Marsden, 1999). Nevertheless, in a review of twenty-eight papers, each detailing the production of population estimates using distance sampling techniques, Elphick (2008) identified only a single example in which the surveyors had sought to maximise detection at zero distance with more than half the papers reviewed not mentioning the issue.

2.3.2. Identification of birds in their original locations

The identification of movement towards or away from the surveyor is a critical component of the distance sampling method, as changes in these parameters will impact any density estimate generated. This is a particular issue for small insectivores, with both Buckland (2006) and Cimprich (2009) finding that density estimates produced using distance sampling were far higher than those generated using traditional territory mapping techniques. These two studies did suggest that their findings were not necessarily due to the birds being attracted to the surveyor, but more likely due to the rapid, unseen, movement of individuals through vegetation whilst feeding. This ultimately resulted in the occurrence of double-counting.

Marsden & Jones (1997) suggested that the issue is also of relevance to parrot species, with movements towards the surveyor often noted amongst psittacine taxa. Nevertheless, Lee & Marsden (2008) stated that attraction towards the surveyor is less common than movement away from the surveyor. Contrastingly, Greene *et al* (2010) found that undetected movement in response to observer presence was insignificant during their study on the South Island kākā (*Nestor meridionalis septentrionalis*).

This issue has a direct impact upon the length of the count period used in point count distance surveys. Historically, a 10 minute count period has been adopted to ensure that all birds at $g(0)$ are accounted for (Casagrande & Beissinger 1997; Marsden, 1999). This count period is still utilised in more recent studies (e.g. Greene *et al*, 2010), but its use does mean that there is an increased potential for birds to move in or out of the survey area during the sampling period (Marsden, 1999). Surveys undertaken using shorter survey periods will minimise this risk, but may compromise other key assumptions of the distance sampling methodology.

In recent years, much debate has concerned the use of a ‘snapshot’ sampling period rather than an extended cumulative count (Buckland, 2006). Using the former method, an observer arrives at a point count, locates birds for a fixed period of time, and then, at the end of this period (the “snapshot” moment), records the distances to the focal birds present (Cimprich, 2009). The value of the ‘snapshot’ is that all measurements are taken at the same moment in time, thus minimising the risk of movement or double-counting. Nevertheless, the method may not be suitable for use with highly active species, or those which are difficult to either visually or aurally track during the run up to the 'snapshot moment' (Cimprich, 2009).

A 'settling down' period has also regularly been utilised upon arrival at a point count location prior to the recording of data using the 'traditional' extended count period. This allowed any birds present to resume their normal behaviour following potential disturbance caused by the accessing surveyor (Bibby, Burgess & Hill, 2000). This process is now generally discounted however (Lee & Marsden, 2008) (and is of minimal consideration when using the 'snapshot' method in any case), as it lends itself to further compromising of the 'movement assumption' and is less time-efficient (Gale, *et al.* 2009).

2.3.3. Accurate measurements of distance

The accurate measurement of distances to survey targets is central to the distance sampling process. This activity is greatly assisted either through the thorough training of surveyors in visually estimating distances under test conditions (Bibby, Jones & Marsden, 1998), or through the use of laser rangefinders. Nevertheless, the accuracy of such measurements will vary between surveyors, within different habitat types, and between point and line transect surveys (Bibby, Burgess & Hill, 2000).

Several issues confound the issues of detectability and accurate distance measurement. Key amongst these are the accurate recording of aural registrations and the 'availability for survey' of the target population. In many point count surveys auditory observations comprise the primary data collected, with aural detections often comprising 95% of all bird detections in forested habitats (Simons *et al*. 2007). Indeed, the kākā study undertaken by Greene *et al* (2010) relied upon aural data for >90% of species registrations.

The accuracy of distance measurements to aural observations (and the accurate numeration of the birds comprising the unseen vocalising group) is often far from ideal. Alldredge, *et al* (2008) demonstrated that even experienced ornithological surveyors could not repeatedly and accurately identify the distance to vocalising individuals. It is therefore possible that population estimates produced using distance sampling are systematically overestimated when most detections are based on sound (Elphick, 2008). Attempts have been made to improve the efficacy of such measurements, including the use of autonomous recording units (Hutto & Stutzman, 2009), but limited success has yet been met.

The availability for detection of birds during distance sampling periods will also vary between species, habitats, and over time. Diefenbach, *et al* (2007) found that during distance sampling surveys of grassland bird populations not all individuals were detected on or near the transect line. This is because the birds must sing and be visible above the grass sward in order to be detected. Similarly, surveys undertaken upon parrot species during the breeding season are less likely to record female birds busy incubating eggs within nest cavities (Casagrande & Beissinger 1997).

2.3.4. Other considerations

In addition to the three main assumptions of distance sampling detailed above, several other issues potentially cloud its use unless taken into account at the survey design stage. One key consideration is the impact of habitat structure upon detectability, which is of particular importance when undertaking studies within areas incorporating differing habitat types (Bibby, Burgess & Hill, 2000).

Casagrande & Beissinger (1997) suggested that point count surveys will underestimate parrot populations within areas of open habitat (due to the production of lower density estimates for such habitat types, potentially resulting from observer-induced movement). In areas of mixed habitat the same study found it difficult to produce robust, pooled, detection functions when using point counts across differing habitat types. They therefore recommended using line transects along habitat gradients, when conditions allow, in order to produce more robust density estimates.

Another issue to consider is the assumption that no 'individual heterogeneity' exists across the survey population during single-species surveys, meaning that all individuals are equally detectable regardless of sex, age, etc (Efford & Dawson, 2009). Distance sampling methods have been shown to be robust to such individual heterogeneity, other than that arising from the distance measurements recorded (Efford & Dawson, 2009). The same cannot be said of other count-based methods however, as these mostly fail to account for distance-related heterogeneity (Reidy *et al*, 2011).

In conclusion, whilst distance sampling allows the generation of real density and population estimates for threatened taxa, rather than indices of abundance, it is still potentially subject to varying levels of bias. Further comparisons of roost count and distance sampling surveys, aimed at identifying and minimising such bias, are therefore to be welcomed.

2.4. Other survey methods

A wide range of alternative methods for generating avian population estimates exist in addition to the roost count and distance sampling methods considered in this thesis. These include occupancy modelling (Royle & Nichols, 2003), and multiple and double observer methods (Alldredge, Pollock & Simons, 2006); both of which could be utilised during surveys of parrot populations. However, both are subject to constraints similar to those posed when undertaking distance sampling, including variations in seasonal behaviour/distribution and accurate species identification.

Other techniques, such as territory mapping (Bibby, Burgess & Hill, 2000), are of limited use in surveying psittacine populations, as few species exhibit territorial behaviour away from the nest site and many smaller species produce little in the way of vocalisations. Similarly, the use of 'long lists' (Szabo *et al*, 2010), detailing the presence and absence of bird species over a certain number of years at a given site (based upon birdwatchers' notebooks) is likely to prove of negligible import. As previously discussed, many parrot species exhibit cryptic behaviour and are unlikely to be detected during such non-targeted surveys, and limited presence/absence data of this kind cannot be used to generate density or population estimates.

The use of Geographic Information Systems (GIS) data and radiotelemetry to produce habitat suitability maps has been pioneered by Reillo & Durand (2008) during their monitoring of Dominica's two endemic *Amazona* species. This method uses a combination of parcel-scale density estimates (produced using radiotelemetry), surveyed habitat parameters, and topographic area to calculate island-wide population estimates. It is potentially of value to surveyors working in other areas exhibiting extreme topography, but of limited value in situations where access is less problematic.

2.5. Study site

Field research was undertaken on the island of Bonaire (Figure 2.1), comprising part of the Dutch Caribbean. The island is located 80km to the north of Venezuela and is approximately 38km long and 5 to 8km wide, creating a surface area of approximately 180km^2. The island supports a population of approximately 15,000 people, with the southern capital of Kralendijk, and smaller Rincon to the north, comprising the two major population centres (all information from www.infobonaire.com).

Figure 2.1: Satellite image of Bonaire (taken from www.google.com/maps)

The island has an average annual temperature of 28°C and receives low, irregular and localised rainfall. The average annual precipitation is 463mm, of which 51% falls in October, November and December (Williams, 2009). The southern third of the island consists of expansive industrial salt works, with the rest dominated by a highly heterogeneous xerophytic plant community (De Freitas, 2005). Much of the natural vegetative habitat has however been removed or degraded since European colonisation in the 16th Century, with continued pressure placed upon remaining communities by the large number of feral herbivores present on the island (Williams, 2009).

3. Methods

3.1. Survey design

Survey design was undertaken in April 2011, prior to the commencement of fieldwork in May. In order for any data collected to be comparable with the previous work of Rivera-Milán & Simal (2011a+b), it was decided that a total of 150 randomly generated point count locations would be designated across the northern two thirds of Bonaire. The southern third of the island comprises commercial saltpans and salinas; neither of which habitats are suitable for use by the YSA (Williams, 2009).

An outline map of Bonaire, with corresponding projected co-ordinate system, was sourced from www.diva-gis.org and imported as a shapefile into ArcGIS. An aerial photograph overlay of the island was then projected onto the outline map (using the ArcGIS Google Earth tool). An arbitrary line was drawn around the northern shore of the Lac Bay mangroves (located on the south-east coast) and then extended to the island's western shoreline (see Figure 3.1). This excluded the predominantly unsuitable parrot habitats to the south and approximated the survey area extent utilised by Rivera-Milán & Simal (2011b).

Following the delineation of the survey area shapefile, all large waterbodies located within it (comprising both salinas and ephemeral freshwater pools) were identified from Google Earth images and a 1:60,000 scale road map of the island (www.berndtson.com) and then digitised. An attempt was also made to identify and digitise the island's broad habitat types for use in survey stratification, but the quality of aerial photographs available precluded this undertaking.

Having digitised any unsuitable aquatic habitats, a 1km square grid was produced in ArcGIS and overlaid upon the survey area shapefile. The ArcGIS Hawths Tools 'create random points' option was then utilised to generate a random point within each of the 220 1km squares incorporating at least half of their total area within the survey area outline. Further proscription was placed upon locating any random point within either a digitised waterbody or within 500m of another point location (Marsden, 1999).

