Using multiple survey methods to detect terrestrial reptiles and mammals: what are the most successful and cost-efficient combinations?

Using Multiple Survey Methods to Detect Terrestrial Reptiles and Mammals: What are the Most Successful and Cost Efficient Combinations?

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Running Title: Cost-effective fauna surveys

Abstract

The selection of survey methods for wildlife surveys is a critical decision that will influence the accuracy and comprehensiveness of the research outcomes. The choice of methods is commonly based on the species of interest, yet is often limited by the project budget. Although several studies have investigated the effectiveness of various survey techniques for detecting terrestrial mammal and reptile species, none have provided a quantitative analysis of the costs associated with different methods. We compared the detection success and cost efficiency of six survey methods for detecting the occurrence of terrestrial mammal and reptile species in urban bushland remnants of Brisbane City, Queensland. We detected a total of 19 target reptile species (8 families) and 9 target mammal species (3 families). Cage traps or Elliott traps coupled with hair funnels were the most cost-effective methods for detecting ground-dwelling mammals, with the success of cage or Elliott traps dependent on species' body sizes. Pit-fall traps and/or direct observations were the most cost effective methods for detecting reptiles, with the effectiveness of each method depending of the species' body-size and behaviour.

Key words: Cage trap, Elliott trap, pit-fall trap, hair funnel, direct observation, scat analysis, Brisbane

Introduction

Managing Australia's terrestrial habitats for mammal and reptile conservation requires a thorough knowledge of the composition and distribution of species within and across the habitats of interest. Wildlife surveys of species occurrence and abundance have long been used to acquire such knowledge. For terrestrial mammal and reptile species, a variety of survey methods have been used by researchers to determine occurrence and abundance. These methods have been specifically designed to target particular species or species' groups (Sutherland 1996a; Menkhorst and Knight 2001), and so vary in their applicability and relative detection success for different taxa. Consequently, the choice of survey method(s) is a critical factor influencing the accuracy and comprehensiveness of survey results.

Several studies have investigated the relative success of different survey methods for detecting mammal and/or reptile species in Australian landscapes including, but not limited to: pit-fall traps with or without drift fences (e.g. Mengak & Guynn 1987; Friend *et al*. 1989; Laurance 1992; Catling *et al*. 1997; Crosswhite *et al*. 1999; Moseby and Read 2001; Ryan *et al*. 2002), Elliott traps (e.g. Laurance 1992; Catling *et al*. 1997; Clemann *et al*. 2005), wire cage traps (e.g. Friend 1978; Laurance 1992; Catling *et al*. 1997), direct observations and/or active searches (e.g. Brown & Nicholls 1993; Catling *et al*. 1997; Crosswhite *et al*. 1999; Ryan *et al*. 2002), hair tubes or funnels (e.g. Catling *et al*. 1997; Lindenmayer *et al*. 1999; Mills *et al*. 2002) and, vocalisations and/or indirect signs such tracks, scats, diggings or scratches (e.g. Friend 1978; Catling *et al*. 1997; Mills *et al*. 2002). Across all of these studies, the common finding is that different survey methods are useful for sampling particular fauna species and no single approach accurately samples all species within a community. Therefore, as advocated by numerous previous researchers, surveys aimed at detecting multiple species must employ a suitable combination a survey methods (e.g. Laurance 1992; Brown and Nicholls 1993; Catling *et al*. 1997; Crosswhite *et al*. 1999; Lindenmayer 1999; Ryan *et al*. 2002; Doan 2003). The selection of these methods should be influenced by the species or species' group of interest, but consideration in the survey design must also be given to the dietary and habitat preferences, behavioural attributes and body size of the target species (Mengak and Guynn 1987; Laurance 1992; Catling *et al*. 1997; Crosswhite *et al*. 1999; Lindenmayer 1999; Mills *et al*. 2002).

In addition to differences in detection success, each wildlife survey method varies in the required degree of effort (person hours) and the cost expended to detect target fauna. Consequently, the choice of survey method is commonly limited by the project financial budget and time frame. It is important, therefore, that the method(s) selected will produce the greatest detection success whilst maintaining low overhead costs. Such information is particularly pertinent for surveys that aim to detect a range of species and species' groups. Although a small number of authors have qualitatively discussed effort associated with various survey techniques (e.g. Catling *et al*. 1997; Crosswhite *et al*. 1999; Mills *et al*. 2002), we could not find any studies that explicitly examined and compared quantitative costs associated with various survey methods.

This paper compares six survey methods for detecting terrestrial reptile and small mammal species in terms of their relative detection success and costs of surveying. Three key questions were posed: (i) What is the relative success of each method for detecting reptiles and mammals? (ii) What is the cost associated with each method? and, (iii) What is the most successful and cost efficient combination of methods? These questions are addressed using results of wildlife surveys conducted within urban remnant habitat fragments of Brisbane City.

Methods

Study area and survey design

The study was conducted within the Brisbane City Council (BCC) Local Government Area (LGA) of southeast Queensland (153º2'S, 27ºE; area 1,220 km^2, population > 1 million) (Figure 1). A total of 59 survey sites were established within lowland, remnant bushland fragments located in the City's southern (Karawatha) and south-eastern (Burbank) suburbs (Figure 1). Brisbane is Australia's fastest growing capital city and has already cleared approximately two-thirds of the pre-European woody remnant vegetation for urban development (Brisbane City Council 2001). This extensive loss and fragmentation of native vegetation has impacted on native wildlife assemblages. Having made significant acquisitions of local forest remnants for conservation, BCC has a strong interest in acquiring sound scientific knowledge that will enhance urban planning, management (both on and off reserves), restoration and, biodiversity conservation decision-making processes. In order to achieve this long-term goal of effectively conserving native wildlife assemblages within remnant habitat fragments, it is essential that we first know the distribution of species across the urban landscape and how this relates to habitat loss, fragmentation and condition.

