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Comparing the Cost-Effectiveness of Methods for Estimating Population Density for Primates in the Amazon Rainforest Peru

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I hereby declare that this thesis has not been and will not be, submitted in whole or in part to another University for the award of any other degree.

Signature:..

Date:...

Abstract

With increasingly extreme fluctuations in flood levels in the Amazon basin (Malhi et al. 2008, Marengo et al. 2012, Bodmer et al. 2014) the future of its' fauna is becoming more uncertain. It is essential therefore that effective monitoring is in place in order to detect drops in population before irreversible damage is done. In developing countries such as the ones situated in the Amazon basin funding for conservation is very limited (Danielsen et al. 2003), it is therefore vital that cost effective methods of monitoring the wildlife of the Amazon are found. Three surveying techniques for monitoring primates are compared in this thesis to find the most cost effective method of estimating population densities of primate species local to the Amazon basin; these are terrestrial transects, aquatic transects and audio-playback point counts. Data was collected in the Pacaya-Samiria National Reserve using these methods over a period of four months, from January to May 2014.

For both terrestrial and aquatic transects, transect lines were traversed and data was recorded every time an individual or group of the 7 primates species were spotted. Audio-playback point counts were used to record data for red howler monkeys (*Alouatta seniculus*) and brown capuchin monkeys (*Cebus apella*). This was done by mimicking primate vocalisations at a point and recording any resultant responses or sightings of the species under observation. Each survey technique was compared with regards to three qualities; precision, ability to react to change and cost.

On average over all 7 species of primate aquatic transects produced the most precise estimations of population density with a mean estimation CV% (percentage coefficient of variance) of 36.35% in comparison the 47.3% averaged by terrestrial transects. Both methods failed to produce precise results for the two rarest species present, the monk saki monkey (*Pithecia monachus*) and the white fronted capuchin monkey (*Cebus albifrons*). Aquatic transects were also shown to react to sudden change in population levels. For the two species *Alouatta seniculus* and *Cebus apella* aquatic transects once again on average gained the most precise results with a mean estimation CV% value of 20.05% in comparison to the 31.08% of terrestrial transects and 36.35% for audio-playback point counts. The estimates created using audio-playback point counts used considerably less time and resources than the other two methods for single species and was also shown to be the quickest to react to immediate changes in population densities. Thus it was concluded that audio-playback point counts can produce relatively precise estimates that react to population changes at low cost. However only one species can be observed at a time using audio-playback point counts; when observing multiple species at one time it was concluded that aquatic transects are by far the cheapest survey technique and the method that produces precise estimates more consistently.

I would therefore recommend for a monitoring effort of several primate species at one given time in the Amazon basin, that aquatic transects be used as it is the most cost-effective overall. However if a single species is a monitoring target, perhaps to be used as an indicator species or because the primate is of most concern, then audio-playback point counts be used as it is possible to gain relatively precise results at a minimal cost. I would also like to suggest that the use of audio-playback point counts be tested on rarer primate species in future as neither terrestrial transects nor aquatic transects could produce a useful estimate in a combined effort of 104 half days. If audio-playback point counts could be used to get good estimates for rare primate species then monitoring strategies could be developed combining the use of audio-playback point counts and aquatic transects to gain precise density estimates for all primate species in an area whilst keeping costs low. A generic decision tree is presented at the end of this thesis as a guideline to cost-effective primate monitoring for any seasonally flooding rainforest study site.

Contents

List of Tables

List of Figures

1   Introduction

1.1   Background Information

The Amazon basin is going through dramatic climate changes that will impact the largest rainforest on Earth. Each year the Amazon River goes through seasonal changes between the flooding period from December to June and the low water period between July to November (Bodmer et al. 2012). In 2009 the Amazon basin was hit by heavy flooding, which resulted in water levels and river discharges with a magnitude and duration that has rarely been observed in several decades (Marengo et al. 2012). Then in 2010 a drought struck again (Marengo et al. 2011), reinforcing the hypothesis that such extremes may become more frequent and intense in future (Cox et al. 2008). Global environmental change has affected the dynamics of the dry and wet seasons, with differences in the amount of flooding in addition to the time periods in which this occurs (Malhi et al. 2008). These changes have been observed in the Pacaya-Samiria national reserve, the largest protected area of rainforest in Peru (May 2013), which endured two extreme flooded seasons in 2011 and 2012 (Bodmer et al. 2014). The changes in seasonal flooding are having a big impact on the wildlife and local people.

Ungulates and other important sources of bush meat are declining in number due to habitat fragmentation caused by flooding in the wet season. The ground dwelling mammals have to seek out floodplain islands or levees when the water is high; this leads to higher competition for food and greater threats from predators as the ungulates are trapped in small areas with nowhere to escape to (Bodmer et al. 2014). Local people rely on bush meat in the high water season as fish are harder to catch, the decline in bush meat has resulted in an increase in fishing both in the dry and wet seasons as local people try to compensate for the lack of other resources (Bodmer et al. 2014). Overall, people who depend on wild protein will substitute wild fish and wild meat for one another, depending on the price and availability of each. This means that a decline in one wild resource tends to drive up unsustainable exploitation of the other (Brashares et al. 2004). This is causing fishing to become unsustainable, meaning that not only are the fish populations on the decline but so too are the predators that rely on the small fish as a food source such as river dolphins and wading birds (Bodmer et al. 2014).

Primate numbers in the Amazon basin have not incurred such a dramatic change in recent years as they inhabit the environment above the physical influences of the changing water level and many of the primate species rely on fruits as their major food, which are still abundant despite the changing climate (Bodmer et al. 2012). However this does not mean primate populations are immune to the effects of climate change, the decrease in food resources for local people raises numerous threats for the primates that belong to the Amazon basin. Firstly primates are hunted frequently throughout Amazonia (Bowler et al. 2014), hunting will only increase as less bush meat and fish become available. This can also lead to the poaching of monkeys in protected areas as situations become more desperate, which is a serious problem as primate numbers are known to plummet with intense hunting (Oates 1996). This is especially true for large primates with low intrinsic rates of population increase (Robinson and Redford 1991) such as woolly monkeys (*Lagothrix sp.*) that, in the Amazon basin, have declined precipitously (Bodmer et al. 1994, Kmpel et al. 2010). The red howler monkey *Alouatta seniculus* are also sensitive to hunting as, not only does it cause direct population loss due to the individuals killed, but it also greatly disrupts the social structure of troops. Disruption to the social structure of groups cause the number of male turnovers and infanticides to increase and the birth rates to decrease (Wiederholt et al. 2010).

Secondly the habitats of these primates are at risk from habitat degradation. "Four main drivers of freshwater ecosystem degradation in the Amazon basin are recognized: deforestation, construction of dams and navigable waterways, pollution, and overharvesting" (Castello et al. 2013). Deforestation has altered at least 697,770 km^2 (10%) of the basin, mostly due to expansion of agriculture and cattle ranching in the southeastern arc of deforestation (Eva et al. 2004). This is why it is important that we can accurately estimate primate numbers in order to monitor them so that action can be taken before any irreversible damage is done through deforestation or hunting.

Accurately determining the population density of a particular species can be difficult, ideally a total count would be taken but taking a complete census is extremely costly in terms of both

resources and time. Other thorough methods such as mark and recapture are very expensive. Conservation research is often funded by charitable organisations meaning that funding is limited, the financial cost of multi-taxa field studies typically exceeds the limited budget of most conservation projects (Margules & Austin 1991; Lawton et al. 1998). This is why it is important to find the most cost-effective technique to estimate population densities for primates local to the Amazon basin, so that we can monitor their numbers whilst keeping costs as small as possible.

Aim

The aim of this project is to use three different surveying techniques to estimate the population densities of primates local to the Amazon basin and to compare the precision and ability to react to change of each method in order to decide which is the most cost-effective technique to estimate population density.

2 Theoretical Foundations

In this project multiple methods of collecting data for estimating primate populations are considered. The effectiveness of each method being analysed in three ways: theoretically by looking at the existing literature; practically by discussing positives and negatives that arose in practice; and statistically by comparing the results gained by each method.

Effectiveness of each method is judged in two ways: by precision and time needed to identify a change in population density. In an ideal world accuracy would also be used to determine effectiveness, however since we do not have a reliable total count for the population size of any of the species of primate present it is not possible to judge which technique produces the most accurate estimates. Precision refers to the ability to replicate tests and produce similar results, i.e. to have a lower variance. The coefficient of variance is therefore used here to evaluate the precision of each method. Power analysis is used in this project to assess each methods' ability to react to change quickly. This is done here by iteratively observing the precision of estimates with increasing sampling effort; if there is a change in population density the method that can produce precise estimates with less sampling effort will be able to reliably detect the change faster.

The methods used in this project are terrestrial transects, aquatic transects and audio-point counts; all of which use distance sampling. Distance sampling is a method of estimating the density D of a population in an area A where it is not possible to reliably count every individual within that area. The idea behind this method is that individuals or groups are less likely to be seen the further away from the transect that they are. So the observations spotted are used to make predictions about the number of individuals missed within the studied area. With collected results a detection function $g(y)$ can be modelled which is the probability of detecting an object, given that it is at a distance y from the line or point (Buckland et al. 2001). This is then used to predict how many individuals we are likely to have missed, a figure that we can then use to estimate the overall density of the species in the study area (Buckland et al. 2001).

To use distance sampling certain assumptions need to be made. Three assumptions are essential for reliable estimation of density from line or point transect sampling, they are given here in order from the most to the least critical (Buckland et al. 2001):

- Objects directly on the line or point are always detected (i.e. they are detected with probability 1, $g(0) = 1$).

- Objects are detected at their initial location, prior to any movement in response to the observer.

- Distances are measured accurately (ungrouped data) or objects are correctly counted in the proper distance interval (grouped data)

3 Literature Review

3.1 Cost-Effective Methods

A lot is written in existing literature about the use of line transects to estimate abundances of primates, yet there is very little published about using point transects to do the same thing. The main reasons for this is that "primates are typically wide-ranging and occur at relatively low densities, requiring a large number of point samples over a wide area and travel between dispersed points, whereas line transects allow you to cover a wider area while recording data simultaneously" (Buckland et al. 2001).

There is, however, an emerging method that uses playback calls coupled with auditory point transect sampling for primates that make clear distinct vocalisations. Dacier et al. (2011) published a study which involved using this method to estimate the population density of Amazonian red titi monkeys (*Callicebus discolor*) and found that it yielded better estimates than traditional line transect surveys. Titi monkeys (genus *Callicebus*) are fairly inconspicuous animals which can make them difficult to spot using a line transect survey. They do however display territorial vocal behaviour, and respond vocally to playbacks performed within their home ranges (Robinson 1981), which explains why using this method proved successful in this scenario. Red titi monkeys are not present in the area of the Amazon where this research took place, however there are primates that are studied with similar characteristics; such as howler monkeys which produce loud calls most mornings, allowing researches to identify the minimum number of groups using sound-based methods (Estrada et al. 2004).

Although there is not a great deal of literature published about using animal vocalisations to estimate density for primates, there are for other taxa such as birds or amphibians. Legare et al. (1999) state that tape playback is often the only efficient technique to survey for secretive birds, however they also go on to recommend caution when making density estimates using tape playback surveys; the study emphasised problems in previous papers with sample areas, as well as variation in bird responses due to factors such as sex or time of season. Strong links have also been shown between errors in data and surrounding ambient noise (Simons 2009), which could cause a problem in the rainforest where noisy fauna is abundant.

Another method is to calculate density by using the size of the home range of a specific group and the degree of overlapping by neighbouring conspecific groups. It is considered to be the most accurate method but it is also the most time consuming (Brugiere & Fluery 2000). Thus it is unlikely to make it a particularly cost-effective method especially when multiple species are being considered. Typically 2-3 months of observation are needed to use this method to estimate primate population densities (e.g. Brugiere et al. 2000, Fashing et al. 2000) which would not make it possible to use such a method for several species in the timescale of this project. In a publication by Fasher et al. (2000) it was deemed necessary to follow multiple groups of one species and analyse their home range sizes to get an accurate estimate of population density, this increases both the amount of researchers needed and the amount of time taken to execute this method effectively. This method has not been considered further in this project as the labour cost to collect data for multiple troops simultaneously for a period of 2-3 months would clearly be much more expensive than conventional methods such as terrestrial transects and thus is not likely to be more cost-effective.

Transect based methods have low operating costs and allow detection of a large number of species, but it is difficult to apply in areas of dense vegetation or where there is too low a density of individuals (Montalvao et al. 2011). There is also the possibility that while traversing the transect line researchers may disturb the animals they are trying to observe, this does not occur with methods where the researcher is stationary such as point transects. Bad paths and obstacles are also an issue with transect lines (Bibby et al. 1992) as they can lead to the observer concentrating on where they are walking rather than on what they are attempting to observe. It can even cause the researcher to travel at varying speeds rather than the recommended 1-2 km/h (Setchell et al. 2003) which can lead to inconsistent data collection. Furthermore, establishing transects consumes considerable time in difficult terrain; it is important that transects are placed in a random fashion (Buckland et al. 2001) which may become difficult in the rainforest landscape especially if water

levels are high at the time of data collection. Randomly placed fixed points are far more time efficient (Nijman & Menken 2005).

Amongst primates, vocalisation studies are becoming more important for conservation management (Eschmann et al. 2008), however to use a playback method we need to be able to rely on the fact that individuals will consistently respond to an audio stimuli. This involves identifying a species that firstly makes clear audible calls and secondly will respond to these calls for either territorial reasons or otherwise. One of the more obvious candidate species of primate local to the study area for this method are the red howler monkeys (*Alouatta seniculus*); howlers engage in long vocal battles during day time when they encounter other troops and solitary individuals at close range (Sekulic 1982). Adult males are challenged by males of neighbouring troops and by solitary males who not only compete for access to females, but may also kill the troop males' offspring (Rudran 1979), which is likely to mean they will respond immediately to any sign of another male such as an audio playback of a foreign red howler vocalisation. However this method may not be quite so effective on less territorial primates or primates that use other methods to ward off competition. Differentiating individuals can be a problem using this method where single individual calling repeatedly may not be distinguishable from a number of individuals calling less often (Sutherland 1996). This suggests that extensive research is required to analyse vocal calls of the species being observed which will take time and resources, however after this has been done once it can be reused for studies of this species in future.

Monitoring and evaluation are important in conservation because "without systematic and transparent approaches to measuring outcomes from conservation strategies, scarce funds available for conservation could be wasted, donors may lose confidence in their investments, policy directives may be misguided, and managers cannot learn from their experiences or benefit from that of others" (Tulloch et al. 2011). "Monitoring is not a stand-alone activity, but rather a part of a larger process of either conservation-oriented science or management" (Nichols & Williams 2006). This is why it is essential that money allocated to monitoring is not wasted and credible results can be produced. With limited funds it is natural to attempt to use the cheapest methods to monitor conservation projects, however if we gain inaccurate results by trying to use shortcuts that significantly affect data then the information gained from the research is likely to be useless if not detrimental.

The notion of cost-effectiveness is therefore key as we need to maximise quality of results at a minimal cost, especially in developing countries where limited internal resources and sporadic international funding destine many data collection efforts to failure (Danielsen et al. 2003). In countries such as this it is important to have monitoring efforts that are able to detect changes in populations effectively, whilst not being so expensive it is unsustainable in the long term (Brushares & Sam, 2005). The effectiveness of a monitoring technique is defined in this project as a method's ability to create estimates that are both precise and can detect populations changes swiftly. Thus for a monitoring technique to be cost-effective it must be possible to gain estimations that possess these two qualities, whilst minimising cost so that resources are not wasted.

3.2   Primate Species

In total there are 12 species of primate local to the Pacaya-Samiria National Reserve where the study site is based, however only 8 of these could be found at the study site; the red howler monkey *Alouatta seniculus*, the night monkey *Aotus nigriceps*, the white capuchin monkey *Cebus albifrons*, the brown capuchin monkey *Cebus apella*, the woolly monkey *Lagothrix lagothricha*, the monk saki monkey *Pithecia monachus*, the saddleback tamarin *Saguinus fuscicollis* and the common squirrel monkey *Saimiri boliviensis*. All of these primates are included in the study apart from the night monkey *Aotus nigriceps*, which is not included due to the fact it is a nocturnal animal and all studies were carried out between 7:00 am and 5:00 pm in the day.

3.2.1   Red Howler Monkey (*Alouatta seniculus*)

Howlers are among the largest of the new world monkeys, with males being substantially larger than females (Peres 1994). *Alouatta seniculus* are a deep reddish brown, they are arboreal and

mainly diurnal forest dwellers (Nowak 1999). Groups range from 2-15 individuals, with 4-7 being most common (Nowak 1999). Most groups contain either 1 or 2 adult males, with one alpha male that has priority access to troop females (Sekulic 1982). Adult males are challenged by males of neighbouring troops and by solitary males who not only compete for access to females, but may also kill the troop males' offspring (Rudran 1979). To ward off foreign males howlers engage in long vocal 'battles' during daytime, when they encounter other troops and solitary individuals at close range (Sekulic 1982). Most troops have little or no area of exclusive use, but they do defend where they happen to be at a given time (Nowak 1999). Howler monkey calls have been described as deep carrying growls comparable to the roar of lions, calls have been observed to be audible 3 km away through the jungle and 5 km away across lakes. The distinct loud calls from red howler monkeys and the severe competition between males of different troops makes this species an ideal candidate for audio-playback point counts, as we can be confident that on production of howler vocalisations we will get a response from any male individuals in the area.

Red howler monkeys are principally vegetarian and probably the most folivorous of New World primates, however their food consumption varies seasonally with mature fruits making up a much larger portion of their diet in the season of peak fruit production (Julliot & Sabatier 1993). In the fruiting season from March to May red howler monkeys are habitat specialists eating mostly fruit, in the season of fruit scarcity that followed the howler monkeys ranged farther into the flooded forest in search of leaves (Palacios & Rodriguez 2001). This seasonal use of habitat will affect the frequency in which red howler monkeys are encountered, as sighting frequency will depend on how much the area surveyed include the specific habitat used by the howler monkeys in that time period.