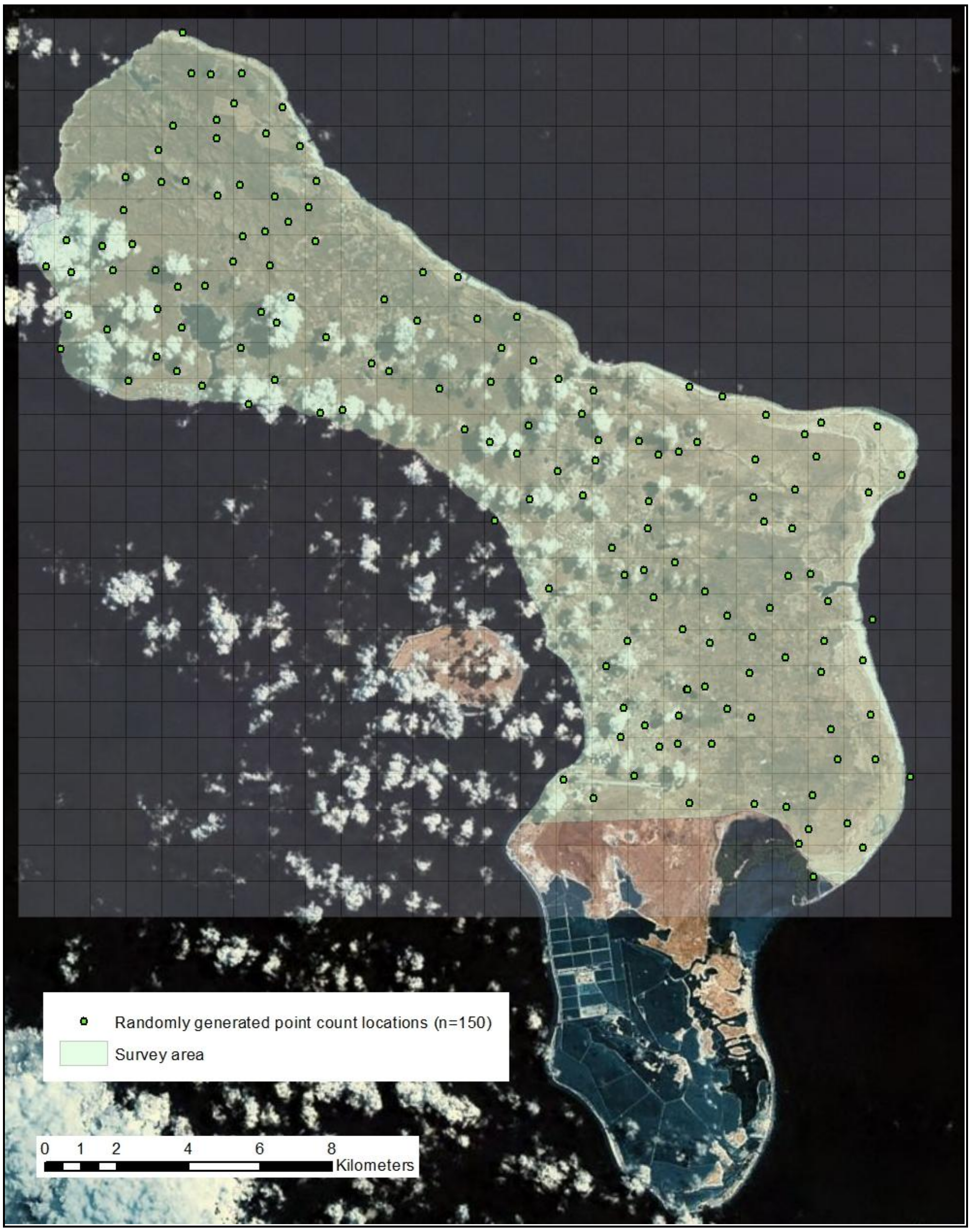

Figure 3.1: Depiction of survey area, 1km grid and location of original 150 randomly generated point count locations prior to commencement of field survey

A further subset of 150 of the original 220 point count locations detailed above were then selected as the finalised field survey sites, using the Hawth's Tools 'select random points' option. Of these points, 6 were found to have been located within the coastal waters off Bonaire and were removed from the study. The remaining 144 count locations were each awarded a numerical identifier associated with their geographic co-ordinates, with this data then tabulated for use during data collection in the field.

Following commencement of the field survey, a further 7 point count locations proved to be completely inaccessible on the ground (with access impossible at >1km from their original position). This inaccessibility was due to either the points' location on private property, within expansive stands of dense vegetation, and/or within areas of severe topography. These 7 points were therefore also removed from the study.

Access proved problematic when accessing many of the remaining 137 points in the field. Due to the forced relocation of several of the points following access difficulties, a revised figure detailing the exact location of the surveyed points was produced post-field survey (see section 4).

3.2. Field survey

The annual YSA roost count survey was undertaken on Bonaire on 29th January 2011 by a group of volunteers co-ordinated by the NGO Salba Nos Lora, in co-operation with STINAPA Bonaire and the Department of Natural Resources and Environment of the Island Government.

All other field survey work on the island was undertaken by the author in a six week period between 18th May and 24th June 2011. During this period each randomly generated point count was surveyed once, either in the morning (between 06:30 and 10:00 hours) or in the afternoon (between 15:30 and 18:00 hours). The absence of survey work during the first half hour of daylight after dawn, and during the last hour of daylight prior to dusk, precluded any influence upon data collection caused by parrots commuting between their overnight roosting and daytime feeding areas. The two daily survey periods were also chosen to coincide with maximum daily parrot activity, excluding the warmer hours of the day during which birds are less active (Rivera, Politi & Bucher, 2007).

3.2.1. Roost counts

Counts were undertaken simultaneously at all identified roost locations using the standard methodology enacted each year on the island since 2000 (S. Williams, *pers.comm*). Paired teams of surveyors arrived at strategic vantage points in proximity to each roost site prior to sunrise on the day of the survey. As the parrots became more active/vocal at sunrise and started to leave, an attempt was made to accurately count all birds leaving the roost, using binoculars when available. Numbers were sometimes estimated at larger/busier roost locations. In addition to parrot numbers, the following data was recorded independently by each observer at each roost to minimise the risk of either under or double-counting, following later comparison: time and point of departure, number of birds, flight direction and destination.

3.2.2. Distance sampling

Fieldwork was undertaken only on dry days with minimal wind to increase the likelihood of recording parrot activity (Matuzak & Brightsmith, 2007). Point count positions were located using a Garmin GPS unit (Etrex H model). At sites where access to the original, randomly generated, point count location proved impossible, surveys were undertaken at the nearest accessible point and the geographic co-ordinates noted. Viewing conditions (in terms of low sun or heat haze) were also noted, as was the date and time at the start of the survey period.

Upon commencement of each count the surrounding landscape was carefully scanned using a pair of Minox 10x42 binoculars, with particular attention paid to areas from which YSA vocalisations could be heard. When parrots were sighted their distance from the surveyor was measured using a handheld laser rangefinder (Bushnell Legend 1200 ARC). Parrots were counted as either individuals or ‘clusters’, with birds loosely associating within approximately 15m of one another identified as part of the same cluster. The distance to clusters was measured from the ‘gravitational centre’ of the group.

Initially unseen vocalising birds proved extremely difficult to detect visually within dense vegetation, with resultant scope for the recording of inaccurate distance measurements to be made. Distance measurements to unseen vocalising individuals were not therefore taken, although the presence of any unseen calling birds at each point location was noted. Overflying birds, or those observed to fly into the survey area after commencement of the survey, were excluded from data collection to minimise bias (Marsden, 1999).

An initial distance sampling period of 6 minutes was used, during which time distance measurements were made to all YSA visually located. A final ‘snapshot’ distance measurement was taken of all YSA still present at the end of the 6 minute survey period, excluding any birds which may have been present earlier but which subsequently moved on prior to survey cessation. All data collected was tabulated within a Microsoft Excel spreadsheet on a daily basis.

3.3. Data analysis

Data analysis consisted of two separate components. The first was a spatial analysis of surveyed point count locations with reference to a range of potentially biasing ecological and anthropogenic landscape features. The second was an analysis of the data gathered using the two different distance sampling survey periods and their effect upon any resultant population estimate produced.

3.3.1. Spatial analysis

The initial Figure 3.1 was revised, with a new figure produced using ArcGIS plotting the finalised locations of the surveyed point counts (see section 4). The Berndtson 1:60,000 scale road map was digitised and used to define the location of all major and minor roads on the island. The extent of the two main urban areas (comprising the towns of Kralendijk and Rincon) and the other large anthropogenic structures on the island (e.g. the airport and Bonaire Petroleum Exporting Company (BOPEC) facility) were also incorporated within the revised figure. The geographic co-ordinates of historic YSA roost locations were provided by Sam Williams and also digitised.

An ArcGIS shapefile depicting the ‘Landscape Ecological Vegetation Map of the Island of Bonaire (Southern Caribbean)’ (De Freitas *et al*, 2005) was kindly provided for use by the Dutch Caribbean Nature Alliance (DCNA). The original 34 vegetation communities identified in the map were amalgamated into 10 broad habitat types, based upon their distribution on the island and botanical affinities. A novel figure was then produced detailing the distribution of surveyed point locations within each of the broad habitat types present. Appendix 1 provides further detail on the structure and floral composition of each habitat type.

The distribution of surveyed point counts within both broad habitat types and in relation to the original, randomly generated, point locations and anthropogenic structures, were analysed using ArcGIS and Microsoft Excel. Analysis of comparative habitat percentage cover and point count distribution within each habitat type was undertaken using a chi-squared test. A comparison of mean distances to anthropogenic structures was undertaken between the original and surveyed point locations using ArcGIS linear measurement tools.

3.3.2. Roost counts and population estimates

Roost count data were tabulated and used to produce a scatter plot. The data were provided as a cumulative figure across all roost sites surveyed in any given year.

Distance sampling data was analysed using Microsoft Excel and the free online software package Distance 6.0 (Thomas *et al*, 2009). Frequency histograms of the combined detection data for both the 6 minute and 'snapshot' datasets were first produced in Excel. An attempt was then made to post-stratify the larger, 6 minute, dataset by broad habitat type, although this proved difficult due to the small number of registrations recorded (see Appendix 2). Data truncation to improve model fit was not undertaken for the same reason.

A series of detection functions were then produced using the half-normal, uniform, hazard-rate, and negative-exponential key functions. The validity of the models produced was compared via visual assessment of data 'goodness-of-fit', changes of ≥2 in Akaike's Information Criterion (AIC) between competing models, and the results of a pooled Chi-squared test undertaken for each model. Following selection of the key function, the cosine and simple polynomial adjustment terms were utilised to further refine the model produced. The density estimate produced from the model was then used to extrapolate the estimated YSA population present within the survey area.

The same process was then undertaken for the 'snapshot' data collected at the end of the 6 minute survey period. Due to the great difficulty in pin-pointing the exact locations of vocalising, unseen, parrots within dense scrub habitats during the survey bouts, only visual registrations of YSA were utilised in the production of all Distance-generated models.

4. Results

The following section is divided into two main subsections; the first examining the presence of any potential bias within survey design and data collection, and the second detailing the findings of the two separate population assessment methods used.

4.1. Spatial analysis

4.1.1. Accessibility

Overall, accessibility proved to be problematic, with only 48% of the surveyed point counts located on or within 10m of their original position (Figure 4.1). Of the remaining point counts, 38% were located more than 50m from their original location, with 9% distributed more than 500m from their original location.

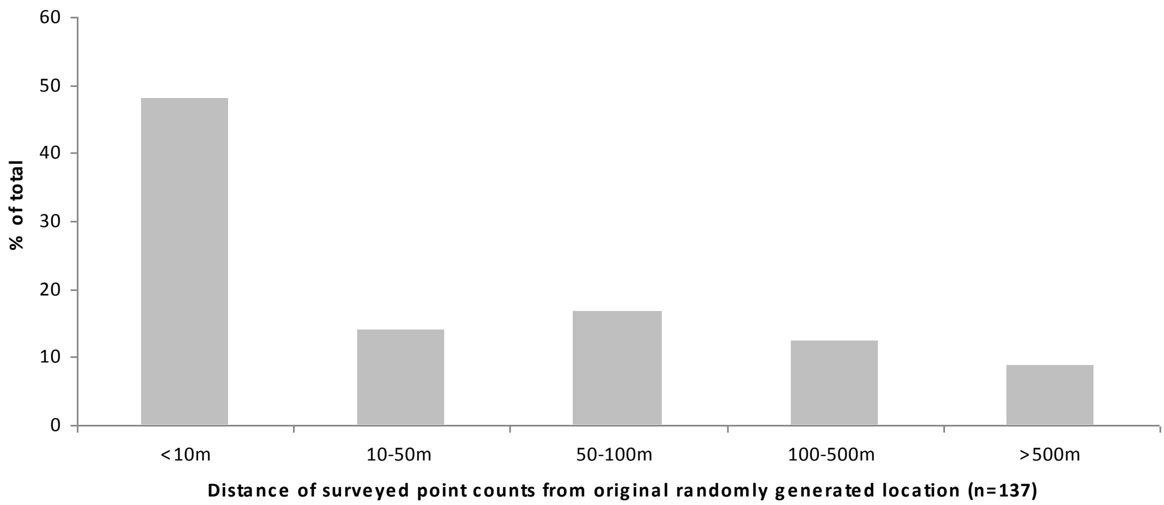

Figure 4.1: Proximity of surveyed points to original randomly generated points

Figure 4.2 depicts both the locations of the original randomly generated point count locations (a) and those points actually surveyed (b). Both sets of points are shown in relation to the major and minor roads present on Bonaire, and other large anthropogenic structures.