INSERT <u>FIGURE 1</u> NEAR HERE

Survey design

To reduce variability in vegetation composition, survey sites were located within the Regional Ecosystem (RE) type 12.9-10.4, which is dominated by scribbly gum (*Eucalyptus racemosa*) woodland located on sedimentary rocks and sandy soils (Young & Dillewaard 1999). Each site measured 20 m x 45 m and was surveyed using three parallel transects 10 m apart, orientated perpendicular to the natural slope of the land. Each site was surveyed using a combination of live-trapping and passive detection methods. Terrestrial reptile and small to medium mammal species (< 3 kg) were surveyed over three consecutive nights during fine weather days in spring and summer. Initial surveys of all sites occurred in 2004. Repeat surveys of 51 sites were conducted in 2005; nine sites were not repeat-surveyed due to recent fire or human interference.

Trapping & detection methods

Each site was surveyed using a combination of: 8 wire cage traps, 10 Elliott traps, 5 dry pit-fall traps (10 L buckets), and 3 hair funnels. Traps were spaced approximately 5 m apart along the three transects (Figure 2) and, wherever possible, were positioned to maximise the chances of being encountered by an animal by placing traps alongside, on, or in logs, grass runways or possible shelter sites (Sutherland 1996b; Cunningham *et al*. 2005). Cage traps, Elliott traps and hair funnels were baited with the standard Australian mammal mixture of peanut butter, rolled oats and honey, with vanilla essence also added (Menkhorst & Knight 2001). In addition, a piece of apple was used as bait in the cage traps and Elliott traps. Pit-fall traps were left unbaited. Direct observations and scat collection were also conducted opportunistically during each site visit.

INSERT <u>FIGURE 2</u> NEAR HERE

Cage traps were used to detect medium-sized terrestrial mammals such as native rodents (e.g. *Rattus fuscipes* and *Rattus lutreolus*) and bandicoots (e.g. *Isoodon macrourus* and *Perameles nasuta*), whereas Elliott traps targeted small-bodied species such as dunnarts (*Sminthopsis* spp.) and antechinus (*Antechinus* spp.). The hair funnels (Faunatech Pty Ltd, Bairnsdale, Victoria). used to detect both small and medium-sized mammals differed in design from other hair sampling devices (e.g. Lindenmayer *et al*. 1999; Mills *et al*. 2000; Scotts and Craig 1988) in having only a single large opening that tapers to an enclosed bait chamber. A specialised wafer was attached to the upper inside surface of the funnel. The wafer was covered with a sticky substance (‘faunagoo’), which replaces the double-sided tape used in previous similar traps to collect hair samples. Dry pit-fall traps were employed primarily to detect small reptile species, with direct observations being used to detect large-bodied reptiles that were unlikely to be detected by other methods. Any scats detected were also collected for *ex situ* analysis.

Cage and Elliott traps were set and baited each afternoon before sunset, checked for captures before dawn the following morning and then closed during the day. Captured animals were identified to species-level using a field guide (Menkhorst & Knight 2001), photographed, weighed, sexed and immediately released at the point of capture. Hair funnels were set and baited at the start of the three day survey cycle and left undisturbed until collection at the end of the survey cycle. All wafers with hair samples were sent for identification *ex-situ* by one of two independent experts (Initial surveys: Michiala Bowen; Repeat surveys: Barbara Triggs). Hair samples were identified to species level wherever possible, with identifications being classified as either “definite” or “probable”. Only definite species identifications were used for subsequent data analyses.

Dry pit-fall traps were established at least one week prior to site surveys to allow species and habitat to recover from the localised disturbance that occurs during placement of the traps. Dense vegetation and fallen woody debris at most sites prevented the use of drift-fences that have previously been used in conjunction with pit-fall traps to improve capture success (e.g. Mengak & Guynn 1987; Friend *et al*. 1989; Crosswhite *et al*. 1999; Menkhorst & Knight 2001). Pit-fall traps were open for the duration of the survey cycle and were checked for captures each morning and afternoon. Captured animals were identified to species-level using a field guide (Wilson 2005), photographed, weighed, sexed (if possible) and immediately released at the point of capture. Between the initial and repeat wildlife survey periods, lids were securely fitted to each pit-fall trap to prevent captures. Direct observations and scat collections were used opportunistically throughout all site visits to identify target species. All scats collected were identified *ex situ* by the same independent experts who analysed the hair samples. Only definite species' identifications were used in subsequent analyses.

The relative success of each survey method was determined by evaluating the total number of species detected by each method across all sites. The total number of "unique" species detected by each method was also examined. Unique species were those species detected by only one survey method (*sensu* Doan 2003). Species' detections from the initial and repeat surveys were collated for analyses.

Cost analysis

The cost of each survey method was calculated independently based on the cost output required to survey a single site over one survey cycle (i.e. over 3 consecutive nights). Four main areas of cost expenditure were considered for each method: equipment costs, bait/analysis costs, personnel costs and travel costs.

Equipment costs included expenditures for acquiring traps as well as additional items required to prepare each trap. Trap acquisition costs for each method were calculated at 2004 purchase prices. Additional preparatory expenses included shade cloth for cage traps, hair wafers for hair funnels and, the hire of a motorised auger for digging pit-fall traps.