3.2.2   White Capuchin Monkey (*Cebus albifrons*)

White capuchin monkeys spend around 80% of their foraging time eating plant material and about 20% of their foraging time eating animal materials; the range in which white capuchins travel varies greatly depending on the type and concentration of food, in a day of foraging white capuchins may travel up to 4-5km (Defler 1979). White capuchin monkeys can spend more than half a day foraging and travelling on the ground, "exhibiting a level of terrestriality not reported for other New World primates" (Defler 1979); a fact that may make white capuchins easier to locate on terrestrial transects, but perhaps more difficult on aquatic transects where the forest floor is less visible. White capuchin monkeys travel in multi-male groups generally larger than brown capuchin group sizes by a factor of two or three (Defler 1982), these groups are known to spread out when foraging creating a broad front up to 250m wide (Defler 1979). This may make white capuchins harder to spot on transects as only a portion of the group may be seen before the rest are alerted to the observer's presence. Another factor that will affect how often white capuchin monkeys are spotted is that they are recorded to be the rarest of the primates on the study site (Bodmer et al. 2014).

White capuchin monkeys exhibit agonistic and territorial behaviour towards adjacent groups, long distance interactions between neighbouring white capuchin groups are both frequent and loud (Defler 1979). It is common for groups to answer the slightest sound from other capuchin groups with the high pitched "yah" or "chatter screams" (Defler 1979). These are characteristics that could be taken advantage of by using audio-playback point counts; this survey technique was not attempted on this species however in this thesis due to time constrictions and the rarity of the species.

3.2.3   Brown Capuchin Monkey (*Cebus apella*)

The subspecies of *Cebus apella* local to the Loreto region is called *Cebus apella maranonis*, this subspecies has a hazel brown body and grey hairs surrounding the face. All capuchins are essentially highly arboreal, preferring forest where there is no under bush (Hill 1960). Groups of *Cebus apella* have been recorded to have troop sizes of thirty to forty individuals, but can also be found travelling in pairs or even singly (Husson 1957). Individual troops do not range very widely and keep to fairly regular tracks in their passage through the forest, and the same tracks may be used at differing times, by differing troops. Capuchins seem to prefer main canopy, but frequently descend to the understory or the ground during both travel and feeding (Fleagle 2013). The nature

of vocalisations of *Cebus* monkeys have given rise to the name 'weeper'. The name relates to the persistent wailing note of somewhat flute-like character which is more or less constantly emitted, presumably as a means of keeping the members of a troop in touch with each other (Hill 1960). Garner (1892) made a recording of the ordinary call of a brown *Cebus* and reproduced it before another monkey of the same kind, who immediately understood the sound and replied to it.

3.2.4 Woolly Monkey (*Lagothrix lagotricha*)

Woolly monkeys (*Lagorthrix lagothricha*) have large round heads with dark grey or brown fur, weighing from 3.6kg to 10 kg (Emmons 1990). They are diurnal and arboreal but often come to the ground, where they walk upright on their hind legs using their arms to balance (Nowak 1999). Common woolly monkeys feed on ripe fruits, seeds, palm nuts, a few leaves and some anthropods (Emmons 1990); fruit pulp being a major item in their diet, but there is considerable seasonal variation (Fleagle 2013). The habitat use of woolly monkeys change according to the variations in fruit supply across vegetation types (Stevenson et al. 1994), this means the concentration of woolly monkeys in certain habitats is likely to change along with the seasonal changes in the flooded forest.

They create loud, descending musical trills, barks, screams and other calls (Emmons 1990). I have not found enough evidence here that woolly monkeys would respond to vocal mimicking and for this reason they have not been included in the audio-playback point count research, however this is a potential idea for further study. Woolly monkeys travel in permanent family units of around 3-9 individuals, but numerous family units will often join to create temporary larger groups (Emmons 1990). Male woolly monkeys maintain an intragroup dominance hierarchy through aggressive behaviour (Nowak 1999). The most intensively hunted monkey, its meat is considered better than that of other large species. This species is particularly susceptible to hunting (Fleagle 2013) and is usually the first species to become locally extinct where subsistence hunting is high. Intolerance to disturbance of vegetation and low reproductive rate makes this species vulnerable to local extinction, but geographic range is large (Emmons 1990).

3.2.5 Monk Saki Monkey (*Pithecia monachus*)

The monk saki monkey (*Pithecia monachus* here on referred to as the "saki monkey") has been exterminated in many parts of Peru, it is hunted for its meat and skin, as well as its tail which is used to make dusters (Wolfheim 1983). Although it is locally abundant in some areas, in others it is very rare and generally its populations in the country are vulnerable (Wolfheim 1983). Saki monkeys are characteristically shy and surprisingly agile (Neville et al. 1976), which is likely to make them difficult to spot on transect surveys. Saki monkeys are seed predators and frugivores (preferring soft fruit), being reported to feed mostly in the upper and middle canopy (15-24 m) and travel in rather lower levels (10-19 m) (Rylands 1987). This may make saki monkeys easier to spot using aquatic transects in high water season as this is when trees close to the river banks start to fruit, feeding at the top of the trees closest to the water should make them clearly visible from the canoe. They live in small family units with average group sizes ranging from 2.4 to 6 individuals (Wolfheim 1983), unlike other monogamous primates the family units often feed and travel separately (Rylands 1987) making it even more difficult to collect population density data for this species using traditional transect methods.

3.2.6 Common Squirrel Monkey (*Saimiri boliviensis*)

Common squirrel-monkeys (*Saimiri boliviensis*) are almost entirely arboreal and live in very large associations of up to several hundred individuals (Hill 1960). Although not as small as the saddleback tamarin *Saguinus fuscicollis* squirrel monkeys are still among the smallest anthropoid primates, with an average adult body mass of 811g (Smith & Jungers, 1997). Squirrel monkeys are small yellow to grey monkeys with short fur and a long, thin tail (Fleagle 2013). They are frugivores and insectivores that specialise on large fruit trees throughout the year, they also spend a lot of time foraging for insects whilst travelling between trees (Fleagle 2013). Squirrel monkeys occupy a variety of rainforest habitats but show a preference for riverine and secondary forests,

where they are commonly found in the lower canopy levels (Fleagle 2013). They communicate frequently throughout the day by means of high pitched whistles and chatter; a group is usually heard well before it comes into view (Fleagle 2013).

A study by Winter (1968) classified 26 different common squirrel monkey vocalisations according to physical parameters and examined the relationship between these calls and the social interaction of the group. He found that squirrel monkeys have a number of different communications for different situations, some of which have potential to be exploited using the audio-playback point counts. For example they use a call referred to as a 'location trill', this is used by the monkey when it is settling down in a favourite resting place; mimicking this vocalisation effectively could signal to groups of squirrel monkeys that there is a desired resting area where the researchers are situated. There is another vocalisation called 'isolation peep' which refers to the noise that squirrel monkeys make when either a member is separated from the group or a baby is taken from its mothers back; successfully replicating this call could cause surrounding squirrel monkeys to repeat the call, thus revealing their presence, or even cause a group to come in search of a lost member or infant. The report also showed that squirrel monkeys reacted to alarm calls replicated using a tape recorder. The problem with this finding however is that it was proved using an 'alarm peep' which caused the group to flee to the highest points of the cage, remaining there for at least 5 seconds in a state of complete motor and vocal inactivity. Obviously causing groups to flee and hide is the opposite of what we aim to do using audio-playback point counts, thus it is vital to understand the different calls and to collect the correct recordings of vocalisations before the potential of using this method for common squirrel monkeys can be utilised.

3.2.7 Saddleback Tamarin (*Saguinus fuscicollis*)

Saddleback Tamarins (*Saguinus fuscicollis*) are the smallest primate to be included in this study with a head-body length ranging from 175mm to 279mm and a weight range of 338-436g in adults (Emmons 1990). Saddleback Tamarins are diurnal and arboreal primates, preferring to travel in the middle and lower levels of the forest in groups of 2-12 individuals. Groups consist of one breeding female, one or more adult males and their young. They are usually wary and difficult to see, but often their birdlike twitters and trills will betray their presence nearby or at a distance they can be heard making loud whistles repeated 7-10 times. In this project an attempt was made to replicate these vocalisation using a pre-recorded mp3 file, however the quality of the recording was deemed not of good enough quality to be fairly assessed. An effective method of collecting recordings of saddleback tamarins would need to be found in future before the audio-playback point counts could be tested with this species. They run actively through the vines and lower branches of larger trees, making many quick jumps across gaps (Emmons 1990). Tamarin diet consists of fruit, animal prey and exudates; in the wet season they are primarily frugivores, whereas in the dry season they rely more on nectar (Fleagle 2013). This means the habitat use of tamarins is likely to change across the seasons according to where they can find most food, the extent at which the habitat type in question is contained within the surveyed area will thus affect the frequency we encounter tamarin groups.

4 Methodology

4.1 Study Site

The Pacaya-Samiria National Reserve, situated in northeastern Peru, is one of the largest protected areas in Peru, spanning over two thousand square kilometres of tropical rainforest (Bodmer et al. 2009). The Pacaya-Samiria National Reserve is a unique flooded forest that has one of the greatest diversities of animals and plants found anywhere on Earth (INRENA 2000).
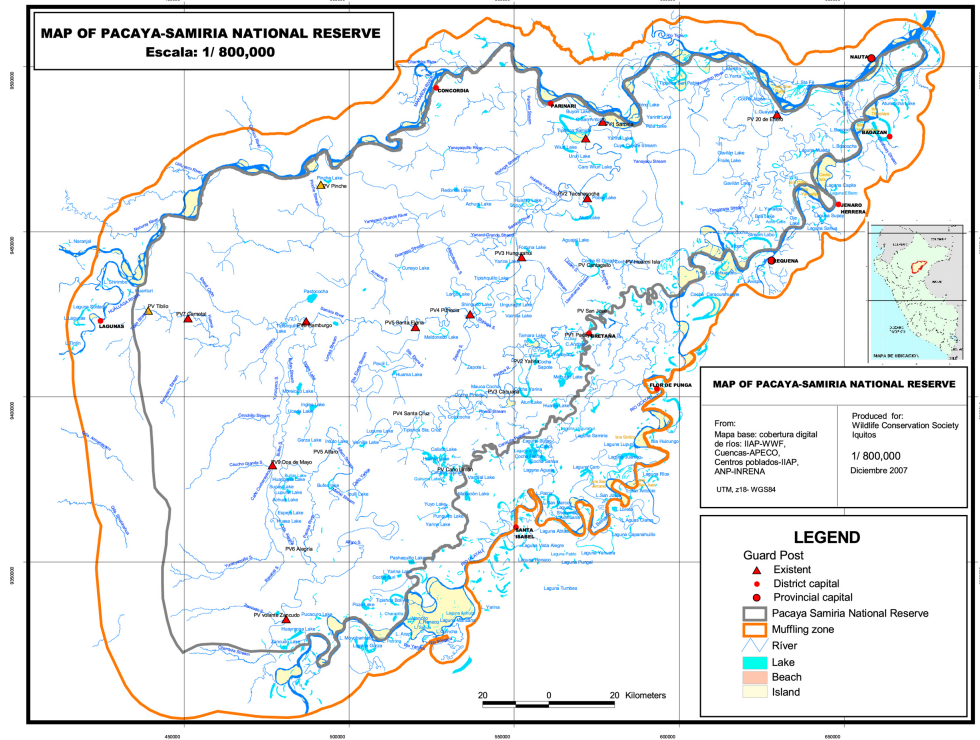
Figure 1: Map of the Pacaya-Samiria National Reserve.

The Pacaya-Samiria National Reserve has approximately ninety-five thousand people living in villages and towns along its boundary (INRENA 2000). Some of the villages lie just inside the reserve, however, there are no human settlements within the core area (Bodmer et al. 2009). Most inhabitants are cocama-cocamilla Indians (Puertas et al. 2000).

4.2 Data Collection

There are four methods of data collection that I will be using in this project; they are line transects, aquatic transects and audio-playback point counts using speakers and human vocal mimicking. The following is a description of how research will be conducted using each method.

4.2.1 Terrestrial transects

When planning transects it is important that transect lines are placed randomly and not subjectively; transects placed subjectively (e.g. 'to avoid dense cover' or 'to be sure the ridge is sampled') are poor practice, and should always be avoided (Buckland et al. 2001). However cutting trails through the rainforest with no regard for the wildlife present may be detrimental, not only because it can cause habitat loss or fragmentation but it can also give poachers easier access to threatened animals. It is therefore important that transects are planned with this in mind and existing paths are somewhat utilized. If transect lines are not positioned randomly, but instead are located on trails, then the burden of proof falls on the researcher to demonstrate that the selected trails provide a representative sample of the population, and that the distribution of animals within the surveyed strip is uniform with respect to distance from the line (Buckland et al. 2010).

Six of the ten transects used started at the centre of the study site radiating out in different directions on both sides of the river, this gave a good representation of the surrounding area crossing several different types of habitat. The remaining transects consisted of one down river, one at the mouth of a channel coming off the river which leads on to a lake, another starting in the lake and the third 5km up river. This meant that all areas around the study site were represented by at least one transect. The trails themselves were made based on the knowledge from local guides of where it is possible to walk, in order to avoid obstacles such as large swamps. This means that the transects were not completely random but still had no bias towards certain types of areas due to the way in which they were plotted, meaning that all different habitats were sufficiently represented to get a reliable representation of the overall study site.

In existing literature line transects often vary anywhere from 1km to 5km (e.g. Plumptre & Reynolds 1994, Haugaasen & Peres 2005, Teelen 2007) but lengths of individual transects will depend on the amount of transects we will use; as a certain distance will need to be traversed in order to get a reliable estimate of population densities. Buckland et al. (2001) suggests that at minimum 10-20 replicate lines should be used to provide a basis for an adequate variance of the encounter rate and a reasonable number of degrees of freedom for constructing confidence intervals. Ten separate line transects were used in this survey, varying from 1.3 km to 3 km in low water season. As water levels increased transects became shorter as sections of trails were cut off due to flooding. Transects were abandoned when it was no longer possible to walk at least 1 km. Terrestrial transect data was collected from the 10th of January 2014 until the 25 of March 2014, with a total of 239 kilometres traversed. Line transects were walked at a pace of approximately 1-2 km per hour in a morning period 07:00-12:00 and an afternoon period 14:00-17:00. Once the end of the transect was reached a pause of at least 30 minutes would be taken to allow movement of animals in the area so that data could be collected on the return journey. Data collected on the return journey is treated as completely separate to the data collected on the initial walk.

The following was recorded for each terrestrial transect: date, transect number, start time, end time, starting gps point, ending gps point, time of resting and distance travelled. Ending gps point would be taken from the point of resting at the end of the transect. Transects would not be traversed in heavy rain due to safety reasons and the greatly increased difficulty of detecting animals. When an individual or group was spotted the following was recorded: species, group size, time at first sighting, perpendicular distance from the transect of the first sighting and the gps point taken at first sighting. A tape measure would be used to measure perpendicular distances where possible, when this was not possible due to obstacles such as swamps or dense forest an estimate of the perpendicular distance was used. To account for these estimations perpendicular distances have been grouped into categories of 5m intervals for data analysis.

4.2.2 Aquatic Transects

Aquatic transects involved slowly paddling in a canoe down a transect line looking for primate species. Five different aquatic transects were used in total, varying from 2 km to 12 km. Aquatic transects were carried out from the 22nd of March until the 30th of April. Ideally all data would have been collected over the same time period, however in order to maximize the quantity of data collected and to get an even amount of kilometres traversed for both terrestrial and aquatic it was necessary to collect all of the non-aquatic data whilst there was still land available to use and the majority of the aquatic data once the land had all flooded. For aquatic transects in the forest it was possible, once the end of the transect was reached, to turn around and collect data on the return journey as the water current was very weak. As in the terrestrial transects a half an hour break was taken at the end of the transect before returning the same way and taking data. This was not possible on the river and in the channel however as the water current was too strong to comfortably paddle against. The speed the transect was taken at would depend on what body of water the transect was on, due to current strength and rate of obstacles. This ranged from 1 km per hour to 4 km per hour, with in the forest being 1-2 km per hour, in the channel 2-3 km per hour and 3-4 km per hour on the river.

The following was recorded for each aquatic transect: date, transect number, start time, end time, starting gps point, ending gps point, time of resting (when necessary) and distance travelled.

Just as in the terrestrial transects, aquatic transects would not be carried out in heavy rain. When an individual or group was spotted the following were recorded: species, group size, time at first sighting, perpendicular distance from the transect of the first sighting and the gps point taken at first sighting. The perpendicular distance of first sighting was always estimated for aquatic transects as it was not possible to get out of the boat and measure the distance to the tree. The perpendicular distance from the first sighting to the transect would be counted as the distance from the first sighted individual to the bank of the river, the bank of the river being the row of trees bordering the river as the actual bank for the most part was flooded and impossible to see.

4.2.3 Audio-Playback Point Counts

A stratified method was used to plot points, using the trails created for terrestrial transects. Every 500m along each transect a point would be plotted at a perpendicular distance of 250m left or right of the transect where possible, at some points it was not possible to walk a total of 250m perpendicular to the transect due to obstacles such as swamps. In these cases the maximum possible distance perpendicular to the transect was walked before plotting the point. In total 43 points were plotted across 10 transects. Playback surveys were not repeated at each point within a 7 day period. This precaution was taken to prevent familiarization to playback vocalizations (Peck et al. 2011) and to minimize any aggravation to the studied primates caused by playback of alarm calls.

There are two techniques of audio-playback that are used and compared in this method. The first is audio-playback using a portable speaker and the second is vocal mimicking. Local people are known to be able to mimic the vocal calls of primates very effectively, which poses a number of possible advantages over using a portable speaker; such as no noise interference or other recording problems. Attempts were made to record vocal calls of each primate species using a shotgun microphone (Sennheiser MKE 400 Shotgun Microphone), however the resultant sound quality was poor so finally pre-recorded mp3 files with primate vocalizations were used. It is necessary to observe vocal production rate for individual primates in order to convert recorded vocal cue density estimates into estimates of animal density (Buckland et al. 2001), in our situation local guides have a very good knowledge of animal calls in the forest. Guides would not only use vocal production rate but types of vocalisations to estimate group size; for example male and female vocalisations or types of vocalisations only made by solitary individuals. Before proceeding with the point counts it was necessary to test approximately how accurately researchers can estimate the distance of an individual by audio detection. This was done using a pilot playback experiment, in which the estimated distance is confirmed by subsequently locating the calling group (Dacier et al. 2011). The accuracy of estimates are likely to decline the further the individual is away from researcher, this therefore needs to be taken into account.