As can be seen from the figure, the majority of the surveyed point counts were either located upon, or fell in close proximity to (i.e. <50m from), the original random points. However, there is evidence of clustering along the main

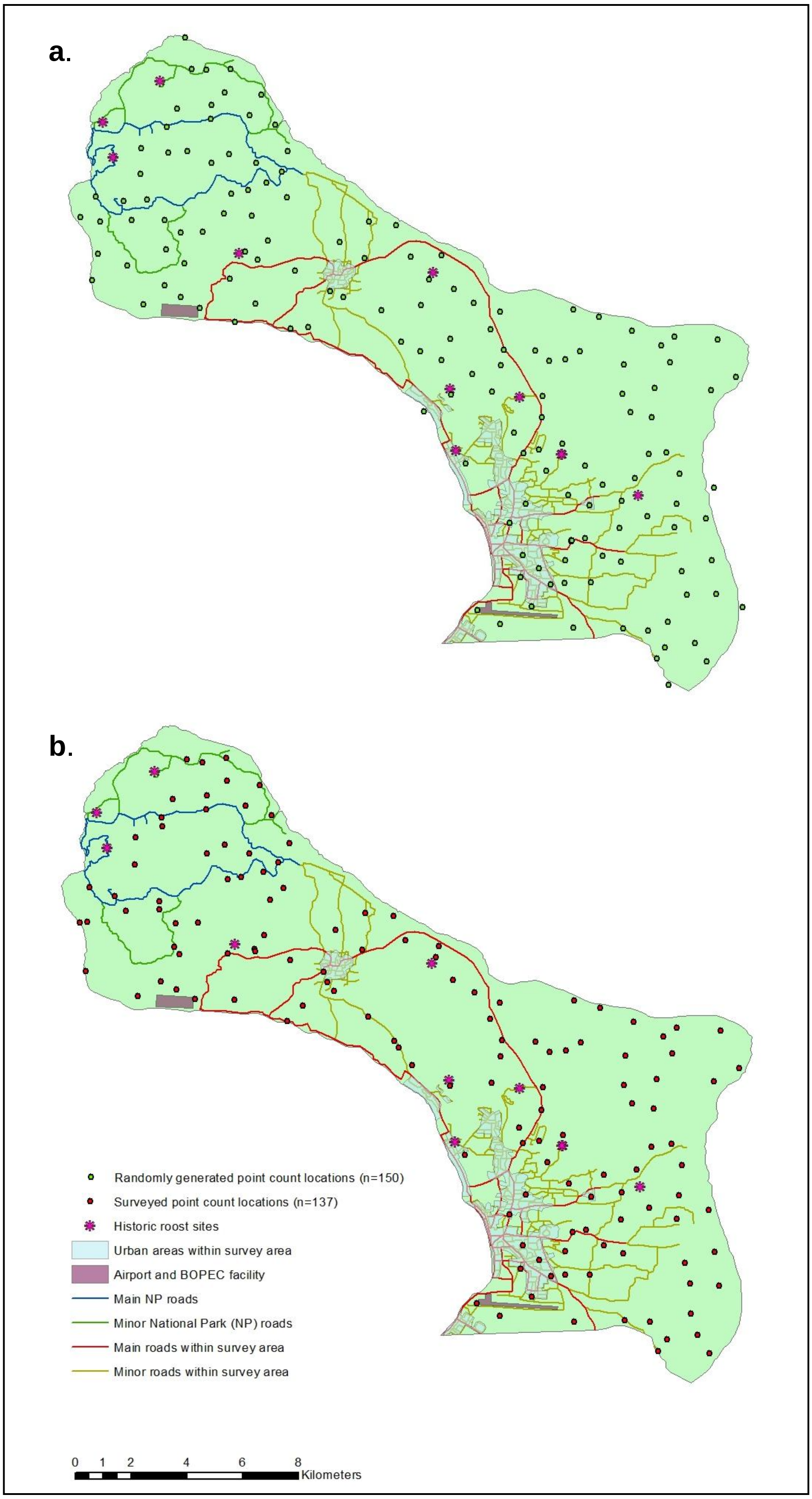

Figure 4.2: Location of point count locations, historic roost sites and anthropogenic features within survey area in relation to (a) original randomly-generated point locations and (b) surveyed point locations

north/south road network running between the towns of Kralendijk and Rincon (Figure 4.3), and, albeit to a lesser extent, within WSNP.

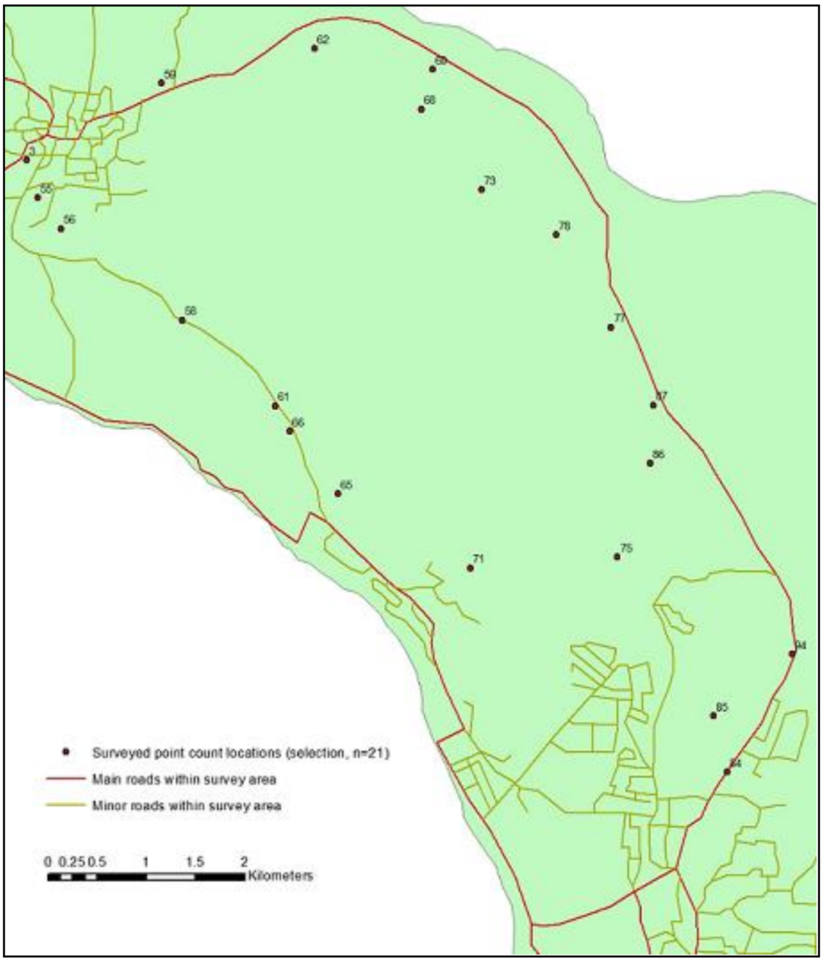

Figure 4.3: Location of surveyed point count locations in central Bonaire in relation to main north/south roads on the island

Indeed, for the 21 point locations identified in Figure 4.3, the average minimum distance to the nearest road is 231.60m, compared to 551.35m for the originally generated points in the same location (see Figure 4.2).

4.1.2. Habitat representativeness

Figure 4.4 depicts the location of the 137 surveyed point locations within the island's 10 broad habitat types. The survey area excludes the expansive salt pans at the island's southern tip, the large salina comprising Lac Bay, and an area of 'middle terrace' vegetation communities adjacent to it.

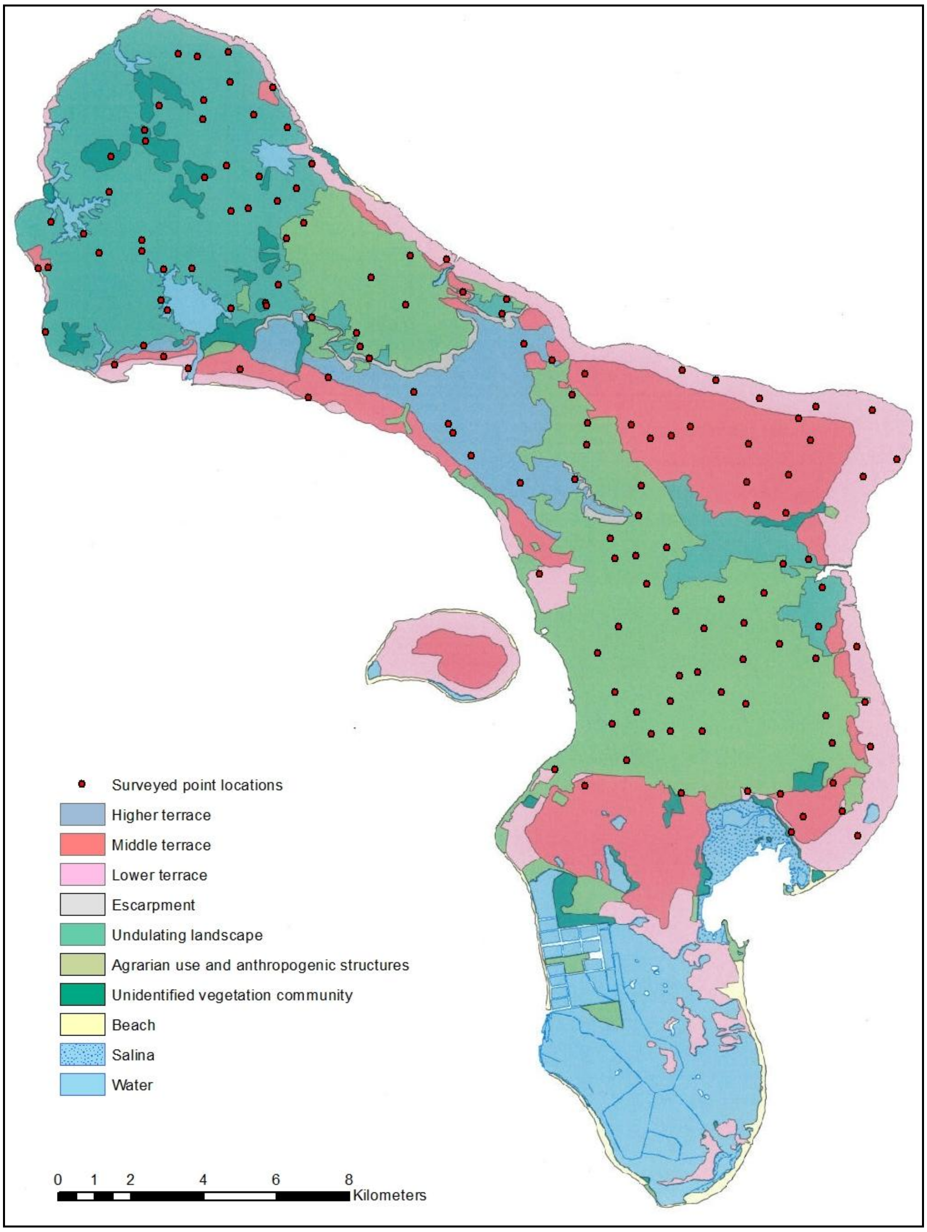

Figure 4.4: Location of surveyed point locations in relation to broad habitat types (*n=137*)

Of the surveyed point counts, 26% and 33% respectively are located within the large extents of habitat identified as ‘undulating landscape’ (UL) and ‘agrarian use and anthropogenic structures’ (AG). A further 17% are incorporated within ‘middle terrace’ (MT) and 11% within ‘lower terrace’ (LT). The relatively small extents of ‘higher terrace’ (HT) and ‘unidentified vegetation community’ (UNID) habitats present (the latter considered to mostly comprise hilltop vegetation) hold 7% of surveyed points each. No points are situated within the small extent of ‘escarpment’ (ES) habitat present.