Bait/analysis costs covered bait expenses as well as *ex situ* hair and scat analysis charges. The cost of bait was calculated based on the cost of bait ingredients per trap over the three night survey cycle. Cage traps and hair funnels used larger peanut butter balls than Elliott traps and the price was adjusted accordingly. For each survey night, fresh bait was used in cage and Elliott traps, whereas the hair funnel bait was left unchanged during the survey cycle. The charge cost for expert analyses of hair and scat samples differed between the two experts and so an average charge was used to calculate costs of hair and scat analyses.

Personnel costs were calculated for two people based on The University of Queensland's minimum hourly wage for a casual research assistant of $19 per hour plus 15.5% on-costs (all prices are given in Australian dollars). Personnel cost calculations incorporated the time taken to prepare traps, establish traps at a site, set and check traps each survey day and, remove traps at the end of the survey cycle. Although observation and scat collection were not standardised, an approximate time for each activity per site was calculated.

Travel costs were based on The Ecology Centre's (The University of Queensland) vehicle hire charge of $0.50/km, with an average of 60 km per return trip, per site visit. The number of return trips was calculated independently for each survey method and included trips to establish, set, check and, remove traps or conduct direct observations/scat collection.

Cost versus success

The most effective survey method or combination of methods was based on both species' detection success per site and trapping cost per site. The total numbers of individuals and species detected per survey method was averaged across sites to give the average numbers of individuals and species detected per method per site. This average detection success plus the average cost of each survey method per site was compared in order to identify the most effective and efficient combination of methods.

Results

Species Detected

A total of 28 target native terrestrial reptile and small mammal species, representing 11 family groups, were detected from the 59 sites surveyed (Table 1). A number of non-target species were also detected, including large terrestrial mammals (wallabies and kangaroos), invertebrates, amphibians, birds, arboreal marsupials and exotic mammal and reptile species.

INSERT TABLE 1 NEAR HERE

Survey method success

Each survey method successfully identified at least two target species, with certain methods detecting up to 14 species (Figure 3a). As expected, each method was mainly suited to detecting either mammals or reptiles, with no method detecting both mammals and reptiles in equal proportions (Figure 3a). Although there was a degree of overlap in the species detected by each survey method, all methods detected at least one species not detected by another method (Figure 3b).

INSERT <u>FIGURE 3</u> NEAR HERE

Cage traps

A total of 2664 trap nights produced a total of 277 captures (capture success = 10.4%). Target reptile and mammal species comprised 6.9% (*n*=19) of the total cage trap captures. Collectively, these species represented three family groups and four species (Table 1). With the exception of one reptile capture (carpet python, *Morelia spilota*), all target species captured by this method were medium-sized mammals. The northern brown bandicoot (*Isoodon macrourus*) was the most commonly captured mammal (*n*=14 across 7 sites). Bush rats (*Rattus fuscipes*) were captured on two nights at a single site and the swamp rat (*Rattus lutreolus*) and carpet python were trapped at one site each, from a single capture. The bush rat, swamp rat and carpet python were not detected by any other survey method (Table 1).

Captures of non-target species included: the common brush-tail possum (*Trichosurus vulpecular)* (*n*=124), exotic black rat (*Rattus rattus)* (*n*=100), introduced cane toad, *Bufo marinus* (*n*=26), Australian magpie (*Gymnorhina tibicen)* (*n*=6), grey butcherbird (*Cracticus torquatus)* (*n*=2) and, Torresian crow (*Corvus orru)* (*n*=1). Overall, cage traps were found closed without captures 6.9% of the time (*n*=184).

Elliott traps

A total of 3330 trap nights produced 55 captures for an overall trap capture success of 1.7%. Of these captures, 34.5% (*n*=19) were target species that represented two mammal species from different families (Table 1). Common dunnarts (*Sminthopsis murina*) were captured more frequently and across a greater number of sites (*n*=12 across 7 sites) than yellow-footed antechinus (*Antechinus flavipes*) (*n*=7 across 4 sites). Both species were detected only by this method (Table 1). Non-target species captured by Elliott traps included: cane toads (*n*=16), house mouse *Mus musculus* (*n*=14), giant white-kneed king cricket (*Australostoma australasiae)* (*n*=4), centipede (*n*=1), and a juvenile common brush-tail possum (*n*=1). Elliott traps were found closed without captures 4% of the time (*n*=133).

Dry pit-fall traps

Of the 568 pit-fall traps used during the survey periods, 105 were successful in capturing target species (18.5%). A total of 12 reptile species (representing three families) and one mammal species were detected (Table 1). The reptile species captured were small-bodied species or juveniles of larger-bodied species (e.g. juvenile bearded dragon (*Pogona barbata*)). Four reptile species were not detected by any other method: Verreaux's skink (*Anamalopus verreauxii*), scute-snouted calyptotis skink (*Calyptotis scutirostrum*), copper-tailed skink (*Ctenotus taeniolatus*) and, eastern stone gecko (*Diplodactylus vittatus*) (Table 1). The only mammal species captured in pit-fall traps was the common planigale (*Planigale maculata*). This species was identified from two captures of individuals at two different sites. The common planigale was detected during surveys only by this method (Table 1).

Non-target species' captures were common in pit-fall traps, with invertebrate species such as ants, spiders, snails and crickets being the most common by-captures. Non-target vertebrate by-captures were all amphibians: cane toads (*n*=16), ornate burrowing frogs (*Lymnodynastes ornatus)* (*n*=7), and copper-backed broodfrogs (*Pseudophryne raveni)* (*n*=5).

