

# **The effect of point count duration on avian density estimates**

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A case study of distance sampling  
surveys of the avifauna of St. Lucia

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## List of Acronyms

- AIC:** Akaike's Information Criterion
- CBD:** Convention on Biological Diversity
- DCG:** Design Construction Properties Ltd.
- EDR:** Effective Detection Radius
- GLM:** Generalised Linear Model
- GLMM:** Generalised Linear Mixed Model
- PEW:** St Lucia Pewee *Contopus oberi*
- RTS:** Rufous-throated Solitaire *Myadestes genibarbis*
- SE:** Standard Error
- SLFD:** Saint Lucia Forestry Department
- SLO:** St Lucia Oriole *Icterus laudabilis*
- SLP:** St Lucia Parrot *Amazona vericolor*
- WBT:** White-breasted Thrasher (*Ramphocinclus brachyurus*)

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## **Abstract**

Conservation agencies, governments, NGO's and scientific institutions utilise avian abundance estimates to guide strategies, funding and prioritisation of conservation activities. Methodologies that calculate abundance rely on satisfaction of the assumption that observations are recorded in a 'snapshot' moment, meaning individuals are not double counted and new arrivals into the plot are not counted. This is entirely possible as generally birds do not behave like stationary objects. A longer count increases the risk of birds moving which in turn increases the chances of the 'snapshot' assumption being violated. Furthermore, the likelihood of violation will differ with the detectability of each species as detectability depends on a host of factors from species behaviour to habitat and environmental conditions.

Until recently the focus of count duration within scientific literature has concentrated on efficiency as opposed to the reliability of abundance estimates. Recently, very few studies have turned their attention to the effect of count duration on abundance estimates, with varying conclusions, and the effect of count duration on estimates when the 'snapshot' assumption is violated has remained an unknown source of bias.

In this study, distance analysis was used to determine density estimates for several St Lucia bird species using different count lengths. An examination of detection patterns determined if observers were violating the 'snapshot' assumption. Altering the point count duration produced massive variation in density estimates where it seemed likely that the 'snapshot' assumption had been violated. Additionally, analysis of recent avian monitoring studies revealed the choice of count duration used in the majority of published studies appeared to be decided upon arbitrarily, with count length rarely based on recommendations or past research. These findings illustrate that studies and monitoring programmes calculating bird abundance estimates could be producing unreliable results by not altering the count duration based on species detectability. The consequences on prioritisation, decision making and resource and funding allocation belong to the agencies, governments, NGO's and scientific institutions that rely upon them.

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# 1. Introduction

Thousands of avian monitoring programmes are used by conservation agencies around the world, primarily using point count methodologies (Alldredge et al., 2008). Such programmes often form a critical component of conservation strategy through providing key information on which to base management decisions. Perhaps the most influential database of species populations is the IUCN Red list of Threatened Species which guides the conservation activities of governments, NGOs and scientific institutions in both prioritisation and allocation of funds, often using the abundance estimates calculated by such monitoring programmes to identify species most at risk of extinction (IUCN, 2010). Furthermore, bird monitoring data can provide useful surrogate information about local biodiversity as birds can be sensitive to environmental change and as such, can act as barometers for the state of ecosystem health and the sustainability of human land use (Gregory et al., 2005). This data is often employed within the wider sphere of environmental management and planning. For example, The Global Wild Bird Index is currently employed by c.20 national governments within the EU, to assess sustainability, environmental health and to measure progress towards the Convention on Biological Diversity (CBD) targets of halting biodiversity loss by 2010 (Biodiversity Indicators Partnership, 2010).

Birds are a comprehensively surveyed taxon, with up to 2,000 independent programmes used to gather long-term data on bird abundance in Canada and the United States alone (Bart, 2005). The subject of how to monitor them has been extensively discussed in scientific literature with point count sampling the most commonly used method to survey and monitor birds in terrestrial habitats (Bibby, 2000). The method involves recording all bird contacts from a fixed point for a pre-determined time period and is versatile enough to be used in a range of habitats on various scales (Bibby et al.). It is the method of choice for many of the large scale national programmes such as the North American Breeding Bird Survey (*1998 BBS Instructions - USGS Patuxent Wildlife Research Center*) and the UK Repeat Woodland Bird Survey (RWBS) (Amar et al 2006).

A number of different point count methodologies are currently used to produce estimates of avian density such as distance sampling (Buckland), time-of-detection methods (Farnsworth et al., 2002; Alldredge, 2007b), and a multiple-observer approach (Nichols et al., 2000). Distance sampling was the method chosen for this case study as not only is it widely used but it estimates detection probability as a function of distance. This has the added advantage of being able to provide density estimates for large areas by use of fairly modest resources and still produce reliable estimates of population densities and trends (Buckland, 2006). One thing all these methodologies have in common though is that they rely on satisfaction of the assumption that birds are counted only once and at a 'snapshot' moment in time (Buckland, 2006). Counting new birds moving into the plot or counting the same individual repeatedly if it moves within the plot, both violate this assumption and both types of error can lead to upward bias in density estimates (Lee & Marsden, 2008). However, because in reality birds do move around and new birds will fly in, in practice this means that the number of birds counted is very much dependant on the length of time spent counting (Dawson et al., 1995).

To that end, point count length is worthy of serious examination and although this issue was flagged by Granholm in 1983 "A critical assumption for methods based on counts is that so little bird movement occurs during the count period that it does not affect density estimates appreciably", it has received little attention since. Understanding the effect of point count length on bird counts and density estimation, and developing methods to mitigate bias generated by violating this key assumption is vital for designing reliable bird population monitoring strategies. Clearly given the importance of bird monitoring in research, management and policy, this question merits investigation.

### **1.1 Aim and objectives**

The aim of this project was to investigate the effect of varying the point count duration on density and abundance estimates produced using point count survey data. Bird species that represented a number of different guilds were chosen along with distance sampling as a methodology that is commonly used in bird surveys to ensure this research was applicable to as many current avian monitoring programmes as possible.

Specifically this project has the following objectives:

1. Evaluate the length of point counts and the reasons behind the choice in recent avian population studies.
2. Calculate density estimates for 5 St Lucia bird species over different count durations (2 minutes, 4 minutes, 6 minutes, 8 minutes and 10 minutes) to ascertain what effect, if any, count duration has on density estimates
3. Examine the relationship between sighting distance and count length to verify if the assumption that a count was recorded in a 'snapshot' moment is being violated.
4. Propose recommendations for count durations for species analysed in this study and recommendations on monitoring protocol to assist selection of appropriate count duration in other monitoring programmes.

It is anticipated that output from this project will bring the issue of the effect that variable count durations have on bird abundance estimates to the appropriate audience of the bird monitoring literature. In turn it is hoped this will assist with long-term conservation strategies of endangered species through helping to provide more accurate estimates of bird densities.

## **1.2 Overview of thesis structure**

Chapter 2 presents an introduction to point count methodology and draws attention to the various issues surrounding species detectability. It also reviews the literature that has been published on point count length, gives an introduction to the study species and to distance sampling including a breakdown of the assumptions required to produce reliable density estimates.

Chapter 3 gives a detailed presentation of the methods used throughout this study beginning with a literature search to assess current use of count duration. This is followed by an introduction to the conservation efforts of Durrell Wildlife Conservation Trust and the St. Lucian Forestry Department, and a thorough description of the field methods employed, distance sampling analysis and the statistical analysis used throughout this study.

The results of the study are presented in chapter 4 and in chapter 5 the results are interpreted and translated into practical recommendations for monitoring of

the survey species and more generally for other monitoring programmes. This is then used to highlight the wider implications for both monitoring and conservation in practice.

## 2. Background

### 2.1 Point Counts

Point count sampling is a method used extensively to monitor birds in terrestrial habitats (Ralph et al. 1995; Bibby, 2000) and is widely employed to establish either indices of abundance or estimate true abundance or density estimates (Rosenstock et al., 2002). The use of point count data to determine abundance indices has been called into question due to the assumed consistency of detection which fails to account for the variable detectability of bird species and incomplete counts of individuals present (Farnsworth et al., 2002; Thompson & Thompson, 2002; Anderson, 2003; Norvell, 2003). In response, several methodologies have been developed that adjust the raw count data by means of a detection probability mechanism (Kery, 2004; Kissling, 2006) that accounts for “birds present but not detected” (Thompson & Thompson, 2002).

These methodologies developed to account for detection probability include distance sampling, which uses the relationship of decreasing detectability with increasing distance between the observer and study subject to estimate detection probability (Rosenstock et al., 2002; Novell et al 2003), a double observer approach that facilitates observer-specific detection probabilities (Nichols et al., 2000), and an adapted removal method (Farnsworth et al., 2002b) and time-of-detection approach (Alldredge, 2007b) which both use a maximum-likelihood estimator by dividing the count into interval periods, enabling estimation of detection probability directly from the count data. A critical assumption these methodologies depend upon to produce reliable density estimates is that birds are counted in a ‘snapshot’ moment. Any new birds moving into the area must not be counted and individuals should not be counted more than once (Farnsworth et al., 2002; Norvell, 2003; Alldredge, 2007b), hereafter this will be referred to as the ‘snapshot’ assumption. A longer count length is more likely to violate the ‘snapshot’ assumption as it increases the likelihood of new birds flying in or birds moving within the plot which in turn increases the risk of double counting. It is therefore important to consider the likelihood of either of these events happening by examining a species detectability and adjust the count period accordingly.

## **2.2 Detectability and point count length**

Analysis of point count length is necessary to determine the length of time required that will minimise violation of the 'snapshot' assumption. Granholm's study in 1983 found that between 36 - 72% of the focal bird species were detected in only one of two consecutive five minute counts. This led him to deduce that at least that proportion of birds had moved across plot boundaries during the 10 minute count period.

As species differ in their biology and behaviour it stands to reason they will also possess varying levels of detectability. Predominantly in relation to species specific traits but also corresponding to a number of different variables pertaining to habitat, the environment and the observer. These factors, discussed below, must be considered when deciding upon count duration to minimise the likelihood of the 'snapshot' assumption being violated.

### **2.2.1 Bird behaviour**

Clearly, noisy and active birds should be easier to detect than cryptic birds, but knowledge of behaviour should comprise an important aspect of survey design. The detectability of any species will probably fluctuate according to their activity, so where parrots are generally thought to be vocal and active, they may be surprisingly cryptic when at rest (Marsden, 1999). Effects of factors such as time of day or season are usually taken into account in monitoring protocol to the extent of determining when a survey takes place (Fuller & Langslow, 1984; Voříšek, 2008). This information also has a bearing on count length and becomes particularly important for multi-species surveys where species may differ in their susceptibility to being counted, and may need to be counted on different scales (Bibby, 2000). Failure to incorporate this information into any decisions on count length could result in an individual being double counted during a lengthy count period whilst waiting to detect a shy and nondescript species.

### **2.2.2 Cue production**

Scheduling monitoring programmes to mitigate low occurrence of singing rates such as utilising the breeding season can capitalise on heightened detectability. This was shown by a study on the song availability for Henslow's Sparrow which was found to drop from 39.1% for a 5min count or 43.9% for a 10min count, to

less than 10% for both count intervals over the course of the breeding season (Diefenbach, 2007). However the fact that cue production was only available for roughly 40% of either count period highlights how detectability is a function of both count duration and singing rate (Alldredge, 2007a). Just as detection probability is not constant, neither is cue production which could mean the probability that a bird sings during a count is often  $<1$ , alternatively song bursts may be clumped so that cues appear multiple times within one count period (McCallum, 2005). An example is Bell's Vireo that was found to sing in bouts averaging 12 minutes interspersed with quiet periods averaging 6 minutes (Scott et al., 2005). To obtain reliable estimates of population abundance, both availability and detectability of cues must be considered in the choice of point count length (Alldredge, 2007).

### **2.2.3 Habitat**

A further consideration for count length is habitat composition (Shiu & Lee, 2003). Although species accumulation functions were used to determine point-count length this example can still highlight the changing detectability rates generated by differing habitats. Shiu and Lee deemed the appropriate count length for tropical forest birds during the breeding season in grassland, coniferous forest and broadleaf forest, to be 1, 2 and 3 minutes respectively. And further highlighting the importance of cue availability are the corresponding count lengths estimated for the non-breeding season in the same habitats which were 3, 9 and 6 minutes respectively. It was unclear if the habitat had also changed with the season but nonetheless it is clear that the detectability of species does vary and the decision on count duration should reflect this.

### **2.2.4 Environmental Conditions**

Many monitoring programmes advise upon the environmental conditions that are deemed satisfactory for monitoring to occur, such as acceptable weather, wind speed and sky conditions (*1998 BBS Instructions - USGS Patuxent Wildlife Research Center*). Extreme weather can affect bird activity and high wind speeds can make it a lot harder to hear call cues (Bibby, 2000). However, experiments by Simons et al (2007) showed that the proportion of birds detected under breezy conditions decreased by 28%. Although bird activity may not be affected by slight changes in weather, the ability of the observer to detect birds at the same rate can be greatly influenced and point count length may need to reflect this.

### **2.2.5 The Observer**

The observer plays a critical role in the data collection process and this is amplified where species detectability is in question. A certain amount of impact bears no relation to the acuity of the observer as an individual bird may alter its natural behaviour simply due to observer presence (Tasker et al., 1984; Lee & Marsden, 2008). For example the average singing rate of the Ovenbird, Wood Thrush, and Northern Cardinal were all found to vary with distance to the observer (McShea & Rappole, 1997). The affect on count duration would depend on the reaction i.e. if birds stay quiet or produce alarm calls. So although availability may largely depend on species behavior, perceptibility is primarily a feature of the observer and the survey conditions (Johnson, 2008). The importance of aural detections was highlighted by Brewster and Simons in 2009 who conducted an experiment to assess auditory and visual detections in a forested habitat. Their findings revealed that of the total number of birds detected, 2.9% of detections were made by deafened observers, 75.1% by blinded observers, and 78.2% by non-handicapped observers, with detections by blinded and non-handicapped observers matching only 54% of the time. This has implications for detectability rates and thus count duration in surveys where surrounding noise levels may be a factor, such as where there is heterogeneity of singing birds. To that end observer accuracy when detecting call cues has been found to greatly improve when call rates are low (Simons et al., 2007).

Observer experience and skill are also factors which have been confirmed to effect detectability with skilled observers tending to have an increased count rate than more inexperienced individuals (Sauer, 1994). Although not a direct function of experience, there is an association between interest levels and experience and observer attentiveness can furthermore affect detectability rates (McCallum, 2005).

Variability in detectability caused by species biology and behaviour, habitat, environmental conditions and the observer can cause bias in abundance estimates if they are not factored into the decision made on count duration (Dawson et al., 1995). This becomes particularly important where programmes look to compare abundances among habitats or over years if these variables are assumed constant. The implications for long-term studies are more severe where

changing environmental conditions could mask a declining population as it becomes more detectable or vice-versa (Dawson et al., 1995), which monitoring strategies should reflect.

The detectability of any species will therefore affect how birds are counted, and specifically the likelihood of them being counted only once and within a 'snapshot' moment, given the length of time they are counted for.

### **2.3 Studies on Count Duration**

Analysis of count duration has historically focused on efficiency, to determine the minimum amount of time that can be spent counting birds whilst still obtaining an accurate record of the population being sampled. Investigation into the differences in mean count frequencies of breeding birds in forested habitats found that count efficiency was maximised at a duration of <6mins (Thompson & Schwalbach, 1995). A number of studies in forested habitats found that more than 70% of all detections occur within the first 5 minutes of a counting period making this the most efficient count length (Fuller & Langslow, 1984; Gates, 1995). Furthermore, by establishing that sufficient detections can be observed in a shorter count period, more points can be visited increasing sample size (Buskirk & McDonald, 1995; Dettmers, 1999) and power for statistical analysis (Barker et al., 1993; Smith & Smith, 1998).

Only a small number of studies have examined the effect of point count length on abundance estimates. Findings differed depending on the species and habitat surveyed. Perhaps the most revealing study of count length was undertaken by Cimprich (2008) who compared the different density estimates of Black-capped Vireos acquired using various count lengths, with a baseline obtained through territory mapping. The behaviour of the birds was noted as "typically active, singing intermittently, and will sometimes move tens of meters between songs" and the study habitat was described as "shrub-dominated" with most detections obtained aurally. Results showed abundance estimates for the shortest count period of 3 minutes were greater than the actual number deemed present from territory mapping although still falling within the corresponding 95% confidence interval. Longer counts gave far greater estimates with confidence intervals that did not include the actual number of birds present. Lee & Marsden (2008) also

looked to improve the accuracy of forest bird abundance estimates by adjusting the count period. Their findings revealed on average density estimates only 13% higher for a 10-min count period than those for a 2-min count period. These results were then used to make recommendations on count length for different bird guilds, generally advocating longer count periods for cryptic species and shorter counts for more detectable birds.

Additionally Buckland (2006) outlined an actual 'snapshot' method to mitigate the effects of a lengthy point count. Observers spend a pre-snapshot moment locating birds, especially those near to the point, then only records those still present when the snapshot moment occurs. If the exact location of an individual cannot be confirmed or it moves away before the snapshot moment takes place, then it is treated as undetected (Buckland, 2006). Insufficient studies testing the 'snapshot' method have been published to make a comparison with timed point counts but it would seem a more appropriate methodology for visual surveys as proving with certainty that an individual detected aurally was still present at a snapshot moment would seem difficult, especially if dealing with more than one individual and in dense habitats.