Figure 4.5 depicts the percentage area coverage of each broad habitat type and the percentage of point counts located within each. It indicates that the distribution of points within the broad habitat types was representative of the percentage

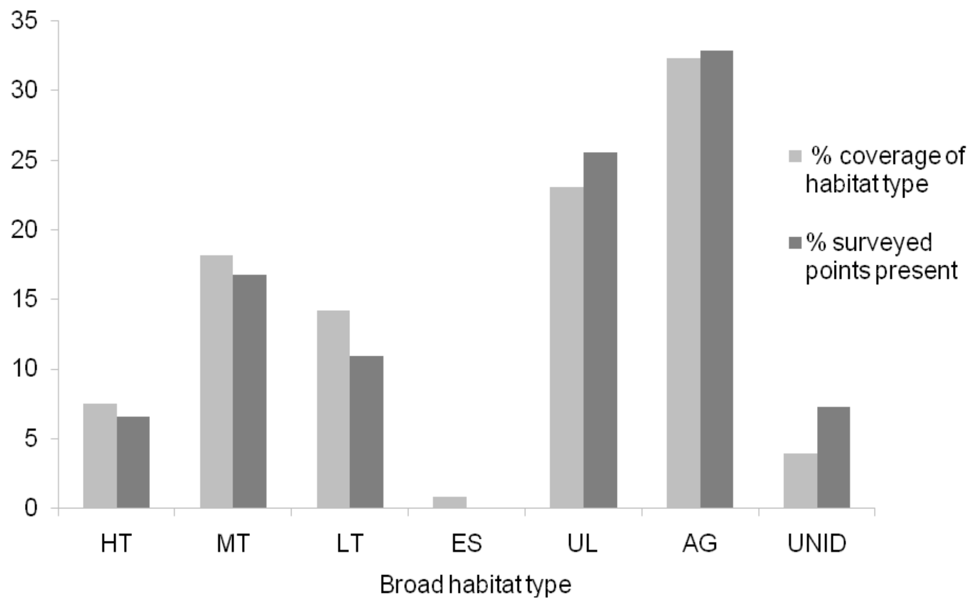

Figure 4.5: Distribution of 137 surveyed point locations within broad habitat types

cover of each habitat type. The undertaken chi-squared test, comparing the idealised habitat-representative point distribution with the actual point distribution, did not prove significant (x^2 = 6.83, df = 6, p = 0.05).

4.2. Population surveys

4.2.1. Roost counts

Roost count data is sporadic between the years 1980 and 2000, with annual surveys commencing from 2000 onwards (Figure 4.6). The annual count varies dramatically, with 550 birds counted in 2011 compared to 800 in 2010. A possible increasing trend in the minimum count of roosting YsA is apparent, although it is difficult to confirm considering the large variation in inter-annual counts.

4.2.2. Distance sampling

An in-depth analysis of the larger, 6 minute, dataset is provided first. Due to the small number of registrations collected during the ‘snapshot’ survey period it has not been possible to analyse that dataset beyond generation of a basic detection function and population estimate parameters.

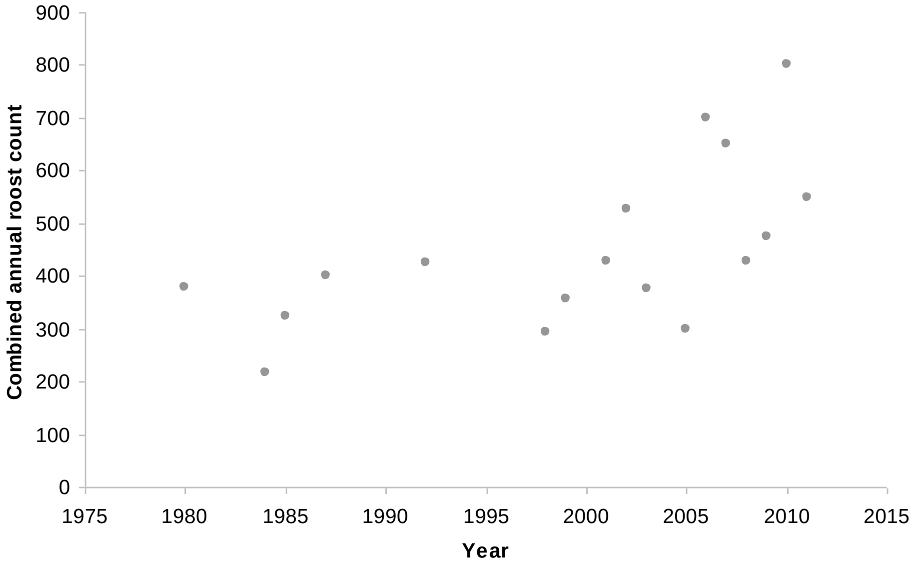

Figure 4.6: Roost count totals since 1980

4.2.2.1. Six minute sampling period

Of the 63 YSA registrations collected during the 6 minute sampling period, 35 comprised visual registrations, with 28 additional records arising from an unseen number of vocalising parrots. The latter figure represents the number of point counts from which unseen/unmeasured vocalisations were recorded, rather than cumulative aural registrations per point.

The 35 visual YSA registrations were collected from 24 of the 137 surveyed point locations (Figure 4.7). The cumulative number of visual registrations recorded per minute increased steadily during the sampling period.

Figure 4.8 depicts a frequency histogram of detection distances for individual YSA from the cumulative 6 minute dataset. An attempt was made to post-stratify the dataset by broad habitat type (Figures A2.1a-e, Appendix 2), but the minimal number of registrations collected for each habitat precluded any further refinement using Distance 6.0. The frequency data shows a peak close to 0 distance, which gradually declines out to a distance of c.300m. A small resurgent peak in detections is apparent between 400 and 700m, with an outlier detection at >900m.

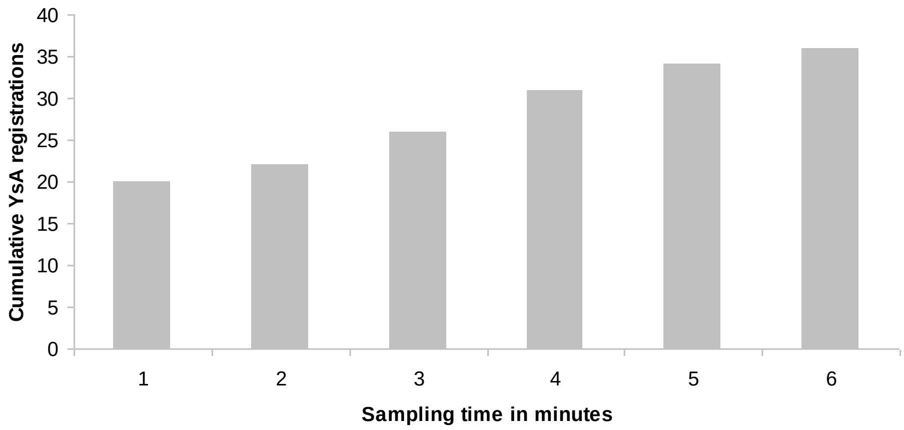

Figure 4.7: Cumulative visual registrations collected during 6 minute sampling period

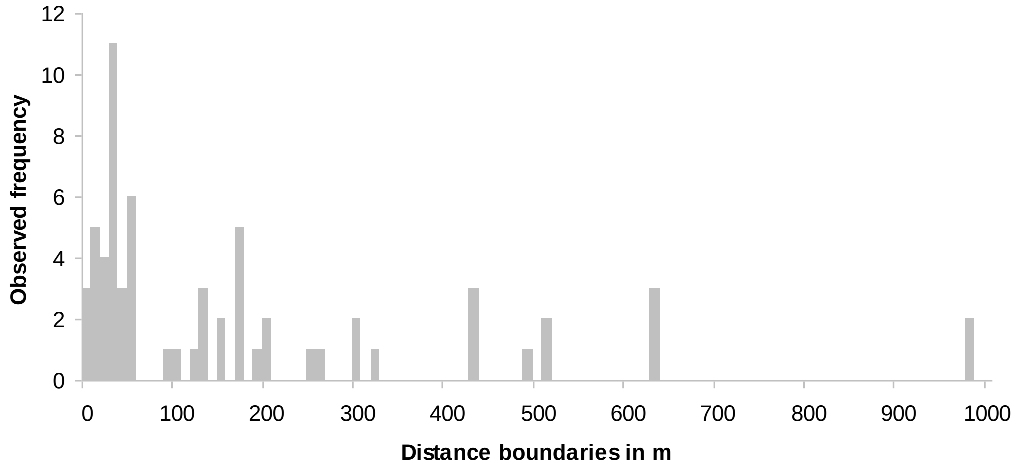

Figure 4.8: Detection distance frequencies of individual YSA from 6 minute distance sampling data

The results of model-fitting using Conventional Distance Sampling (CDS) in Distance 6.0 are shown in Table 4.9. The model produced using the hazard rate (HR) key function exhibited the lowest AIC value, with all other models produced exhibiting ΔAIC values of >2. The HR model also exhibits a better 'goodness-of-fit', exhibiting the lowest pooled x^2 value of the models, in addition to utilising 2 parameters and 4 degrees of freedom. It also exhibits the highest probability of a greater x^2 value, however.

Table 4.9: Comparison of different models describing 6 minute survey data using CDS

Key function	Adjustment term	AIC	ΔAIC	No. parameters	x^2	df	Probability of greater x^2
Hazard rate	Cosine	116.92	0.00	2	1.81	4	0.77
Negative exponential		123.65	6.73	1	8.07	3	0.04
Half normal		125.33	8.41	5	7.97	4	0.09
Uniform		153.55	36.63	2	63.24	3	0.00

Further refinement of the HR model, using both simple polynomial and hermite polynomial adjustment terms, proved redundant, with all three models exhibiting identical AIC values. The initial HR cosine model was therefore selected for use in the production of a population density estimate.

The detection function model produced is presented in Figure 4.10. It indicates that detection probability = 1 up to a distance of c.50m from the surveyor, with a broadly-defined 'shoulder' apparent, prior to detection probability declining rapidly between c.70m and 150m from the surveyor. A long 'tail', comprising non-truncated outlier data, then stretches out to the 1000m cut-off point.