Hair funnels

A total of 341 wafers were used during the surveys, of which 84 (24.6%) contained hair samples. Of the 84 wafers with hair samples, 17 (20.2%) contained hair that was able to be definitely identified to the species level, with seven of these representing target species. Three target mammal species were positively identified from hair samples: brown antechinus (*Antechinus stuartii*), northern brown bandicoot, and long-nosed bandicoot (*Perameles nasuta*). The brown antechinus and long-nosed bandicoot were identified only by this method (Table 1). Although hair funnels specifically target mammal species, a live reptile by-catch of a single garden skink (*Lampropholis delicata*) was found on a wafer at one site.

Direct observations and scat analyses

Opportunistic species identifications through direct observations and scat collection and analyses respectively identified a total of 14 target reptile species and two target mammal species (Table 1). Direct observations identified six reptile species not detected by any other method (Table 1). Of the two mammals detected from scats (Table 1), the *Melomys* could not be positively identified to species level, although the grassland melomys (*M. burtoni*) was considered probable. As this was the only detection from this genus, the genus record was included in subsequent analyses.

Cost of detection methods

There were significant variations in cost among the survey methods (Figure 4). Total costs to survey a single site over three nights ranged from $178.86 for hair funnels to $925.66 for cage traps. Elliott trapping was the most expensive method ($815.18) after cage trapping, despite more Elliott traps than cage traps being used to survey a site (*n*=12 and *n*=10, respectively). Pit-fall traps, direct observation, and scat analysis were all similar in cost ($626.37, $655.52, $660.52 per site respectively). The main differences in costs resulted from equipment and travel expenses associated with each method (Figure 4).

INSERT FIGURE 4 NEAR HERE

Cost vs. success

Overall, it appeared that pit-fall trapping was the most effective and efficient survey method, detecting both the highest number of species (*n*=0.0018) and captures (*n*=0.003) per dollar (Figure 5a). Direct observations, followed by hair funnels were the next most successful and efficient survey methods (Figure 5a). Elliott traps and cage traps were roughly similar in their cost per species and cost per capture, yet both were substantially less economic than hair funnels (Figure 5a). Comparatively, scat detection/analysis had the lowest detection success for money spent, with 0.0000941 species and captures detected per dollar (Figure 5a).

For reptiles, the most successful survey methods mirrored those for overall detection costs. Pit-fall traps produced the highest species detection (*n*=0.0017) and capture success (*n*=0.0029) per dollar outlay (Figure 5b). Similarly, direct observations were the next most effective and efficient method (Figure 5b), with per dollar values for number of species detected and number of captures equal to those shown in Figure 5a, as mammals were not detected using this method (Figure 3a). The remaining four methods failed to detect reptiles, with the exception of the single, unusual by-catch in a hair funnel and a cage trap.

For mammals, pit-fall trapping and direct observations were the least successful and most costly methods (Figure 5c). Hair funnels were found to produce the greatest number of species detections (*n*=0.00066) and captures (*n*=0.00076) per dollar, implying the lowest cost per species detected and per capture (Figure 5c). Elliott traps were the next most cost efficient and successful method, detecting more species (*n*=0.00025) and captures (*n*=0.000395) per dollar than cage traps (0.000165 species and 0.00033 captures per dollar) (Figure 5c). Scat detection/analysis produced more species detections and captures (*n*=0. .0000941) per dollar than pit-fall trapping (*n*=0.0000541) (Figure 5c). However, both scat detection/analysis and pit-fall trapping had a higher cost per detection and capture than the other methods, with the exception of direct observations which were not useful for detecting any target mammal species (Figure 5c).

INSERT FIGURE 5 NEAR HERE

Discussion

No one survey method independently detected all species recorded during the surveys, yet each method was important for detecting between 1-6 species that were not detected by any other method. There were distinct biases between methods in terms of the species' group (reptiles or mammals) most successfully detected. Pit-fall traps and direct observations were substantially more successful in detecting reptile species, whereas hair funnels, scat detection/analysis, cage traps and Elliott traps were more useful for detecting mammal species. Such detection biases correspond to the purpose for which each method was designed (Sutherland 1996a). However, it also indicates that, as noted by Laurance (1992), the use of only a single method in fauna community surveys will "…be biased toward a non-random subset of species in the community..." (p. 654). Therefore, when surveying fauna communities, it is essential that combination of survey methods are employed in order to adequately sample a range of species. This finding is consistent with previous studies that have also advocated the use of a combination of techniques for surveying a range of wildlife species (e.g. Mengak & Guynn 1987; Laurance 1992; Catling *et al*. 1997; Lindenmayer *et al*. 1999).

We found a considerable difference among methods in terms of the cost outlay required for detecting ground-dwelling mammal and reptile species. However, these calculations were based on the complement of traps used during the study to survey each site and therefore, such costs may vary for other studies depending on the number of each survey method utilised, the duration of active searches and, the analysis of hair/scat samples relative to the success of these methods. To help provide a direct comparison between the success and cost of each survey method, success was interpreted in terms of 'value for money'; that is, the number of species and the number of captures per dollar spent for each method. Using these calculations, we found that the methods most successful for detecting various species and species' groups were also those that produced the most number of mammal and reptile species' detections and captures at the least cost.

Reptiles

Based on the results of this study, the most effective trapping methods for terrestrial reptile surveys are a combination of pit-fall traps and direct observations. Despite being opportunistic rather than standardised, direct observations detected more overall reptile species, as well as more unique species than pit-fall trapping. However, pit-fall trapping was more cost effective than direct observations, detecting more species and captures per dollar. This suggests that pit-fall trapping would produce the highest species detection and capture success for the least amount of money. However, the unique species detected by each of these methods was significantly biased by body size and behaviour. Large-bodied reptiles such as lace monitors, snakes and dragons that were unlikely to be captured in pit-fall traps were detected by direct observation. The exception was a pit-fall trap capture of a single juvenile bearded dragon that was too small to escape from the trap.