An individual bird must only be detected once to calculate a reliable density estimate. Using the accumulation of counts to derive a cutoff point in count length supports the argument for efficiency but does not necessarily lead to the establishment of reliable density estimates and this method may still give biased results (Granholt, 1983). As it is not practicable or indeed appropriate to apply territory mapping to all species (Bibby, 2000) as a comparison tool, the detectability of a species should be used to determine the optimal count length for counting individuals present in a snapshot moment, and only counting them once.

#### **2.4 Case study species**

The numerous yet diverse bird species of St Lucia present a useful case study for examining the effects of point count length on density estimates. Additionally the threats facing many species on St Lucia further emphasise the importance of monitoring programmes and the wider implications involved with being able to measure the success of a conservation intervention. Five species were chosen

which represent a good cross-section of both a variety of bird guilds and conservation issues. The St Lucia Parrot (SLP; *Amazona vericolor*) is a canopy frugivore, described as both noisy and highly mobile in the morning and evenings (R. Young pers. comm.), it has since 1979 been granted the title of St Lucia's national bird. Restricted to the decreasing tropical moist forest in the montane interior of island (Keith, 1997), by the mid-1970's as little as 100 individuals remained. At this point the St Lucia Forestry Department (SLFD) initiated a breeding programme with Durrell Wildlife Conservation Trust (Durrell), instigated a hunting ban and established the "pride campaign" with RARE to raise public awareness of and sensitivity to their new national symbol. Together these mechanisms have been credited with the success of what appears to have been a recovery in numbers (Butler, 2000) and thus a down-grading on the IUCN Red list to vulnerable with an increasing population trend (BirdLife International, 2008), however no quantifiable measures of SLP density have been calculated until now.

From a conservation point of view the highest priority species for monitoring abundance on St Lucia is the White-breasted Thrasher (WBT; *Ramphocinclus brachyurus*). The WBT is a ground foraging insectivore that has been described as inquisitive and one of the easier species to survey (Keith, 1997). It is however listed as 'Endangered' on the IUCN Red list with a decreasing population trend (BirdLife International, 2008). Occurring as 2 sub-species, one in Martinique (*R. b. brachyurus* estimated as 250-500 individuals) and the other in St Lucia (*R. b. sanctaeluciae* estimated as c.1200) (Young et al., 2010), habitat loss and fragmentation are continuing to threaten the outlook for the WBT (Toussaint et al., 2009). A main cause for concern for the St Lucia sub-species is the Design Construction Properties Ltd (DCG) tourist resort developed in 2007 on a 554 acre site deemed to contain as much as 25% of the global population of WBTs (Antony, 2005). The DCG land and surrounding dry forest was estimated to comprise of up to 1050 individuals of the St Lucia population (Young et al., 2010) adding significant weight to the monitoring programme for this species.

The remaining 3 species are all included in the St Lucia suite of 16 priority bird species which were chosen because of their endemism (at the species and subspecies level), and the severity of threats to their survival at a global and

national level (Toussaint et al., 2009). The Rufus-throated Solitaire (RTS; *Myadestes genibarbis*) is principally a frugivore inhabiting primary rainforest predominantly at high elevations and much less frequent in secondary rain forest and elevations below 450m (Keith, 1997). It is generally encountered infrequently but this is attributed to its restricted distribution (Toussaint et al., 2009) and somewhat innocuous colouring (Cruz, 1976). The St Lucia Oriole (SLO; *Icterus laudabilis*) is a nectarivore and found in coastal vegetation, dry scrub, edges of banana plantations, plantation forest, secondary & primary forest (Keith, 1997), it is thought to be widespread but patchily distributed (Toussaint et al., 2009) and furthermore is susceptible to brood parasitism by the shiny cowbird *Molothrus bonariensis minimus* (Keith, 1997). Finally the St Lucia Pewee (PEW; *Contopus oberi*) is an understory sallying insectivore primarily found in moist forest at high altitude and although is thought to be widely distributed (Toussaint et al 2009) it has a very timid behaviour (Keith, 1997) and thus provides a good comparison for sampling protocol to species such as the SLP.

## **2.5 Distance Sampling**

Distance sampling (Buckland, 2001) was chosen as the methodology for this study and to represent those techniques where detection probability is used to enable calculation of species densities. As a further advantage, it is generally a low cost and straightforward approach that does not require direct sampling, marking, capturing or recapturing of individuals (Royle et al., 2004) which can all prove costly in terms of effort and resources (Borchers et al., 2002). As such, it is now one of the more widely used tools in density estimation (Marques et al., 2007).

### **2.5.1 Introduction to Distance Sampling**

Distance sampling utilises two sampling techniques, either line based transect sampling or point count sampling. Both methods work to the same principle that the further an object is from the line or point, the less detectable it will be. Observers estimate or measure the distance of all objects with distance  $w$  (which can be either a pre-set fixed distance or unlimited) to the line or point. As not all objects within  $w$  will be detected, distance sampling uses the objects that were seen to model a detection function,  $g(y)$  which is the probability of detecting an object, given that it is at distance  $y$  from the point (Buckland, 2001). Avian monitoring programmes utilising distance sampling are inclined to use point

transects for several reasons. 1) as soon as the observer reaches the point, efforts can be concentrated on detecting and identifying birds as oppose to simultaneously attempting to traverse perhaps difficult terrain, 2) the easiest route into and away from the point can be used whereas line transect protocol dictates the observer follow a pre-determined route and 3) differing habitats can be sampled more easily enabling a density estimate for each type to be estimated or indeed estimates can be post-stratified by habitat to increase precision (Buckland, 2001).

### **2.5.2 Assumptions of Distance Sampling**

The detection probability mechanism that operates with distance sampling makes a number of assumptions in order to calculate density estimates (Buckland, 2001). As discussed, the assumption (1) that no new birds moving into the plot are counted, along with no recounting of moving birds within the plot, is one that is common across all methodologies that calculate density estimates. A further caveat for distance sampling in this regard is that birds must be detected at their initial location (which may be inferred from the 'snapshot' concept although exact location is not critical for other methodologies). This is because it is the distance of objects to the point that influence density estimation therefore if a bird moves in relation to the observer the 'snapshot' assumption will be violated, although random movement is not seen as a problem (Buckland, 2001).

A second assumption (2) of distance sampling is that birds on the point are certain of detection, i.e. that  $g(0)=1$ . Distance sampling methodology therefore relies on all bird species on or near the point being available for detection (i.e. producing calls) during the count period. However birds can have irregular call and silence rates (Scott et al., 2005) so there is no guarantee that this will happen. Studies have confirmed in avian distance sampling that testing of the  $g(0)=1$  assumption is largely ignored in practice (Bächler, 2007).

A third assumption (3) is that distance measurements must be accurately measured, especially critical for point count surveys as measurement errors generate substantially more bias in density estimates than do errors of similar magnitude in line transect sampling (Buckland, 2006). However this problem can

be resolved with the use of a rangefinder which significantly reduces the bias that measurement errors cause (Buckland, 2006).

Point count length must therefore mitigate between assuring all birds on or near the point are detected and maximising the likelihood that birds are detected at their initial location with no new birds flying in (Granholm, 1983). If a bird moves around a great deal it is more likely to be detected more than once and probably when it is closer to the observer generating upward bias and violating assumption (2) (Buckland, 2006). But for cryptic species or those that do not sing frequently, assumption (1) is more likely to be breached (Buckland, 2006).

These assumptions are critical to achieving reliable estimates of density. The practical implications for survey design are obvious when the issues of bird behaviour, habitat and surroundings, and observer experience are factored into point count duration. Point counts used to generate density estimates must ensure minimal violation of these assumptions and I propose that analysis of point count duration can assist with this matter.

### **3. Methods**

#### **3.1 Published studies using point counts**

Web of Science was used as an online search engine to determine how many published articles utilise point count methodologies to generate abundance or density estimates, and specifically which of those articles gave a justification regarding the point count length that was used. Topic search terms “avian” and “point count” were initially used but yielded a small number of studies, replacing “avian” with “bird” generated a far larger number of articles, proceedings papers and reviews. The search was limited to a time span from 2007 to the present day as the volume of articles returned from a longer time period was beyond the scope of this project.

The articles returned in the search employed point count procedures for several different purposes such as presence-absence surveys (Collier et al., 2010), probability of nest detection (Smith, 2009) and evaluating call-up techniques on bird detection (Conway, 2010). Those included for further analysis were the ones that looked to produce an abundance estimate that in itself was used as a result, albeit as an actual population study (O’Dea & Whittaker, 2007), to carry out a comparison of different techniques (Kubel, 2007) or evaluate the effectiveness of different aspects of point count methods (Simons, 2007).

#### **3.2 St Lucia bird monitoring**

In 2009, a partnership begun in 1975 between Durrell Wildlife Conservation Trust (Durrell) and the St Lucia Forestry Department (SLFD), re-engaged on the St Lucia Parrot (SLP) project by inaugurating a rainforest bird monitoring survey. The purpose being to obtain an accurate estimate of parrot density following the unquantified but seemingly successful conservation work of the last 35 years. The rainforest bird monitoring survey was also used to collect data on RTS, SLO and PEW as density estimates were also required for these species.

Together Durrell and the SLFD have also been conducting annual dry-forest monitoring surveys since 2006 to determine White-breasted Thrasher (WBT) densities within its southern most range on the island. Efforts are being

concentrated in this area due to the DCG tourist development project to ensure any impact on WBT numbers is quantified.

Alongside Durrell and the SLFD, volunteers assist in all survey data collection and make monitoring programmes on these scales possible.

### **3.2.1 Survey Design - Rainforest Bird Survey**

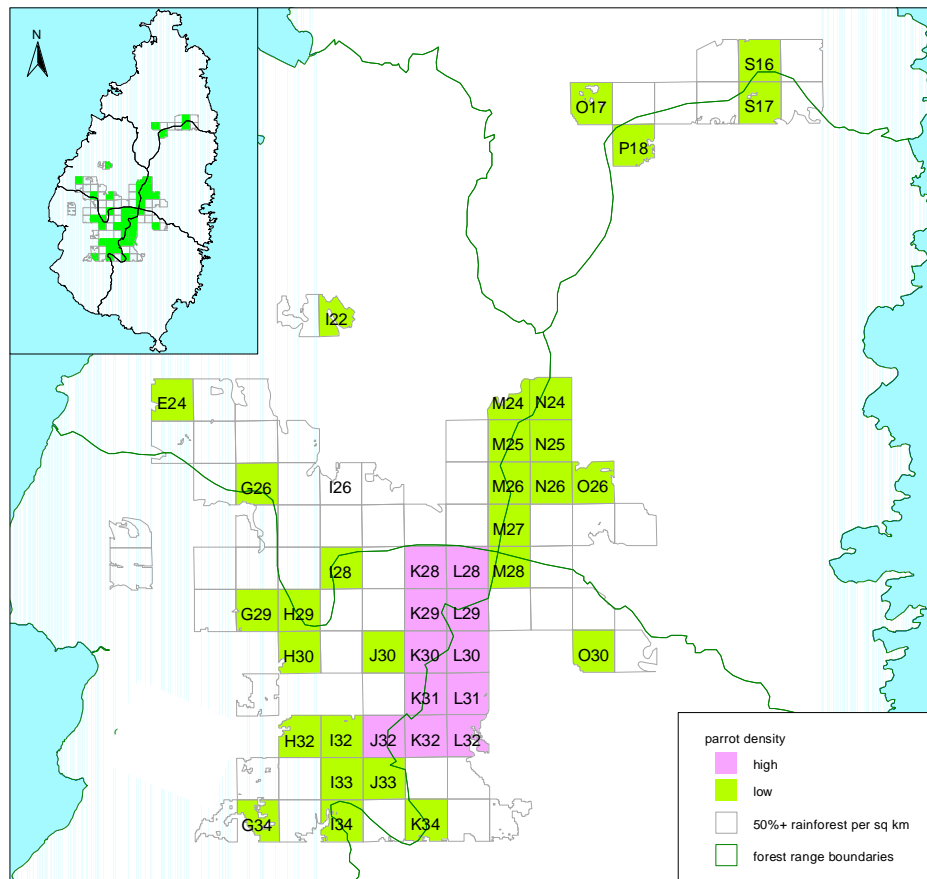
The St Lucia rainforest bird survey was designed primarily for observing the St Lucia Parrot. It was thus completed during the period of 28th January - 10th March 2009 as it is believed that parrots remain in the rainforest during this time, effectively making the survey area a closed plot (Durrell, SLFD: *Field Manual for the St Lucia Amazon Survey 2009*).

The rainforest was divided into 1 x 1 km squares and those with 50% or more rainforest cover were included in the survey design (Figure 3.1). These squares were divided into those deemed to have low and high parrot densities, judged so by members of the SLFD (experts with >20yrs experience of parrots in the forest) along with a pilot study carried out by Durrell and SLFD in 2007 which supported this opinion. All high density squares were sampled and of the low density area, sample squares representing about 25% of all possible squares were randomly chosen. Points were allocated along trails and away from trails in both high and low density areas, at a distance of 200m apart. The pilot study showed that the majority of useful information gathered during these counts and used in distance sampling, was obtained from bird observations measured at 50m or less. Counts at points 200m apart were therefore judged to be independent (Durrell, SLFD: *Field Manual for the St Lucia Amazon Survey 2009*).

The system of combining high density / low density with on-trail / off-trail points was designed to take advantage of the ease of access that surveying trails permits whilst still systematically sampling all off-trail areas. This ensured a representative picture of the whole rainforest was attained with the benefit of allowing more survey effort (more points) in the area of forest believed to have the highest parrot density, whilst still systematically sampling all of the areas

believed to contain a lower parrot density (Durrell, SLFD: *Field Manual for the St Lucia Amazon Survey 2009*).

Each point was intended to be surveyed at least twice, alternating between a morning and afternoon survey period although this was dictated by resource availability, terrain and weather conditions (M. Morton pers. comm.).



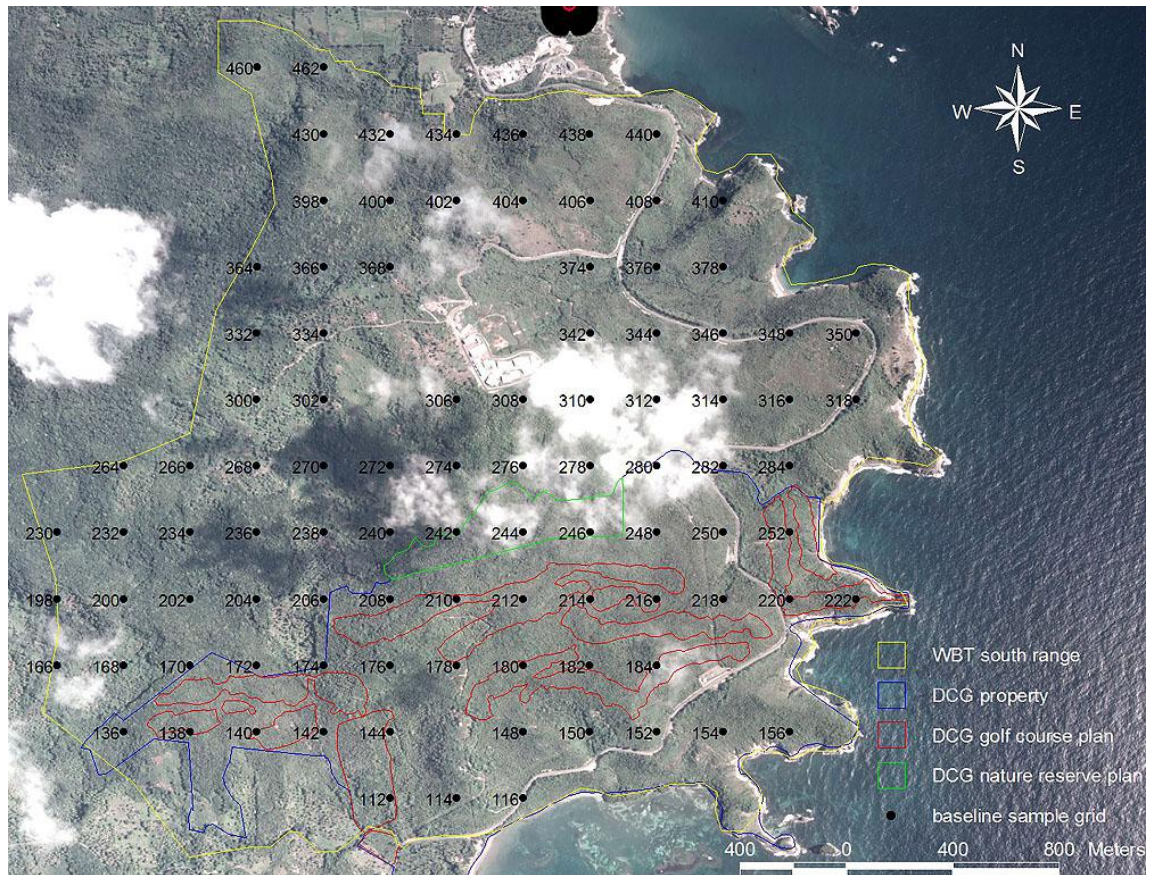
**Figure 3.1:** Map of St Lucia rainforest divided into 1x1 km squares (or part-squares around edges of rainforest) with density levels judged as high (pink) and low (green). Map supplied by Durrell, SLFD 2009

### 3.2.2 Survey Design - Dry-forest Bird Survey

The St Lucia dry-forest survey took place from 2006 - 2010 during the dry season which occurs in January, February and March. During this period the vegetation is less dense than throughout other times of the year meaning detectability rates are usually higher (Young et al., 2010).