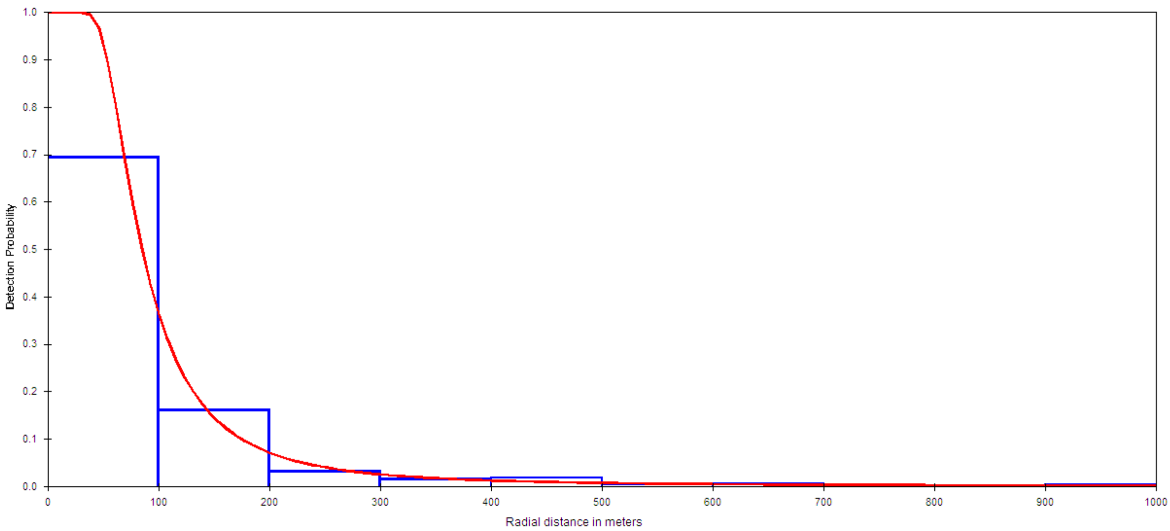

Figure 4.10: Detection function for 6 minute dataset using HR cosine model

Figure 4.11 depicts the probability density function of the model. It indicates that the relative density of YSA registrations was highest c.70m from the surveyor, before steeply decreasing prior to 200m.

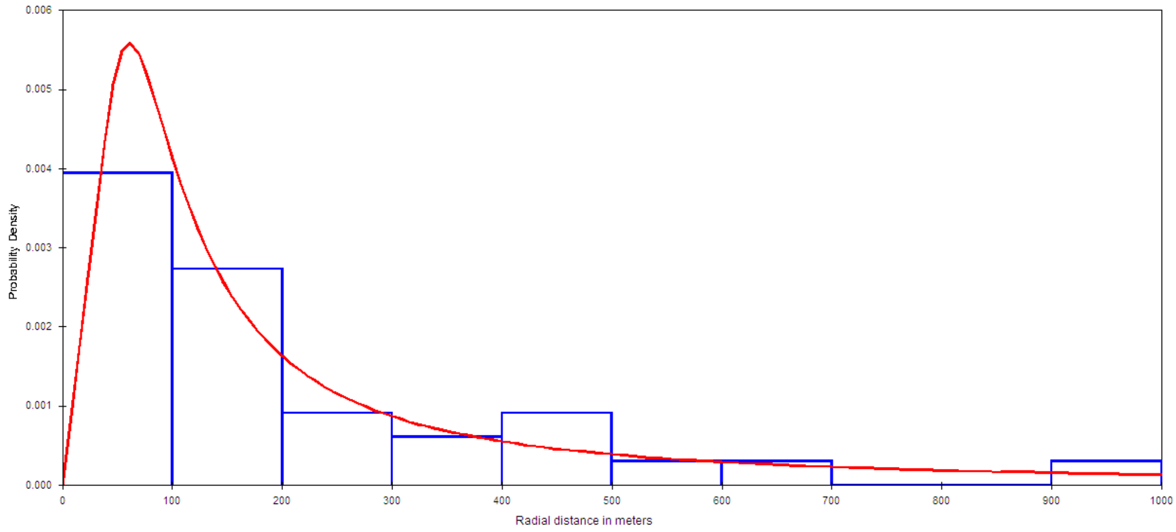

Figure 4.11: Probability density function for 6 minute dataset using HR cosine model

The estimated population parameters produced using the model are presented in Table 4.12. The total population (N) is calculated using density (D) and the area of the entire survey area, minus the area of permanent freshwaterbodies and Salinas, (22,111 ha in total).

Table 4.12: Population parameter estimates using 6 minute dataset

Parameter	Point estimate	Standard error	Percent coefficient of variation	95% confidence interval	
Estimate of cluster density (DS)	0.43E-01	0.24E-01	55.70	0.15E-01	0.13
Estimate of expected value of cluster size (E(S))	2.25	0.23	10.09	1.83	2.77
Estimate of density of parrots (D)/ ha	0.98E-01	0.55E-01	56.61	0.33E-01	0.29
Estimate of number of parrots in specified area (N)	2,169	1,227.8	56.61	742	6,339

4.2.2.2. 'Snapshot' sampling period

20 visual registrations were recorded during the 'snapshot' sampling period (undertaken at the end of the 6 minute sampling period). Habitat post-stratification was not attempted due to the very small number of registrations made.

The HR model was again selected for use in describing the data, as it exhibited the lowest AIC value, performed well in the 'goodness-of-fit' test, and exhibited the lowest x^2 value (Table 4.13).

Table 4.13: Comparison of different models describing 'snapshot' survey data using CDS

Key function	Adjustment term	AIC	ΔAIC	No. parameters	X^2	df	Probability of greater X^2
Hazard rate	Cosine	73.32	0.00	2	1.56	3	0.67
Negative exponential		78.88	5.56	1	4.52	3	0.21
Half normal		79.18	5.86	2	8.09	3	0.04
Uniform		82.30	8.98	3	13.07	2	0.001

Further analysis using the simple polynomial and hermite polynomial adjustment terms again produced no difference in AIC values, and so the cosine adjustment term was utilised in the chosen model.

The detection function model produced is presented in Figure 4.14. The figure indicates that detection probability = 1 up to a distance of c.15m from the surveyor before declining rapidly to c.70m from the surveyor. A long 'tail', comprising non-truncated outlier data, then stretches out to the 650m cut-off point.

Figure 4.15 depicts the model probability density function of the 'snapshot' dataset. It indicates that the relative density of YSA registrations was highest c.35m from the surveyor, before steeply decreasing prior to 150m.

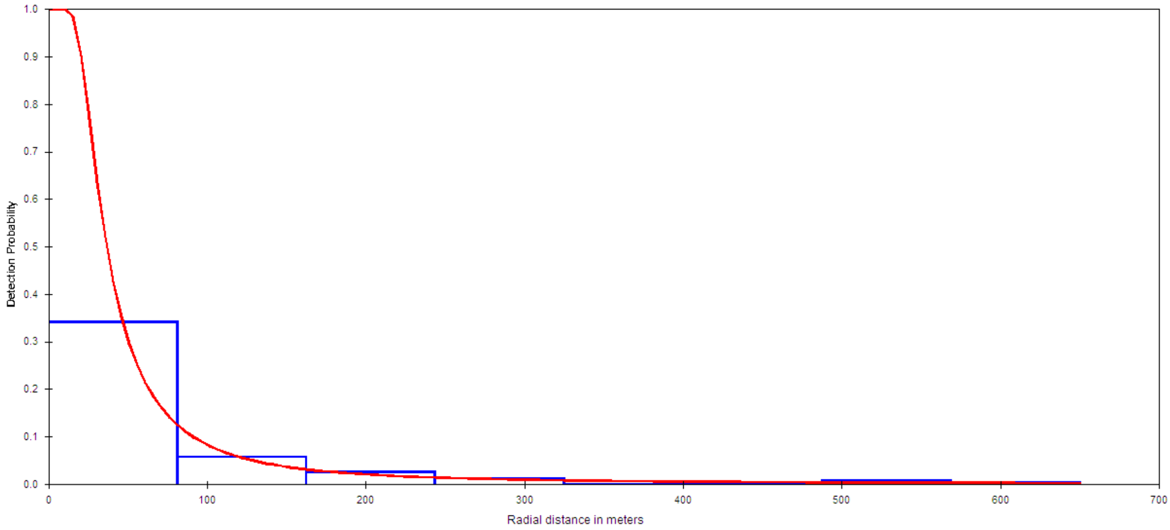

Figure 4.14: Detection function for 'snapshot' dataset using HR cosine model

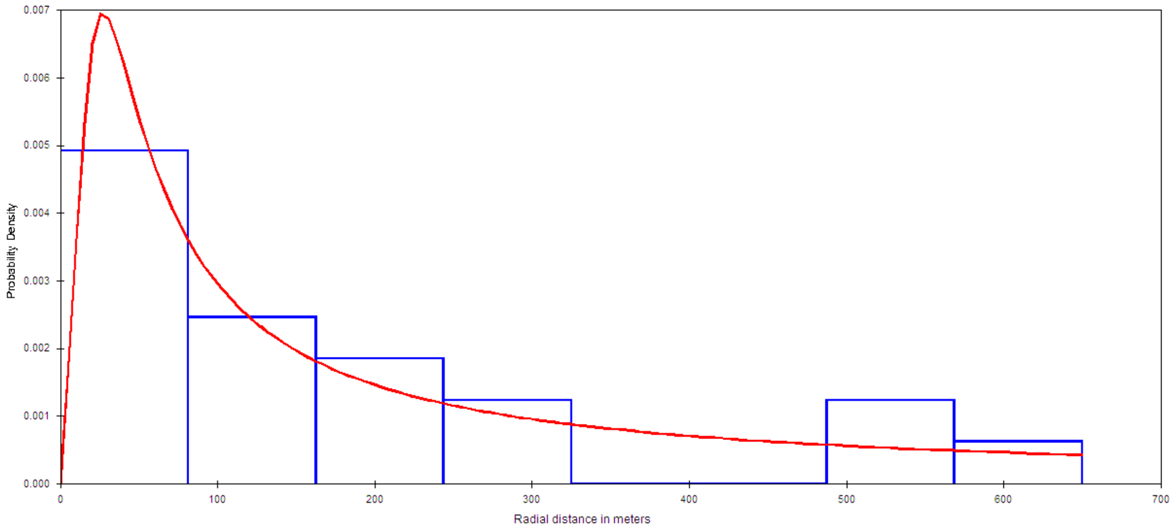

Figure 4.15: Probability density function for 'snapshot' dataset using HR cosine model

Both of the preceding figures appear superficially similar to those produced using the 6 minute sampling dataset. Nevertheless, the estimated population parameters produced using the 'snapshot' dataset model (Table 4.16) are very different, comprising a higher density and (N) value, but also exhibiting far larger 95% confidence intervals.

Table 4.16: Estimates of population parameters using 'snapshot' dataset

Parameter	Point estimate	Standard error	Percent coefficient of variation	95% confidence intervals	
Estimate of cluster density (DS)	0.83E-01	0.15	177.28	0.67E-02	1.01
Estimate of expected value of cluster size (E(S))	1.71	0.18	10.50	1.38	2.13
Estimate of density of parrots (D)/ ha	0.14	0.25	177.59	0.12E-01	1.73
Estimate of number of parrots in specified area (N)	3,127	5,553.2	177.59	255	38,321

5. Discussion

The following section is split into three main subsections. The first discusses the results of the spatial analysis, the second discusses the population survey data and examines for potential sources of bias, and the third compares the relative merits of the methods under study.