Comparatively, the species detected by pit-fall traps were small-bodied, cryptic, nocturnal and/or burying reptiles such as small skinks, eastern stone geckos, and Verreaux's skinks. The relative species detection success of pit-fall traps is expected to have been even greater than direct observations if it had been possible to use drift fences and larger traps (buckets). Crosswhite *et al*. (1999), for instance, showed that more reptiles were captured using pit-fall traps combined with drift-fences than through active searches and Catling *et al*. (1997) concluded that increasing the size of the buckets used as pit-fall traps would likely have increased the capture success of larger-bodied species which were able to otherwise escape. However, increasing the trap size and/or incorporating drift fences would also have increased the cost associated with pit-fall trapping.

Similarly, given that all direct observations were opportunistic, it may be expected that a dedicated, time-constrained active search period would have identified additional species. However, in accordance with reports by Crosswhite *et al*. (1999) and Ryan *et al*. (2002), pit-fall trapping is still likely to have detected the highest number of species and captures. Furthermore, additional costs and limitations associated with personnel time and experience is likely to influence the accuracy of active search results, thereby potentially offsetting any increase in species detections through time-constrained searches (Crosswhite *et al*. 1999; Silveira *et al*. 2003).

Based on the cost efficiency and detection success of pit-fall trapping and direct observations, we recommend that pit-fall trapping be used as the primary technique for surveys of small-bodied terrestrial reptiles. Where habitats and budgets allow, drift fences should also be used to increase capture success (Friend *et al*. 1989; Moseby and Read 2001). For surveys focussing on larger-bodied reptiles, time-constrained active searches are recommended as the most cost efficient and productive detection method. However, when attempting to survey a range of terrestrial reptile species, a combination of pit-fall traps and active searches are likely to be the best combination of survey methods for detecting the highest number of species and captures per dollar. Furthermore, when used in combination, the travel costs for each survey method were approximately 50% less, which may compensate for increased expenses associated with the inclusion of drift-fences and even increased search times.

Mammals

Mammal species were detected by five of the six survey methods employed. Optimum trapping methods for terrestrial, small- and medium-sized mammal surveys were hair funnels, followed by Elliott traps and cage traps, as well as scat analysis and pit-fall traps to a lesser degree. Although hair funnels, Elliot traps and cage traps all detected the same number of unique species, the cost effectiveness of these captures varied significantly. Hair funnels were the most economical form of surveying target mammals, detecting more species and captures per dollar than the other mammal survey methods. The relative cost effectiveness of hair funnels is most likely related to the advantages this method has over live trapping methods in being less labour-intensive, able to detect more than one species or individual per funnel, and able to capture hair from species of various body-sizes (Lindenmayer *et al*. 1999; Mills *et al*. 2002). However, unlike live trapping methods, differentiating between individuals of the same species is not possible using hair funnels, thereby limiting the usefulness of this method for surveys aimed at determining species' abundance. Furthermore, accurately identifying hair samples to the species level is a difficult process that is susceptible to hair samples being incorrectly identified or not able to be identified at all. Lobert *et al*. (2001), for instance, tested the accuracy of hair identification by two independent experts and found that almost half of the samples analysed involved some degree of identification error. Furthermore, the identification of dog hair from a hair funnel used in Lindenmayer *et al*.'s (1999) study was questionable given the hair sample was from an arboreal funnel (see also Kavanagh & Stanton 1998). However, the positive species identifications from hair samples collected during this study are reasonable and were considered to be accurate.

There were also clear associations between the body size of mammals and the success of various methods for detecting different species. Elliott traps, given their size, detected only small-bodied mammal species, with the exception of a single by-catch of a juvenile brush-tail possum at one site. Similarly, small-bodied species, such as dunnarts and antechinus were not captured in cage traps probably due to the lower sensitivity of cage trap treddles and the light weight of small-bodied species. Cage traps were, however, successful in capturing medium-sized species such as rodents and bandicoots, whose body size prevented captures in Elliott traps. Due to their tapered design and large surface area for capturing hair samples, hair funnels detected both medium- and small-bodied terrestrial mammals, including species not captured by live trapping methods (e.g. long-nosed bandicoot and brown antechinus).

Furthermore, although more commonly used for reptile surveys, pit-fall trapping was the only method to detect the occurrence of planigales during this study. This is consistent with previous studies that have found pit-fall traps to be useful for detecting small, elusive mammal species that rarely enter other traps (e.g. Milledge 1991, Laurance 1992, Catling *et al*. 1997, Menkhorst & Knight 2001). Therefore, unless a project is specifically targeting planigales (or similar elusive, shy species), or has a sufficiently large budget, pit-fall traps are not recommended for mammal surveys. Scat detection and analysis also identified one small mammal (*Melomys* spp.) not detected by any other method. However, these scat samples were not able to be positively identified to the species level, suffering the same analysis difficulties as hair sample identifications. Based on our results, both pit-fall trapping and scat detection/analysis methods would require a substantial cost outlay in order to detect as many species and captures as the other methods. As such, these methods are recommended as supportive methods only if the project budget allows. Alternatively, excess funding could be allocated to increasing the survey-intensity of optimal survey methods or, by exploring the use of additional bait types, such as meat products, to help improve the range of species detected (e.g. herbivores as well as omnivores and carnivores) (Laurance 1992; Mills *et al*. 2002).