A systematic grid system was used throughout the southern range totaling 96 points placed 250m apart as shown in Figure 3.2. On average the width of a WBT territory was deemed to be c.70m (Temple, 2006) making it probable that points

at these distances were independent. Certain points were excluded where it was deemed they were placed in unsuitable WBT habitat (defined as agriculture, open ground and urban development) (Temple 2005 in Young et al., 2010). Of the total 96 points that cover the entire area, 63 fall outside the DCG development boundary and 33 within. Sample points were visited either once or twice in each year depending on available resources (Durrell; SLFD: *Field Manual for the St Lucia White-breasted Thrasher Survey 2010*)



**Figure 3.2:** WBT southern range survey grid with coloured outlines denoting DCG land. Map supplied by Durrell, SLFD 2010

### 3.2.3 Data Collection Protocol

For the rainforest survey, point counts were conducted by teams of 3-4 surveyors and took place in either early morning or late afternoon when parrots were expected to be feeding and thus active (SLFD, 2010). The dry-forest survey used teams of 2 people and only took place in early morning although observers were able to continue if thrashers were still being seen after midday up until a maximum of 2pm.

Length of count period in both surveys was 10 minutes divided into 2 minute intervals (0-2mins, 2-4mins etc) with bird detections assigned to the interval in

which they were first seen or heard. Observers began searching for birds immediately on arrival at the point with no settling down period included in the count. All sightings were recorded along with information on whether the birds were perched or flying during the count or a combination of the two. Any birds flushing on arrival at the point were recorded as perched-flying and included in the 0-2minute interval.

Survey protocol dictated that efforts were concentrated on detecting birds near to the point (within 0-30m) to maximise the chance of observing all individuals at close distances (Buckland, 2006). The radial distance between the point and the location at which birds were first seen or heard was measured to the nearest meter, using a rangefinder for distances >10m distance from the point and a tape-measure for distances  $\leq 10$ m. If birds were in clusters, measurement was taken to the distance at the centre of the cluster and the number of birds in the cluster was recorded.

Other bird species were recorded during both surveys, however observers were instructed that should monitoring all birds become too difficult, to make the SLP the priority in the rainforest survey and the WBT the priority in the dry-forest survey.

### **3.3 Data analysis**

For analysis in distance, observations from both St Lucia bird surveys were limited to those of individuals or clusters of birds that were either perched throughout the count period, those that flushed on arrival at the point or those that flew away during the count (perched-flying), providing the observer was confident of recording their location before any movement had occurred. Birds flying into the area (flying-perched) were excluded to satisfy the assumption that observations were recorded of a 'snapshot' moment. Birds flying over the study area were excluded as recommended by Marsden (1999).

To evaluate the effect of count length on White-breasted Thrasher (WBT) density estimates, only data from the points located outside the boundary of DCG land was used to minimise the effects of habitat change on both detectability and actual WBT abundance over the period 2006 - 2010 (Johnson et al., 2006).

### **3.3.1 Distance Analysis**

Density estimates (individuals/hectare<sup>2</sup>) were calculated using DISTANCE v6.0 Release 2 (Thomas et al., 2010), with individual points assigned as sampling units and number of visits (sampling effort) pooled as recommended by (Buckland, 2001).

Initial exploration of frequency histograms examined the full 10 minute data sets for individual species to remove any obvious outliers which contain little information used for density estimation (Buckland, 2001). Histograms were also inspected for evidence of rounding or heaping and to check for evasive movement away from the observer. While there was no indication of evasive movement, there was evidence of rounding by certain observers, however the effect was reduced when the data were pooled across all observers alleviating the need for grouping to moderate the effects of rounding on bias (Buckland, 2001).

Rainforest bird density estimates were post-stratified by region (high density on-trail, high density off trail, low density on-trail, low density off-trail) to estimate the number of birds in each area. Overall population density was calculated as the mean of the stratum estimates weighted by the stratum area. The WBT estimates were post-stratified by year and to evaluate the effect of point count length on density estimates, an overall population density was calculated as the mean of the stratum estimates weighted by the total effort in the strata, with strata marked as replicates.

Where birds were recorded as either individuals or in clusters (SLP and WBT), the size bias regression method was used if regression was significant at an alpha level of 0.15, if it was not significant at this level, the mean cluster size was used. All other species used with distance analysis were entered as individuals and therefore no cluster size estimation method was necessary.

#### **3.3.1.1 Model Selection**

Selecting the key function is the first step in model selection and Distance uses three models deemed to have the desired properties of model robustness, shape criterion and estimator efficiency (Buckland, 2001). The key functions are Uniform, Half-normal and Hazard-rate and can be used alone or with a series

expansion which can be used to adjust the key function, using 1 or 2 more parameters to improve the fit of the model to the distance data (Buckland, 2001).

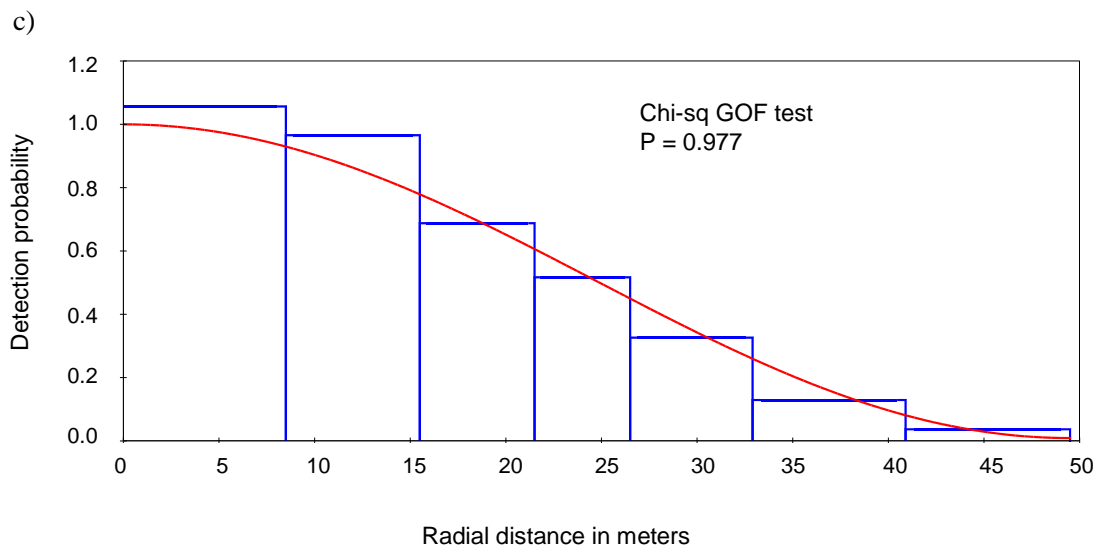
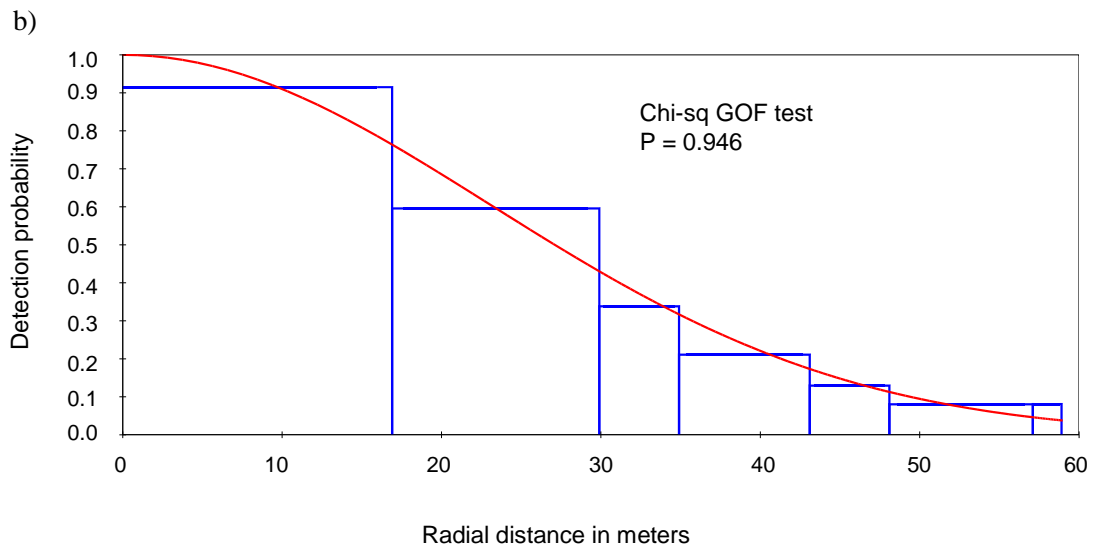
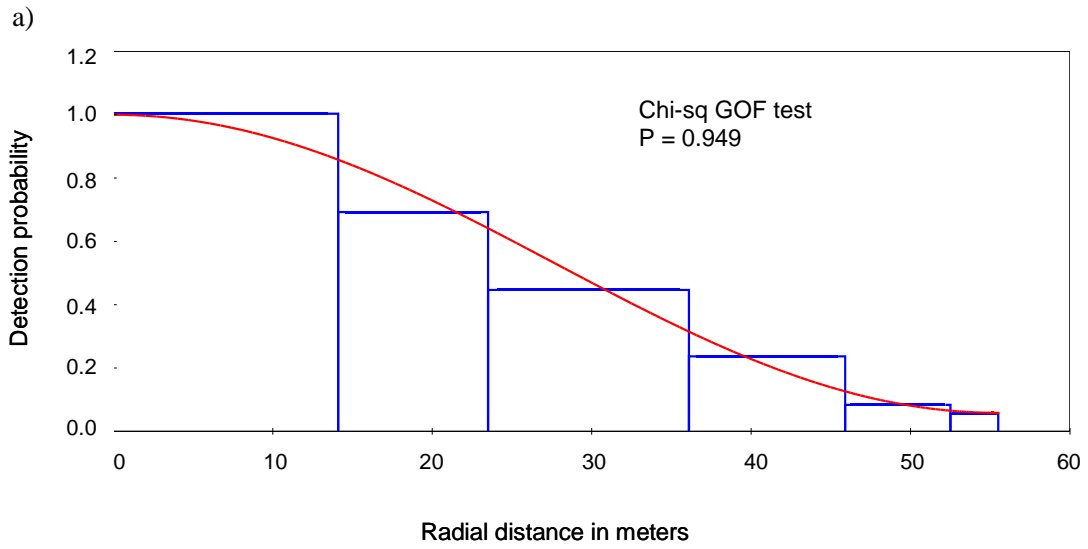
Following initial truncation, analysis was run using the detection models outlined above, and as recommended by Buckland et al (2001): uniform function with cosine/simple polynomial adjustment, half-normal function with cosine/hermite polynomial adjustment, and hazard-rate function with cosine/simple polynomial adjustment.

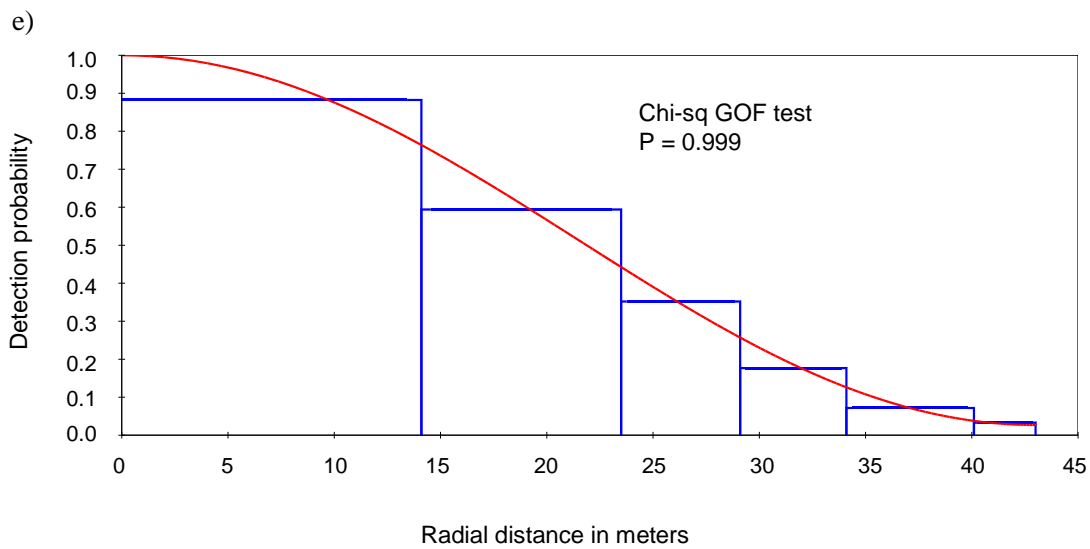
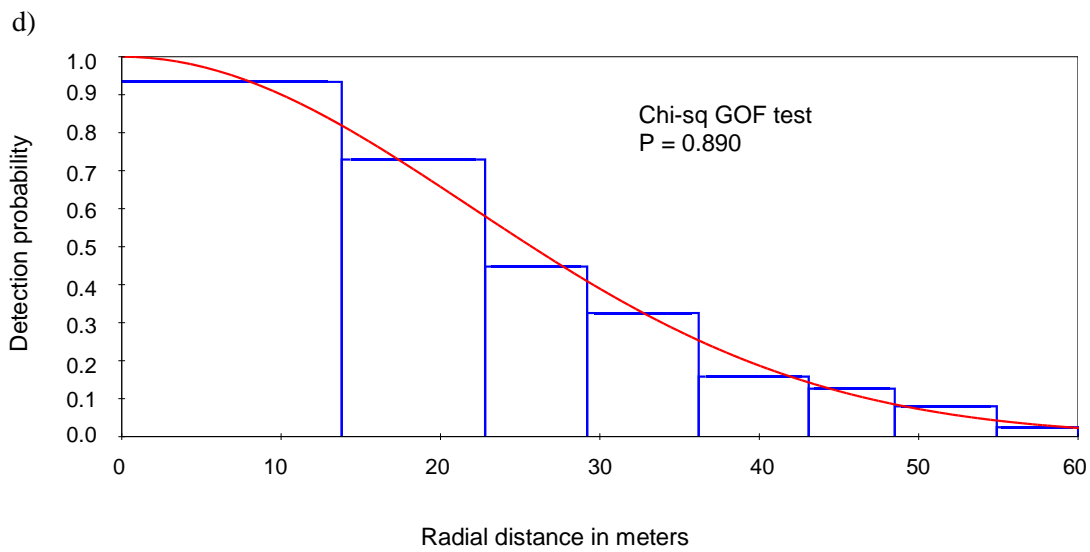
Akaike's information criterion values (AIC) were used as selection criteria for model robustness and therefore the model with the lowest AIC was chosen for further analysis. If more than one model performed well they were all used in the next stage of analysis, only those performing considerably poorly in comparison were removed at this point.

Histograms were further explored by transforming the data into intervals for analysis using manual cutpoints as recommended by Thomas et al. (2009). The data was initially partitioned into 20 groups to get a detailed view of the distance data. This led to further truncation and regrouping until the optimal data inputs were chosen using visual assessment of the detection probability plots and goodness of fit tests (Figure 3.3). The best performing model, using lowest AIC, was run for all count interval periods (0-2 minutes, 0-4 minutes etc.) except where the model with the lowest AIC was different across the intervals. Where this was the case, the model that performed best across all 5 interval periods was chosen and in all cases this meant using a model that was within 2 AIC points of the optimal model (Burnham and Anderson, 2002) (Table 3.1).

**Table 3.1:** Key functions and series expansions used in Distance analysis for each species

Species	Key Function	Series Expansion
SLP	Uniform	cosine adjustments of order 1
RTS	Half-normal	n/a
SLO	Uniform	cosine adjustments of order 1
PEW	Half-normal	n/a
WBT	Uniform	cosine adjustments of order 1





**Figure 3.3:** Distance sampling detection probability plots and p-values for Chi-sq goodness-of-fit tests for 10 minute point counts of a)SLP b)RTS c)SLO d)PEW and e)WBT

Testing of the assumption  $g(0)=1$  was beyond the scope of this project and although rangefinders were used to mitigate the bias caused by estimated distances (Buckland, 2006), again this assumption was assumed to have been met during this study.

### 3.4 Statistical Analysis

All statistical analysis was carried out using statistical package 'R' v.2.11.0.

A Generalised Linear Model (GLM) with poisson distribution was used to analyse the count frequency as a function of count interval. A poisson distribution has advantages for analysing count data in that the probability for negative count values is 0, the response variable must be an integer and heterogeneity is allowed for in the mean variance relationship (Zuur et al., 2008). Overdispersion was detected in the poisson GLM and the standard errors were corrected using a quasi-GLM model. Multiple contrast tests using Tukey all-pairwise comparisons between count intervals were used to assess the relationship between the number of observations and each sequential count interval.

Density estimates generated by DISTANCE v6.0 Release 2 (Thomas et al., 2010) were tested for normality via Q-Q plots and Shapiro-Wilk tests and were found to be normally distributed (Appendix A). They were therefore analysed using linear regression to assess the relationship between density and count length.