Two types of primate were used for this method; the red howler monkey *Alouatta seniculus* and the brown capuchin monkey *Cebus apella*. Red howler monkey vocalisations were mimicked using a pre-recorded mp3 file, whereas a whistle was used to mimic the vocalisations of brown capuchin monkeys. Each point count lasted for a total of 16 minutes, where the vocalisations were played or mimicked periodically throughout. Once a point count had started any vocalisations of the species under observation within a maximum radius were recorded. A maximum radius of 500m was used for *Alouatta seniculus* and 250m for *Cebus apella*. The difference in distance was due to the audible range of the speakers used for the howler monkeys being approximately double that of the vocal mimicking used for the brown capuchins. Radial distances were estimated, to keep consistency the same guide and researcher was used for each point. If individuals of the species being counted were sighted in this 16 minute period they were assumed to have been attracted by the vocalization being played out and thus recorded. Playback data was recorded from the 11th of February until the 20th of March.

For each point the following was recorded: species under observation, date, point number, start time, end time. It was not possible to carry out this method for red howler monkeys whilst it was raining as electrical equipment was necessary to play recordings, for this reason this method was not used for brown capuchins under rainy conditions to conserve consistency between the data collection of both methods. When a group of the species under observation was spotted or heard the following was recorded: type of detection, number of individuals, distance, time of first sighting

and any other observations for example other primate species seen. Type of detection fell under two categories; sighted or heard. Each instance a group was sighted it was assumed they were heard as well, so when a group has been both sighted and heard it is simply marked as sighted. If a group was sighted an exact count of how many individuals were visible was taken, if a group was only heard an estimation of how many individuals were present was made. Estimations were made based on frequencies of vocalizations and types of call, for example male and female red howler monkeys make different vocalizations, so if both are heard at the same time it is possible to infer that there are at least 2 individuals present. For sighted groups distance was measured with a tape measure, where possible, from the central point to the point the first individual was sighted. When groups were only heard and in cases where it was not possible to reach the point of the first sighted individual distances were estimated. The accuracy of estimation is subject to the expertise of the guide, to conserve consistency the same guide was used for each audio point count.

Audio-Playback Point Counts - Red Howler Monkey   For the red howler monkey *Alouatta seniculus* audio-playback point counts a laptop and speaker were used to periodically play a 47 second long recording of red howler monkeys vocalising. Every 2 minutes during the point survey the recording was played with the speaker at chest height, firstly facing north and then east, south and west. The recording was played in each direction 2 times in an attempt to reach red howler monkeys in all directions around the point and create a circular surveyed area. If a group was heard and not seen the amount of individuals was estimated using the frequency of vocalisations and the type of calls. Male and female red howler monkeys have distinctly different types of calls, this fact helped when estimating group size as the frequency of howler vocalisations for male and female howlers could be counted separately. Thus meaning if multiple males and multiple females can be heard we know that at least 4 individuals are present.

Audio-Playback Point Counts - Brown Capuchin Monkey   For brown capuchin monkeys *Cebus apella* a whistle was used to mimic vocalisations in order to provoke responses. The whistle consisted of a folded piece of metal with 2 holes, one in the top half and one in the bottom, which were used to generate the whistling sound. The whistling sound was repeated periodically throughout the 16 minute survey. When a group was heard but not seen the frequency of vocalisations and the types of call were used to estimate how many individuals were present. Brown capuchins make different calls when they are alone compared to when they are in groups, the guide used has numerous years of experience searching for this species of primate so I am confident he could estimate effectively the quantity of individuals using these differences. When brown capuchin monkeys are in groups of only 1 or 2 individuals their vocalisation is slower and calmer as they are less likely to want to provoke other groups into confrontation because they do not have the numbers to defend themselves. Whereas brown capuchins in groups of numerous individuals (3-8) are likely to sound louder and perhaps more confrontational because they have the confidence of being in a larger group.

4.3   Data Analysis

4.3.1   Distance Sampling

As mentioned in section 2 data is analysed in this project using distance sampling. Distance sampling is used with line transects as a method of estimating the density D of an area A, $A = 2Lw$ where L is the length of the transect and w is the maximum width we observe to each side. The value w may be the perpendicular distance to the furthest group observed or it may be a truncated width where observations further than the value w are not included in analysis. Point counts can be treated as line transects of zero length (Buckland et al. 2001) where instead of a width w to each side of the observer we have a radial width r that creates a circular area, so that $A = \pi r^2$. To estimate the population density within this area A we record how many individuals we can see along a transect or from a point, we then use this data to create a detection function $g(y)$. The detection function $g(y)$ is equal to the likelihood that we will spot individuals or groups at a distance y from the observer; this helps us to estimate how many individuals there were within the area that we failed to spot and thus create an estimation for the overall density.

Detection Function $g(y)$ To create a robust model for our data $g(y)$ uses both a key function and a series expansion as follows:

$$g(y) = key(y)[1 + series(y)] \tag{1}$$

First a key function is selected as a starting point, possibly based on visual inspection of the histogram of distances after truncation of obvious outliers (Buckland et al. 2001). The key functions that are considered in this project are the uniform, half-normal and hazard rate functions. The uniform key function is the simplest of the three with no parameters, whereas the half-normal has one unknown parameter and the hazard-rate has two unknown parameters to be estimated. Secondly the series expansion is selected to adjust the key function, using perhaps one or two more parameters to improve the fit of the model to the distance data (Buckland et al. 2001). The series expansions considered in this project are the cosine series, simple polynomials and hermite polynomials. Table 1 shows all possible combinations of the key function and series expansion that are considered in this project listed along with their respective formulas:

Key Function	Formula	Series Expansion	Formula
Uniform	$1/w$	Cosine	$\sum_{j=1}^{m} a_j cos(j\pi y/w)$
Uniform	$1/w$	Simple Polynomial	$\sum_{j=1}^{m} a_j (y/w)^{2j}$
Half-normal	$exp(-y^2/2s^2)$	Cosine	$\sum_{j=1}^{m} a_j cos(j\pi y/w)$
Half-normal	$exp(-y^2/2s^2)$	Hermite Polynomial	$\sum_{j=1}^{m} a_j H_{2j}(y_s)$
Hazard-rate	$1 - exp(-(y/s)^b)$	Cosine	$\sum_{j=1}^{m} a_j cos(j\pi y/w)$
Hazard-rate	$1 - exp(-(y/s)^b)$	Simple Polynomial	$\sum_{j=1}^{m} a_j (y/w)^{2j}$

Table 1: Formulas of key function and series expansion combinations.

Where s is the standard deviation, $y_s = (y/s)$ and m is the number of parameters estimated. When beginning making the decision of which model to use we firstly look at a histogram of our collected data with frequency of occurrence plotted against perpendicular distance. Different models may be used for each different species depending on which model fits best to each group.

If frequency of sighting only decreases slightly with greater distance then perhaps a uniform key function would be preferred as it is not a complicated model yet it would still describe the shape of the histogram well. If the histogram declines markedly with distance from the line then the half-normal will often represent a good choice of key function (Buckland et al. 2001). The hazard-rate key function better models histograms with a shoulder that starts off almost flat before dropping harshly over distance.

Once we have a visual idea of a good match we can start to use statistical tests to determine the best fit. The χ^2 test can be used to determine whether there is a significant difference between the curve $g(y)$ and the data, if there is a significant difference then it suggests that the modelled curve perhaps isn't the best fit. So if we are using the standard $\chi^2 < 0.05$ to signify there is a significant distance then we would want to see a χ^2 greater than 0.05 to imply there is not a significant difference between the modelled curve and the actual data. However considered to be the best quantitive method for model selection is *Akaike's Information Criterion*, normally abbreviated to *AIC*. *AIC* is defined as:

$$AIC = 2log_e(L) + 2q \tag{2}$$

where $log_e(L)$ is the log-likelihood function evaluated at the maximum likelihood estimates of the model parameters and q is the number of estimated parameters in the model (Buckland et al. 2001). When we add parameters to improve the fit of a model we decrease the degrees of freedom and increase variance. So when we increase parameters in a model to fit the data it is important to analyse whether the change is worth the cost of added complexity. The *AIC* is a value for

this as the first term of the equation $2log_e(L)$ is a measure of how well the model fits the data and the second term $2q$ is a 'penalty' for the addition of parameters (Buckland et al. 2001). So we look to find the $g(y)$ function which gives us a AIC value closest to 0. In almost all cases the key function and series expansion with the smallest AIC value is chosen, however when AIC values are almost equal other quantities may come into consideration such as coefficient of variance.

Truncation   To model each data set correctly it is important to exclude any outliers so that I am not attempting to estimate the population density of an additional area for which we possess little information about. For example, say there is a data set which contains perpendicular sightings of up to a width w but there are one or two sightings that are closer to double this width. If all observations are included we are then attempting to estimate a density with width $2w$ when the majority of our data only reaches up to a perpendicular distance of w. This means that we have very little information of about half of the area included in our observation, making modelling $g(y)$ very difficult and leaving the estimation open to a great deal of variability. However if we truncate the data in this example to w we can get an estimate of much greater accuracy and precision for our new area. Given that the transects have been created at random throughout the study site, we can effectively use this estimate for the rest of the study site. The maximum perpendicular width for each data set will be denoted as w.

In this project species-specific truncation is used so that the larger species of primate have a greater w value as they are more likely to be spotted from a further distance; w values in metres are listed along with their corresponding species in table 2. Although woolly monkeys (*Lagothrix lagothricha*) are a similar size to red howler monkeys (*Alouatta seniculus*), woolly monkeys have been allocated a larger w simply due to the lack of sightings of the primate within the 20m radius of the transect.

Species	w
Alouatta seniculus	20
Cebus albifrons	20
Cebus apella	20
Lagothrix lagothricha	30
Pitechia monachus	20
Saguinus fuscicollis	15
Samiri boliviensis	15

Table 2: Truncation limit w listed in metres for each primate species.

Distance Grouping   Due to the density of forest, swamps and various other obstacles, perpendicular data further away from the transect sometimes had to be estimated. Also trees large enough to contain arboreal mammals would not be located directly on transects but more likely at least 2 or 3 metres to the side, meaning it was very rare to record any individuals or groups at perpendicular distance 0 from the transect. In order to keep with assumptions stated in section 2, model data effectively whilst making certain I reflect the reality of what has been recorded, perpendicular distances have been grouped into intervals of length 5m. This has been done with all transect data sets in order to keep consistency.

With the audio-playback method it was not possible to know accurately how far away individuals or groups were when visual cues were lacking, this can subject data to substantial measurement error due to the difficulty of estimating the distance to a sound source (Simons et al. 2009). Distances therefore had to be estimated which led to the need for radial distance data to be grouped into categories, thus they have been grouped into 50 metre length categories (e.g. 0-50m, 50-100m, 100-150m e.t.c.).

Analysis Software   To analyse data recorded gained from terrestrial transects, aquatic transects and audio point-counts Distance 6.0 was used. Distance 6.0 is a distance sampling program which takes transect or point count data to model $g(y)$ and create a density estimate. Distance 6.0 also automatically does additional statistical tests such as χ^2 and AIC amongst others. To analyse

and compare regression lines for power analysis the program Prism was used, with this program it is possible to plot regression lines and test to see if their gradient or y intercept is significantly different to other regression lines. Prism is also used to plot the semi-log-transformed model of CV% against cost, fitting a line of best fit for each data set in order to extrapolate for what cost incurred are we likely to reach the desired CV% value of 30%.

4.3.2   Result Analysis

As stated previously in this project results are judged with respect to two qualities; precision and ability to react to change quickly. Accuracy is not used to define effectiveness in this project as to judge accuracy reliably a total count or something of similar effect would be necessary; in the circumstances, with the resources present, this was not possible. Precision is measured using percentage coefficient of variance referred to in this thesis as CV%. The coefficient of variation measures the variability of a series of numbers independently of the unit of measurement used for these numbers (Abdi 2010). In the context of this project, although the unit of scale is always consistent, the magnitude of densities are not. For example, let us say that we will see groups of common squirrel monkeys (*Samiria boliviensis*) and red howler monkeys (*Alouatta seniculus*) with equal probability, but with very different average group sizes. Group sizes of common squirrel monkeys usually range from 25 to 75 individuals (Boinski 1999) and red howler monkey groups commonly range from 4 to 7 (Nowak 1999). The resultant densities of these two species are likely to be on approximately a 10:1 scale making their variances incomparable. The coefficient of variance is a statistic that allows comparisons of variability between species as the standard deviations are divided by the mean giving a standardised measure of variability.

We determine the relationship between increasing sampling effort and increasing precision using power analysis. This shows us which methods can gain precise estimates with a small sampling effort, thus suggesting which method is capable of earlier detection of significant change in population densities. Using power analysis we modelled increasing precision by the rate at which CV% decreased with increased sampling effort. In this report power analysis is used on the data sets of red howler monkeys (*Alouatta seniculus*) and brown capuchin monkeys (*Cebus apella*) for all three techniques. With audio-playback point counts 7 half days were spent recording data on howler monkeys and 11 half days were spent on recording data for brown capuchins; this leaves a limited amount of sampling effort intervals to make estimations. For this reason estimates will be made using each method for both species every half day until these limits are reached. There is then further comparison of all 7 species using only terrestrial transects and aquatic transects, where estimates are made every 5 half days until the 40 half day mark (the number of half days spent on aquatic transects). Once estimation sets are made for each survey technique, regression lines are made to fit them. The next step is to check whether there is a significant difference ($P < 0.05$) between each regression line and the line $x = 0$, in order to determine whether the regression lines are actually decreasing significantly over time. After this the regression lines for one given species are all compared together to determine whether there is a significant difference between the rates at which the CV% values are declining for each method. If significant differences are detected then the slopes of the regression lines are compared to find which method provides the greatest improvement in precision for effort. It is also important to compare the y intercepts of each regression line; it may be the case that one method has a fast rate of precision but that the original CV% is so high that it actually takes a long time to gain more precise estimates than the other methods.

4.3.3   Cost Analysis

There are three main interrelated resource requirements for sampling biodiversity: monetary cost, time investment and the availability of adequate technical expertise (Ferraro & Simpson 2002). To define generic values to quantify costs that apply to rainforest study sites across the globe is difficult due to varying costs of labour and petrol; the easiest resource requirement to quantify in a manner that is transferable to other study sites is time. Although the time taken to carry out research may vary in different terrains with differing levels of access to study areas, this variation is insignificant in comparison to the variation in labour and resource price from region to region.

The unit of time to measure sampling effort in this project is one half day, as research was undertaken in two half day periods throughout the day: in the morning period 9:00 - 12:00 and in the afternoon period 14:00 - 17:00.

Adequate technical expertise is more difficult to quantify than time and cost, one fact that can be used in this project is that an equal level of technical expertise is necessary for all methods. Each method needed a minimum of one researcher (with adequate expertise to both collect research and analyze resultant data) and one local guide. There are two papers (Gardner et al. 2008, Kessler et al. 2011) which define cost of labour in very similar ways for two different rainforest study sites; despite using different currencies, both papers use the same ratio of paying "MSc students, PhD students and postdoctoral researchers" and "field assistants and other workers". In order to define labour costs that are generic enough to apply to other study sites I will use the same ratio of 100:20; so per day the cost of a skilled researcher is £100 and the cost of a guide is £20, thus for one unit of sampling effort (one half day) a skilled researcher will cost £50 and a guide will cost £10.

Capital costs such as accommodation and food for field staff vary significantly depending on the particular nature of a given study site, and greatly distort our ability to reveal direct differences in survey costs (Ferraro & Simpson 2002). Travel to and from transects or points can also vary based on the landscape of the study site, yet cost of travel in this investigation was far from equal for all methods so it is worth considering. To reach some terrestrial transects and points, and almost all aquatic transects a motorised canoe was needed. Petrol at the study site at the time this research was undertaken cost approximately £2 per gallon, in the motorised canoes used one gallon of petrol could allow for 15km of travel.

Costs for field equipment is consistent for all three methods with the exception of the speaker system. The speakers used for audio-playback cost £60, recordings were played on a laptop connected to the speakers via an auxiliary cable. However cheaper devices can be used to the same effect, giving the whole system a possible cost of approximately £100. This value is worth mentioning when considering the cost of each survey, but this quantity has not been given too much weight as the price is insignificant when compared to other equipment costs such as the price of the motorised canoe for example.

To evaluate the relationship between survey cost and benefit it is possible to use simple linear regression with log-transformed cost data (Gardner et al. 2008). In this thesis a semi-log-transformed model is used to plot CV% against cost, the semi-log model was applied as it generated good fit to CV% against cost values with the majority of R^2 values at 0.8 or higher. These regression lines are used in this paper to estimate increase in precision with increasing investment costs. In this paper we have used a CV% of 30% as a reference comparison point when comparing costs of each method. Clearly, this is an arbitrary choice and future field work is likely to decide on higher levels of precision to obtain acceptable estimates of population density.

5 Results

5.1 Terrestrial Transect

5.1.1 Histograms

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Figure 2: Histogram for terrestrial transect data sets of all species observed with observation frequency plotted on the y-axis and perpendicular distance in metres from the transect along the x-axis. The histograms are for the following species from left to right, top to bottom: red howler monkey *Alouatta seniculus* (A), white capuchin monkey *Cebus albifrons* (B), brown capuchin monkey *Cebus apella* (C), woolly monkey *Lagothrix lagothricha* (D), monk saki monkey *Pithecia monachus* (E), saddleback tamarin *Saguinus fuscicollis* (F) and the common squirrel monkey *Saimiri boliviensis* (G).

The histogram of red howler monkey data (Figure 2) shows no shoulder as the graph rises towards 10m but then drops dramatically after this point, suggesting a half-normal key function may be appropriate to model this data. The white capuchin monkey data is more abnormal with two small spikes, one at the beginning and one after 10m. This is simply due to lack of sightings of this particular species, a uniform curve is likely to be more effective here as it is an excellent omnibus model which has been shown to perform well in a variety of situations (Buckland et al. 2001). The histogram for brown capuchin monkey data is perhaps more what we would expect to see, with a gradual reduction in sightings over distance. At first visual inspection both uniform and half-normal key functions look like equally functional candidates for this data set, however the use of a uniform key function is likely to be more effective as it uses fewer parameters and therefore describes the data just as well in a less complex manner. The woolly monkey data is unlike the other sets as there are no sightings between 0m and 10m. After this point the graph shows a clear half-normal shape, starting with a higher frequency close to the observer and which reduces towards w.