Therefore, based on the results from this study, we propose that optimal survey methods for detecting medium-bodied terrestrial mammals are a combination of cage traps and hair funnels. Comparatively, small-bodied terrestrial mammals are best surveyed using Elliott traps and hair funnels. Complementary pit-fall traps should also be used if attempting to detect planigales or similarly elusive mammal species. However, if only planigales or similar species are being targeted, then intensive pit-fall trapping should be adopted as the primary survey method. Like reptile surveys, drift fences may be adopted to increase capture success (e.g. Mengak and Guynn 1987). In habitats with sparse ground cover, scat detection may prove more successful than found in this study, although it is best used as a supplementary method with other techniques only if funds permit.

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References

Brown, G. W., Nicholls, A. O. (1993). Comparative census techniques and modelling of habitat utilization by reptiles in northern Victoria. In 'Herpetology in Australia: a Diverse Discipline'. (Ed. D. Lunney and D. Ayers.) pp. 283-290. (Royal Zoological Society of New South Wales: Mosman.)

Brisbane City Council. (2001). State of the Environment Report: Brisbane 2001. Brisbane City Council. (Brisbane City Council: Brisbane.)

Catling, P. C., Burt, R. J., Kooyman, R. (1997). A comparison of techniques used in a survey of the ground-dwelling and arboreal mammals in forests in north-eastern New South Wales. *Wildlife Research* **24**, 417-432.

Clemann, N., Long, K., Skurrie, D., and Dzuris, J. (2005). A trapping survey of small, ground-dwelling vertebrates in the Little Desert National Park, Victoria. *Australian Zoologist* **33**, 119-126.

Crosswhite, D. L., Fox, S. F., Thill, R. E. (1999). Comparison of methods for monitoring reptiles and amphibians in upland forests of Ouachita Mountains. *Proceedings of the Oklahoma Academy of Science* **79**, 45-50.

Cunningham, R. B., Lindenmayer, D. B., MacGregor, C., Barry, S., and Wlesh, A. (2005). Effects of trap position, trap history, microhabitat and season on capture probabilities of small mammals in a wet eucalypt forest. *Wildlife Research* **32**, 657-671.

Doan, T. M. (2003). Which methods are most effective for surveying rainforest herpetofauna? *Journal of Herpetology* **37**, 72-81.

Friend, G. R. (1978). A comparison of predator scat analysis with conventional techniques in a mammal survey of contrasting habitats in Gippsland, Victoria. *Australian Wildlife Research* **5**, 75-83.

Friend, G. R., Smith, G. T., Mitchell, D. S., and Dickman, C. R. (1989). Influence of pitfall and drift fence design on capture rates of small vertebrates in semi-arid habitats of Western Australia. *Australian Wildlife Research* **16**, 1-10.

Kavanagh, R. P., and Stanton, M. A. (1998). Nocturnal birds and arboreal marsupials of the southwestern slopes, New South Wales. *Australian Zoologist* **30**, 449-466.

Laurance, W. F. (1992). Abundance estimates of small mammals in Australian tropical rainforest: a comparison of four trapping methods. *Wildlife Research* **19**, 651-655.

Lindenmayer, D. B., Incoll, R. D., Cunningham, R. B., Pope, M. L., Donnelley, C. F., MacGregor, C. I., Tribolet, C., and Triggs, B. E. (1999). Comparison of hairtube types for the detection of mammals. *Wildlife Research* **26**, 745-753.

Lobert, B., Lumsden, L., Brunner, H., and Triggs, B. (2001). An assessment of the accuracy and reliability of hair identification of south-east Australian mammals. *Wildlife Research* **28**, 637-641.

Mengak, M. T., Guynn, Jr. D. C. (1987). Pitfalls and snap traps for sampling small mammals and herpetofauna. *American Midlands Naturalist* **118**, 284-288.

Menkhorst, P., and Knight, F. (Eds.) (2001). ‘A Field Guide to the Mammals of Australia.’ (Oxford University Press: Melbourne.)

Milledge, D. (1991). A survey of the terrestrial vertebrates of coastal Byron Shire. *Australian Zoologist* **27**, 66-90.

Mills, D. J., Harris, B., Claridge, A. W., and Barry, S. C. (2002). Efficacy of hair-sampling techniques for the detection of medium-sized terrestrial mammals. I. A comparison between hair-funnels, hair-tubes and indirect signs. *Wildlife Research* **29**, 379-387.

Moseby, K. E., and Read, J. L. (2001). Factors affecting pitfall capture rates of small ground vertebrates in arid South Australia. II. Optimum pitfall trapping effort. *Wildlife Research* **28**, 61-71.

Ryan, T. J., Philippi, T., Leiden, Y. A., Dorcas, M. E., Wingley, T. B., and Gibbons, J. W. (2002). Monitoring herpetofauna in a managed forest landscape: effects of habitat types and census techniques. *Forest Ecology and Management* **167**, 83-90.

Scotts, D. J., and Craig, S. A. (1988). Improved hair-sampling tube for the detection of small mammals. *Australian Wildlife Research* **15**, 469-472.

Silveira, L., Jácomo, A. T. A., Diniz-Filho, J. A. F. (2003). Camera trap, line transect census and track surveys: a comparative evaluation. *Biological Conservation* **114**, 351-355.

Sutherland, W. J. (Ed.) (1996a). 'Ecological Census Techniques: a Handbook.' (Cambridge University Press: Cambridge.)

Sutherland, W. J. (1996b). Mammals. In 'Ecological Census Techniques: a Handbook.' (Ed. W. J. Sutherland.) pp. 260-280. (Cambridge University Press: Cambridge.)

Wilson, S. (Ed.) (2005). 'A Field Guide to Reptiles of Queensland.' (New Holland Publishers Pty. Ltd.: Sydney.)