Sighting distance was analysed as the response variable to determine if there was a relationship between sighting distance and count interval. A proportion of the data from the rainforest survey was collected when an expert in distance field methodology and the St Lucia avifauna was present (n=35). This was analysed separately to enable a comparison to the whole dataset which was collected by volunteers (n=549 (truncated at <100m to equal the scale of the expert data)). Sighting distances were tested for normality via Q-Q plots and Shapiro-Wilk tests which found them to be non-normally distributed. Box Cox transformations were carried out to determine the optimal transformation needed to normalise the distribution of distance data. Once the appropriate power transformation had been determined, an analysis of variance (ANOVA) was carried out on both datasets to establish if similar patterns were present in the relationship between sighting distance and count length.

In distance sampling, the effective detection radius (EDR) is the distance at which the probability of detecting an individual further away equals the probability of missing an individual within that radius. The EDR for all rainforest

birds had an average of 30m across all count intervals and an average of 24m for the WBT. Using this figure as a cut-off distance at which to term observations as 'near' (observations that influence density estimates) or 'far' (observations with little effect on density estimates), plots were drawn up for all rainforest data, rainforest data where an expert was present and for each individual species, to enable visual inspection of the number of detections both 'near' and 'far' across the count period.

To see if there was a significant relationship between count interval and sighting distance, a GLM with poisson distribution was fitted to the data for both the rainforest and dry-forest bird surveys. To ensure counts were not reduced to a value of 1 due to the varying distances of all observations, sighting distances were grouped into the 'near' and 'far' distance bands, making distance a categorical explanatory variable. Count frequency was used as the response variable and an interaction was included between count interval and sighting distance as the explanatory variables. A process of model simplification was followed until the minimum adequate model was established.

Generalised linear mixed models (GLMM) take into account that categorical explanatory variables may have both random and fixed effects (Crawley, 2007). A GLMM was deemed appropriate for the St Lucia point count data as the point would be considered as a random effect where the count interval at each point is a fixed effect. A GLMM with poisson error distribution was fitted to the count data, however low frequency of observations meant each observation at a given point within a given time interval was unique. Due to the low sample size in relation to the number of points, point as a random effect could account for none of the variance in the data.

## 4. Results

### 4.1 Variation in point count length in published studies

A search for studies published online since 2007 found 105 articles which reported using point counts for surveying birds. Of the papers readily accessible, 56 used the point count data to establish an abundance or density estimate using a variety of point count lengths as shown in Table 4.1.

Table 4.1: Differing count lengths used by avian point count surveys from 2007 - 2010 to generate abundance estimates

Settling Down Period	Point Count Length	No. of studies
None	3mins	4
None	5mins	11
None	6mins	1
None	10mins	25
None	12mins	1
None	15mins	1
1 minute	5mins	1
1 minute	8mins	1
2 minutes	5mins	1
2 minutes	8mins	1
2 minutes	10mins	2
5 minutes	20mins	1
not stated	not stated	6

Of the 56 studies analysed >91% gave no explanation regarding the choice of point count length. A further 5% either analysed data collected during national breeding bird surveys or followed the recommended protocol from a national breeding bird survey and <4% reported they had used a recommendation. (For a full table of papers see appendix B)

### 4.2 St Lucia Bird Surveys

The 2009 St Lucia Rainforest Bird Survey yielded 129 SLP, 202 PEW, 149 RTS and 80 SLO observations from 357 points that were altogether sampled 730 times.

The dry-forest survey ran from 2006 - 2010 inclusively and recorded 47, 67, 39, 44 and 38 WBT observations across the years. The survey was comprised of 63 sample points with the exception of 2010 when only 60 of the points were visited. It was intended that each point would be surveyed twice each year to give a sampling effort of 126 (120 in 2010). This was attained in all years except in 2006 where survey effort was 87.

#### 4.2.1 Effect of point count length on observations

The majority of observations for all rainforest bird species and WBT observations from 2006 - 2010 occurred at the beginning of the 10 minute count period (Figure 4.1). A total of 42% of SLP observations, 45% of RTS, 45% of SLO, 35% of PEW and 37% of all WBT observations occurred in the first 2 minutes. For both SLP and WBT species the remaining observations were distributed as a fairly equal percentage across the rest of the count period (Figure 4.2 a) and b)). For RTS, SLO and PEW species the percentage of observations declined as the count progressed before increasing, and for the RTS and SLO, decreasing a second time (Figure 4.2 c), d) and e)).

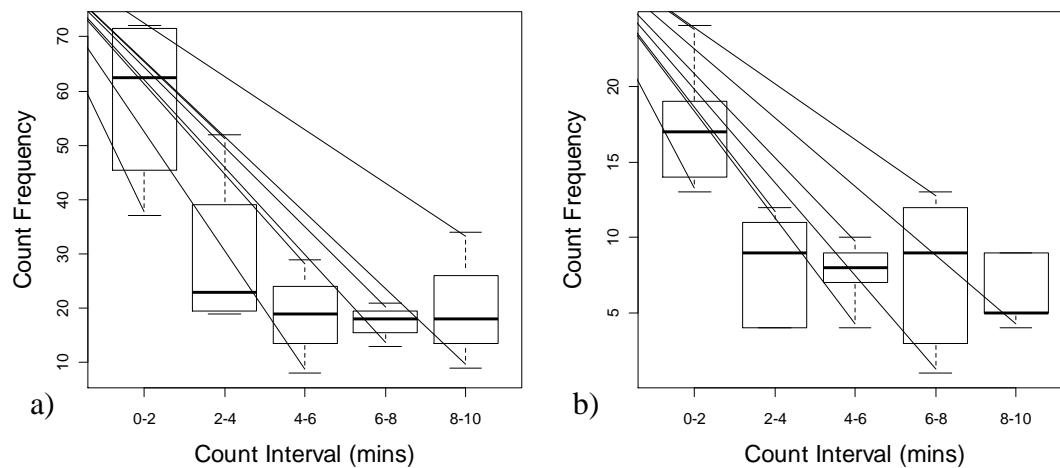
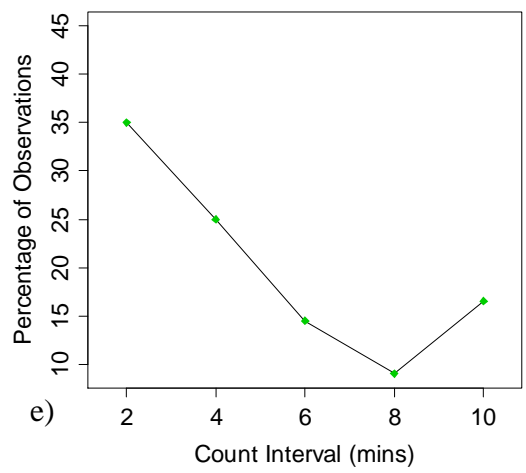
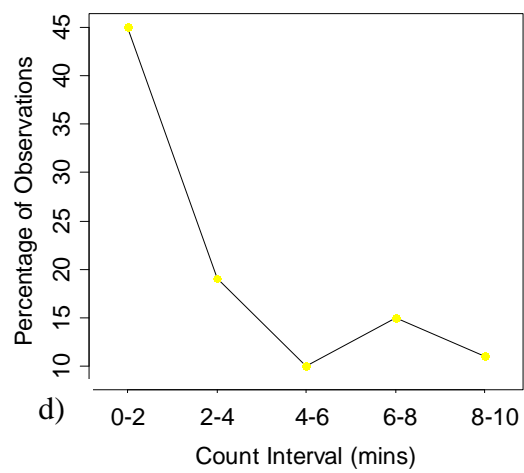
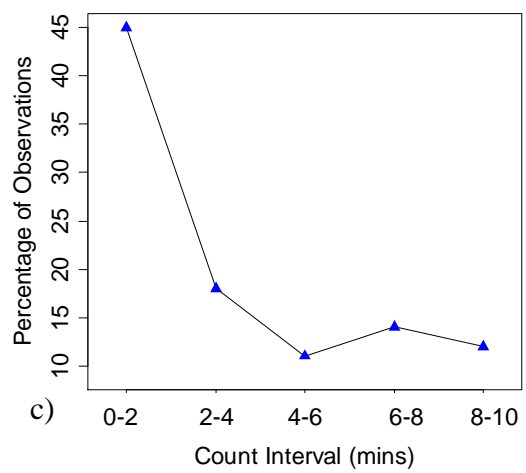
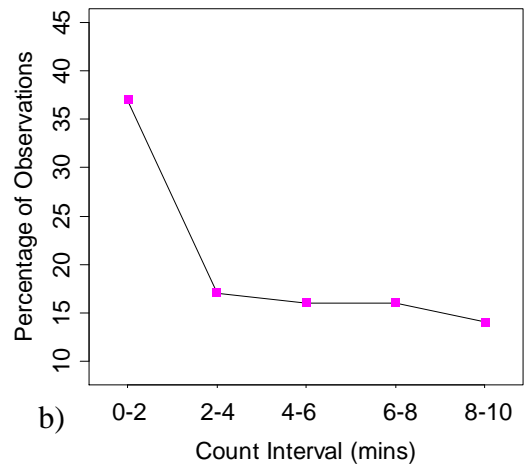
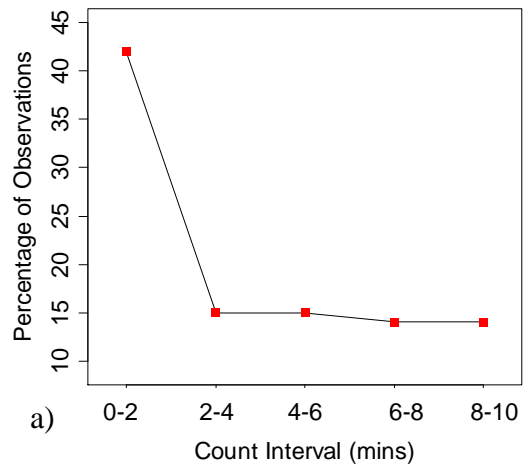


Fig 4.1: Box plots of sample minimum, lower quartile, median, upper quartile, and sample maximum number of observations in each count interval from 0-2 minutes through to 8-10 minutes for a) all rainforest bird species in 2009 and b) WBT observations pooled over survey years 2006 - 2010.



**Figure 4.2:** Percentage changes in overall number of observations (10 minute total) for each sequential count interval for a) SLP, b) WBT, c) RTS, d) SLO and e) PEW

Generalised Linear Models (GLM) using multiple comparisons verified the decline in new observations for all surveys was significant between 0-2 minutes and 2-4 minutes but not between any of the other sequential count intervals as shown in Table 4.2.

Table 4.2: Parameter estimates, standard errors (SE), *z* and *p*-values for multiple comparisons between consecutive count interval periods conducted on generalised linear models for both rainforest and dry-forest surveys, significant results(*p*-value <0.05) given in bold.

	St Lucia Rainforest Bird Survey				St Lucia Dry-forest Bird Survey			
	Estimate	SE	<i>z</i> -value	<i>p</i> -value	Estimate	SE	<i>z</i> -value	<i>p</i> -value
0-2min - 2-4min	-0.69315	0.24233	-2.860	0.0334	-0.69315	2.464e-01	-2.860	0.01361
2-4min - 4-6min	-0.44469	0.31658	-1.405	0.6180	-0.44469	2.921e-01	-1.405	0.99978
4-6min - 6-8min	-0.06899	0.35569	-0.194	0.9997	-0.06899	2.958e-01	-0.194	1.00000
6-8min - 8-10min	0.12095	0.35131	0.344	0.9969	0.12095	3.094e-01	0.344	0.98092

### 4.3 Effect of point count duration on density estimates

Distance analysis using Distance 6.0. Release 2 (Thomas et al., 2010) carried out on all species from the rainforest bird survey in 2009, and on the WBT data from the dry-forest survey 2006-2010, showed continuing increases in density estimates over time. The minimum increase in density estimates from a 2 minute count to a 10 minute count was for the SLO which had an increase of 94%. All other species had increases over 100% ranging from the SLP with 110%, the RTS with 140%, the WBT with 165% through to the PEW with an increase of 170%, see Figure 4.3.

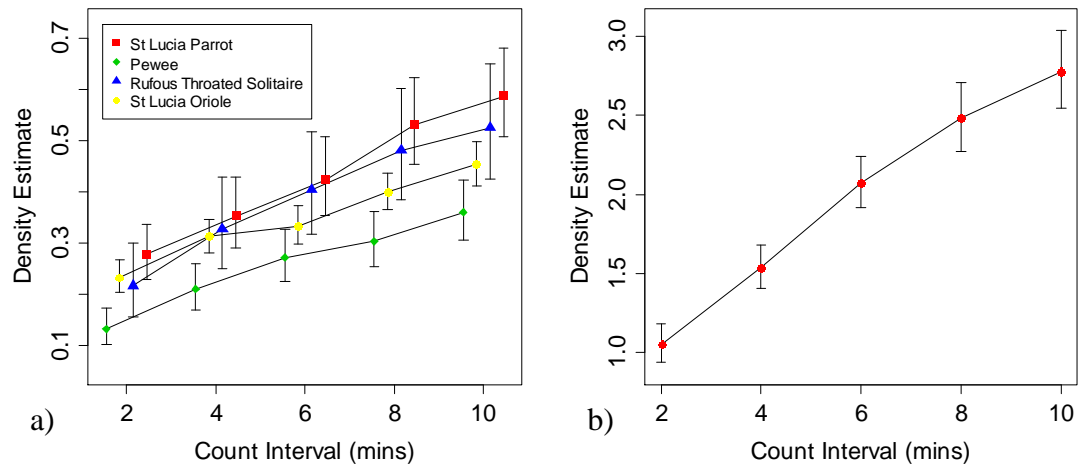
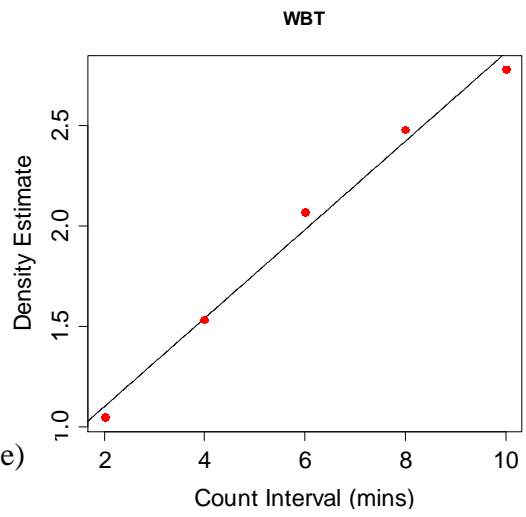
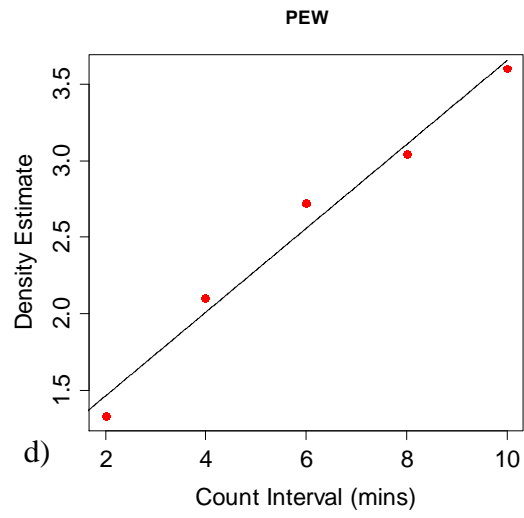
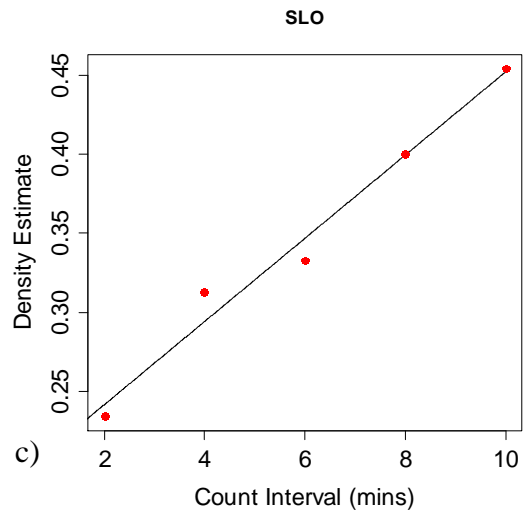
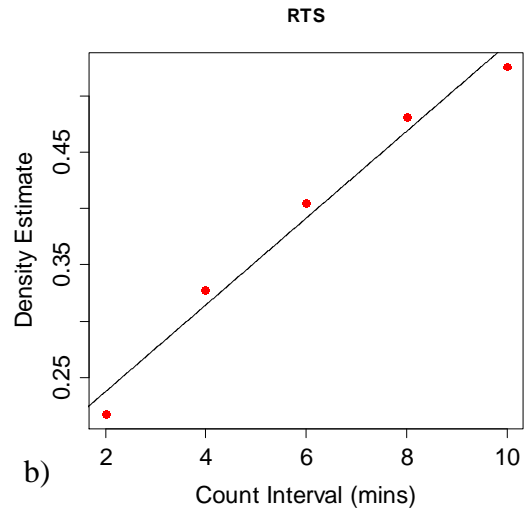
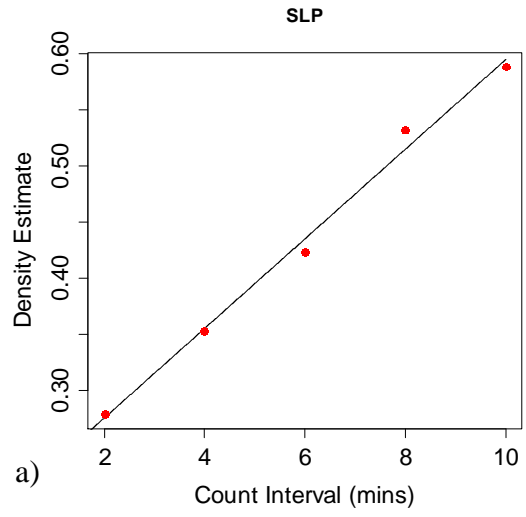


Figure 4.3: Density estimates (Individuals/hectare<sup>2</sup>) and 95% Confidence Intervals for cumulative 2 minute intervals of a 10minute count period. Density estimates shown for a) St. Lucia Rainforest birds (PEW density estimates divided by 10) and b) WBT data pooled over 5 years.