The monk saki monkey data (Figure 2), like the white capuchin monkey set, is affected by the lack of sightings. However the sightings that we do have show a clear shoulder dropping dramatically towards w. The hazard-rate key function may describe the shoulder and sudden drop in frequency more accurately, but for the added complexity it may be better to use the half-normal model. The saddleback tamarin graph is slightly irregular as it drops considerably between 5m and 10m but then rises again towards 15m. Overall the frequency drops from 0 until w so the half-normal key function could be usable, but the uniform key function is a more versatile and less complex model which may be better suited to this data set. The common squirrel monkey histogram is very similar to the brown capuchin monkey data set with a slightly greater slope towards w, both uniform and half-normal key functions could be applicable here.

5.1.2 Analytical Data

Species	Key function	Series expansion	Density Estimate (per km²)	%CV
Red Howler (*Alouatta seniculus*)	Uniform	Cosine	13	37.2
White Capuchin (*Cebus albifrons*)	Uniform	Cosine	2.7	58.5
Brown Capuchin (*Cebus apella*)	Uniform	Cosine	9.4	24.9
Woolly Monkey (*Lagothrix lagothricha*)	Uniform	Cosine	4	61.7
Saki Monkey (*Pithecia monachus*)	Uniform	Cosine	3.9	80.2
Saddleback Tamarin (*Saguinus fuscicollis*)	Uniform	Simple Polynomial	20.9	24.6
Common Squirrel Monkey (*Saimiri boliviensis*)	Uniform	Cosine	42.7	43.9

Table 3: Terrestrial transect density estimates listed with used key function, series expansion and corresponding CV%.
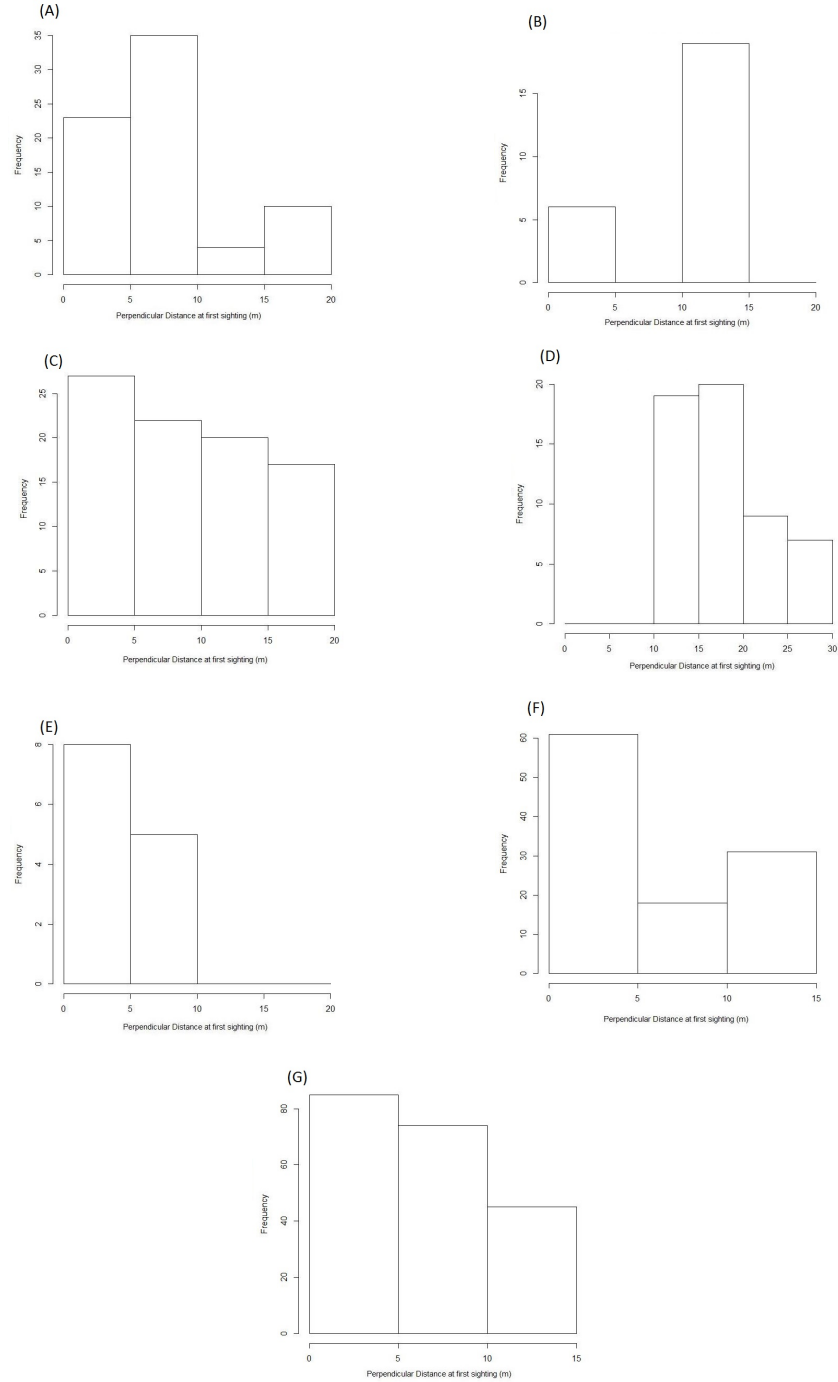
5.2 Aquatic Transect

5.2.1 Histograms
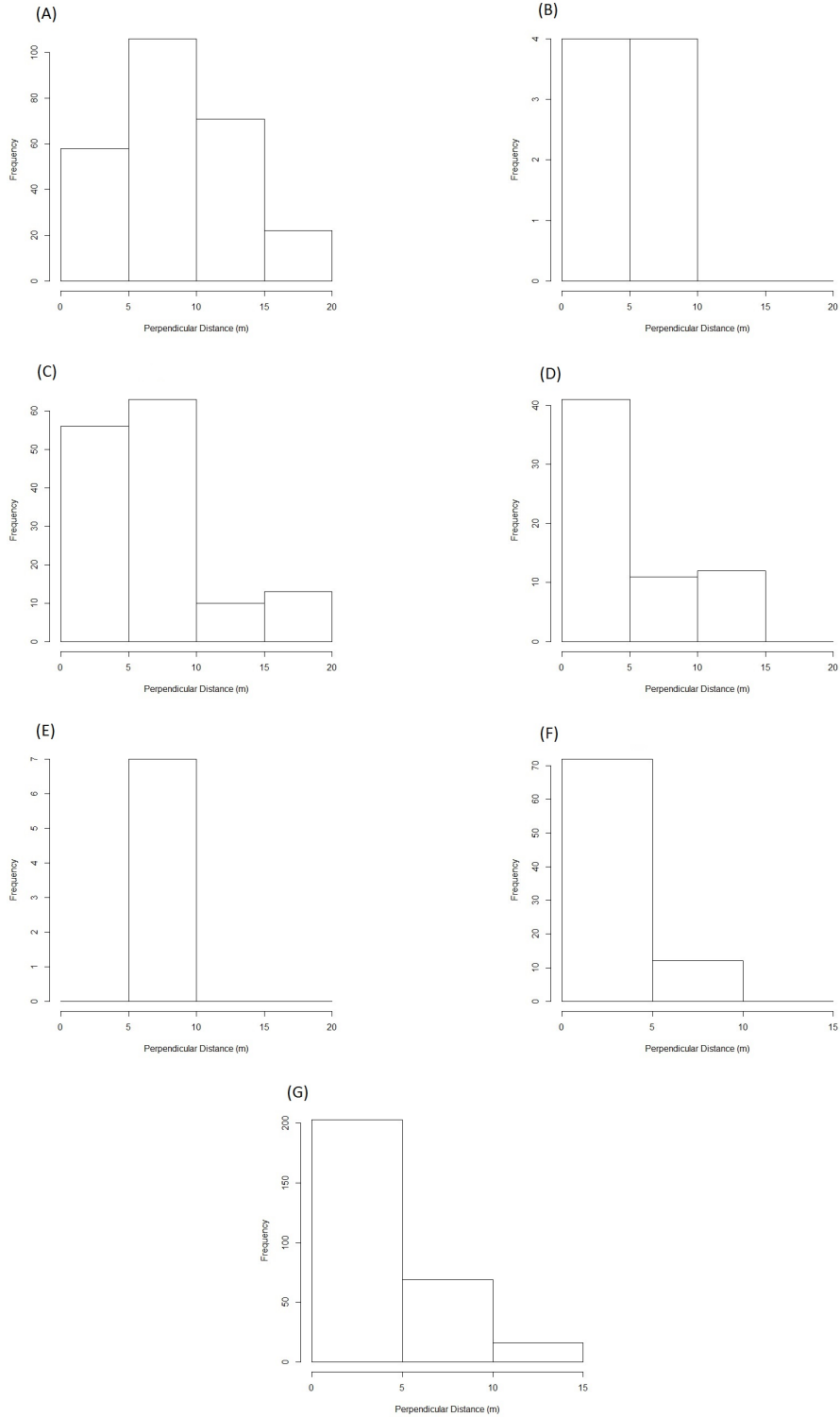
Figure 3: Histogram for aquatic transect data sets of all species observed with observation frequency plotted on the y-axis and perpendicular distance in metres from the transect along the x-axis. The histograms are for the following species from left to right, top to bottom: red howler monkey *Alouatta seniculus* (A), white capuchin monkey *Cebus albifrons* (B), brown capuchin monkey *Cebus apella* (C), woolly monkey *Lagothrix lagothricha* (D), monk saki monkey *Pithecia monachus* (E), saddleback tamarin *Saguinus fuscicollis* (F) and the common squirrel monkey *Saimiri boliviensis* (G).

The histogram of red howler monkey data shows no shoulder, rising sharply from 0m to 10m, with a large frequency of observations between 5m and 15m, the data set only greatly decreases after 15m. From visual inspection a uniform model looks to fit this data set as well as either of the other two key functions without the added complexity making it likely to be the best option. The data set for white capuchin monkey observations is limited due to few sightings, all sightings coming before 10m and dropping to 0 after this point. A hazard-rate key function could be a good option to model this data as the graph shows a solid shoulder that drops sharply, however because it is a data set with an abnormally low amount of sightings it is possible uniform could be the best option.

The graphs for both the brown capuchin monkey and woolly monkey observations have the same shape, starting with a large frequency of observations close to the observer and then dropping greatly. Half-normal are a possible good fit for both data sets, with hazard-rate an option for the woolly monkey data as there is a much sharper drop in observations closer to the observer. The saki monkey data set is similar to the white capuchin monkey as there are very limited observations, as for the white capuchin monkey the uniform key function is probably going to accommodate for the lack of observations better than the other choices. The saddleback tamarin histogram shows a shoulder with a large amount of observations close to the user, decreasing sharply towards the width limit. On first view a hazard-rate model looks to fit this data set well, it is possible a half-normal curve could also work with less complexity. The shape of the squirrel monkey histogram is similar to the saddleback tamarin's, the difference being that its slope is more gradual, this leads to the conclusion that a half-normal key function could be better for modelling this data set.

5.2.2   Analytical Data

Species	Key function	Series expansion	Density Estimate (per km^2)	%CV
Red Howler (*Alouatta seniculus*)	Hazard-rate	Cosine	36.1	16.1
White Capuchin (*Cebus albifrons*)	Uniform	Simple Polynomial	2.3	75.7
Brown Capuchin (*Cebus apella*)	Uniform	Cosine	32.2	23.8
Woolly Monkey (*Lagothrix lagothricha*)	Uniform	Simple Polynomial	14	36.1
Saki Monkey (*Pithecia monachus*)	Uniform	Cosine	0.7	48.7
Saddleback Tamarin *Saguinus fuscicollis*	Uniform	Simple polynomial	29.8	29.2
Common Squirrel Monkey (*Saimiri boliviensis*)	Half-normal	Cosine	117.2	24.6

Table 4: Aquatic transect density estimates listed with used key function, series expansion and corresponding CV%.

5.3 Audio-playback Point Count

5.3.1 Histograms
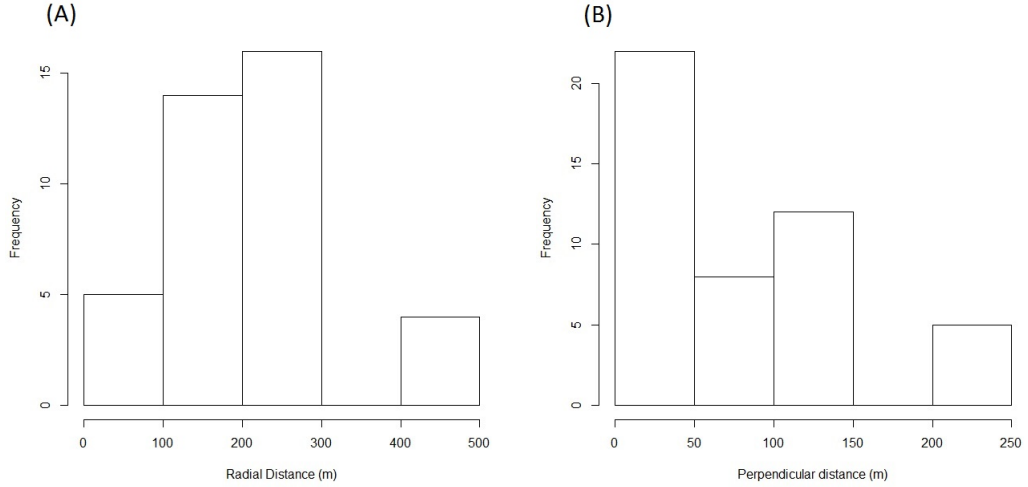
Figure 4: Histogram for audio-playback point counts data sets of *Alouatta seniculus* and *Cebus apella* observation frequency plotted on the y-axis and perpendicular distance in metres from the transect along the x-axis.

The red howler monkey audio-playback point count graph shows a rise in observations as the radial distance increases towards 300m, there is then a dramatic drop as we go towards the maximum distance of 500m. It is possible a uniform key function would be best here to model the spike of the histogram in the middle of the graph. The brown capuchin monkey audio-playback point count histogram has a clear shoulder with a large frequency close to the observer, which decreases as we go further away from the observer. For this reason it is likely that the half-normal key function could be a better fit for this data set.

5.3.2 Analytical Data

Species	Key function	Series expansion	Density Estimate (per km^2)	%CV
Red Howler (*Alouatta seniculus*)	Uniform	Cosine	4.9	25.5
Brown Capuchin (*Cebus apella*)	Half-normal	Cosine	21.3	43

Table 5: Audio-point count playback density estimates listed with key function, series expansion and corresponding CV%.

5.4 Comparison of Results

5.4.1 Density Estimates

The average CV% over all 7 species was 47.3% for terrestrial transects and 36.35% for aquatic transects; both of which included one outlier of over 75%. For the two rarest species included in this project (Table 6), the white capuchin monkey *Cebus albifrons* and the monk saki monkey *Pitechia monachus*, terrestrial and aquatic transects surveys did not produce precise estimations. The smallest CV% for both of these species is 48.77% which is still a large amount of variation, showing that neither surveying method is equipped to deal with rarer primate species. Just concentrating on the average CV% of the two species *Alouatta seniculus* and *Cebus apella* terrestrial transects averaged 31.08%, aquatic transects 20% and audio-playback point counts 34.27%. On the aquatic transects these two species were the most common to be sighted which explains the very low CV%.

Species	Terrestrial Transect		Aquatic Transect		Audio-playback Point Count	
	D km^2	CV%	D km^2	CV%	D km^2	CV%
Red Howler (*Alouatta seniculus*)	13	37.21	36.1	16.18	4.9929	25.51
White Capuchin (*Cebus albifrons*)	2.7	58.46	2.4	75.76	NA	NA
Brown Capuchin (*Cebus apella*)	9.4	24.95	32.2	23.83	21.3	43.03
Woolly Monkey (*Lagorthix lagothricha*)	4	61.7	14	36.09	NA	NA
Saki Monkey (*Pithecia monachus*)	3.9	80.2	0.7	48.77	NA	NA
Saddleback Tamarin (*Saguinus fuscicollis*)	20.9	24.62	29.8	29.22	NA	NA
Common Squirrel Monkey (*Saimiri boliviensis*)	42.7	43.9	117.2	24.63	NA	NA

Table 6: Table showing all final density estimations in individuals per kilometre squared for each species, listed along with corresponding CV% to represent the precision of each estimate.

5.4.2 Power Analysis

Over 7 half day intervals the audio-playback point count method generated an estimation with a CV% value of 25.5%, this is much smaller than the aquatic transects' 39.06% and the terrestrial transects' 94.68% (Table 7). The regression lines of all three methods are significantly different to the line $x = 0$, showing, along with their negative gradients, that the CV% of each survey technique does decline with time over the 7 half days. The regression lines of the audio-playback point count and the aquatic transects were both significantly different to the regression line of the terrestrial transect; both having a much steeper gradient than that of the terrestrial transect showing that for *Alouatta seniculus* terrestrial transects had the slowest rate of change of precision over this time period. The terrestrial transect method also had the highest y intercept, highlighting that it was the least effective method for gaining a precise estimate in a small amount of time. When testing the slopes of the audio-playback point count and aquatic transect regression lines for a significant difference the P value produced was 0.055, showing that there is not quite a significant difference between the two slopes. The y intercepts of both estimations were also not significantly different with a P value of 0.9; this means that, although the audio-point count method did produce a steeper regression line and lower an estimate with lower CV% over the 7 days than the aquatic transects, we cannot say that the rate of precision for audio-playback point counts is a significant improvement on that of the aquatic transects.

Method	Y Intercept	Gradient	P		
			Terrestrial Transect	Aquatic Transect	Audio-Playback Point Count
Terrestrial Transect	118.7	-4.98		0.048	0.014
Aquatic Transect	87.088	-9.57	0.048		0.055
Audio-Playback Point Count	113.43	-18.63	0.014	0.055	

Table 7: Power analysis table for *Alouatta seniculus* data set over 7 half days, showing the y intercept and slope gradient of the regression line created using each survey technique. For each combination of surveying techniques the table shows a P value to signify if there is a significant difference ($P < 0.005$) between the regression lines of both methods.