5.1. Spatial analysis

5.1.1. Accessibility

The results show that the accessing of point locations can be problematic during field surveys. Fewer than half of the 137 point count locations utilised in this study fell within 10m of their original, randomly generated, location. Perhaps more importantly, 9% of the surveyed locations fell >500m from their original locations.

This indicates that the 500m spacing between point counts, stipulated at the survey design stage, may not have been met on the ground, with several of the points surveyed falling within close proximity to one another. Distance sampling is however robust to the violation of independent detections (Rivera-Milán, *et al*. 2005), meaning that the potential recording of the same parrot cluster from more than one point count should not have biased any density estimate produced (Buckland *et al*. 2001).

The distribution of surveyed point count locations in closer proximity to the main north/south road network on the island has greater potential to impact the generation of a robust population estimate however. Studies have shown that bird densities alongside roads and tracks are unlikely to be representative of the wider population within the survey area (Buckland *et al*. 2001; Bächler & Liechti, 2007), despite engendering easier access and better visibility for the surveyor. The non-random location of several points along main roads may therefore have biased the density estimates produced, with studies undertaken on other poached parrot populations (e.g. Dallimer & King, 2008) indicating avoidance of roads and associated capture risk.

The previous distance sampling studies undertaken on Bonaire by Rivera-Milán & Simal (2010a+b) do not identify access difficulties as a core constraint, and it is considered likely that pathways were cut through areas of dense thorn scrub prior to survey commencement. Should the surveys be replicated on the island then this approach is recommended, along with consultation with private landowners to formally agree access arrangements prior to the undertaking of field research.

5.1.2. Habitat representativeness

The results indicate that the 137 surveyed point count locations were representative of parrot habitat on Bonaire, with the points distributed within all suitable habitat types in proportion to their individual areas of extent. This confirms the efficacy of using a randomised design when allocating point count locations.

5.2. Population surveys

5.2.1. Roost counts

The roost count survey undertaken on Bonaire in February 2011 produced a minimum population estimate of 550 YSA. There is however much between-year variation in the population estimates produced using the method, with 650, 429, 475, and 800 birds recorded in the years 2007 to 2010, respectively. It is unlikely that the sudden increase in the minimum roost count in 2010 is due to exceptional breeding success and subsequent recruitment. This is due to the constraints posed upon breeding by the limited number of suitable nest sites on Bonaire and the fact that only c.25% of YSA are estimated to breed in any one year (Williams, 2009).

The large decrease observed in the roosting population in 2011 may however have been caused by the unusually high rainfall levels experienced on Bonaire during the winter of 2010/11 (S.Williams, *pers.com*). During periods of severe weather birds may be reticent to travel long distances and roost in smaller groups. Additionally, food sources are likely to be more plentiful and evenly distributed across the landscape following periods of rainfall within xerophytic habitats (Williams, 2009). This abundance can also lead to a decrease in the number of birds joining communal roosts.

The high variation in roost attendance indicated by the roost count data suggests that movement between known and unknown roost locations occurs on a regular basis. If this is the case, then the undertaking of the annual roost count on a single morning means that any interpretation of the data collected should be cautious at best (Cougill & Marsden, 2004). Furthermore, the minimum population roost count estimates produced do not allow the calculation of variance, meaning that confidence levels for any population estimate cannot be calculated either.

The efficacy of roost count surveys undertaken on Bonaire could be improved via an increase in survey effort, i.e. repeat surveys are undertaken over an extended period rather than once a year. Ideally, counts would be randomly undertaken during each month of the year, as recommended by Cougill & Marsden (2004), which would assist in the production of a more robust minimum and mean population estimate.

Several other factors will impact the efficacy of any future roost count undertaken, including; seasonality, the reliability of individual counts (Gnam & Burchsted, 1991; Casagrande & Beissinger 1997), and the variable number of birds that enter the roost each evening (Cougill & Marsden, 2004). Furthermore, the continuing reliance upon volunteer surveyors to undertake roost counts on Bonaire suggest that the increased time-costs and more complicated logistics associated with increasing the frequency of roost counts on the island may not be tenable. Surveyor capacity could however be potentially increased through continued community outreach and increased funding availability to the co-ordinating local conservation NGO's.

5.2.2. Distance sampling

The non-stratified 6 minute and 'snapshot' distance sampling detection models indicated that detection probability differed between the two sampling regimes. Detection probability was c.1 up to approximately 50m from the surveyor in the case of the 6 minute dataset, and c.15m for the 'snapshot' data. This is similar to the findings of Rivera-Milán & Simal's earlier study (2010a), in which they found a detection probability of 1 up to c.40m from the surveyor. The Effective Detection Radius (EDR) of the 6 minute detection model produced in the current study was approximately 132m, in comparison to approximately 75m in the 'snapshot' detection model. Again, these are similar to the findings of Rivera-Milán & Simal (2010b), who recorded an EDR of 117m.

Analysis of the 6 minute dataset produced an average YSA density estimate of 0.01/ha and an average population of 2,169 parrots. The 'snapshot' dataset produced average estimates of 0.14/ha and 3,127 YSA, respectively. Both population estimates compare well with the average YSA density of 0.17/ha and minimum population size of 2,829 parrots produced for Bonaire by Rivera-Milán & Simal (2010b) using a cumulative 6 minute sampling window. Both the 2011 datasets exhibit very large confidence intervals, although these are far greater for the 'snapshot' estimates. This is considered indicative of the extremely small sample size used to calculate the 'snapshot' estimates.

5.2.3. Potential sources of bias

The following subsections discuss the possible explanations for the discrepancies observed between the density and population estimates produced in the two recent distance sampling surveys undertaken on Bonaire. They also investigate the effect of bias upon the density and population estimates produced using both the 6 minute and 'snapshot' data in the more recent survey.

5.2.3.1. Size of dataset

The robustness of density and population estimates produced using both distance sampling datasets was decreased due to the small number of registrations collected in each survey period. Neither dataset comprises the 50 to 100 registrations recommended by Buckland *et al*, (2001) for production of robust density estimates using Distance 6.0 (Thompson *et al*, 2009).

Due to the small number of registrations recorded during both survey periods, distance data was not truncated to remove outliers, as is usually recommended when fitting detection functions using Distance 6.0 (Buckland *et al*, 2001). During their distance sampling survey undertaken on the Bahama parrot (*A. leucocephala bahamensis*), Rivera-Milán, *et al* (2005) did not truncate data due to small sample size. Furthermore, Stanbury & Gregory (2009) found that by truncating distance data at >100m from the surveyor both density estimates and confidence intervals were increased.

Other studies have encountered similar problems in acquiring sufficient data, with a study undertaken on the citron-crested cockatoo (*Cacatua sulphurea* *citrinocristata*) by Cahill, Walker & Marsden (2006) requiring the survey of 627 point count locations over a two year period to yield a reasonable number of registrations (108 in that instance). The previous study undertaken on Bonaire by Rivera-Milán & Simal (2010b) recorded 119 YSA registrations from 110 point count locations, although their study combined data from separate surveys undertaken in December 2009 and March 2010. Seasonal variation in parrot behaviour between these two periods, comprising the annual movement of parrots into urban areas during the winter and movement back out to rural habitats during the spring (Williams, 2009), could potentially therefore have confounded the undertaking of a robust analysis due to double counting.

The large number of registrations required by distance sampling methods is considered one of its greatest drawbacks (Marsden, 1999; Barraclough, 2000; Gottschalk & Huettmann, 2011). Evidence from the current study, in addition to those of both Rivera-Milán & Simal (2010b) and Cahill, Walker & Marsden (2006), indicates that an extended survey period and/or an increased number of point count locations will therefore be required in any future survey undertaken on the island in order to record an adequate number of parrot registrations.

5.2.3.2. Length of point count sampling period

The density and population estimates produced using the 6 minute and ‘snapshot’ survey datasets differed, with the average population estimate produced using the latter being higher than that produced using the 6 minute dataset. Use of the ‘snapshot’ method (following what was, in effect, a 6 minute ‘settling in’ period) did however allow more time to accurately locate, count and measure the distance to any parrots present. The movement of parrots initially sighted during the 6 minute sampling period (and thus counted in the cumulate 6 minute dataset) away from the survey area, prior to the ‘snapshot moment’, is a potential issue however.

The use of an extended ‘settling in’ period is at odds with currently recommended distance sampling methods (Lee & Marsden, 2008), which seeks to minimise the impact of surveyor disturbance upon survey targets. Evidence of surveyor-induced flushing from, or attraction towards, point count locations during access was limited (*pers.obs*.) and its impact upon the current study is considered to be negligible.

The mobile nature of the YSA on Bonaire exhibits inherent potential to lead to an upward bias in registration accumulation over an extended recording time, resulting from unobserved parrot movement and subsequent double-counting (Marsden, 1999). The use of the 'snapshot' method, including a short preceding observation period to locate birds present in the vicinity of the point count location, is therefore recommended during any future surveys undertaken on the island.

This may nevertheless introduce some downward bias in registration accumulation, due to the difficulties associated with locating vocalising parrots within often dense stands of vegetation. However, the production of a potentially conservative density and population estimate will be of more value to conservation managers utilising the precautionary principle when applied to the threatened YSA population on Bonaire.

5.2.3.3. Identification of all parrots at *g*(0)

In the case of point counts located within the open expanses of 'lower terrace', urban areas, and the several exposed vantage point-like locations within areas of 'upper terrace' areas, it can be confirmed that detectability was 1 at *g*(0) (*pers.obs*; see Appendix 3 for representative photographs). However, for many of the points located in often densely vegetated 'middle terrace', 'undulating landscape' and agrarian areas it was not possible to confirm this for non-vocalising birds, following Marsden (1999), due to the impenetrable nature of the thorn scrub present.

Any future study undertaken on Bonaire will need to take this issue into account and set in place safeguards to minimise the violation of this key assumption. The use of double surveyor teams, as used in the recent studies by Rivera-Milán & Simal (2010a+b), may aid the location of cryptic individuals, although it is considered that parrots will always remain difficult to detect at short distances in dense vegetation (Rivera-Milán, *et al*. 2005).

5.2.3.4. Parrot movement

The avoidance of surveyor-induced movement by the survey target is a critical constraint of the distance sampling method. During data collection, movement towards or away from the surveyor was considered minimal, with birds noted to flush due to presumed surveyor disturbance on only a single occasion (*pers.obs*).

Similar rates of apparent flushing have been noted in other parrot studies (e.g. Greene *et al*, 2010). All other observed movement in and out of the survey area observed during the point count sampling periods appeared to comprise either natural foraging behaviour or avian predator avoidance.

The frequency histogram produced for the combined 6 minute dataset shows an abundance of sightings in close proximity to the surveyor which gradually peter out with increasing distance, again indicating that surveyor-induced disturbance was not an issue.

One impact which cannot be quantified, or rectified, within this study is that of predator presence upon data collection. Crested caracara (*Caracara plancus*), one of the few remaining predatory birds on Bonaire, were noted to flush birds on at least seven occasions during point count surveys (*pers.obs*). On several of these occasions it was not possible to note exactly from where the flushed birds had originated. These individuals, had they remained present and commenced calling (thus enabling location by the surveyor), would have been included within the distance sampling datasets. Other studies (e.g. Cougill & Marsden, 2004) have identified the presence of caracara as a major cause of disturbance to parrot species.

5.2.3.5. Accurate distance measurement

The recording of accurate distances during distance sampling surveys relies on a number of factors, including: surveyor competence; the ability to accurately locate vocalising individuals, and; the accurate measuring or estimation of the distances involved.