Linear regression was carried out on all density estimates to confirm the linear relationship between count length and density estimates, (Figure 4.4).

#### 4.4 Effect of count duration and observer experience on sighting distance

Analysis of variance (anova) tests were used to establish if mean sighting distances for all bird species varied over the duration of the count. The mean WBT observation sighting distance varied between 19.1m and 24.6m and the mean sighting distance for all rainforest bird species ranged between 26.0m and 32.5m, across the count period. In both cases there was no significant difference in mean sighting distances as the point count length increased. Rainforest survey data gathered when an expert in distance sampling was present was analysed separately and showed no significant differences in observation sighting distances with a p-value of <0.05 although p-values at 6-8 minutes and 8-10 minutes were smaller than those for the overall rainforest dataset (Table 4.3).



**Figure 4.4:** Relationship of count interval and density estimate as for  
 a) SLP  $r^2=0.99$ , 1 and 3d.f.,  $P=0.0002$ ,  
 b) RTS  $r^2=0.97$ , 1 and 3d.f.,  $P=0.001$ ,  
 c) SLO  $r^2=0.97$ , 1 and 3d.f.,  $P=0.001$ ,  
 d) PEW  $r^2=0.97$ , 1 and 3d.f.,  $P=0.001$ ,  
 e) WBT  $r^2=0.98$ , 1 and 3d.f.,  $P=0.0004$

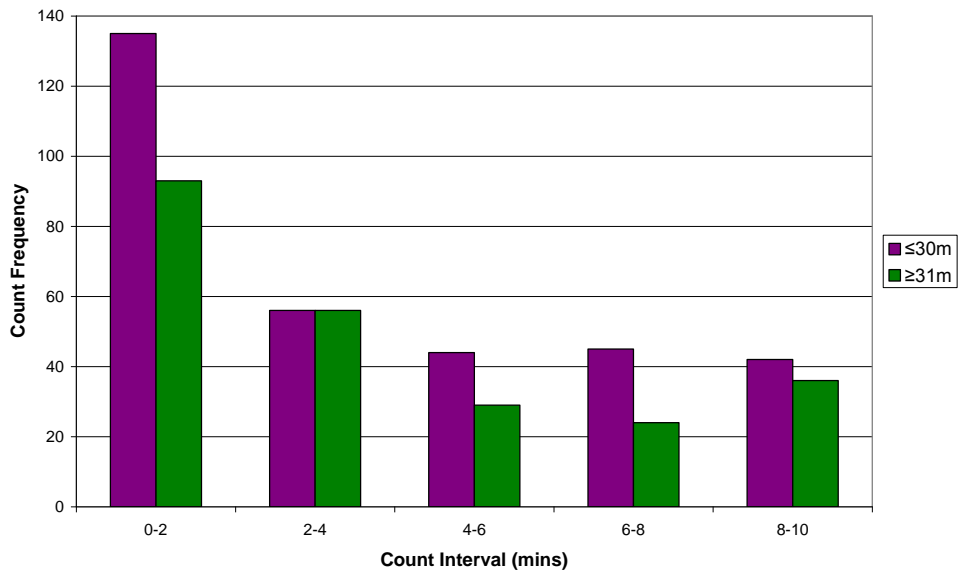
Table 4.3: Parameter estimates, standard errors (SE) and  $p$ -values for anova tests looking at the effect of count interval on observation sighting distance for all rainforest data, and data collected when an expert in distance sampling was present.

	All Data			Expert Data		
	Estimate	SE	$p$ -value	Estimate	SE	$p$ -value
0-2min	2.66494	0.03412	<2e-16	31.087	3.406	3.67e-10
2-4min	0.08914	0.05937	0.134	-5.587	12.042	0.6460
4-6min	-0.05375	0.06907	0.437	10.663	8.849	0.2376
6-8min	-0.10466	0.07099	0.141	28.913	16.686	0.0934
8-10min	0.04229	0.06735	0.530	14.513	8.060	0.0818

Within the whole rainforest dataset, there were more observations within the average effective detection radius (EDR) of 30m in every count interval period, with the exception of 2-4 minutes where there was an equal number of observations both within and beyond the EDR (Figure 4.5 a)). Where an expert was present, there were more observations within the EDR at 0-2 minutes, an equal number of observations at 2-4 minutes and more observations beyond the EDR for the remainder of the count period (Figure 4.5 b)).

Figure 4.6 allows visual inspection of ‘near’ and ‘far’ observations for the separate rainforest species and WBT. These show the SLP (a) had a greater number of observations with sighting distances beyond the average EDR in count intervals 2-4 minutes and 4-6 minutes but the majority of observations beyond 6 minutes are within the average EDR. The RTS (b), PEW (c) and WBT (d) all had a greater number of observations within the average EDR across all count intervals, except the RTS at 8-10 minutes where ‘near’ and ‘far’ were equally represented. The SLO (e) had a greater number of ‘near’ detections during count interval 0-2 minutes, 4-6 minutes and 6-8 minutes but a greater number of ‘far’ detections at both 2-4 minutes and 8-10 minutes.

a)



b)

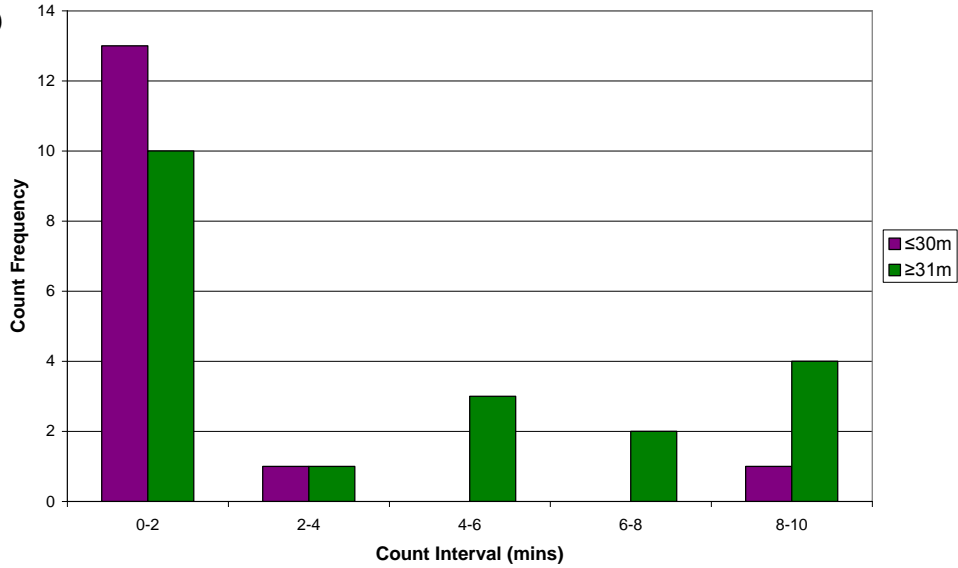
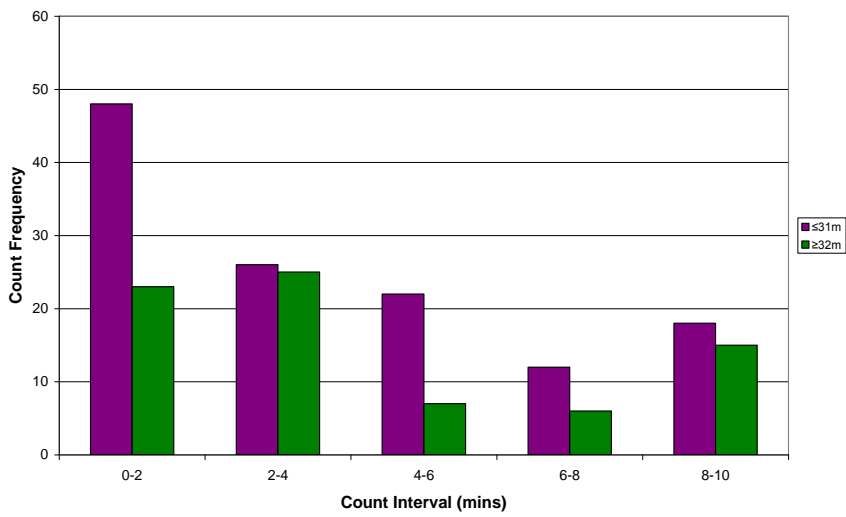
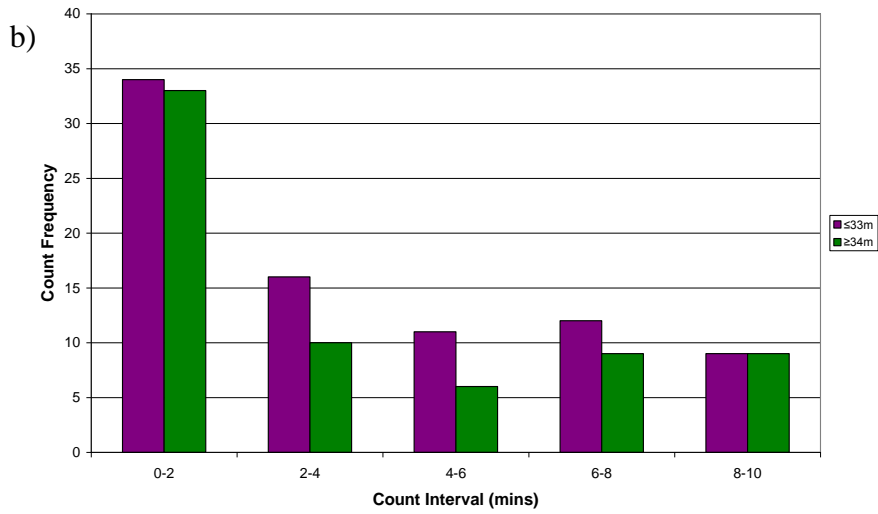
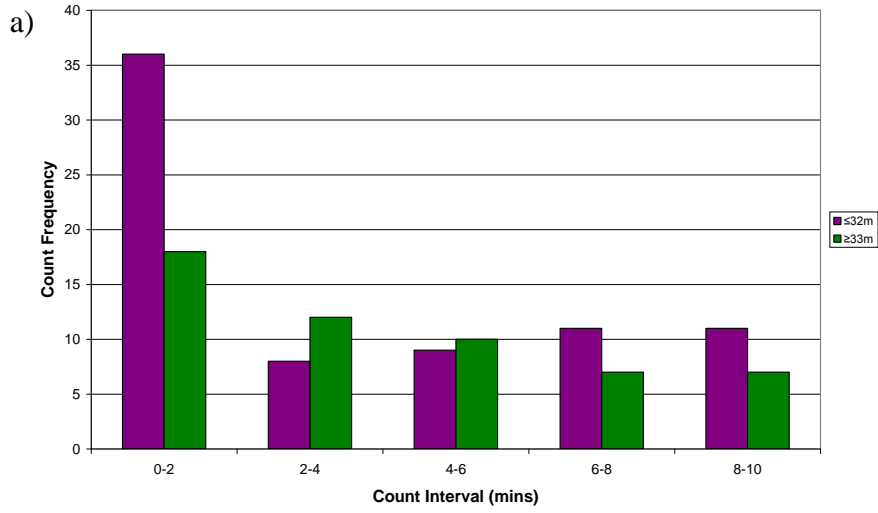


Figure 4.5: Number of observations at distances within EDR (purple) and beyond EDR (green) for each 2 minute count interval for a) All data collected in the rainforest bird survey and b) rainforest survey data collected where an expert in distance sampling was present.



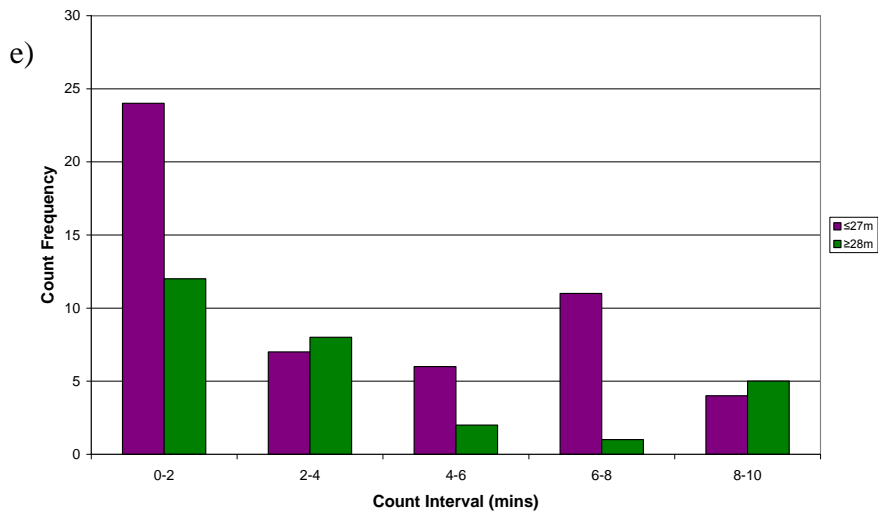
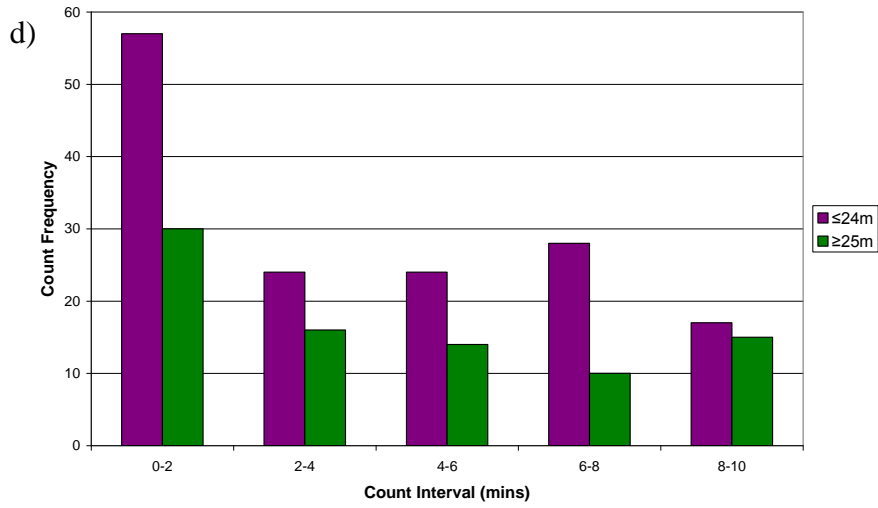


Figure 4.6: Number of observations at distances within EDR (purple) and beyond EDR (green) for each 2 minute count interval for a) SLP b) RTS c) PEW d) WBT and e) SLO

#### **4.5 Testing observations for interactions between count interval and distance**

A GLM with a Poisson error structure using count frequency as the response variable, was fitted with an interaction between explanatory variables count interval and sighting distance as either 'near' or 'far' (using the average EDR) to all 5 bird species. This produced saturated models for all species with no degrees of freedom and thus no explanatory power. To simplify the models the interaction of count interval and sighting distance was tested using an anova with chi-square test. This confirmed the interaction of count interval and sighting distance was not significant for any of the species, SLP  $p= 0.2548$ , RTS  $p= 0.7000$ , SLO  $p= 0.0666$ , PEW  $p= 0.1376$  and WBT  $p= 0.4657$ .

Removing the interaction resulted in the minimum adequate model for species SLO, PEW and WBT. The  $p$ -values for distance 'near' were all significant at  $<0.05$  once the interaction was removed SLO  $p=0.008268$ , PEW  $p=0.000500$ , WBT  $p=<0.0001$ . The low  $p$ -values confirm there is a significantly higher number of observations 'near' to the observer across the whole count period. Further simplification was needed for both SLP and RTS as the  $p$ -values for sighting distance 'near' vs 'far' were not significant. This involved removing distance as an explanatory variable altogether leaving count interval as the sole explanatory variable.

Full minimal adequate model outputs from 'R' for each of the aforementioned models can be found in Appendix C.

## **5. Discussion**

### **5.1 Effect of point count length on density**

The effect of count length on density estimates was significant and produced estimates with an increase of around 100 - 200% for a 10 minute count compared to a 2 minute count. These results would indicate that one of two things is happening, either it is taking the whole 10 minutes to count all individuals, regardless of the species, and perhaps even longer counts are required, or the assumption that only birds in a snapshot moment are being counted, is being violated. These findings differ from those of Lee and Marsden (2008) where density estimates reach an asymptotic curve over the count duration but seem more similar to those of Cimprich (2008) who found a large increase in density estimates over time. Cimprich was able to prove the counting assumption was being violated in the longer counts by comparing figures with territory mapping results. It cannot be verified with 100% certainty that the counting violation occurred in this study. Further examination of patterns in the count frequency and observation sighting distances can however help to determine which explanation is causing the correlated increase in density estimates.