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The power analysis carried out on the brown capuchin monkey data sets appeared to gain much more even results between the three survey techniques, with a much more competitive set of estimations found using the terrestrial transect method. Once again over the 11 days the audio-playback point count method created the estimation with smallest CV% of 43.04%, however this time the precision of estimations made by terrestrial and aquatic transects are much closer at 51.58% and 53.38% respectively (Table 8). Again the slopes of all three regression lines are significantly different to the line $x = 0$. The slopes of the regression lines fitted for terrestrial transects and aquatic transects are significantly different, where the gradient of the aquatic transect regression line is almost twice as steep. This shows the rate of precision is faster once again for the aquatic transect, however the y intercept for the aquatic transect is considerably higher between the two showing that for a very sudden change in population density the aquatic transect method may not immediately gain a more precise result than terrestrial transects. The regression line slope of the audio-playback point count is not significantly different from either of the other methods; its' y intercept is significantly lower than the y intercept of the aquatic transect regression line but not significantly different to that of the terrestrial transect. This paints a much more even picture of the rates at which each survey method produce precise results and thus detect change.

Method	Y Intercept	Gradient	P		
			Terrestrial Transect	Aquatic Transect	Audio-Playback Point Count
Terrestrial Transect	82.27	-3.64		0.048	0.014
Aquatic Transect	108.36	-7	0.03		0.16
Audio-Playback Point Count	88.48	-5.56	0.15	0.16	

Table 8: Power analysis table for *Cebus apella* data set over 11 half days, showing y intercept and slope gradiant of the regression line created using each survey technique. For each combination of surveying techniques the table shows a P value to signify if there is a significant difference ($P < 0.005$) between the regression lines of both methods.

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For the *Alouatta seniculus* power analysis data set over the 40 half day period both aquatic and terrestrial transects produced regression lines that have a slope significantly different to $x = 0$. These slopes are also significantly different to each other where $P = 0.022$ (Table 9); the gradient of the terrestrial transect regression line is much steeper than that of the aquatic transect. However the y intercept of the terrestrial transect is so much greater that over the 40 half day period the aquatic transect method still produces the estimate with a much smaller CV% value of 16.18% in

comparison to the 33.2% (Table 9) of the terrestrial transect estimate. This means that, despite the steep gradient of the terrestrial transect regression line, it is the aquatic transect method that has the better rate of precision for this species.

For *Cebus albifrons* there is no significant difference between the regression lines as $P = 0.5126$, the y intercepts are also very similar with a value of 82.7 for the terrestrial transect data set and 87.43 for the aquatic transect data set (Table 9). This is due to the fact that neither method could produce a precise estimation for this species, the slopes of both regression lines are gradual with a slope of 0.0116 for terrestrial transects and -0.1956 for aquatic transects. This shows no difference between the rates of precision of both methods.

Once again much closer power analysis sets are produced for *Cebus apella*, where over the 40 half days aquatic and terrestrial transects produce estimates with CV% values of 25.81% and 23.83% respectively (Table 9). The regression lines gradients of both methods are significantly different to $x = 0$, though they are not significantly different to each other producing a P value of 0.34. The y intercepts of both methods are also not significantly different, showing the rate of precision for both survey methods to be even for the brown capuchin monkey.

There is a significant difference in the regression slopes for terrestrial transects and aquatic transects for the *Saguinus fuscicollis* data set with a P value of 0.00818 (Table 9). It is the aquatic transect method that produced the regression line with a steeper slope of -1.429 in comparison to the -0.6331 gradient of the terrestrial transect regression line; however the y intercept for the aquatic transect is 82.82, much greater than that of the terrestrial transect which is 49.65. Due to this fact the regression lines do not actually cross until the 40 half day mark, meaning that for the *Saguinus fuscicollis* species the terrestrial transect method has the ability to react to change faster.

There is no significant difference between the regression lines of the two methods for the *Samiri boliviensis* with a large P value of 0.827; there is also not a great difference between the two y intercepts, 107.93 for the terrestrial transect regression line and 86.355 for the aquatic transect line (Table 9). This shows no difference in either method's ability to react to change quickly.

Species	Terrestrial Transect		Aquatic Transect		P
	Y Interval	Slope	Y Interval	Slope	
Red Howler (*Alouatta seniculus*)	107.49	-11.45	46.72	-4.06	0.022
White Capuchin (*Cebus albifrons*)	82.76	0.0116	87.43	-0.1956	0.5126
Brown Capuchin (*Cebus apella*)	84.01	-8.27	101.35	-12.29	0.034
Saddleback Tamarin (*Saguinus fuscicollis*)	49.65	-0.6331	82.82	-1.429	0.00818
Common Squirrel Monkey (*Saimiri boliviensis*)	107.93	-1.863	86.35	-1.679	0.827

Table 9: Power analysis table for *Alouatta seniculus*, *Cebus albifrons*, *Cebus apella*, *Saguinus fuscicollis* and *Samiri boliviensis* data sets, showing y intercept and slope gradiant of the regression line created using each survey technique. For each combination of surveying techniques the table shows a P value to signify if there is a significant difference ($P < 0.005$) between the regression lines of both methods.

Lagothrix lagothricha* and *Pithecia monachus It was not possible to fit regression lines for the full power analysis data sets for both the woolly monkey and the monk saki monkey, as one method for each species failed to gain density estimations until a sampling effort of 25 half days. This is due to the fact that before this point of sampling effort there were no sightings of the primate, so it was therefore not possible to create a density estimate. For both species, since there are no quantifiable values for one method for the first four points, it is not possible to fit regression lines from 5 until 40 half days.

That said, it is still useful to analyse the results of the attempted power analysis for both of these species. For the woolly monkey data set once a sampling effort of 25 half days was reached terrestrial transects produced its first CV% value of 105.32%, aquatic transects by this point produced a CV% value of 47.64% (Table 10). When the sampling effort of 40 was reached terrestrial transects produced a CV% value of 85.9% in comparison to the 36.07% produced by aquatic transects. This clearly shows that for the woolly monkey aquatic transects produced precise results at a much quicker rate, as terrestrial transects were not able to produce a precise result over the whole 40 half days.

In contrast if we look at the data set for the monk saki monkey, aquatic transects produced its first CV% value of 66.09% at 25 half days, by this point terrestrial transects produced a CV% of 102.17% (Table 11). So, although terrestrial transects produced density estimates for the first 4 sampling effort intervals where aquatic transects did not, these density values are of little use as the CV% values are so high. At the 40 half days point terrestrial transects produced a CV% of 67.12, whereas aquatic transects produced a CV% value of 48.7%. So, despite not creating CV% values for the first 4 sampling effort intervals, aquatic transects managed to produce a much smaller final CV% value at 40 half days. Considering the first monk saki monkey was seen on aquatic transects at the 25 half day point, the CV% values decline quickly in comparison to terrestrial transects, whose CV% values go from 94.82% at 5 half days to 67.12% at 40 half days. Thus, since the estimates created by both methods before the 25 half day point are of little use and the fact that after this point aquatic transects produced much smaller CV% values, I conclude that aquatic transects produce precise density estimates at a faster rate for the monk saki monkey.

Overall aquatic transects produced faster rates of precision for three of the primate species, whereas terrestrial transects only produced a faster rate of precision for one of the primate species; there being no difference between the data sets of the three remaining species. So in conclusion on average over all of the species the aquatic transect method produced the faster rate of precision and thus showed a better ability to react to change quickly.

Method	Sample Effort							
	5	10	15	20	25	30	35	40
Terrestrial Transect	NA	NA	NA	NA	105.32	71.95	73.35	85.9
Aquatic Transect	113.32	83.55	69.69	43.44	47.64	49.99	40.55	36.07

Table 10: CV% of density methods made using aquatic and terrestrial transects for *Lagothrix lagothricha* at 5 half day intervals; sampling effort ranges from 5 to 40 half days. Values marked NA show that at this point it was not possible to gain a CV% for the density estimate using the software package Distance 6.0.

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Method	Sample Effort							
	5	10	15	20	25	30	35	40
Terrestrial Transect	94.82	102.07	104.23	101.54	102.17	70.72	68.59	67.12
Aquatic Transect	NA	NA	NA	NA	66.09	63.7	54.47	48.7

Table 11: CV% of density methods made using aquatic and terrestrial transects for *Pithecia monachus* at 5 half day intervals; sampling effort ranges from 5 to 40 half days. Values marked NA show that at this point it was not possible to gain a CV% for the density estimate using the software package Distance 6.0.

5.4.3 Survey Costs

Terrestrial transects incurred the largest labour cost by a significant margin, with over 30% more time taken than the data collection for aquatic transects (Table 12). Whereas aquatic transects required the longest travelling distance in the motorised canoe, with the distance travelled over double that of the terrestrial transects. Both audio-playback point count survey technique unsurprisingly cost much less in terms of labour and petrol, yet audio-playback point counts incurred the only additional equipment cost of £100 (Table 12); this cost is quite insignificant though in comparison to the labour costs of terrestrial and aquatic transects. Since the cost of labour as defined in this thesis far outweighs petrol costs or costs of additional equipment the terrestrial transect has by far the largest overall cost of £3,861 in comparison to the £2,443 of aquatic transects and the £521 and £762 of the audio-playback point counts for red howler monkeys and brown capuchin monkeys respectively.

Method	Time Taken		Transport		Additional	Total
	Half Days	£	Km	£	Equiptment (£)	Cost (£)
Terrestrial Transect	64	3,840	154	21	0	3,861
Aquatic Transect	40	2,400	320	43	0	2,443
Audio-playback *Alouatta seniculus*	7	420	10	1	100	521
Audio-playback *Cebus apella*	11	660	14	2	100	762

Table 12: The breakdown of costs for each survey method. Costs are split into three categories: time taken to collect data, transport in motorised canoe and costs of additional equiptment. Time taken is split into amount of half days and labour cost in pound sterling. Motorised canoe travel is split into Km traveled and cost of petrol in pound sterling. The total cost of data collection using each method is then listed in the final column.

For the semi-log-transformed models all lines of best fit with R^2 values lower than 0.8 have been rejected (displayed in Table 13 as NA) as the poor fit of these lines make estimates unreliable. For the two species where all three survey techniques were used (the red howler monkey and the brown capuchin monkey) audio-playback point counts in both cases was the cheapest option (Table 13). When considering this it is important, however, to remember that the costs of audio-playback point counts are for the data collection of one species as data cannot be recorded for multiple species simultaneously as with aquatic and terrestrial transects.

For the three primate species where it was possible to create best of fit lines for both terrestrial and aquatic transect data terrestrial transects incurred an average cost of £2,357, whereas aquatic transect estimates on average cost a lower £1,755. The cases where Prism could not produce lines of best fit with $R^2 \geq 0.8$ suggest that for the corresponding data set CV% does not decline with increased cost at the exponential rate expected. By observation we can see in Figure 5 that best fit lines with $R^2 \leq 0.8$ (Table 13) are much flatter, with CV% declining at a much slower rate as cost increases. This suggests that for these data sets a much greater cost is incurred in order to reach a CV% value of 30%. This only occurred once for aquatic transects and not at all for audio-playback point counts, however for terrestrial transects Prism could not produce best fit lines with $R \geq 0.8$ for 4 species. Thus over all 7 species there is likely to be a much greater difference between the average cost incurred to gain precise estimates between terrestrial transects and aquatic transects. Showing aquatic transects to be the cheaper method to use out of the two.

Species	Method	Y Intercept	Slope	R²	Cost for CV% = 30% (£)
Red Howler (*Alouatta seniculus*)	Terrestrial Transects	286.7	-74.3	0.8033	2,850
	Aquatic Transects	137.4	-35.58	0.8905	1,043
	Audio-Playback Point Counts	881.7	-315.2	1	503
White Capuchin (*Cebus albifrons*)	Terrestrial Transects	228.3	-44.42	0.6904	NA
	Aquatic Transects	120.2	-11.88	0.1074	NA
Brown Capuchin (*Cebus apella*)	Terrestrial Transects	224.8	-58.08	0.9046	2,259
	Aquatic Transects	382.4	-109.9	0.8737	1,608
	Audio-Playback Point Counts	301.3	-89.9	1	1,034
Woolly Monkey (*Lagothrix lagothricha*)	Terrestrial Transects	349.1	-80.69	0.6686	NA
	Aquatic Transects	319	-84.47	0.9384	2,638
Saki Monkey (*Pithecia monachus*)	Terrestrial Transects	211	-40.35	0.5508	NA
	Aquatic Transects	351.4	-89.1	0.936	4,047
Common Squirrel Monkey (*Samiri boliviensis*)	Terrestrial Transects	233.4	-54.17	0.4376	NA
	Aquatic Transects	263.1	-70.11	0.9852	2,112
Saddleback Tamarin (*Saguinus fuscicollis*)	Terrestrial Transects	108	-23.69	0.8904	1,961
	Aquatic Transects	227.9	-57.91	0.9251	2,614

Table 13: Table describing best fit lines for semi-log-transformed models of data setsof CV% value p lotted against cost. Values for the Y intercept, slope gradient and R^2 for each curve are listed next to the estimated cost for each method to reach a CV% value of 30% or lower.
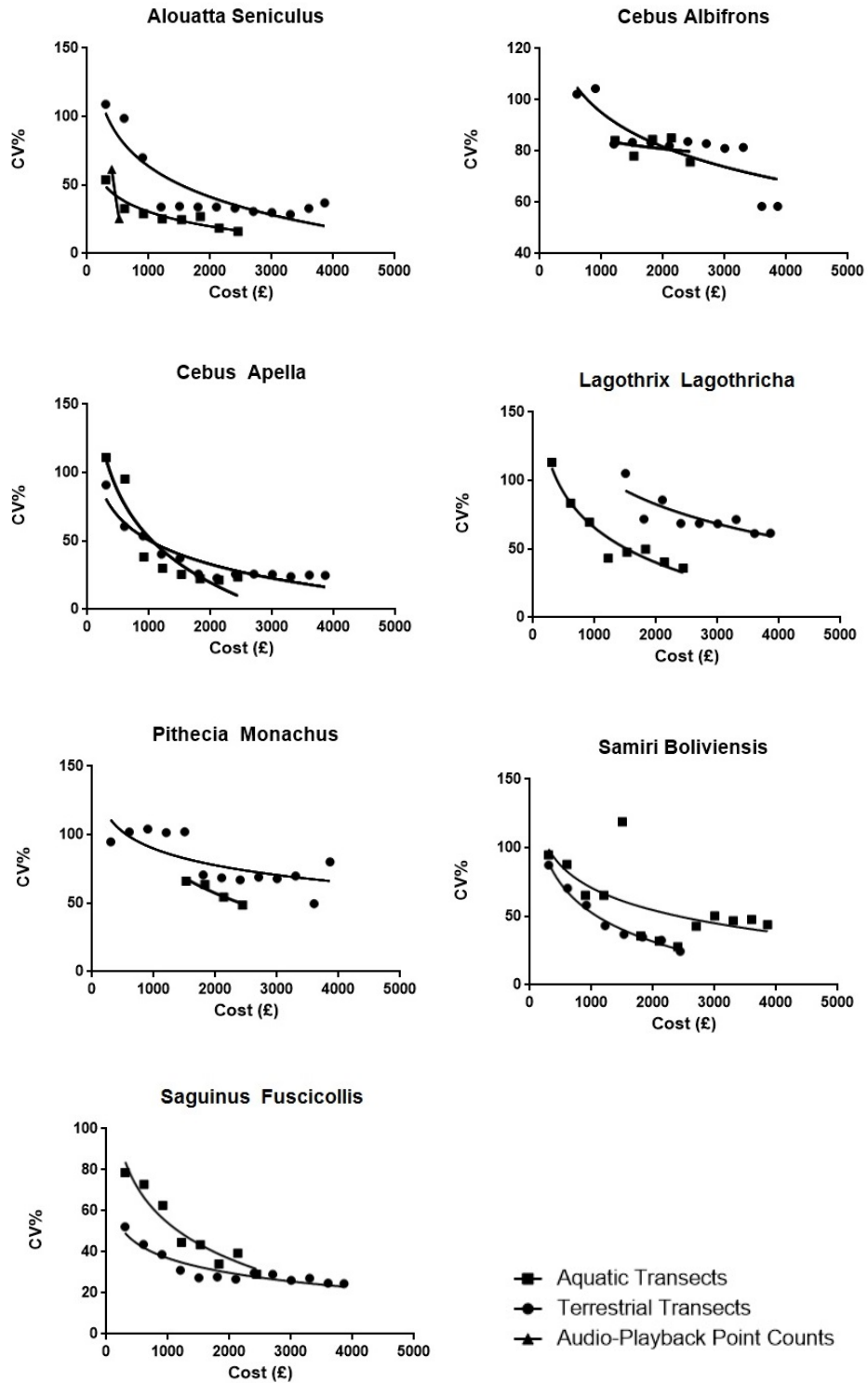
Figure 5: Graphs showing reduction in CV% against cost incurred using all survey techniques for each primate species (audio-playback point counts are only used for the red howler monkey *Alouatta seniculus* and the brown capuchin monkey Cebus apella). Lines of best fit have been fitted to the semi-log transformed models. From left to right the graphs correspond to the red howler monkey, white capuchin monkey, brown capuchin monkey, woolly monkey, monk saki monkey, common squirrel monkey, saddleback tamarin and finally there is the key to show which symbols correspond to which survey techniques.

6 Discussion

6.1 Interpretation of Density Results

Before discussing the precision and ability to react to change of each survey technique, it is important to look at the population density estimates themselves to see what they suggest about the effectiveness of each method. Since there are no reliable estimates of the true values of population densities we cannot comment on how accurate the estimates created in this study are. However there is use in comparing density estimates of each survey technique for one species in an attempt to find any extreme results, if there are large differences in density estimates we can then explore the possible explanations as to why this might be.