Young, P. A. R., and Dillewaard, H. A. (1999). Southeast Queensland. In 'The Conservation Status of Queensland's Bioregional Ecosystems' (Eds. P. S. Sattler and R. D. Williams.) pp. 12/1-12/48. (Environmental Protection Agency: Brisbane.)

Figure 1. Map of study area showing location of (a) Brisbane and central business district (CBD), and site locations within (b) Karawatha area and (c) Burbank area. GIS data provided by Brisbane City Council.

Figure 2. Site schematic showing trap layout along the three transects. ▲ Hair funnels; ■ Elliott traps; ▦ Cage traps; ○ Pit-fall traps.

Figure 3. (a) The total number of species detected by each survey method, and (b) the number of unique species detected by each survey method. ■ Reptiles; □ Mammals.

Figure 4. Relative cost of each survey method in isolation as used during this project to survey one site over a three night period. Total cost for each method comprised expenses relating to: ▨ equipment, ■ bait/analysis, □ personnel time and, ■ travel.

Figure 5. Average success of each survey method per site, per dollar. For clarity, the cost of success is shown as success per thousand dollars for: (a) all target species detected; (b) reptiles detected; and (c) mammals detected. For all graphs: □ average number of species per site per thousand dollars; ■ average number of captures per site per thousand dollars.

Table 1. Collated species list and method/s by which they were detected. ✓ Species that were detected by only a single survey method; ● species detected by more than one survey method.

	Family Group	Scientific Name	Common Name	Survey Method CT	ET	PF	HF	Obs	S
Native Mammals	Dasyuridae	*Antechinus flavipes*	Yellow-footed antechinus		✓				
		Antechinus stuartii	Brown antechinus				✓		
		Planigale maculata	Common planigale			✓			
		Sminthopsis murina	Common dunnart		✓				
	Muridae	*Melomys* sp.	Likely: Grassland melomys						✓
		Rattus fuscipes	Bush rat	✓					
		Rattus lutreolus	Swamp rat	✓					
	Peramelidae	*Isoodon macrourus*	Northern brown bandicoot	●			●		●
		Perameles nasuta	Long-nosed bandicoot				✓		
Native Reptiles	Agamidae	*Diporiphora australis*	Tommy round-head			●		●	
		Physignathus lesuerii	Eastern water dragon					✓	
		Pogona barbata	Bearded dragon			●		●	
	Colubridae	*Dendrelaphis punctulata*	Common tree snake					✓	
	Elapidae	*Pseudechis porphyriachus*	Red-bellied black snake					✓	
	Gekkonidae	*Diplodactylus vittatus*	Eastern stone gecko			✓			
	Pygopodidae	*Lialis burtonis*	Buton's snake-lizard					✓	
	Pythonidae	*Morelia spilota*	Carpet python	✓					
	Scincidae	*Anamalopus verreauxii*	Verreaux's skink			✓			
		Calyptotis scutirostrum	Scute-snouted calyptotis skink			✓			
		Carlia foliorum	Tree-base litter-skink			●		●	
		Carlia pectoralis	Open-litter rainbow skink			●		●	
		Carlia vivax	Storr's rainbow skink			●		●	
		Cryptoblepharus virgatus	Fence skink			●		●	
		Ctenotus taeniolatus	Copper-tailed skink			✓			
		Eulamprus quoyii	Eastern water skink					✓	
		Lampropholis amicula	Secretive skink			●		●	
		Lampropholis delicata	Garden skink			●	●	●	
	Varanidae	*Varanus varius*	Lace monitor					✓	

Figure 1.