### **5.2 Examination of Observational Patterns**

Studies have shown that when counting birds the majority of observations are made very quickly (Shiu & Lee, 2003). The highest proportion of observations in any count interval was during 0-2 minutes in both the rainforest survey and dry-forest survey regardless of the species being sampled. The SLP and SLO are both birds with bright colouring and the RTS is known to be particularly vocal, so it is perhaps not surprising that over 40% of all observations for these species were detected within the first 2 minutes. Both the WBT and PEW had slightly fewer observations within this time but still over 35% of all observations were spotted or heard within the first

count interval. So it would seem that even cryptic birds like the PEW are spotted relatively quickly.

The manner in which the observations are seen over the duration of the count differs per species as would be expected for birds with different detection probabilities. A priori it is expected that the number of new observations will decrease over time as eventually all birds present in the snapshot moment would be counted (Shiu & Lee, 2003). However, both the SLP and WBT observations dropped after 2 minutes but then remained constant throughout the rest of the count period. This could be an indication of bird movement and a resulting counting violation as the WBT is known to be inquisitive, with birds potentially moving towards the observer (Keith, 1997), and the SLP is known to be highly mobile (R. Young pers. comm.). If this is the case then the assumptions of the methodology will have been violated.

The numbers of RTS, SLO and PEW observations did decrease over time but in all cases this is followed by an increase towards the end of the count period. As all three species are perhaps not as detectable as the SLP or WBT, a slower accumulation of counts may be expected, especially for a cryptic species like the PEW. This rise in observations, following a decrease could also indicate double counting or counting of new arrivals to the plot. Any violation of the counting assumption would have implications for calculating reliable density estimates.

### **5.3 Examination of mechanisms driving density estimates**

In distance sampling, it is observations near to the point that influence density estimates. Statistical analysis confirmed there was no relationship between sighting distance and count interval for any of the species, meaning birds were as likely to be spotted 'near' to the point as they were 'far' throughout the whole count period. This also contradicts the Lee and Marsden (2008) study where observations later in the count were detected at distances far enough away from the point to have little

effect on density estimation. Furthermore a study looking at how observers generally count birds (i.e. not specifically for distance sampling) showed a time-distance interaction with observations later in the count period occurring at greater distances from the point (Gates, 1995). And critically, distance sampling data collection protocol dictates that observers should search the area for objects closest to the point first, precisely because of their importance in estimating density (Buckland, 2001). With this in mind, a priori expectations of density estimation would suggest that over time an asymptotic curve of density would be produced, providing that no double counting or counting of new individuals was taking place (Lee & Marsden, 2008). In theory, the steepness of the curve should provide an indication of detectability with highly detectable species reaching a plateau more quickly than cryptic species.

The lack of relationship between time and distance in this study suggests that observers are violating counting assumptions (for the purposes of clarity this shall be referred to as the 'expected' relationship). It is recommended that the same observer should be used to reduce bias, especially if abundances are to be used to assess population change (Dawson et al., 1995). However this is sometimes neither logistically practical nor feasibly possible where there are limited resources and a large area to sample. The majority of observers collecting both the rainforest and dry-forest survey data in this study were volunteers with varying levels of experience. Although training was given to all volunteers, including an introduction to distance sampling, visual aids for bird identification and teaching of call cues, it appears that a certain level of counting violations did occur. To further corroborate this, observations recorded when an expert in distance sampling was present during the rainforest survey also conform to the 'expected' pattern between distance and time. 66% of all observations occurred within the first 2 minutes and only 1 observation out of 35 was made within the average effective detection radius (EDR) beyond 4 minutes in the count period. However, the number of observations recorded when an expert was present was small and could only be analysed with all rainforest bird species pooled together. Nonetheless it provides an interesting

perspective and adds weight to the supposition that the snapshot assumption is being violated. It should also be noted that the Lee and Marsden (2008) study was undertaken by an expert ornithologist with experience in distance sampling. Analysis of more specific observer effects (i.e. assigning groups an experience rating) could not be undertaken during this study as the logistics and practicalities of the survey negated the possibility of keeping observers in the same group.

#### **5.4 Recommendations for study species**

If we believe that violation of the counting assumption is occurring, and our aim is to reduce the count duration to minimise this problem, closer inspection of count frequency and observation sighting distances, examined with what we know of species behaviour can direct us to a more appropriate count duration for each species.

#### **SLP**

The SLP sighting distance observations followed an 'expected' pattern up to the 6 minute mark with a greater number of observations further from the point at both 2-4 minutes and 4-6 minutes, although the number of 'near' observations also increased at 4-6 minutes. This could indicate a violation of counting assumption that begins on average somewhere between 4-6 minutes. Taking into account that we know the SLP is both vocal and mobile, and there was no decline in count frequency between 4 and 6 minutes, a count period of 4 minutes would seem more appropriate.

#### **RTS**

Little has been documented regarding RTS behaviour other than the knowledge that it is usually seen rather than heard. This would be supported by the data collected here as only 6% of observations were visual. With the majority of all observations occurring 'near' to the point, there was a decline in both 'near' and 'far' detections up to 6 minutes before both categories increased in occurrence. An increase in count

frequency also occurred after 6 minutes. In lieu of further behavioural information it is difficult to report an appropriate count period although it appears there is a change in detection patterns at 6 minutes which would minimise the chances of a counting violation occurring far more than a 10 minute count.

### **SLO**

Similarly to the SLP, SLO observations seem to follow the more 'expected' composition up until 4 minutes. Density estimates also appear to plateau at this point, however at 6 minutes the majority of observations occur 'near' to the observer with a sharp increase at 6-8 minutes, along with an increase in the percentage of detections at this time. Again it is a species where not much behavioural information has been reported but with what we know about its visual detectability and rapidity of count accumulation, a count period of 4 minutes would seem more suitable.

### **PEW**

The PEW was regarded as the most cryptic of all species and although the significant number of observations were 'near' to the point, both 'near' and 'far' observations decline in frequency until 8 minutes before increasing, as does the percentage of observations. This would support the theory that it can take longer to observe, although with a count of 8 minutes the risk of bird movement both within and into the plot is higher. Again without further information it is difficult to suggest an exact count length but anything beyond 8 minutes would seem too long for this habitat.

### **WBT**

WBT observations were significantly greater 'near' to the point than 'far' across the whole count period. The WBT is known to be inquisitive and the steep increase in 'near' observations at 6-8 minutes could support this information. The percentage of counts at both 6 and 8 minutes is exactly the same indicating a 6 minute count period would be more appropriate for the WBT.

In comparison to the adjusted count periods recommended for each species, a 10 minute count produced a density estimate 67% greater for the SLP, 30% greater for the RTS, 45% greater for the SLO, 18% greater for the PEW and 34% greater for the WBT. Based on these recommendations, a 10 minute count produced false positive results for all species, in particular for the SLP. This has implications for successful conservation of species in monitoring programmes all over the world, where density estimates are used to monitor the success of management action and guide future policy. This is especially true where volunteers with varying levels of ability are used to collect the data as is probably common practice in many schemes.

### **5.5 Determining appropriate count length**

There are some relatively straightforward practices that could be implemented in current monitoring programmes to reduce the bias in density estimates produced by an unadjusted count.

#### **1. Behaviour studies**

Short studies to document the behaviour of target species would be beneficial and relatively simple to undertake. A few days spent locating target birds and documenting how much they move, call or stay still from the point of contact until they move out of range or a until a pre-determined time, can be used to decide what an appropriate count duration for that habitat type, time of day and time of year, may be.

#### **2. Count Intervals / timing of counts**

Counts can be timed so the exact moment of detection can be recorded making patterns in bird observations more accurate. However if this is too much for the observer to do then count intervals of 1 or 2 minutes would still be beneficial. Count frequency can be examined to look for patterns such as were found here and this can be considered with the information from the behavioural study.

3. If using distance analysis the relationship between sighting distance and time can also be included with the above analysis to explore if the 'expected' relationship is occurring.

#### 4. Training

Critical to any monitoring programme is observer training but this cannot be emphasized enough when the observers are volunteers with differing levels of expertise and ability. Observers must be trained in both visual and aural identification of target species and, if deemed necessary, tested on ability so they can be paired or grouped appropriately. If possible, groupings should be kept the same so any effect that a particular observer or observer group may have on estimates can be analysed.

The visual and statistical analysis of the data as used here is also a useful way to monitor observers to judge if counting protocol is being violated, once it has been established what the 'expected' count for that species should look like. This can then be used to evaluate training programmes and adjust future training or retrain any individuals or groups as needed.

#### **5.6 Implications for monitoring**

In recent years, nearly 100% of studies carried out to determine avian abundance estimates used an arbitrary count duration. The variety of count lengths chosen, with the majority being unique to each study, would indicate that this is an area in survey design for which the effects are little understood. Only one study (Aben, 2008) reported to base the count length on the results of another study, which is unpublished data, and no further explanation was given as to why that particular duration was chosen. The most popular count duration used in avian point count studies to produce abundance estimates was 10 minutes, accounting for almost half the studies analysed. This is the same count duration that was provisionally used in the bird monitoring programme analysed here and, as has been shown, can produce

unreliable results with massive overestimates of density. The abundance estimates derived from these studies must be deemed questionable if they are unable to guarantee or give evidence of an attempt to mitigate the violation of the assumption that the snapshot moment was achieved.

Although the focus of this study has been to examine point count length in relation to methodologies that adjust the count by means of a detection probability, it also holds true for methods generating indices of abundance that the length of time spent counting affects the number of birds counted, with similar connotations for the results produced.

### **5.7 Implications for conservation**

Accurate estimates of population size are critical to conservation efforts. They facilitate interventions by establishing reliable estimates of species abundance, either as a baseline figure or in response to threats or management actions (Yoccoz, 2001). With so many species at risk in the wild today, reliable abundance estimates can enable prioritisation of critically endangered populations and secure funding for immediate and future conservation work (Brooks et al., 2006). Additionally, monitoring a population's response to specific threats can allow predictions of where future problems may occur and enable mitigation of the threat or provide alternative solutions to be identified (Wilson, 2006).

Density estimation relies on the 'snapshot' assumption being satisfied which in practice can be commonly violated rendering estimates inaccurate. The reality for many conservation agencies is that volunteers of varying ability must be used to enable avian monitoring to take place, which can increase the probability of the 'snapshot' assumption being violated. Furthermore, the arbitrary count lengths currently used in practice with no rationale reported in published literature mean it is an overlooked issue receiving little exposure to reviews and improvement (Sutherland, 2004). Adjusting the count duration based on species detectability will

help satisfy the 'snapshot' assumption ensuring reliable estimates of density are produced. Considering count duration as part of survey protocol and reporting choices in published literature will help point count length become both a used and useful component of monitoring strategies.

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# Appendices

## Appendix A

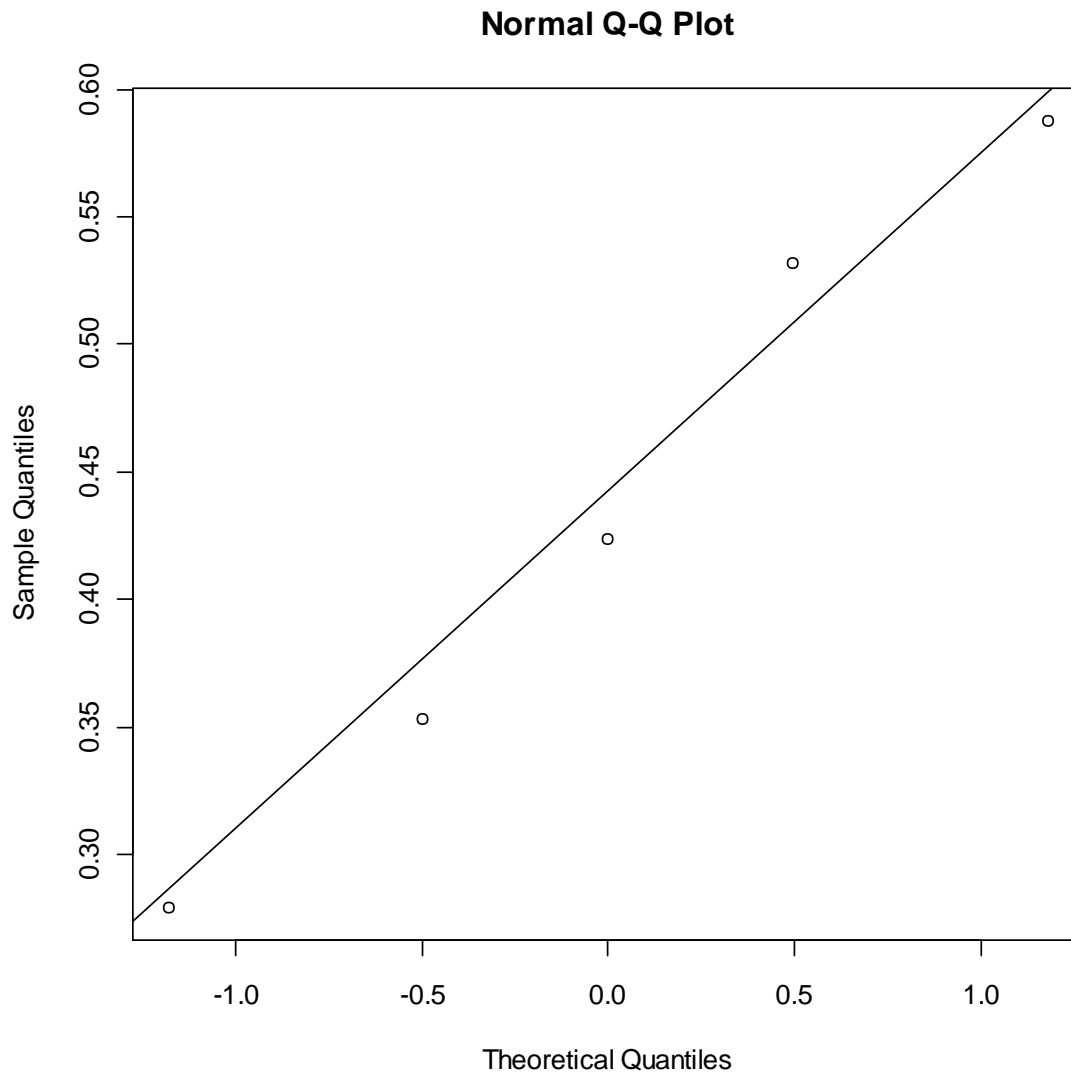
Normal Q-Q plots and associated Shapiro-Wilk normality tests (W) for density estimates for all species surveyed. P-value > 0.05 indicates normality