For red howler monkeys *Alouatta seniculus* audio-playback point counts produced the smallest estimated population density; there is nothing to suggest that this estimate is not accurate, however it is worth exploring possible reasons as to why this technique may have underestimated the population density for this species. It may be the case that, for the howler monkeys, the situation created was not quite life like enough to consistently provoke responses. Red howler monkeys prefer to spend their time high up in the main canopy and emergent levels (Fleagle 2013), with this in consideration it may be confusing for the red howlers to hear vocalisations coming from the floor. There is also a chance that because the recordings of red howler vocalisations were not from the area, they may also sound foreign to the local population of red howler monkeys. In my experience, despite the intimidating howl they produce, red howler monkeys were a shy species when it came to human presence. On transects it wasn't uncommon for a group of howler monkeys, heard to be howling with full force close to the researching group, to immediately go silent and hide as soon as they became aware of the researchers. It is thus possible that if the recorded vocalisation was not convincing enough then it could have done more to scare the red howler monkeys than to actually encourage them to engage in an exchange of vocalisations.

The estimate made using audio-playback point counts for brown capuchin monkeys *Cebus apella* was not extreme in the sense it was neither the smallest or largest population density estimate for this species; no inference as to the estimates accuracy can be made with this information. Despite not being able to tell whether the estimate is higher or lower than the true value it is still important to mention the following weaknesses of using audio-playback point counts to monitor brown capuchin monkey populations, weaknesses that also apply to using this method for red howler monkeys. The first issue with audio-playback point counts is the over/underestimation of group size. When groups were heard the number of individuals were estimated based on the type of vocalisations made, doing this relies heavily on the knowledge of the guide present. This also assumes that all primates present are vocalising which often may not be the case. Predicting group sizes in this way still leaves a good deal of uncertainty regardless of the expertise present, small group size estimation errors for each group can cause a large estimation error for the total recorded. Another similar problem that would have the same effect is over/underestimating the distance of individuals heard. If the distance to recorded groups was consistently underestimated, for example, then it could be the case that we were using primates from a larger area to make estimations for our circle of radius 250m. This would then cause the population of primates appear to be more densely packed around each point than they actually were, with the reverse problem occurring if distances are consistently overestimated.

For 5 out of the 7 species studied aquatic transects produced the largest population estimates, with most of these values being much larger than the density estimates created with the other survey techniques. Although since we do not know true population density values we cannot draw any strong conclusions about accuracy, the fact that aquatic transects consistently produced a much larger population density estimate implies that this surveying technique may generally overestimate population densities. It is thus important to explore reasons as to why aquatic transects could be overestimating population densities for certain species. If there truly was an overestimation it could possibly be due to the fact that, unlike the other two methods, the aquatic transects did not cover a great number of different habitats. The majority of aquatic transects took place on the river or in the channel as long transects through the forest were not widely available. This was partly due to the fact that the lake, where several known aquatic pathways through the forest exist in the flooded season, was inaccessible as large quantities of floating vegetation blocked any access.

This meant that the majority of habitat observed on aquatic transect surveys were the riverine habitat which is located at the banks of rivers or channels. From my observations it appeared clear that several of the primate species were present in greater number around the river banks in high water season, this is likely to be due to the fruiting of trees exclusive to the riverine habitat in this period. If this was the case, although using aquatic transects may have created accurate estimations for the riverine habitat, it would cause an overestimation for the overall study site as it covers numerous different habitat types. This possibility is feasible for several of the observed species, such as the common squirrel monkey (*Samiri boliviensis*) which shows a preference for the riverine habitat and specialises on large fruit trees (Fleagle 2013).

A paper by Stevenson et al. (1994) recorded habitat use and food consumption of woolly monkeys *Lagothrix lagothricha* in relation to plant phenology in Columbia; woolly monkeys were recorded to eat mostly fruit with the peak of the fruit production of flooded forest trees coming in the middle of the wet season. A similar study on a group of red howler monkeys *Alouatta seniculus* by Palacios and Rodriguez (2001) showed the howler monkeys spend more time eating fruits in the fruiting season from March to May; in the season of fruit scarcity that followed the howler monkeys ranged farther into the flooded forest in search of leaves. In the paper by Stevenson (1994) woolly monkeys were more active in periods where fruit was plentiful, spending the periods of fruit sparcity resting. If this were true amongst the other species of primate that were apparently overestimated in the aquatic transects, it may be the case that in actual fact primates are just easier to spot in the wet season as they are more active thus resulting in researchers being able to spot more individuals. However in the paper by Palacios and Rodriguez (2001) red howler monkeys had the smallest home range in this period, as quantity and diversity of fruiting trees allowed howlers to meet their energy needs while expending less energy moving and searching for food.

In this study for the small period where terrestrial transect and aquatic transect data cross over (between 21/03/2014 and 26/03/2014 with 4 time slots spent on each method) a total of 2 groups were recorded in the forest on terrestrial transects, whereas 18 groups were recorded on aquatic transects in the riverine habitat. With only four time periods spent on each we cannot say that this shows a migration of primates to the riverine habitat, yet it is a slight indication that this could be the case. If this is the case a possible topic for future research could be to study what fruit primates are feeding on in this habitat in the flooded season in order to understand this apparent mini migration to water banks, information which would give us a greater understanding of the threats of habitat degradation in seasonally flooded forests.

It may be the case that aquatic transects actually produce estimations much closer to the true population density estimate and that it is terrestrial transects that consistently underestimate population densities. If this were true it may be due to the view of the forest given by aquatic transects on rivers or channels in comparison to the view given from underneath the canopy on terrestrial transects. The way the water dissects the forest gives a cross sectional view on both sides, this can be advantageous for spotting primates and also for when a group is spotted as the entire group is likely to be more visible with a lack of trees obstructing the view of them. This may lead to an increase in the number of groups spotted and the proportion of individuals within each group that we can actually count. This could be especially true for primates such as the red howler monkey that can be difficult to spot from the forest floor when they are inactive sitting at the top of the canopy with leaves and branches obstructing the researchers view, whereas from the bank edge their bright red coat can be very noticeable contrasting against the colour of the sky.

With regards to precision, over all 7 species of primate the average CV% of estimations made using aquatic transects is 10.95% (Table 5) lower than that of the estimations made using terrestrial transects. This shows aquatic transects to be the more precise on average out of the two methods. This appeared to be due to the large amount of groups sighted in aquatic transects as for each species CV% increased as number of groups spotted increased. To illustrate this point take the data collected using aquatic transects for 3 primate species *Alouatta seniculus*, *Samiria boliviensis* and *Cebus albifrons*; in total groups of *Alouatta seniculus* were spotted 61 times giving an estimation with CV% 16.18%, *Samiria boliviensis* groups were spotted 31 times and, despite 67 more individuals being spotted, gave an estimate with higher CV% 24.6% and lastly *Cebus*

albifrons groups were only spotted on two occasions resulting in an estimate with CV% 75.76%.

With this in mind, consider the three species that in past papers have been suggested to flock to the large fruit trees of the riverine habitat in the high water season: *Alouatta seniculus* (Palacios and Rodriguez 2001), *Lagothrix lagothricha* (Stevenson 1994) and *Samiri boliviensis* (Fleagle 2013). The average CV% for these three species using data collected from terrestrial transects is 47.2%, whereas aquatic transects produced an average CV% of 25.6%. There is a considerable difference between these averages; suggesting that if a certain species concentrates itself in a smaller area at a specific time, then surveying said species whilst they are concentrated in such a way will lead to more precise density results. If these primate species do truly migrate to the riverine habitat in the flooded season then it is possible to use data we collect using aquatic transects over this period as a representation of the primate species over the whole study site. Using this sample from the riverine habitat we may not necessarily get accurate density estimates over the whole site; however if we can gain precise estimations of this sample year after year then we can reliably detect whether there has been a change in the population density of the primates concentrated into this small area, which will indicate whether there has been a change in the overall population density of this species. It would be important to research the habitat use of these primate species over a complete year; because if it is the case that these primates are attracted to the large fruit bearing trees on the river banks during the high water season, then we can take advantage of that fact to reliably monitor whether there are any changes in population levels.

Both aquatic and terrestrial transects failed to gain precise estimations for the two rarest species. The ability to get accurate and precise results for the species with smaller populations is vital as they are likely to be under greater threat; it has not been possible to achieve this in this investigation using terrestrial and aquatic transects. A possible area of further study would be to attempt to use audio-playback point counts to study these rarer species. I have experienced both of these species reacting to guides mimicking their vocalisations, with one case of a white capuchin monkey bizarrely confronting the research group whilst the vocalisation of the red howler monkey was being played; suggesting the use of audio-playback point counts could potentially be a better alternative for these species. The white capuchin monkey has great potential as a test species for determining the effectiveness of audio-playback point counts for rarer primate species as they engage in loud and frequent calling interactions with neighbouring groups, displaying agonistic and territorial behaviours to opposing white capuchin troops (Defler 1979).

For the two species *Alouatta seniculus* and *Cebus apella* aquatic transects once again produced on average the lowest CV% values, with audio-playback point counts and terrestrial transects producing estimations that had relatively even precision. On first glance this suggests that aquatic transects are the most precise survey method out of the three with audio-playback point counts and terrestrial transects being fairly even, however, it is important to take into account far less time was used collecting data for point counts. For all methods a significant relationship was shown between time spent researching and value of CV% (at $P < 0.05$), where CV% declines with time. Approximately 4 times the amount of time was spent on aquatic transects as on each audio-playback point count, which suggests that for the cost (time taken) audio-playback point counts still create a relatively precise estimation. However when considering the cost to precision relationship it is important to remember that aquatic transects produced 7 density estimations, whereas the point counts only produced 1 estimation each.

When power analysis was conducted on all three methods over a short time period terrestrial transects showed the least ability to detect a change in population density. For both *Alouatta seniculus* and *Cebus apella* the regression line slope of aquatic transects is significantly steeper than that of the terrestrial transect; the audio-point count regression lines gradient is also significantly steeper than the regression line of terrestrial transects for the red howler monkey data but not for the brown capuchin. There is less difference between the regression lines of the audio-point counts and the aquatic transects, with no significant difference in slope gradient or y intercepts of regression lines of these methods for both primate species. Over these short time periods audio-playback point counts produced a more precise estimation for both species than aquatic transects; this suggest that audio-playback point counts may be quicker to react to a very sudden impact on population sizes, but since there are no significant difference in regression line gradients or y

intercepts we cannot judge which is likely to react to a change in population faster. Over the 40 half day period terrestrial transects and aquatic transects were a lot more even, but, as with audio-point counts and aquatic transects, aquatic transects did seem to show that it was more equipped to react to a sudden drop in population density.

6.2   Interpretation of Survey Costs

By definition in this project labour costs far outweigh the other costs of petrol and equipment. Despite this it is still important to draw conclusions from the costs of transport and equipment for each method, as these costs are not trivial with regard to overall expenditure in conservation projects. Cost of onsite transport will differ from site to site depending on the necessity of motorised canoes to get to and from surveys and the price of petrol in the region; this makes it difficult to apply conclusions gained here about transport costs to other projects in other areas. This report can then at least provide an example of how transport costs are likely to differ between these surveys. In this project the most petrol was used in aquatic transect surveys, with over double the distance travelled in a motorised canoe than terrestrial transects and approximately 13 times the distance than both audio-playback point counts combined. Less time was spent doing the audio-playback point counts so we would expect less distance to be travelled in the canoe for this survey, however if we look at the ratio of time spent to distance travelled for both surveys the difference in petrol cost becomes very apparent; the time taken to distance travelled for aquatic transects is 1:8, for terrestrial transects this ratio is approximately 1:2.4 and the approximate ratio for audio-playback point counts is 1:1.3. Although something to consider with these ratios is that all point counts were plotted along the transects, apart from the furthest two, which explains why audio-playback point counts have a much smaller distance travelled in canoes and highlights the fact that this cost can vary not only in different sites, but even in different uses of the same site.

That said, any site based along the Amazon river or its contributories will need a motorised canoe to access survey areas that are not reachable on foot. It can be possible to canoe to transects using paddles, however this can be very difficult and inefficient as the speed of the river is great due to the magnitude of water flowing through the Amazon river which discharges an average of 6,300 km^3 of water annually (Mulligan et al. 2013). This is especially true in the flooded season due to the sheer amount of water flowing through the river. This is when aquatic transects are most likely to take place as access to the forest in canoes is possible, the Samiria river was recorded in this project to travel on average at 4-5km/hr when the water was around its highest level. So although the petrol usage is likely to vary greatly in different research sites across the Amazon basin, the situation is likely to be similar where motorised canoes are necessary. For this reason the petrol costs of each survey in this project can be used as a good example of the approximate ratio of how much each is likely to cost across other sites.

Additional equipment costs only apply to audio-playback point counts here, with approximately £100 needing to be spent on speaker system including playback device. This cost is insignificant when compared with labour costs, petrol costs and the cost of staying on site; but it may be the case that with more investment into the equipment used for the audio-playback will result in better estimations of population densities. This could range from buying speakers with greater volume and sound quality, microphones capable of recording primate vocalisations first hand or even equipment for climbing trees to place speakers higher in the canopy. This equipment would no doubt come at a substantial cost and would become comparable with the other costs of research, but for this project the equipment costs are on too small a scale to make an impact to cost-effectiveness in comparison to labour and petrol.

Terrestrial and aquatic transects are simple to compare in terms of the amount of data it is possible to collect for cost spent, we can compare time taken and motorised canoe travel to collect the same distance of survey data. It is a little more difficult to compare the amount of data registered for cost spent of audio-playback point counts with transect surveys as distance is not traversed in point counts so there is not that direct comparable quantity. Attempting to compare areas can be misleading, if we consider the truncated width of our transect to define its area, the space within this area is inspected with a great deal more scrutiny than the area enclosed by the

radial distance around an audio-playback point. It was therefore made difficult to determine how many point counts had to be carried out to collect the same amount of distance data. For this reason the estimated cost of each method to gain precise results has been calculated (Table 13) in order to give us a comparable value for cost between all methods; estimates have been defined as sufficiently precise when a CV% value of 30% or less is reached. This was done by plotting CV% against cost incurred and fitting an exponentially decaying curve to the data set in order to be able to estimate the cost incurred for any given CV%.

For the 3 species where it was possible to create best fit lines with $R^2 \geq 0.8$ terrestrial transects on average cost £2,357 to gain estimations with a CV% of 30% or less, whereas aquatic transects on average only cost £1755. Where Prism could not create best fit lines with sufficiently low R^2 values we can see that the data is much flatter (Table 13 & Figure 5), meaning that CV% declines at a much slower rate with respect to increasing cost. For these data sets a much greater cost is likely to be incurred to reach a CV% value of 30%; this was the case for 4 of the primate species using terrestrial transects and only one of the species for aquatic transects, suggesting that the true gap in average cost of producing precise estimates between both transect methods is much larger. One of the key reasons for this difference is likely to be due to the fact that it is possible to collect the same amount of data using aquatic transects in a much shorter time than when using terrestrial transects. With aquatic transects the same distance of survey was traversed in approximately two thirds of the time. This was mainly due to aquatic transects along the river and channel (which made up a large portion of the aquatic transects) ranging from 2-5km per hour depending on the water current, whereas the walking speed for terrestrial transects would much more consistently stay at 2km per hour. It could be argued that this is likely to mean that more animals were missed on the canoe surveys than whilst walking. Yet I would like to highlight the fact that on terrestrial transects a total of 762 primates were recorded (before truncation) and on aquatic transects 898 primates were recorded, although this says nothing about the proportion of individuals recorded in comparison to the amount missed it is still worth noting that it was possible to record a similar quantity of species despite the difference in speeds. Due to the fact labour costs in this project far outweigh the cost of petrol, the fact much less time was spent collecting data with aquatic transects results in it being a much cheaper survey technique.

For both red howler monkeys (*Alouatta seniculus*) and brown capuchin monkeys (*Cebus apella*) audio-playback point counts produced sufficiently precise estimates at the cheapest cost. That said, it is important to remember that audio-playback point counts can only generate data for one species at a time, whereas with both terrestrial and aquatic transects data about all species present can be recorded. So although far less was spent on collecting audio-playback point count data, only 2 species were monitored as opposed to the 7 species present monitored using the other survey methods. Thus terrestrial and aquatic transects exploit the economies of scale from surveying different taxa that are amenable to the same sampling methodology, reducing cost and consequently improving cost-effectiveness (Gardner et al. 2008); this is not possible with audio-playback point counts as different taxa cannot be simultaneously sampled by the same field workers.

Kessler et al. (2011) looked at biodiversity monitoring cost-effectiveness using survey cost per species; it is not useful here as such to consider the costs of methods per species as for both terrestrial and aquatic transects surveying less species simultaneously does not make the cost of the survey any cheaper. We can however estimate how much it would cost to use the audio-playback point counts for all species (assuming that the point counts are equally as effective for each species). To do this firstly take the average of the costs needed to get precise estimates for the two audio-playback methods (Table 13) which is £768.50, now consider for every additional species new equipment does not need to bought so it will only cost approximately a further £668.50. Since terrestrial transects and aquatic transects can be used to survey numerous species simultaneously at the same cost as a single species, we can use the average cost of each transect method to compare with our estimate cost of using audio-playback point counts to survey all species present.To compare this with the two transect methods we need to calculate this cost for 3 primate species as we have rejected the cost estimates for species where best fit lines have $R^2 \leq 0.8$. So for 3 primate species audio-playback point counts would cost approximately £2,105, which is cheaper than the £2,357 average cost of terrestrial transects but more expensive than the £1,755 average cost of aquatic transects. Thus audio-playback point counts is a much cheaper option when few individual

species are being surveyed, however when numerous species are being surveyed simultaneously as in this situation aquatic transects are the cheapest option.