The ability of a surveyor to accurately identify and count their target species is long-known, but rarely quantified, variable in the analysis of distance sampling data, which has received little study (Elphick, 2008). In this particular study it is however considered that observer error introduced limited bias, as the YSA is an easily identifiable species (both visually and vocally), with the only possible confusion species on the island (an endemic subspecies of the brown-throated parakeet *Aratinga pertinax xanthogenus*) producing obviously different-sounding calls. Additionally, the surveys were undertaken by an experienced ornithologist, thus decreasing the risk of misidentification occurring.

The ability to accurately locate vocalising individuals within stands of dense vegetation proved more problematic during the current study, especially within those areas consisting of closed canopy mature scrub/forest, prevalent in many areas of WSNP and other 'middle terrace' habitats. Rivera-Milán & Simal (2010b) utilised unseen aural registrations in their production of population estimates for parrots on Bonaire, although no indication is given of what proportion of the total registrations they comprised. During the current study, unseen vocalising birds comprised 44% of registrations collected during the 6 minute sampling period.

The utilisation of such vocalising birds within distance analyses can introduce bias, as the size of the vocalising cluster may not be appreciated (Greene *et al*, 2010). The influence of such bias increases in severity when the issue of sound attenuation is also considered. This can occur through changes in call quality and orientation, habitat structure, environmental conditions and observer acuity (Bibby, Burgess & Hill, 2000; Buckland *et al*. 2001: Greene *et al*, 2010).

As such, the use of auditory survey data in generating density and population estimates on Bonaire should be treated with caution due to the increasing body of evidence pointing towards its inherent bias (Brewster & Simons, 2009). Any future survey undertaken on the island will need to consider this, with potential mitigating actions including the intensive training of surveyors in acoustic measurements prior to commencement of fieldwork (Lee & Marsden, 2008), or utilisation of additional observers at satellite locations to the point count centre. Institution of the latter does increase the risk of flushing birds during access, but may improve the ability of surveyors to accurately locate unseen calling birds.

The use of a laser rangefinder in the current study, to measure distances to all observed parrots, meant that the accuracy of measurement to all visual registrations is considered high. Similar equipment should be utilised in all future population surveys undertaken on Bonaire, if utilising the distance methodology.

5.2.3.6. Influence of habitat type upon detection

The drawing of any strong conclusions from the post-stratified 6 minute dataset frequency histograms (Figures A2.1a-e, Appendix 2) is problematic due to very small number of registrations used in their production. Nevertheless, the apparent extreme registration distances recorded for both 'lower terrace' and the 'unidentified vegetation community' may be explained by habitat structure. The majority of point counts located within the former habitat type were situated in open expanses of bare coastal plain, with the closest suitable parrot habitat often located several hundred metres distant along ridges and escarpments (see Appendix 3).

Similarly, the 'unidentified vegetation community' identified on the DCNA habitat map was found to mainly comprise hilltop vegetation communities within WSNP (*pers.obs*). As such, point counts located within them generally comprised of high elevation vantage points with long views over surrounding forest and scrub, thus explaining the paucity of records within the immediate vicinity of the surveyor.

5.2.3.7. Influence of parrot behaviour upon detection

The influence of YSA behaviour upon the different survey methods used in the current study is difficult to quantify. Nevertheless, as observed in Rivera-Milán & Simal's study (2010a+b), parrots recorded in the more open habitats of the 'lower terrace' and 'undulating landscape' were commonly observed feeding on the fruits of tall columnar cacti (comprising *Subpilocereus* and *Ritterocereus* species). This meant that individuals could be visually detected at greater distances, as the cacti formed emergent perches above the much lower scrub layer. Conversely, parrots observed in the generally more forested landscape of the 'higher terrace' and 'middle terrace' were often only located when calling, as they fed and perched within the denser vegetation.

This 'cactus feeding' behaviour caused a larger detection radius, and may also have increased the impact of surveyor disturbance, in cactus-dominated areas. Although difficult to prove using the limited 6 minute dataset, this could cause differing detection functions and population density estimates within the varied habitat types, as found by Rivera-Milán & Simal (2010a).

The impact of rainfall upon parrot ecology and distribution on Bonaire has already been mentioned in respect to the results of the 2011 roost count. The distance sampling surveys detailed in the current study were undertaken following an exceptionally wet winter, with additional unseasonal and heavy rainfall experienced during the survey period itself (*pers.obs*).

Although no data are available to confirm so, it is highly probable that these unusual levels of precipitation increased the availability of naturally occurring food items for the YSA in the wider landscape (Williams, 2009). This would explain the apparent absence of parrot registrations from the urban areas of Kralendijk and Rincon, which are primarily visited during the dry season when the fruits and seeds of introduced shrubs and trees form a significant proportion of the parrots' diet (Williams, 2009; Rivera-Milán & Simal, 2010b).

The undertaking of the current study during a single, environmentally and temporally, homogenous period will have decreased the influence of any bias resulting from such precipitation-induced seasonality in parrot behaviour. Conversely, the amalgamation of survey data (from December 2009 and March 2010) in the previous study undertaken by Rivera-Milán & Simal (2010b) may have impacted the robustness of their estimated parrot densities and population due to the differing spatial distributions exhibited by the YSA on Bonaire during the winter and spring months.

The undertaking of the current study during May and June meant that sampling was still being undertaken at the start of the 2011 YSA breeding season. This meant that breeding pairs were potentially more evenly spread across the landscape, thus comprising a randomly distributed (non-clumped) population more suitable for survey using distance sampling methods (Buckland, 1991). Nevertheless, the potential non-availability of brooding females during the sampling period may have negatively impacted the collection of parrot registrations (Gale *et al*, 2009) and led to the calculation of lower density and population estimates.

It is therefore recommended that any future distance sampling survey undertaken on Bonaire is carried out during the period March to April, thus avoiding the winter concentrations of YSA within urban areas and minimising the likelihood of removing breeding females from the survey population.

5.3. Comparison of survey methods

The use of distance sampling methods to monitor avian populations has been widely adopted by conservationists. Nevertheless, the choice of method used to survey parrot populations is dependent upon the characteristics of the population concerned, terrain, and logistical constraints (Casagrande & Beissinger, 1997). Ultimately, count methods must be easy to use, practical, cost-effective, repeatable, and provide reliable information (Greene, *et al*. 2010).

The distance sampling surveys undertaken on Bonaire in both 2010 and 2011 have been shown to exhibit varying degrees of bias in the way that both the surveys were designed and the data collected. The 2011 survey was compromised by the minimal number of YSA registrations recorded. This was compounded by the exclusion of all aural registrations during the analysis undertaken upon the two generated datasets. Nevertheless, it is argued that the inclusion of aural registrations would have compromised the data more fully than the minimisation of the datasets resulting from their exclusion.

As such, the density and population estimates produced using data from the surveys are considered tentative, unless the methods can be refined following the recommendations identified in sections 5.1 and 5.2. Despite not necessarily providing an estimate of true density (Bächler & Liechti, 2007), distance sampling does still potentially comprise an important tool in the monitoring of the YSA on Bonaire when compared to roost counts, as the latter method will only ever be able to provide a minimum population estimate in its current configuration.

The undertaking of roost counts on Bonaire does have potential to provide important demographic data (Berg & Angel, 2006) and should be considered useful as an indicator of population change. Cougill and Marsden (2004) indicated that a 20% change in a parrot population may be detected over three to five years, thus signalling any untoward change in population size. Indeed, Casagrande & Beissinger (1997) suggest that roost surveys (when undertaken over extended periods) may prove as precise as point count surveys, although they require up to three times as many man-hours to complete. Furthermore, if roost counts continue to be undertaken on only a single day each year then it is considered that the production of a robust population estimate for the YSA on Bonaire will not be feasible.

It should also be remembered that the use of volunteer surveyors in the annual roost count survey adds value to the undertaking. The two endemic *Amazona* species of Dominica's diverse rainforest ecosystem have, for example, both proven to be effective conservation flagships (Reillo & Durand, 2008). Therefore, the use of the YSA as an emblematic species for conservation action on Bonaire, and the maintenance of its high profile within the island community (via activities such as the annual roost count), will pay added dividends even if the data collected is of limited value in monitoring population trends.

In conclusion, it is recommended that the annual roost count is continued on Bonaire due to its value in terms of public engagement and demographic data collection. The future undertaking of distance sampling to provide robust population estimates (using a 'snapshot' sampling period) is however also recommended, pending enactment of the methodological improvements suggested in this thesis.

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Appendix 1: Broad habitat type descriptions

The following broad habitat descriptions are adapted from De Freitas *et al* (2005).

Undulating landscape

This consists of the Washikemba Formation areas in the western and central sections of the island. Five sub-landscapes can be distinguished: *Eragrostis-Cyperus* landscape (1.7%); *Haematoxylon-Casearia* landscape (6.3%); *Prosopis-Casearia* landscape (20.1%); *Prosopis-Subpilocereus* landscape (2.6%); and, *Prosopis-Opuntia* rooi (0.2%). Outside the Washington-Slagbaai National Park, *Prosopis-Casearia* and *Haematoxylon-Casearia* form the largest continuous areas of this landscape type. The habitat is predominantly structured around low trees and shrubs, with some areas supporting columnar cacti species and low herbaceous plants too. It also often incorporates former agrarian areas.

Lower terrace

Lower terrace is found along the entire coast of Bonaire and Klein Bonaire, locally bordering beach habitats. The width of lower terrace is very variable along the coasts. Salt spray and wind strongly influence the vegetation present. Vegetation is mainly present in cracks on solid limestone rock and in small erosional pits or otherwise shallow soils. Areas of lower terrace abutting middle terrace receive a significant amount of soil material washed down from nearby Washikemba Formation areas via rainwater through gullies.

Five different vegetation communities comprise the lower terrace: *Lithophila - Sesuvium* (3.0%); *Conocarpus* (1.4%); *Lithophila-Euphorbia* (2.7%); *Lantana-Corchorus* (1.2%); *Euphorbia-Corchorus* (0.7%); *Caesalpinia-Metopium* (0.8%); *Croton-Prosopis* (2.0%); *Prosopis-Capparis* (1.3%), and; *Prosopis-Subpilocereus* (1.9%). The habitat is predominantly structured around low shrubs and herbaceous layers. Some areas also support columnar cacti species and small trees.

Middle terrace

Middle terrace is present across most of Bonaire and consists of both depositional and erosional terraces. It is less continuous than the lower terrace. The transition between the middle terrace and the other terraces and the undulating landscape is not always clear. The most extensive areas of the middle terrace landscape are found in the central portion of Bonaire, at Bolivia.

Nine different vegetation communities comprise the lower terrace: *Lithophila* (0.1%); *Aristida-Melocactus* (2.1%); *Conocarpus* (0.9%); *Coccoloba-Melocactus* (4.1%); *Aristida-Jatropha* (1.7%); *Haematoxylon-Croton* (2.8%); *Acacia-Croton* (5.6%); *Haematoxylon-Caesalpinia* (3.2%), and; *Prosopis-Euphorbia* (4.1%). It primarily consists of a mix of open and dense scrub, with varying numbers of cacti and trees.

Higher terrace

Higher terrace is only found in the central part of Bonaire, and includes some of the less disturbed vegetation types of the island. Plateau land (erosional) higher terrace areas with deeply incised gorges) form part of this landscape. Two different vegetation communities can be distinguished: *Haematoxylon-Croton* (7.1%), and; *Erithalis-Bourreria rooi* (0.1%), the latter supporting the tallest vegetation of all broad habitats present, including trees up to 5.6m in height.