### SLP

Shapiro-Wilk normality test

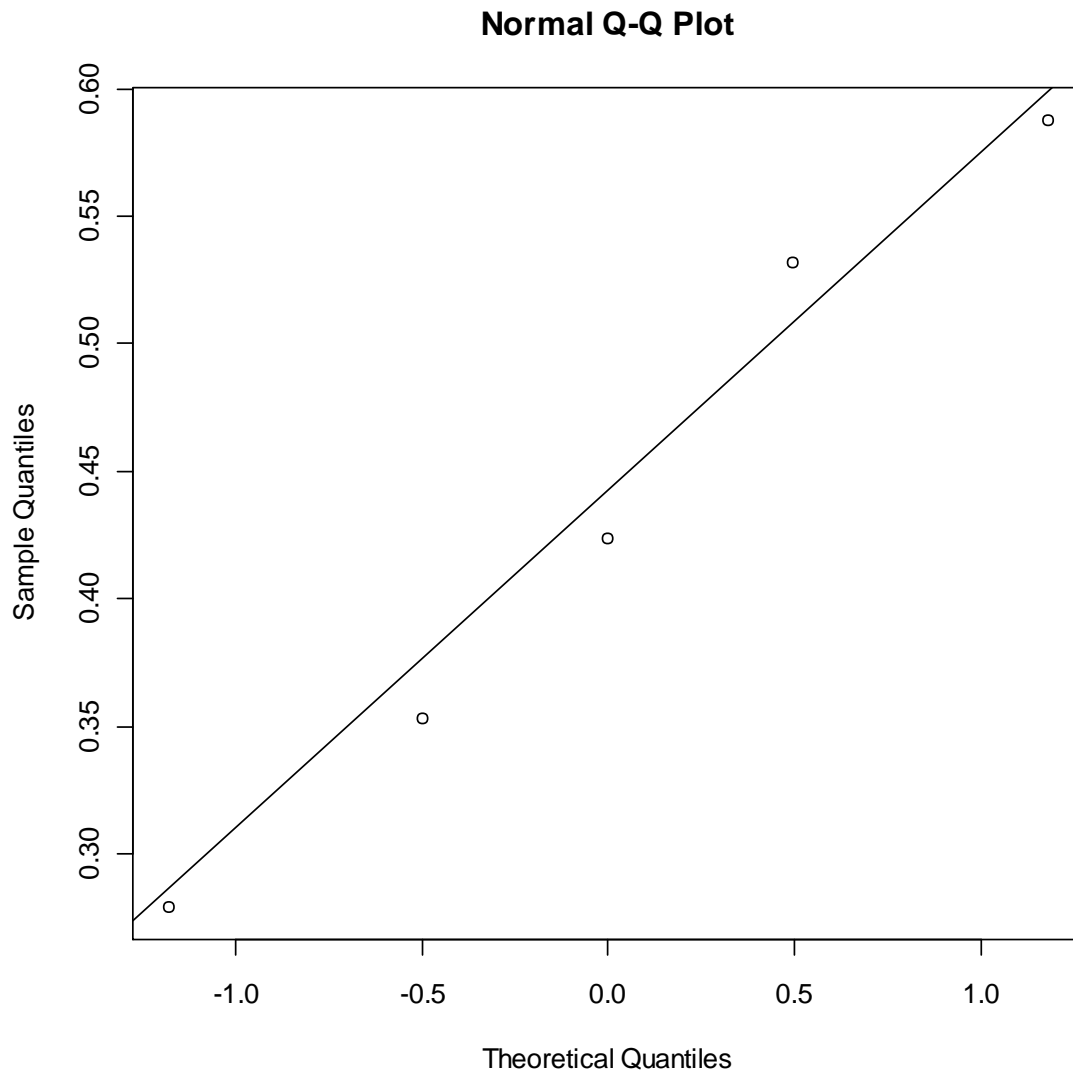
data: Density

W = 0.9655, p-value = 0.8456



RTS

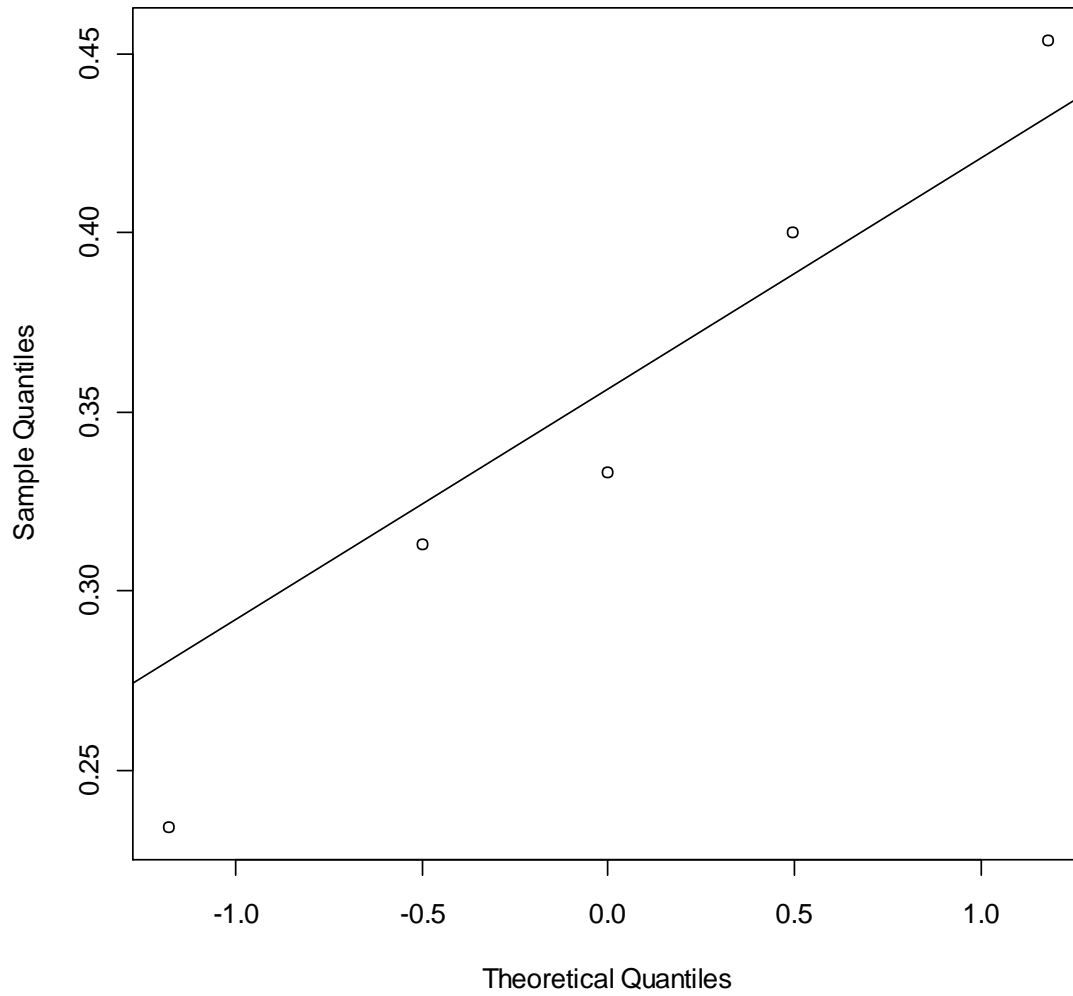
Shapiro-Wilk normality test  
data: Density  
W = 0.9652, p-value = 0.844



SLO

Shapiro-Wilk normality test  
data: Density  
W = 0.9853, p-value = 0.9609

Normal Q-Q Plot



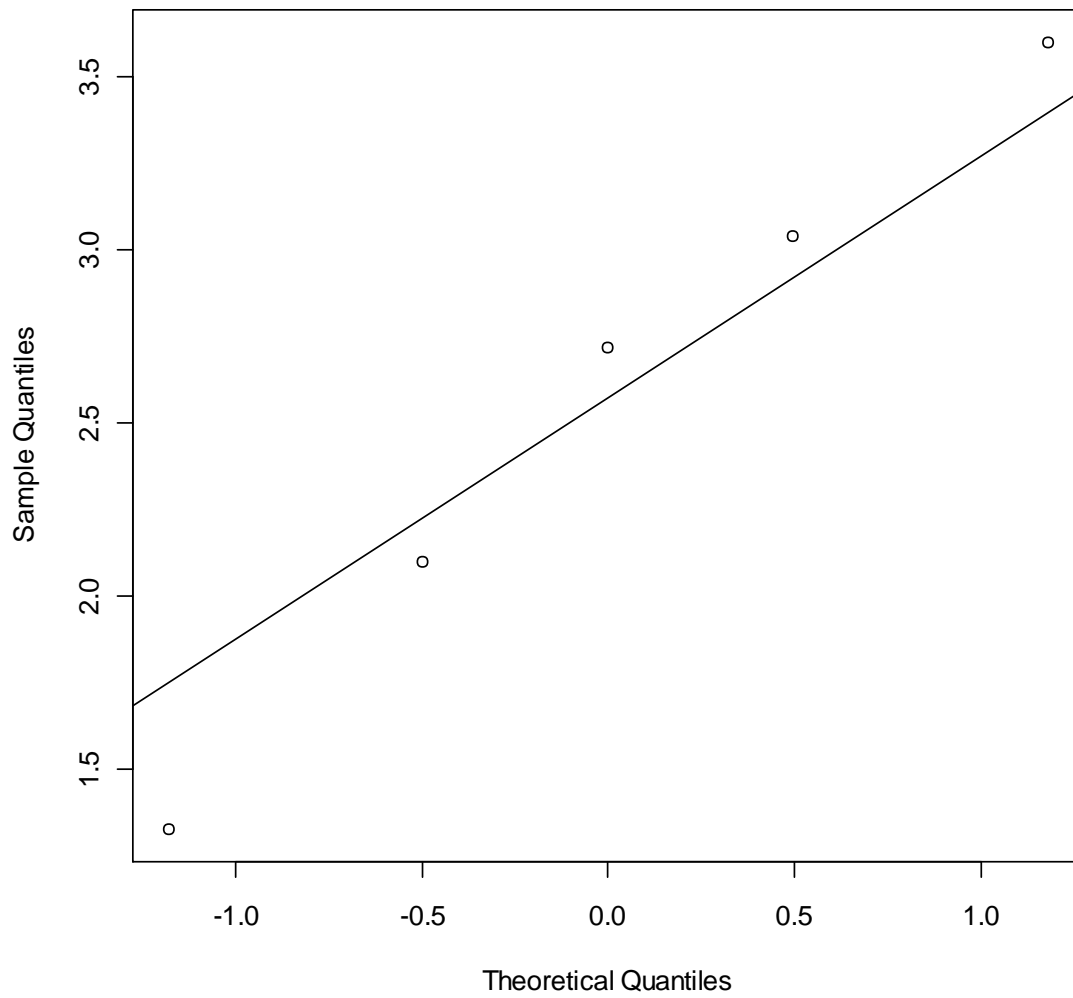
PEW

Shapiro-Wilk normality test

data: Density

W = 0.9839, p-value = 0.9543

Normal Q-Q Plot



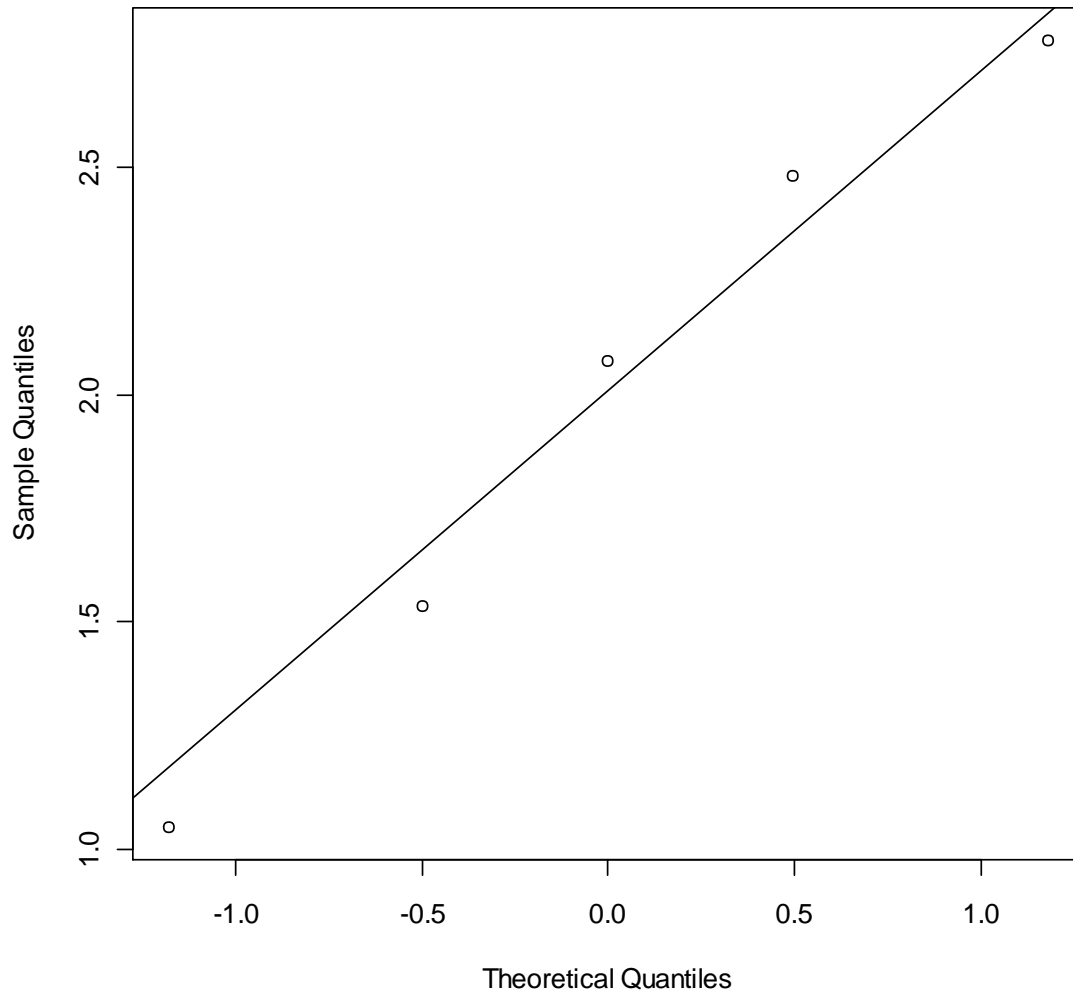
WBT

Shapiro-Wilk normality test

data: Density

W = 0.9678, p-value = 0.8607

Normal Q-Q Plot



## Appendix B

Author	Title	Point Count Length	Reason Given
Barlow et al 2007	The value of primary, secondary and plantation forests for Amazonian birds	10 minutes	None
Brown 2007	Body mass, habitat generality, and avian community composition in forest remnants	10 minutes	None
Gordon et al 2007	Biodiversity, profitability, and vegetation structure in a Mexican coffee agroecosystem	10 minutes	None
Kubel and Yahner 2007	Detection probability of Golden-winged Warblers during point counts with and without playback recordings	3 minutes	None
Mendelsohn et al 2007	Diversity of terrestrial avifauna in response to distance from the shoreline of the Salton Sea	5 minutes	None
O'Dea and Whittaker 2007	How resilient are Andean montane forest bird communities to habitat degradation?	10 minutes	None
Shahabuddin and Kumar 2007	Effects of extractive disturbance on bird assemblages, vegetation structure and floristics in tropical scrub forest, Sariska Tiger Reserve, India	2 minute settling down period 10 minute count	None
Veech 2007	Increasing and declining populations of northern bobwhites inhabit different types of landscapes	North American Breeding Bird Survey	None
Aben et al 2008	Human Disturbance affects a Deciduous Forest Bird Community in the Andean Foothills of Central Bolivia	12 minutes	Based on results of a previous study in Los Volcanes (SKH unpublished data)
Arriaga-Weiss et al 2008	Bird communities in rainforest fragments: guild responses to habitat variables in Tabasco, Mexico	10 minutes	None
Bas et al 2008	Accounting for weather and time-of-day parameters when analysing count data from monitoring programs	5 minutes	None
Betts et al 2008	Dynamic occupancy models reveal within-breeding season movement up a habitat quality gradient by a migratory songbird	10 minutes	None

Confer et al 2008	Field tests of the Rosenberg-Blancher method for converting point counts to abundance estimates	3 minutes	None
Author	Title	Point Count Length	Reason Given
Duncan and Bednekoff 2008	Nesting with an enemy: The abundance and distribution of preferred and secondary prey near nesting Cooper's hawks, <i>Accipiter cooperii</i>	10 minutes	None
Farley et al 2008	Characterizing complex mixed-species bird flocks using an objective method for determining species participation	10 minutes	None
Fujisaki et al 2008	Detecting population decline of birds using long-term monitoring data	Data used from the North American Breeding Bird Survey	None
Gonzalo-Turpin et al 2008	Teasing out biological effects and sampling artifacts when using occupancy rate in monitoring programs	10 minutes & 20 minutes	None
Heldbjerg and Fox 2008	Long-term population declines in Danish trans-Saharan migrant birds	Data used from the Danish Common Birds Census	None
Jones et al 2008	Breeding abundance and distribution of Long-billed Curlews ( <i>Numenius americanus</i> ) in north America	5 minutes	None
Lambert et al 2008	Decline of a New Hampshire Bicknell's Thrush Population, 1993-2003	5 minutes	None
Liebezeit and Zack 2008	Point counts underestimate the importance of Arctic foxes as avian nest predators: Evidence from remote video cameras in Arctic Alaskan oil fields	10 minutes	None
Lloyd 2008	Abundance and patterns of rarity of <i>Polylepis</i> birds in the Cordillera Vilcanota, southern Peru: implications for habitat management strategies	5 minute settling down period 20 minute count	Cites Bibby et al. (2000) for the 5 minute settling down period.
Massimino et al 2008	Population trend assessment on a large spatial scale: integrating data collected with heterogeneous sampling schemes by means of habitat modelling	10 minutes	None
Nur et al 2008	Regional analysis of riparian bird species response to vegetation and local habitat features	5 minutes	None
Powlesland et al 2008	Was Tropical Cyclone Heta or hunting by people responsible for decline of the Lupe ( <i>Ducula pacifica</i> ) ( <i>Aves</i> : <i>Columbidae</i> ) population on Niue during 1994-2004?	5 minutes	None
Reinkensmeyer et al 2008	Winter and early spring bird communities in grasslands, shrubsteppe, and juniper woodlands in central Oregon	1 minute settling down period 8 minute count	None

Author	Title	Point Count Length	Reason Given
Uezu et al 2008	Can agroforest woodlots work as stepping stones for birds in the Atlantic forest region?	10 minutes	None
Acharya et al 2009	Indigenous knowledge of Lepcha community for monitoring and conservation of birds	5 minutes	None
Anderson 2009	Ground versus canopy methods for the study of birds in tropical forest canopies: implications for ecology and conservation	10 minutes	None
Bakaloudis et al 2009	Breeding habitat preferences of the turtledove ( <i>Streptopelia turtur</i> ) in the Dadia-Soufli National Park and its implications for management	10 minutes	None
Celis-Murillo et al 2009	Using soundscape recordings to estimate bird species abundance, richness, and composition	10 minutes	None
Chamberlain et al 2009	Sparrowhawk <i>Accipiter nisus</i> presence and winter bird abundance	Not stated	None
Darrah and Kremetz 2009	Distribution and Habitat Use of King Rails in the Illinois and Upper Mississippi River Valleys	Not stated	North American Standardized Marsh Bird Survey (Conway 2005)
Garwood et al 2009	High mountain lakes provide a seasonal niche for migrant American dippers	Not stated	None
Gifford et al 2009	Importance of an urban pine barrens for the conservation of early-successional shrubland birds	10 minutes	None
Grouios and Manne 2009	Utility of Measuring Abundance versus Consistent Occupancy in Predicting Biodiversity Persistence	3 minutes	None
Hancock et al 2009	Associations between distance to forest and spatial and temporal variation in abundance of key peatland breeding bird species	5 minutes	None
Hutto and Stutzman 2009	Humans versus autonomous recording units: a comparison of point-count results	10 minutes	None
Ippi et al 2009	Annual variation of abundance and composition in forest bird assemblages on Navarino island, cape horn biosphere reserve, Chile	6 minutes	None
Lefort and Grove 2009	Early responses of birds to clearfelling and its alternatives in lowland wet eucalypt forest in Tasmania, Australia	2 minute settling down period 5 minute count	None
Lencinas et al 2009	Alternative silvicultural practices with variable retention improve bird conservation in managed South Patagonian forests	2min settle 8 min count	None
Author	Title	Point Count Length	Reason Given