6.3 Decision Tree

In this section I have developed a generic decision tree which can be used when designing a primate monitoring strategy to be used in any similar seasonally flooding rainforest study site across the globe.
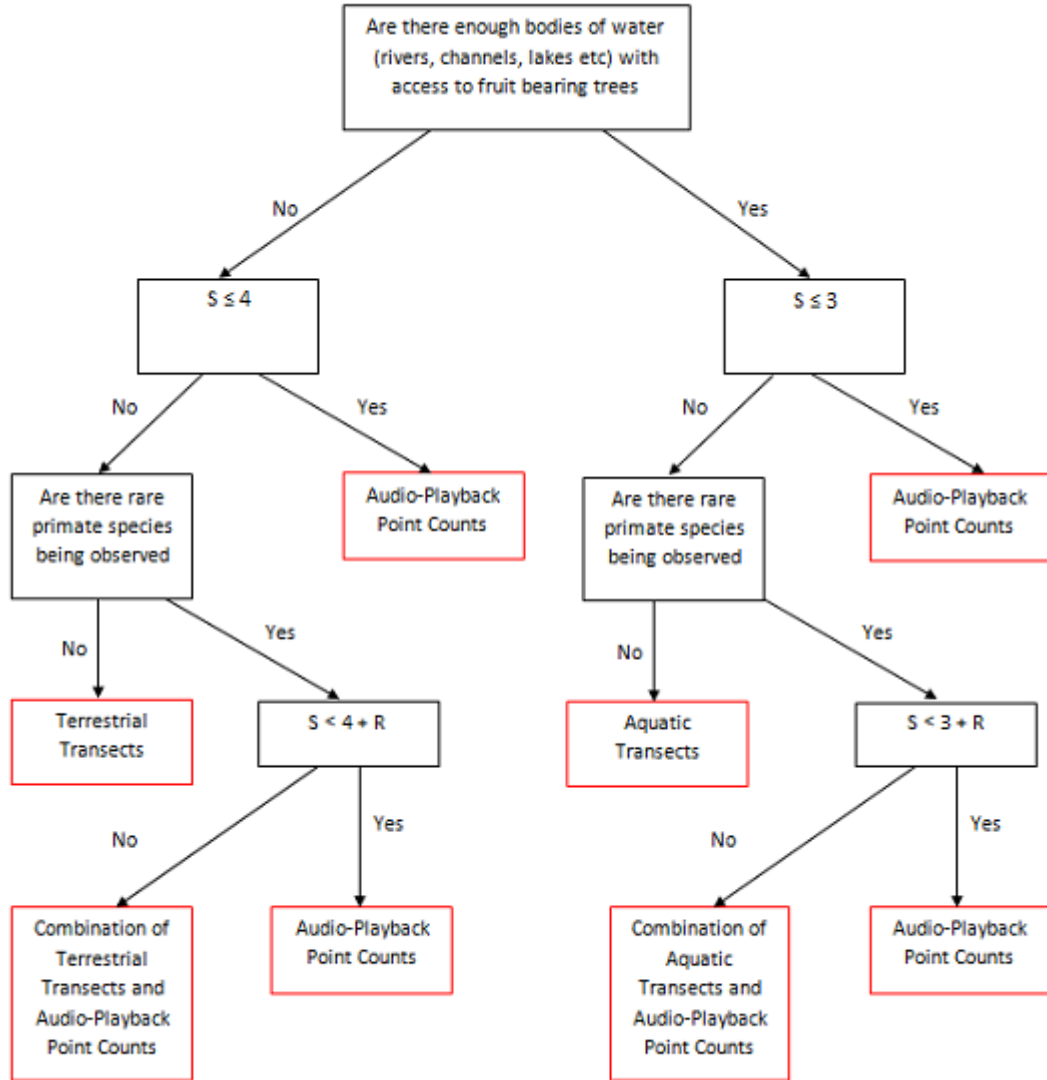
Figure 6: Decision tree to be used when deciding a primate monitoring strategy for any similar seasonally flooding rainforest study site. S is the number of primate species to be studied; R is the number of primate species being studied that are considered to be rare.

This decision tree works under the following assumptions:

- Primates local to the study site are predominantly frugivores.

- Trees that bear fruit in high water season are located next to river banks.

- Audio-playback point counts work equally well for all primates on the study site as it does for the two tested species in this thesis (the red howler monkey and the brown capuchin monkey).

The reason for the first two assumptions is that there is a clear bias towards aquatic transects in the decision tree, yet if primates are not in high concentration near to the river banks then this survey method is not likely to be so effective. Although it is not proven in this thesis that primate species flock to the river bank in the high water season due to fruiting trees, what is

published about the seasonality of the diets of primates included in this project (Stevenson et al. 1994, Palacios and Rodriguez 2001, Fleagle 2013) accompanied by the high density of observed primates close to the river bank in this time period suggest that this could be the case. The third assumption is in place as the use of audio-playback point count method requires the primate species under observation to reliably respond to vocal calls; both brown capuchin monkeys and red howler monkeys have been shown to do this however it is not possible to know if this method will be as effective for other primate species, thus to make a generic guideline it is important to make this assumption so this method can be included.

It is important to note that when creating this decision tree all costs were rounded to the nearest £50 for simplicity. Costs used here are taken from the estimated cost of creating density estimates with a CV% value of 30%. An average cost was taken for audio-playback point counts to try and reflect how much audio-playback will cost to conduct in general for any primate species. All costs used when developing this decision tree are listed in Table 14.

Method	Fixed Costs (£)	Variable Costs (£)	Total Cost (£)
Terrestrial Transect	0	2,350	2,350
Aquatic Transect	0	1,750	1,750
Audio-Playback Point Count	100	700	800

Table 14: Costs used in decision tree. Fixed costs refer to costs that will always stay the same regardless of how long is spent using the survey method (i.e. equipment), variable costs refer to labour and petrol costs which do change depending on how much sampling effort is done with each method. Audio-playback point count costs are an average of the two different versions of the audio-playback point counts used in this thesis (for red howler monkeys and brown capuchin monkeys).

The first question in the decision tree essentially asks if the study site is suitable for aquatic transects; if it is then the right half of the tree is followed which decides which is the preferred method between aquatic transects, audio-playback point counts or a combination of the two, if the left half of the tree is followed then the choice is between terrestrial transects, audio-playback point counts or a combination of the two. The reason for this is that aquatic transects have been shown to be the more effective than terrestrial transects in terms of precision and ability to react to change so long as conditions are as required, so if the study site accommodates aquatic transects well then there is no longer any reason to consider terrestrial transects as terrestrial transects have not been shown to possess any other advantages apart from not requiring bodies of water.

The second level of the decision tree asks whether it is more cost-effective to use a transect method or audio-playback point counts based on the number of primate species being observed. The number of species required to make audio-playback point counts the cheaper method is based on the following equation (3), where P is equal to the total cost of using audio-playback point counts and S is equal to the number of species being observed.

$$P = 100 + 700S \tag{3}$$

Here the constant 100 refers to the initial cost of equipment, the figure 700 refers to the amount of additional cost incurred per primate species. Since terrestrial transects cost £2,350, the researcher needs to be studying 4 different primate species before terrestrial transects become the cheaper option. Aquatic transects cost £1,750, so only 3 species need to be studied before aquatic transects become cheaper.

The next layer of the decision tree asks whether any rare species of primates are being studied; neither terrestrial or aquatic transects could produce precise density results for the rarer species of primate, so at this point if rare species are included audio-playback point counts are used to some extent despite the fact it will result in a greater cost. Although audio-playback point counts have not been proven to be effective at surveying rare primate species, under the assumption that audio-playback point counts work equally well for all primate species on the study site they will perform better than both transect methods for rare primate species. If rare primate species are included, then the next layer asks whether it is more cost-effective to use audio-playback point

counts for all species or to use a combination of audio-playback point counts for rare primate species and the transect method for the remaining primate species. If there are only a few rare primate species it may be the case that it is more cost-effective to use audio-playback for those few species whilst data is collected simultaneously for all non-rare species using a transect method. However if the proportion of rare primate species is large in comparison to the non-rare, then it may be the case that there are not enough species that can be simultaneously observed to make using transects along with audio-playback point counts cost-effective.

To decide whether to use a combination of methods or only audio-playback point counts the following inequalities are used (4 & 5). Where T is equal to the cost of using a combination of terrestrial transects and audio-playback point counts and A is equal to the cost of using a combination of aquatic transects and audio-playback point counts. R is equal to the number of rare primate species being studied. Once again P is equal to the cost of using audio-playback point counts and S is equal to the number of species under observation. Firstly we define P, T and A:

$$P = 100 + 700S$$

$$T = 2350 + 100 + 700R = 2450 + 700R$$

$$A = 1750 + 100 + 700R = 1850 + 700R$$

When using a combination of transects and point counts, point counts are only used for rare species; thus we have the 700 (price of using point count per species) multiplied by the amount of rare species present, this is then added to the fixed costs of using point counts (100) and the total cost of the transect method. To use a combination of transect method and point counts instead of only audio-playback point counts then the combination must be cheaper than just using audio-playback point counts for all species (for example $T \leq P$ to use a combination of terrestrial transects and point counts over just point counts). Thus the relevant inequality must be satisfied (using (4) for the left side of the decision tree and (5) for the right):

$$T = 2450 + 700R \leq P = 100 + 700S \tag{4}$$

$$\rightarrow 2350 + 700R \leq 700S$$

$$\rightarrow 4 + R \leq S$$

Thus for it to be more cost-effective to use a combination of terrestrial transects and audio-playback point counts the number of rare primate species + 7 must be less than or equal to the number of species in total.

$$A = 1850 + 700R \leq P = 100 + 700S \tag{5}$$

$$\rightarrow 1750 + 700R \leq 700S$$

$$\rightarrow 3 + R \leq S$$

For it to be more cost-effective to use a combination of aquatic transects and audio-playback point counts the number of rare primate species + 3 must be less than or equal to the number of species in total.

6.4   Conclusion

The aim at the start of this project was to compare the precision and ability to react to change of each method to decide which is the most cost-effective technique to estimate population density. When comparing density estimates between data collection methods aquatic transects in general produced much larger density estimates, suggesting that aquatic transects may have overestimated population densities for numerous species. Though we cannot use this comparison to judge accuracy, it does help to highlight the possibility that if the aquatic transect method did create

overestimations for several of the species observed then it could be due to the amount of primates along the water banks at this period of the year due to the phenology of trees in the riverine habitat. Numerous publications talk about the seasonality of the diets and habitat use of certain species observed in this project (Stevenson et al. 1994, Palacios and Rodriguez 2001, Fleagle 2013), this combined with the amount of observed individuals of these primate species (i.e. red howler monkeys, woolly monkeys, common squirrel monkeys) along the river edges suggests that these species of primate in the Pacaya-Samiria National Reserve are attracted to the riverine habitat in the flooded season due to the abundance of fruiting trees present. We cannot conclude that this is the reality of the situation however as no data was collected in this investigation regarding primate diet or tree phenology; further study into this would be of great interest to determine if it is true that primates migrate to this habitat towards the peak of the flooded season in April. It may be then possible to work out an approximate proportion of the primate populations situated in the riverine habitat at any given time in the flooded season, the aquatic transect method could then be tweaked to include this information so that it can produce accurate density estimates over all habitat types in the study area. This could lead to vast improvements in the cost-effectiveness of studies in the area, as monitoring would only need to take place in the high water months of April and May instead of a constant research effort throughout the year.

Overall when considering a monitoring program for primate species in a seasonally flooding rainforest it becomes a case of situation as illustrated in section 6.3; if it is necessary to observe multiple species at the same time then I would suggest the use of aquatic transects. Aquatic transects have shown the ability to gain precise results for numerous species simultaneously for a much cheaper cost than both terrestrial transects and audio-playback point counts, the consistency of precise estimations in relation to surveying costs gives a more cost-effective method when several species are being observed at one time. Furthermore aquatic transects have been show to gain precise estimates quickly, suggesting a method that is capable of earlier detection of significant change in population densities. From a conservation point of view it is important to identify trends from year to year; if there truly is a seasonal migration of primates to the riverine habitat in the flooded season then the precise estimations made by using aquatic transects in the period of a month around April has the potential to be just as effective at noticing population trends as an all year round study using terrestrial transects.

If only specific species are being targeted for observation that have similar characteristics to red howler monkeys and brown capuchin monkeys then I would recommend audio-playback point counts as the most cost-effective method. The audio-playback point count method has the obvious disadvantage of only being able to concentrate on one species at a time. For this reason it is not a particularly cost-effective method for monitoring 7 species simultaneously; however if there is a situation where it is only necessary to monitor one or two species, perhaps if one primate species is used as an indicator species or special attention is being given to a certain endangered species, then audio-playback point counts are a very cost-effective way to achieve this. This method has been shown to produce precise results in a very short amount of time and to have the ability to react to changes in population rapidly. Both terrestrial and aquatic transects have been shown to be inept at gaining precise results for the rarer species of primate observed, there is possibly great potential therefore to attempt to use audio-playback point counts to gain better estimations of population densities for these species. If this was to work then conservation strategies could be developed to use a combination of audio-playback point counts for the rarer primates species, whilst transects are used to estimate the densities of the more abundant primate species.

References

[1] Abdi, H. (2010). Coefficient of variation. Encyclopedia of Research Design. SAGE Publications, Inc., Thousand Oaks, CA: p.169-171.

[2] Bibby, C.J., Burgess, N.D., Hill, D.A. (1992). Bird Census Techniques. London: Academic Press.

[3] Bodmer, R.E., Fang, T.G., Moya, I. (1994). Managing wildlife to conserve Amazonian forests: population biology and economic considerations of game hunting. Biological Conservation 67: 29-35.

[4] Bodmer, R.E., Puertas, P., Fang, T.G. (2009). Comanaging wildlife in the Amazon and the salvation of the Pacaya-Samiria national reserve in Peru. Wildlife and society: the science of human dimensions. Island Press, Washington DC, USA: p.104-116.

[5] Bodmer, R. E., Fang, T.G., Puertas, P.E., Antnez, M., Chota, K., Bodmer, W.E. (2014). Cambio climtico y fauna silvestre en la Amazona peruana. Iquitos: p.149.

[6] Boinski, S. (1999). The social organisations of squirrel monkeys. Evolutionary Anthropology. 8: p.101-112.

[7] Bowler, M., Anderson, M., Montes, D., Prez, P., Mayor, P. (2014). Refining reproductive parameters for modelling sustainability and extinction in hunted primate populations in the Amazon. PloS One 9.4: e93625.

[8] Brashares, J.S., Arcese, P., Sam, M.K., Coppolillo, P.B., Sinclair, A.R.E., Balmford, A. (2004). Bushmeat hunting, wildlife declines and fish supply in West Africa. Science 306: p.1180-1183.

[9] Brashares, J.S., Sam, M.K. (2005). How much is enough? Estimating the minimum sampling required for effective monitoring of African reserves. Biodiversity and Conservation 14: p.2709-2722.

[10] Brugiere, D. & Fluery, M-C. (2000). Estimating Primate Densities Using Home Range and Line Transect Methods: A Comparative Test with the Black Colobus Monkey Colobus satanas. Primates, 41(4): p.373-382.

[11] Buckland, S.T., Anderson, D.R., Burnham, K.P. (2001). Introduction to Distance Sampling: Estimating Abundance of Biological Populations, Oxford: Oxford University Press.

[12] Buckland, S.T., Plumptre, A.J., Thomas, L., Rexstad, E.A. (2010). Design and analysis of line transect surveys for primates. Primatol 31: p.833-847.

[13] Castello, L., McGraph, D.G., Hess, L.L., Coe, M.T., Lefebvre, P.A., Petry, P., Macedo, M.N., Reno, V.F., Arantes, C.C. (2013). The vulnerability of Amazon freshwater ecosystems. Conservation Letters 6.4: p.217-229.

[14] Cox, P.M., Harris, P.P., Huntingford, C., Betts, R.A., Collins, M., Jones, C.D., Jupp, T.E., Marengo, J.A., Nobre, C.A. (2008). Increasing risk of Amazonian drought due to decreasing aerosol pollution. Nature 453: p.212-215.

[15] Dacier, A., Luna, A.G., Fernandez-Duque, E., Di Flore, A. (2011). Estimating population density of Amazonian red titi monkeys (Callicebus Discolor) via playback point counts. Biotropica 43 (2): p.135-140.

[16] Danielsen F., Mendoza, M.M., Alviola, P., Balete, D.S., Enghoff, M., Poulsen, M.K., Jensen, A.E., (2003). Biodiversity monitoring in developing countries: what are we trying to achieve? Oryx 37: p.407-409.

[17] Defler, T.R. (1979). On the ecology and behavior of Cebus albifrons in eastern Colombia: I. Ecology. Primates 20 (4): p475-490.

[18] Defler, T.R. (1982). A comparison of intergroup behavior in Cebus albifrons and Cebus apella. Primates 23 (3): p385-392.

[19] Emmons, L. H. (1990). Neotropical Rainforest Mammals: A Field Guide. Chicago and London: The University of Chicago Press.

[20] Eschmann, C., Moore, R., Nekaris, K.A.I. (2008). Calling patterns of Western purple-faced langurs (Mammalia: Primates: Cercopithecidea: Trachypithecus vetulus nestor) in a degraded human landscape in Sri Lanka. Contributions to Zoology 72 (2).

[21] Estrada, A., Luecke, L., Van Belle, S., Barrueta, E., Meda, M. R. (2004). Survey of black howler (Alouatta pigra) and spider (Ateles geoffroyi) monkeys in the Mayan sites of Calakmul and Yaxchilan, Mexico and Tikal, Guatemala. Primates, 45: p.33-39.

[22] Eva, H.D., Belward, A.S., Miranda, E.E., Bellaz, C.M., Gond, V., Huber, O., Jones, S., Sgrenzaroli, M., Fritz, S. (2004). A land cover map of South America. Global Change Biol., 10: p.731-744.

[23] Fashing, P.J. & Cords, M. (2000). Diurnal Primate Densities and Biomass in the Kakamega Forest: An Evaluation of Census Methods and a Comparison with Other Forests. American Journal of Primatology 50: p.139-152.

[24] Fleagle, J.G. (2013). Primate Adaption and Evolution, Third Edition. New York: Stony Brook University.

[25] Ferraro, P.J. & Simpson D.R. (2002). The cost-effectiveness of conservation payments. Land Economics 78(3): p.339-353.

[26] Gardner, T.A. Barlow, J. Araujo, I.S., vila-Pires, T.C., Bonaldo, A.B., Costa, J.E., Peres, C.A. et al. (2008). The cost-effectiveness of biodiversity surveys in tropical forests. Ecology letters 11(2): p.139-150.

[27] Garner, R. L. (1892). The speech of monkeys. New York, C. L. Webster & Co. p.217.

[28] Haugaasen, T. & Peres, C.A. (2005). Primate assemblage structure in amazonian flooded and unooded forests. American Journal of Primatology 67: p.243-258.

[29] Hill, W. C. O. (1960). Primates: Comparitive anatomy and taxonomy, IV Cebidae, part A. Edinburgh: Edinburgh University Press.