Escarpment

This habitat type is limited to the escarpments of the ‘plateau land’ surrounding the village of Rincón and the limestone hill of Seru Largu. Escarpments are the result of the exposure of the volcanic material underlying the harder limestone caps as a result of weathering. The presence of limestone rocks and boulders on the slopes gives evidence of this process. The top of the escarpment is almost perpendicular, whereas the lower slopes become less steep (about 10-30° on Bonaire). Two vegetation communities can be distinguished: *Prosopis-Casearia* (0.7%), and; *Prosopis-Subpilocereus* (0.1%). Of these, the former covers the largest area. Both have among them the tallest vegetation on Bonaire, with an average vegetation height of 3.5m and 3.1m respectively.

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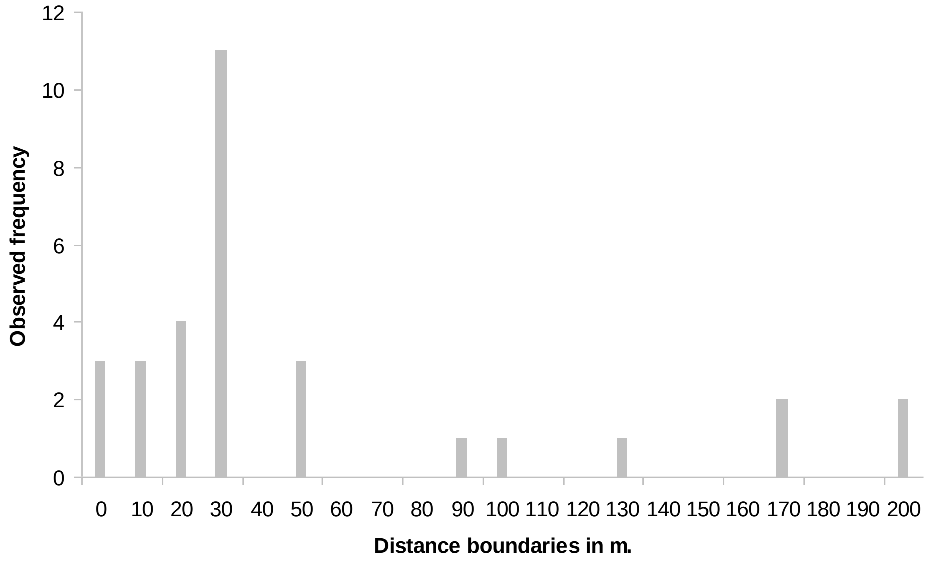
Appendix 2: Post-stratified detection frequency histograms

a.



b.

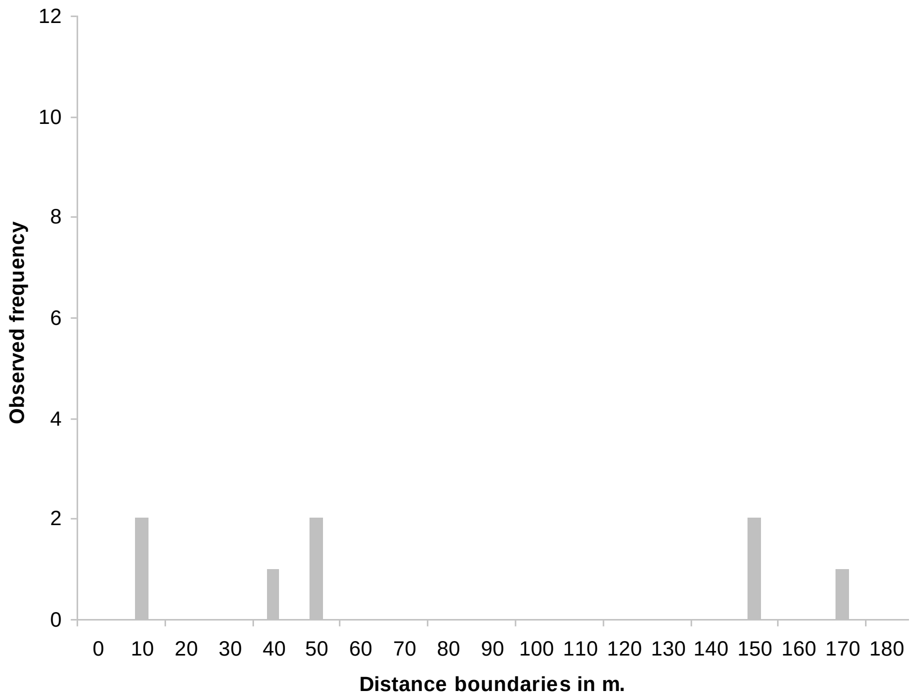
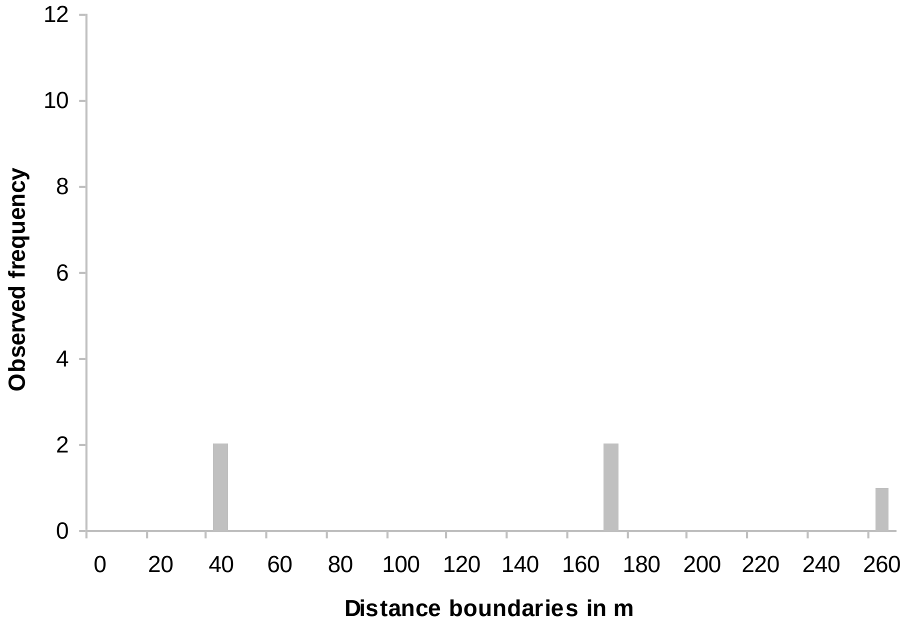


Figure A2a-b: Detection frequency histograms for individual YSA within 'undulating Landscape' (a) and 'higher terrace' (b) habitats using 6 minute dataset c.



d.

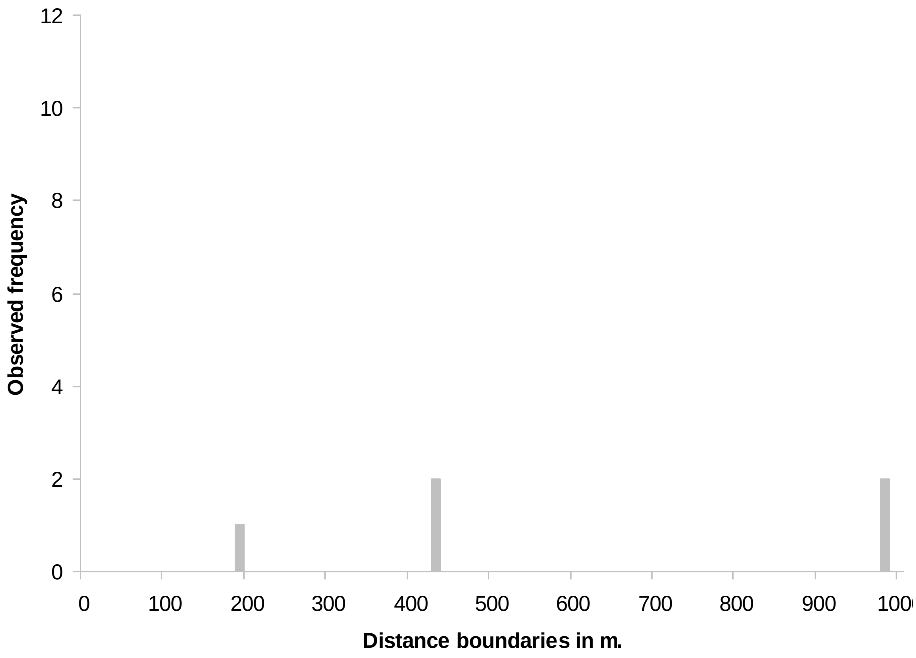


Figure A2c-d: Detection frequency histograms for individual YSA within 'middle terrace' (c) and 'lower terrace' (d) habitats using 6 minute dataset

e.

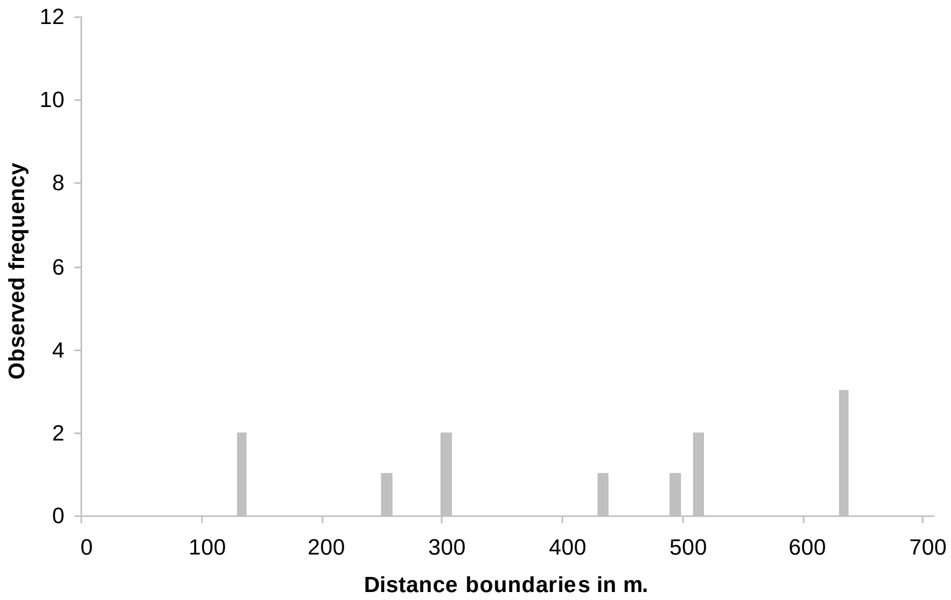


Figure A2e: Detection frequency histogram for individual YSA within 'unidentified vegetation community' habitat using 6 minute dataset

Appendix 3: Representative point count photographs

Figure A3.1: Dense coastal scrub of the 'middle terrace' (Point Count 2).

Figure A3.2: Raised vantage point overlooking 'undulating landscape' within WSNP (Point Count 34).

Figure A3.3: Overgrazed cactus scrub within ‘undulating landscape’ of WSNP (Point Count 38).

Figure A3.4: Low thorn scrub with emergent columnar cacti within ‘undulating landscape’ of WSNP (with attendant YSA) (Point Count 40).

Figure A3.5: Non-vegetated coastal plain of the 'lower terrace' (Point count 48).

Figure A3.6: Dense thorn scrub flanking the 'higher terrace' Rincon-Kralendijk road (Point Count 58).