		10 minutes (divided into initial 3 minute, subsequent 2 minute, and final 5 minute periods)	Check??
McConnell et al 2009	Mountain Plovers in Oklahoma: distribution, abundance, and habitat use		
McWethy et al 2009	Edge effects for songbirds vary with forest productivity	10 minutes	None
Norris et al 2009	Effects of Wildlife Forestry on Abundance of Breeding Birds in Bottomland Hardwood Forests of Louisiana	10 minutes	None
Rush et al 2009	Occupancy of select marsh birds within northern gulf of Mexico tidal marsh: current estimates and projected change	Not stated	None
Russell et al 2009	Modeling the effects of environmental disturbance on wildlife communities: avian responses to prescribed fire	5 minutes	None
Ruvalcaba-Ortega et al 2009	Riparian bird community from the Rio Sabinas, Coahuila, Mexico	10 minutes	None
Volpato et al 2009	The use of the point count method for bird survey in the Atlantic forest	15 minutes	None
Acharya et al 2010	The bird community of Shingba Rhododendron wildlife sanctuary, Sikkim, Eastern Himalaya, India	5 minutes	None
Berges et al 2010	Bird species diversity in riparian buffers, row crop fields, and grazed pastures within agriculturally dominated watersheds	10 minutes	None
Di Giacomo et al 2010	Landscape associations of globally threatened grassland birds in the Aguapey river Important Bird Area, Corrientes, Argentina	10 minutes	None
Hedblom and Soderstrom 2010	Landscape effects on birds in urban woodlands: an analysis of 34 Swedish cities	2 minute settling down period 10 minute count	None
Moradi and Mohamed 2010	Responses of babblers (timaliidae) to the forest edge-interior gradient in an isolated tropical rainforest in peninsular Malaysia	10 minutes	None
Nikolov 2010	Effects of land abandonment and changing habitat structure on avian assemblages in upland pastures of Bulgaria	1 minute settling down period 5 minute count	None
Zmihorski 2010	The effect of windthrow and its management on breeding bird communities in a managed forest	10 minutes	None
Zurita and Bellocq 2010	Spatial patterns of bird community similarity: bird responses to landscape composition and configuration in the Atlantic forest	5 minutes	None

## Appendix C

Full minimal adequate model outputs from 'R' for Poisson GLM testing count frequency as the response variable, fitted with an interaction between explanatory variables count interval and sighting distance

### SLP:

```
> M7<-glm(Count~Interval*Distance,poisson)
> summary(M7)
```

Call:

```
glm(formula = Count ~ Interval * Distance, family = poisson)
```

Deviance Residuals:

```
[1] 0 0 0 0 0 0 0 0 0 0
```

Coefficients:

	Estimate	Std. Error	z value	Pr(> z )
(Intercept)	2.8904	0.2357	12.263	<2e-16 ***
Interval2-4	-0.4055	0.3727	-1.088	0.2766
Interval4-6	-0.5878	0.3944	-1.490	0.1361
Interval6-8	-0.9445	0.4454	-2.120	0.0340 *
Interval8-10	-0.9445	0.4454	-2.120	0.0340 *
DistanceN	0.6931	0.2887	2.401	0.0163 *
Interval2-4:DistanceN	-1.0986	0.5401	-2.034	0.0419 *
Interval4-6:DistanceN	-0.7985	0.5426	-1.472	0.1411
Interval6-8:DistanceN	-0.2412	0.5631	-0.428	0.6685
Interval8-10:DistanceN	-0.2412	0.5631	-0.428	0.6685

---

Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for poisson family taken to be 1)

Null deviance: 4.0806e+01 on 9 degrees of freedom  
Residual deviance: 1.1102e-15 on 0 degrees of freedom  
AIC: 62.766

Number of Fisher Scoring iterations: 3

```
> M8<-update(M7,~.-Interval:Distance)
> anova(M7,M8,test="Chi")
Analysis of Deviance Table
```

Model 1: Count ~ Interval \* Distance

Model 2: Count ~ Interval + Distance

Resid. Df Resid. Dev Df Deviance P(>|Chi|)

```
1    0 1.110e-15
2    4  5.3333 -4 -5.3333  0.2548
> summary(M8)
```

Call:

```
glm(formula = Count ~ Interval + Distance, family = poisson)
```

Deviance Residuals:

```
 1    2    3    4    5    6    7    8
0.8028 -1.1280 -0.6364  0.1640  0.1640 -1.0045  1.1765  0.6975
 9   10
-0.1972 -0.1972
```

Coefficients:

```
      Estimate Std. Error z value Pr(>|z|)
(Intercept)  3.1182    0.1711  18.221 < 2e-16 ***
Interval2-4  -0.9933    0.2618  -3.795 0.000148 ***
Interval4-6  -1.0445    0.2667  -3.916 9.00e-05 ***
Interval6-8  -1.0986    0.2722  -4.037 5.42e-05 ***
Interval8-10 -1.0986    0.2722  -4.037 5.42e-05 ***
DistanceN    0.3285    0.1785   1.841 0.065671 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

(Dispersion parameter for poisson family taken to be 1)

Null deviance: 40.8055 on 9 degrees of freedom  
Residual deviance: 5.3333 on 4 degrees of freedom  
AIC: 60.099

Number of Fisher Scoring iterations: 4

### **RTS:**

```
> M9<-glm(Count~Interval*Distance,poisson)
> summary(M9)
```

Call:

```
glm(formula = Count ~ Interval * Distance, family = poisson)
```

Deviance Residuals:

```
[1] 0 0 0 0 0 0 0 0 0 0
```

Coefficients:

	Estimate	Std. Error	z value	Pr(> z )
(Intercept)	3.49651	0.17408	20.086	< 2e-16 ***
Interval2-4	-1.19392	0.36098	-3.307	0.000941 ***
Interval4-6	-1.70475	0.44381	-3.841	0.000122 ***
Interval6-8	-1.29928	0.37605	-3.455	0.000550 ***
Interval8-10	-1.29928	0.37605	-3.455	0.000550 ***
DistanceN	0.02985	0.24437	0.122	0.902768
Interval2-4:DistanceN	0.44015	0.47140	0.934	0.350450
Interval4-6:DistanceN	0.57628	0.56329	1.023	0.306273
Interval6-8:DistanceN	0.25783	0.50414	0.511	0.609056
Interval8-10:DistanceN	-0.02985	0.53098	-0.056	0.955164

---

Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for poisson family taken to be 1)

Null deviance: 5.2874e+01 on 9 degrees of freedom  
Residual deviance: 1.5543e-15 on 0 degrees of freedom  
AIC: 63.892

Number of Fisher Scoring iterations: 3

```
> M10<-update(M9,~-Interval:Distance)
> anova(M9,M10,test="Chi")
Analysis of Deviance Table
```

```
Model 1: Count ~ Interval * Distance
Model 2: Count ~ Interval + Distance
  Resid. Df Resid. Dev Df Deviance P(>|Chi)
1      0 1.554e-15
2      4  1.82207 -4 -1.82207  0.76844
> summary(M10)
```

Call:  
glm(formula = Count ~ Interval + Distance, family = poisson)

Deviance Residuals:

1	2	3	4	5	6	7	8
-0.4794	0.4387	0.5229	0.1295	-0.2924	0.5153	-0.5073	-0.6182
9	10						
-0.1453	0.3128						

Coefficients:

	Estimate	Std. Error	z value	Pr(> z )
(Intercept)	3.4054	0.1521	22.387	< 2e-16 ***
Interval2-4	-0.9466	0.2311	-4.097	4.19e-05 ***

```
Interval4-6 -1.3715 0.2716 -5.050 4.41e-07 ***
Interval6-8 -1.1602 0.2501 -4.639 3.50e-06 ***
Interval8-10 -1.3143 0.2655 -4.951 7.40e-07 ***
DistanceN 0.2020 0.1647 1.227 0.22
```

---

Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for poisson family taken to be 1)

Null deviance: 52.8736 on 9 degrees of freedom  
Residual deviance: 1.8221 on 4 degrees of freedom  
AIC: 57.714

Number of Fisher Scoring iterations: 4

### **SLO:**

```
> M11<-glm(Count~Interval*Distance,poisson)
> summary(M11)
```

Call:

```
glm(formula = Count ~ Interval * Distance, family = poisson)
```

Deviance Residuals:

```
[1] 0 0 0 0 0 0 0 0 0 0
```

Coefficients:

	Estimate	Std. Error	z value	Pr(> z )
(Intercept)	2.4849	0.2887	8.608	<2e-16 ***
Interval2-4	-0.4055	0.4564	-0.888	0.3744
Interval4-6	-1.7918	0.7638	-2.346	0.0190 *
Interval6-8	-2.4849	1.0408	-2.387	0.0170 *
Interval8-10	-0.8755	0.5323	-1.645	0.1000
DistanceN	0.6931	0.3536	1.961	0.0499 *
Interval2-4:DistanceN	-0.8267	0.6268	-1.319	0.1872
Interval4-6:DistanceN	0.4055	0.8898	0.456	0.6486
Interval6-8:DistanceN	1.7047	1.1027	1.546	0.1221
Interval8-10:DistanceN	-0.9163	0.7583	-1.208	0.2269

---

Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for poisson family taken to be 1)

Null deviance: 4.4200e+01 on 9 degrees of freedom  
Residual deviance: 2.8866e-15 on 0 degrees of freedom  
AIC: 56.374

Number of Fisher Scoring iterations: 3

```
> M12<-update(M11,~-Interval:Distance)
> anova(M11,M12,test="Chi")
Analysis of Deviance Table
```

Model 1: Count ~ Interval \* Distance

Model 2: Count ~ Interval + Distance

```
Resid. Df Resid. Dev Df Deviance P(>|Chi)
1      0 2.887e-15
2      4  8.7880 -4 -8.7880  0.0666
> summary(M12)
```

Call:

```
glm(formula = Count ~ Interval + Distance, family = poisson)
```

Deviance Residuals:

```
 1    2    3    4    5    6    7    8
0.1235 -0.9279 0.3424 1.0784 -0.8117 -0.1704 1.1133 -0.5041
 9    10
-1.8788 0.9594
```

Coefficients:

```
      Estimate Std. Error z value Pr(>|z|)
(Intercept)  2.5337    0.2258  11.220 < 2e-16 ***
Interval2-4  -0.8755    0.3073  -2.849 0.004389 **
Interval4-6  -1.5041    0.3909  -3.848 0.000119 ***
Interval6-8  -1.0986    0.3333  -3.296 0.000981 ***
Interval8-10 -1.3863    0.3727  -3.720 0.000199 ***
DistanceN    0.6190    0.2344   2.641 0.008268 **
```

---

Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for poisson family taken to be 1)

```
Null deviance: 44.200 on 9 degrees of freedom
Residual deviance: 8.788 on 4 degrees of freedom
AIC: 57.162
```

Number of Fisher Scoring iterations: 5

**PEW:**

```
> M13<-glm(Count~Interval*Distance,poisson)
> summary(M13)
```

Call:  
glm(formula = Count ~ Interval \* Distance, family = poisson)

Deviance Residuals:  
[1] 0 0 0 0 0 0 0 0 0 0

Coefficients:

	Estimate	Std. Error	z value	Pr(> z )
(Intercept)	3.13549	0.20851	15.037	< 2e-16 ***
Interval2-4	0.08338	0.28893	0.289	0.77289
Interval4-6	-1.18958	0.43167	-2.756	0.00585 **
Interval6-8	-1.34373	0.45842	-2.931	0.00338 **
Interval8-10	-0.42744	0.33188	-1.288	0.19777
DistanceN	0.73571	0.25360	2.901	0.00372 **
Interval2-4:DistanceN	-0.69649	0.37785	-1.843	0.06529 .
Interval4-6:DistanceN	0.40943	0.50262	0.815	0.41531
Interval6-8:DistanceN	-0.04256	0.56063	-0.076	0.93949
Interval8-10:DistanceN	-0.55339	0.43190	-1.281	0.20009

---  
Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for poisson family taken to be 1)

Null deviance: 6.1619e+01 on 9 degrees of freedom  
Residual deviance: -4.4409e-16 on 0 degrees of freedom  
AIC: 66.892

Number of Fisher Scoring iterations: 3

```
> M14<-update(M13,~-Interval:Distance)
> anova(M13,M14,test="Chi")
Analysis of Deviance Table
```

```
Model 1: Count ~ Interval * Distance
Model 2: Count ~ Interval + Distance
  Resid. Df Resid. Dev Df Deviance P(>|Chi|)
1      0 -4.441e-16
2      4  6.9681 -4 -6.9681  0.1376
> summary(M14)
```

Call:  
glm(formula = Count ~ Interval + Distance, family = poisson)

Deviance Residuals:  
1 2 3 4 5 6 7 8

```

0.5504 -1.0645 0.8891 0.2279 -0.5822 -0.7361 1.2671 -1.2680
  9    10
-0.3027 0.7099

```

Coefficients:

```

      Estimate Std. Error z value Pr(>|z|)
(Intercept)  3.2851    0.1493 22.003 < 2e-16 ***
Interval2-4  -0.3309    0.1836 -1.802 0.071470 .
Interval4-6  -0.8954    0.2204 -4.063 4.85e-05 ***
Interval6-8  -1.3723    0.2639 -5.200 1.99e-07 ***
Interval8-10 -0.7662    0.2107 -3.637 0.000276 ***
DistanceN    0.5055    0.1452  3.481 0.000500 ***

```

---

Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for poisson family taken to be 1)

Null deviance: 61.619 on 9 degrees of freedom  
Residual deviance: 6.968 on 4 degrees of freedom  
AIC: 65.86

Number of Fisher Scoring iterations: 4

### **WBT:**

```

> M1<-glm(Count~Interval*Distance,poisson)
> summary(M1)

```

Call:

```
glm(formula = Count ~ Interval * Distance, family = poisson)
```

Deviance Residuals:

```
[1] 0 0 0 0 0 0 0 0 0 0
```

Coefficients:

```

      Estimate Std. Error z value Pr(>|z|)
(Intercept)  3.4012    0.1826 18.629 < 2e-16 ***
Interval2-4  -0.6286    0.3096 -2.031 0.04230 *
Interval4-6  -0.7621    0.3237 -2.355 0.01854 *
Interval6-8  -1.0986    0.3651 -3.009 0.00262 **
Interval8-10 -0.6931    0.3162 -2.192 0.02839 *
DistanceN    0.6419    0.2256  2.846 0.00443 **
Interval2-4:DistanceN -0.2364    0.3938 -0.600 0.54828
Interval4-6:DistanceN -0.1029    0.4049 -0.254 0.79949
Interval6-8:DistanceN  0.3878    0.4320  0.898 0.36935
Interval8-10:DistanceN -0.5167    0.4200 -1.230 0.21857

```

---

Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for poisson family taken to be 1)

Null deviance: 5.9125e+01 on 9 degrees of freedom  
Residual deviance: -1.9984e-15 on 0 degrees of freedom  
AIC: 68.855

Number of Fisher Scoring iterations: 3

```
> M2<-update(M1,~-Interval:Distance)
> anova(M1,M2,test="Chi")
Analysis of Deviance Table
```

```
Model 1: Count ~ Interval * Distance
Model 2: Count ~ Interval + Distance
  Resid. Df Resid. Dev Df Deviance P(>|Chi|)
1      0 -1.998e-15
2      4  3.5805 -4 -3.5805  0.4657
> summary(M2)
```

Call:

```
glm(formula = Count ~ Interval + Distance, family = poisson)
```

Deviance Residuals:

1	2	3	4	5	6	7	8
0.19615	-0.30628	-0.05193	0.74194	-0.78077	-0.26378	0.39593	0.06866
9	10						
-1.06209	0.96249						

Coefficients:

	Estimate	Std. Error	z value	Pr(> z )
(Intercept)	3.4490	0.1379	25.019	< 2e-16 ***
Interval2-4	-0.7770	0.1910	-4.067	4.75e-05 ***
Interval4-6	-0.8283	0.1944	-4.260	2.05e-05 ***
Interval6-8	-0.8283	0.1944	-4.260	2.05e-05 ***
Interval8-10	-1.0002	0.2067	-4.838	1.31e-06 ***
DistanceN	0.5680	0.1358	4.184	2.87e-05 ***

---

Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for poisson family taken to be 1)

Null deviance: 59.1250 on 9 degrees of freedom  
Residual deviance: 3.5805 on 4 degrees of freedom

AIC: 64.436

Number of Fisher Scoring iteration