[30] Husson, A. M. (1957). Notes on the primates of Suriname. Studies on fauna of Suriname and other Guyanas, Amsterdam 1.2: p.13-40.

[31] INRENA (Instituto Nacional de Recursos Naturales). (2000). Plan maestro para la conservacin de la diversidad biolgica y el desarrollo sostenible de la Reserva Nacional Pacaya-Samiria y su zona de Amortiguamiento. Lima: Instituto Nacional de Recursos Naturales.

[32] Julliot, C. & Sabatier, D. (1993) Diet of the red howler monkey (Alouatta seniculus) in French Guiana. International Journal of Primatology 14 (4): p527-550.

[33] Kesler, M. et al. (2011). Cost effectiveness of plant and animal biodiversity indicators in tropical forest and agroforest habitats. Journal of Applied Ecology, 48(2): p.330-339.

[34] Kümple, N., Milner-Gulland, E., Cowlishaw, G., Rowcliffe, J. (2010). Assessing sustainability at multiple scales in a rotational bushmeat hunting system. Conservation Biology 24: p.861-871.

[35] Lawton, J.H. Bignell, D.E. Bolton, B. Bloemers, G.F. Eggleton, P. Hammond, P.M. et al. (1998). Biodiversity inventories, indicator taxa and effects of habitat modification in tropical forest. Nature 391: p.72-76.

[36] Legare, M.L., Eddleman, W.R., Buckley, P.A., Kelly, C. (1999). The effectiveness of tape playback in estimating black rail density. Journal of wildlife management 63(1): p.116-125.

[37] Malhi, Y., Arago, L.E.O.C., Galbraith, D., Huntingford C., Fisher, R., Zelazowski P., Sitch S., McSweeney C., Meir, P. (2008). Exploring the likelihood and mechanism of a climate-change induced dieback of the Amazon rainforest. Proceedings of the National Academy of Sciences of the United States of America. 106: p.20610-20615.

[38] Marengo, J.A., Tomasella, J., Alves, L.M., Soares, W.R., Rodriguez, D.A. (2011). The drought of 2010 in the context of historical droughts in the Amazon region. Geophys Res Lett.

[39] Marengo, J.A., Tomasella, J., Soares, W.R., Alves, L.M., Nobre, C.A. (2012). Extreme climatic events in the Amazon basin: Climatological and hydrological context of recent floods. Theor Appl Climatol 107: p.73-85.

[40] Margules, C.R. & Austin, M.P. (1991). Nature Conservation: Cost Effective Biological Surveys and Data Analysis. Melbourne: CSIRO.

[41] May, A. (2013). Feeding strategies in sympatric red howler monkeys (Alouatta seniculus), saddleback tamarins (Saguinus fuscicollis) and squirrel monkeys (Saimiri boliviensis), in the Pacaya-Samiria national reserve, Peru. The Plymouth Student Scientist, 2013, 6(2): p.4-19.

[42] Montalvao, J. & Sousa, M.C. (2011). Computational vocalization recognitionan alternative to transect sampling in Tropical Forests.

[43] Mulligan, M., Rubiano, J.R., Burke, S., Van Soesbergen, A. (2013). Water Security in Amazonia. Report for Global Canopy Programme and International Center for Tropical Agriculture as part of the Amazonia Security. Agenda project.

[44] Neville, M., Castro, N., Mármol, Revilla, J. (1976). Censusing Primate Populations in the Reserved Area of the Pacaya and Samiria Rivers, Department Loreto, Peru. Primates, 17 (2): p151-181.

[45] Nichols, J.D., Williams, B.K. (2006). Monitoring for conservation. Trends in Ecology & Evolution 21: p.668-673.

[46] Nijman, V.& Menken, S. B. J. (2005). Assessment of census techniques for estimating density and biomass of gibbons (Primates: Hylobatidae). Raffles Bulletin of Zoology 53: p.201-211.

[47] Nowak, R. M. (1999). Primates of the world. Baltimore: The Johns Hopkins University Press.

[48] Oates, J. (1996). African primates: status survey and conservation action plan. Switzerland, Gland: IUCN.

[49] Palacios, E. & Rodriguez, A. (2001). Ranging pattern and use of space in a group of red howler monkeys (Alouatta seniculus) in a southeastern Colombian rainforest. American Journal of Primatology 55(4): p.233-251.

[50] Peck, M., Thorn, J., Mariscal, A., Baird, A., Tirira, D., Kniveton, D. (2011). Focusing conservation efforts for the critically endangered brown-headed spider monkey (Ateles fusciceps) using remote sensing, modeling, and playback survey methods. International Journal of Primatology 32: p.134-148.

[51] Peres, C. A. (1994). Which are the largest new world monkeys? Journal of Human Evolution 26: p.245-249.

[52] Plumptre, A. J. & Reynolds, V (1994). The effect of selective logging on the primate populations in the Budongo Forest Reserve, Uganda. Journal of Applied Ecology 31 (4): p.631-641.

[53] Puertas, P., Bodmer, R.E., Lpez, J., del Aguila, J., Calle, A. (2000). La importancia de la participacin comunitaria en los planes de manejo de fauna silvestre en el nor oriente del Per. Folia Amaznica 11(1-2): p.159-179.

[54] Robinson, J.G. (1981). Vocal regulation of inter- and intragroup spacing during boundary encounters in the titi monkey, Callicebus moloch. Primates, 22: p.161-172.

[55] Robinson, J. & Redford, K. (1991). Sustainable harvest of neotropical forest mammals. Neotropical wildlife use and conservation p.415-429.

[56] Robinson, J. & Redford, K. (1994). Measuring the sustainability of hunting in tropical forests. Oryx 28 (4): 249-256.

[57] Rylands, A.B. (1987). Primate communities in Amazonian forests: their habitats and food resources. Experientia 43 (3): p265-279.

[58] Rudran, R. (1979). The Demography and Social Mobility of Red Howler (Alouatta seniculus) Population in Venezuela. Vertebrate Ecology in the Northern Neotropics. D.C., Washington: Smithsonian Institution Press.

[59] Sekulic, R. (1982). The Function of Howling in Red Howler Monkeys (Alouatta seniculus). Behaviour 81 (1): p.38-54.

[60] Setchell, J.M. & Curtis, D.J. (2003). A Practical Guide: Field and Laboratory Methods in Primatology.Cambridge: University Press.

[61] Simmons, T.R., Pollock, K.H., Wettroth, J.M., Alldredge, M.W., Pacifici, K., Brewster, J. (2009). Sources of measurement error, misclassification error and bias in auditory avian point count data. Modeling demographic processes in marked populations. Springer US: p.237-254.

[62] Smith, R.J., Jungers, W.L. (1997). Body mass in comparative primatology. Journal of Human Evolution 32: p.523-559.

[63] Sommerville, M.M., Milner-Gulland, E.J., Jones, J.P.G. (2011). The challenge of monitoring biodiversity in payment for environmental service interventions. Biological Conservation 144: p.2832-2841.

[64] Stevenson, P.R., Quioses, M.J., Ahumada, J.A. (1994). Ecological Strategies of Woolly Monkeys (Lagothrix lagotricha) at Tinigua National Park, Colombia. American Journal of Primatology 32: p.123-140.

[65] Sutherland, W.J. (1996). Ecological Census Techniques: a Handbook. Cambridge: University Press. p.270.

[66] Tulloch, A., Possingham, H.P., Wilson, K. (2011). Wise selection of an indicator for monitoring the success of management actions. Biological Conservation 144: p.141-154.

[67] Teelen, S. (2007). Primate abundance along five transect lines at Ngogo, Kibale National Park, Uganda. American Journal of Primatology 69: p.1030-1044.

[68] Wiederholt, R., Fernandez-Duque, E., Diefenbach, D.R., Rudran, R. (2010). Modeling the impacts of hunting on the population dynamics of red howler monkeys (Alouatta seniculus). Ecological Modelling 221(20): p.2482-2490.

[69] Winter, P. (1968). Chapter 9: Social Communication in the Squirrel Monkey. The Squirrel Monkey. Academic Press, London: p.235-252.

[70] Wolfheim, J.H. (1983). Primates of the world: distribution, abundance and conservation. Psychology Press: p320.

Electronic Reference

Bodmer, R., Puertas, P., Antunez, M., Fang, T., Gil, G. (2012) Impacts of climate change on wildlife conservation in the Samiria river basin of the Pacaya-Samiria national reserve, Peru. Available at http://opwall.com/wp-content/uploads/Samiria-2011-Report.pdf (accessed between 15th September 2013 and 15th Spetember 2014).

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Appendix

This appendix contains tables showing results gained using each method. For each species a table is displayed showing estimations gained using each recommended combination (Buckland et al. 2001) of key function and series expansion. In the majority, if not in all, cases the key function and series expansion are chosen by the lowest AIC value unless the method produces other values that are particularly abnormal or undesirable.

Terrestrial Transect Results

Alouatta Seniculus .

Key Function	Series Expansion	Estimated Density (per km^2)	%CV	Chi-p	AIC
Uniform	Cosine	13.435	37.21	0.20517	51.589
Uniform	Simple Polynomial	6.5435	27.36	0.18143	52.270
Half-normal	Cosine	7.7734	31.59	0.20159	51.699
Half-normal	Hermite-polynomial	7.7734	31.59	0.20159	51.699
Hazard-rate	Cosine	7.8131	35.14	0.22206	53.008
Hazard-rate	Simple Polynomial	7.8131	35.14	0.22206	53.008

Cebus Albifrons .

Key Function	Series Expansion	Estimated Density (per km^2)	%CV	Chi-p	AIC
Uniform	Cosine	2.7436	58.46	0.11161	11.090
Uniform	Simple Polynomial	2.7436	58.46	0.11161	11.090
Half-normal	Cosine	7.1989	113.55	0.045703	13.042
Half-normal	Hermite-polynomial	7.1989	113.55	0.045703	13.042
Hazard-rate	Cosine	6.3657	86.47	0.046270	13.223
Hazard-rate	Simple Polynomial	6.3657	86.47	0.046270	13.223

Cebus Apella .

Key Function	Series Expansion	Estimated Density (per km^2)	%CV	Chi-p	AIC
Uniform	Cosine	9.4381	24.95	0.85901	69.315
Uniform	Simple Polynomial	9.4381	24.95	0.85901	69.315
Half-normal	Cosine	12.101	35.88	0.69486	71.267
Half-normal	Hermite-polynomial	12.101	35.88	0.69486	71.267
Hazard-rate	Cosine	10.489	33.31	0.52545	72.967
Hazard-rate	Simple polynomial	10.489	33.31	0.52545	72.967

Lagothrix lagothricha .

Key Function	Series Expansion	Estimated Density (per km^2)	%CV	Chi-p	AIC
Uniform	Cosine	4.04	61.7	0.11877	25.085
Uniform	Simple Polynomial	4.04	61.7	0.11877	25.085
Half-normal	Cosine	3.8073	65.44	0.053480	27.085
Half-normal	Hermite-polynomial	3.8073	65.44	0.053480	27.085
Hazard-rate	Cosine	4.0949	58.52	0.018499	29.042
Hazard-rate	Simple polynomial	4.0949	58.52	0.018499	29.042

Phitecia monachus .

Key Function	Series Expansion	Estimated Density (per km^2)	%CV	Chi-p	AIC
Uniform	Cosine	3.95	80.2	0.48088	8.6041
Uniform	Simple Polynomial	3.9498	80.19	0.99557	6.5077
Half-normal	Cosine	4.3957	84.40	0.95155	6.6521
Half-normal	Hermite Polynomial	4.3957	84.40	0.95155	6.6521
Hazard-rate	Cosine	4.3082	75.90	0.99432	8.4988
Hazard-rate	Simple Polynomial	4.3082	75.90	0.99432	8.4988

Saguinus fuscicollis .

Key Function	Series Expansion	Estimated Density (per km²)	%CV	Chi-p	AIC
Uniform	Cosine	21.618	24.53	0.10000	52.141
Uniform	Simple polynomial	20.909	24.62	0.054879	51.344
Half-normal	Cosine	22.879	28.87	0.093367	52.839
Half-normal	Hermite polynomial	22.879	28.87	0.093367	52.839
Hazard-rate	Cosine	24.138	35.77	-1.0000	53.983
Hazard-rate	Simple polynomial	18.115	26.40	0.028792	54.126

Saimiri boliviensis .

Key Function	Series Expansion	Estimated Density (per km²)	%CV	Chi-p	AIC
Uniform	Cosine	42.722	43.9	0.58388	32.016
Uniform	Simple Polynomial	42.732	43.90	0.82415	31.774
Half-normal	Cosine	43.004	48.12	0.62115	31.964
Half-normal	Hermite Polynomial	43.004	48.12	0.62115	31.964
Hazard-rate	Cosine	40.103	48.72	-1.0000	33.725
Hazard-rate	Simple Polynomial	40.103	48.72	1.0000	33.725

Aquatic Transect Results

Alouatta Seniculus .

Key Function	Series Expansion	Estimated Density (per km²)	%CV	Chi-p	AIC
Uniform	Cosine	38.240	33.39	-1.0000	164.01
Uniform	Simple Polynomial	37.653	22.65	0.011065	162.12
Half-normal	Cosine	42.723	18.02	0.0063033	163.75
Half-normal	Hermite-polynomial	39.677	26.46	0.004941	163.60
Hazard-rate	Cosine	36.103	16.18	0.0137987	161.58
Hazard-rate	Simple Polynomial	36.103	16.18	0.013798	161.58

Cebus Albifrons .

Key Function	Series Expansion	Estimated Density (per km²)	%CV	Chi-p	AIC
Uniform	Cosine	0.87336	68.52	0.57241	5.5452
Uniform	Simple Polynomial	2.3662	75.76	0.90484	4.9905
Half-normal	Cosine	2.5799	87.26	0.78067	5.3473
Half-normal	Hermite-polynomial	2.5799	87.26	0.78067	5.3473
Hazard-rate	Cosine	0.87336	68.52	NA	NA
Hazard-rate	Simple Polynomial	0.87336	68.52	NA	NA

Due to too few observations it was not possible to determine *Chi-p* and *AIC*.

Cebus Apella .

Key Function	Series Expansion	Estimated Density (per km²)	%CV	Chi-p	AIC
Uniform	Cosine	32.210	23.83	0.29574	100.12
Uniform	Simple Polynomial	26.059	23.29	0.14781	101.98
Half-normal	Cosine	33.005	25.59	0.27071	100.27
Half-normal	Hermite-polynomial	33.005	25.59	0.27071	100.27
Hazard-rate	Cosine	30.770	28.04	0.19186	101.25
Hazard-rate	Simple Polynomial	30.770	28.04	0.19186	101.25

Lagothrix lagothricha .

Key Function	Series Expansion	Estimated Density (per km²)	%CV	Chi-p	AIC
Uniform	Cosine	13.873	36.51	0.11036	30.792
Uniform	Simple Polynomial	14.002	36.09	0.081174	30.525
Half-normal	Cosine	15.775	41.23	0.19220	30.643
Half-normal	Hermite-polynomial	15.775	41.23	0.19220	30.643
Hazard-rate	Cosine	26.105	181.81	0.090551	32.362
Hazard-rate	Simple polynomial	26.105	181.81	0.090551	32.362

Phitecia monachus .

Key Function	Series Expansion	Estimated Density (per km²)	%CV	Chi-p	AIC
Uniform	Cosine	0.76419	48.77	0.11161	5.5452
Uniform	Simple Polynomial	0.76419	48.77	0.11161	5.5452
Half-normal	Cosine	1.6099	75.08	0.12547	6.4941
Half-normal	Hermite Polynomial	1.6099	75.08	0.12547	6.4941
Hazard-rate	Cosine	0.76419	48.77	NA	NA
Hazard-rate	Simple Polynomial	0.76419	48.77	NA	NA

Saguinus fuscicollis .

Key Function	Series Expansion	Estimated Density (per km²)	%CV	Chi-p	AIC
Uniform	Cosine	30.555	34.80	-1.0000	19.822
Uniform	Simple polynomial	29.8	29.2	1.0000	15.003
Half-normal	Cosine	18.402	34.77	0.88577	15.043
Half-normal	Hermite polynomial	18.402	34.77	0.88577	15.043
Hazard-rate	Cosine	18.101	30.30	-1.0000	17.003
Hazard-rate	Simple polynomial	18.10130.30	-1.0000	17.003	

Saimiri boliviensis .

Key Function	Series Expansion	Estimated Density (per km²)	%CV	Chi-p	AIC
Uniform	Cosine	103.69	22.41	0.43858	54.944
Uniform	Simple Polynomial	88.790	22.43	0.20871	55.982
Half-normal	Cosine	117.24	24.60	0.55977	54.666
Half-normal	Hermite Polynomial	112.52	25.50	0.55977	54.666
Hazard-rate	Cosine	111.44	36.89	-1.0000	56.320
Hazard-rate	Simple Polynomial	111.44	36.89	-1.0000	56.320

Audio-playback Point Count Results

Alouatta Seniculus .

Key Function	Series Expansion	Estimated Density (per km²)	%CV	Chi-p	AIC
Uniform	Cosine	4.9929	25.51	0.33140	49.528
Uniform	Simple Polynomial	8.6226	29.56	0.069595	50.752
Half-normal	Cosine	6.6146	38.93	0.38526	49.011
Half-normal	Hermite-polynomial	6.6146	38.93	0.38526	49.011
Hazard-rate	Cosine	6.2923	53.55	0.13043	50.935
Hazard-rate	Simple Polynomial	6.2923	53.55	0.13043	50.935

Here the uniform/cosine key function and series expansion is chosen as the *AIC* is less than half a unit greater than the *AIC* of half-normal/cosine and the CV% is much lower.

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Cebus Apella .

Key Function	Series Expansion	Estimated Density (per km²)	%CV	Chi-p	AIC
Uniform	Cosine	20.873	40.80	0.34112	33.287
Uniform	Simple Polynomial	21.248	52.37	0.18348	34.510
Half-normal	Cosine	21.300	43.03	0.29225	32.371
Half-normal	Hermite-polynomial	21.300	43.03	0.29225	32.371
Hazard-rate	Cosine	31.018	76.23	0.35762	33.252
Hazard-rate	Simple Polynomial	31.018	76.23	0.35762	33.252