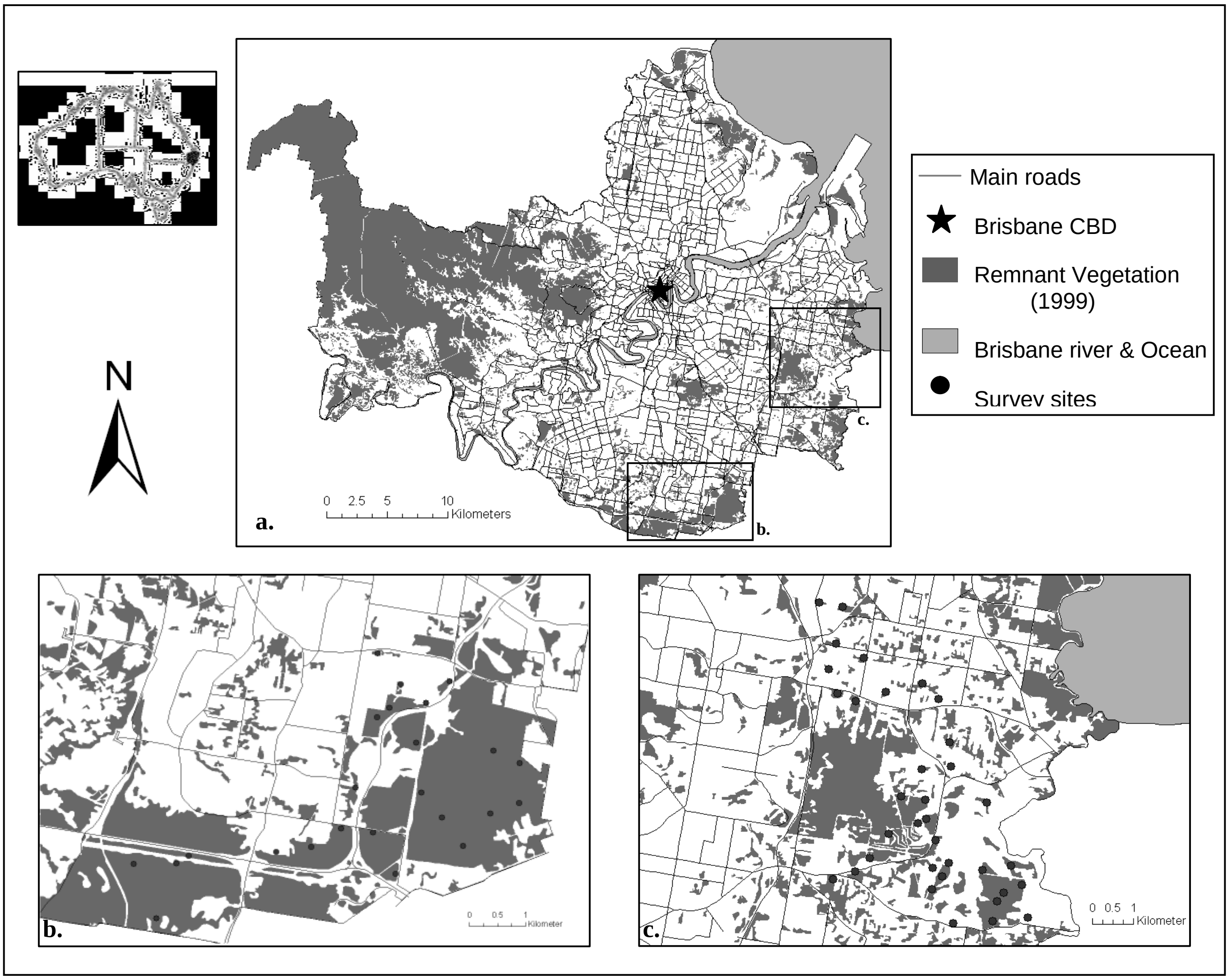

N
a.
0 2.5 5 10
Kilometers
b.
c.
Main roads
Brisbane CBD
Remnant Vegetation
(1999)
Brisbane river & Ocean
Survey sites
0 0.5 1
Kilometer
0 0.5 1
Kilometer

Figure 2.

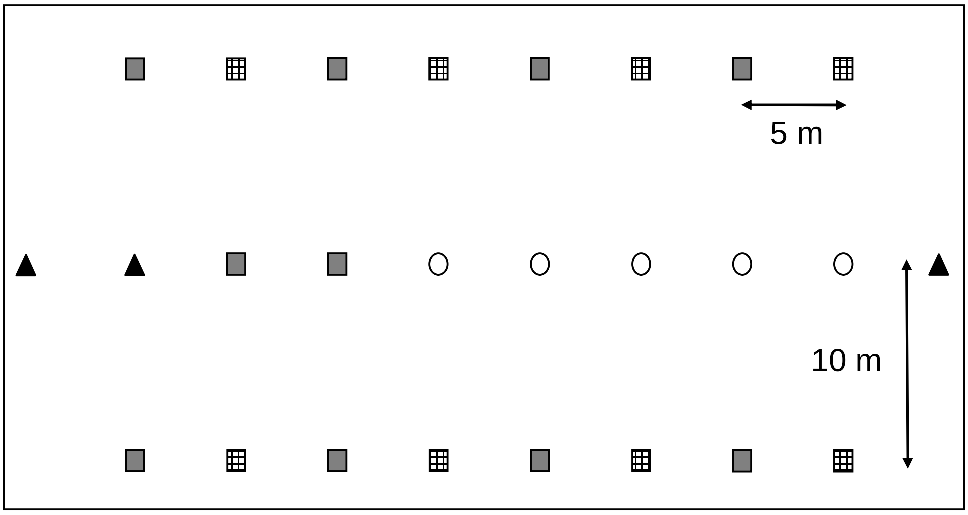


Figure 3a.

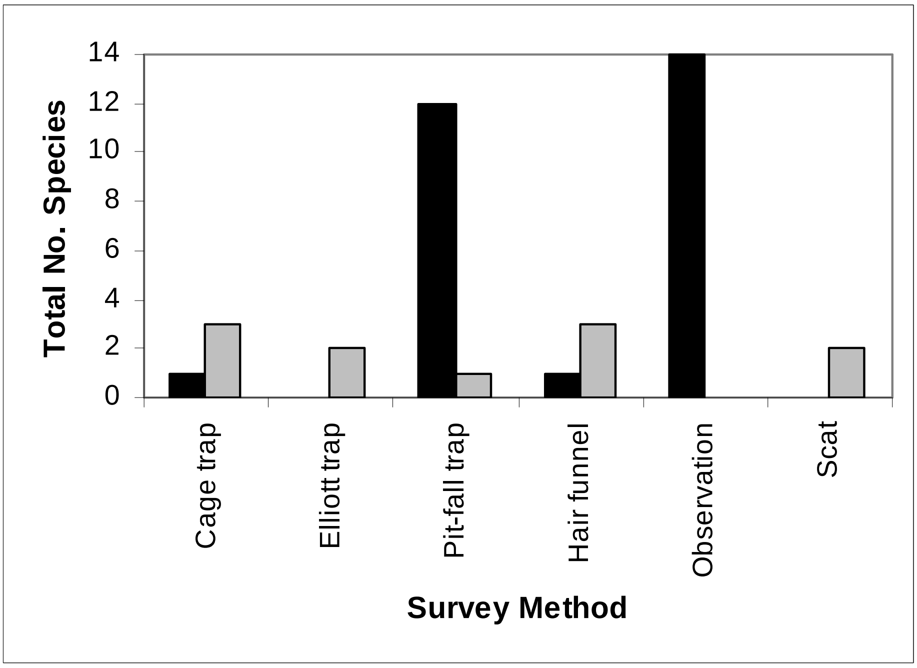


Figure 3b.

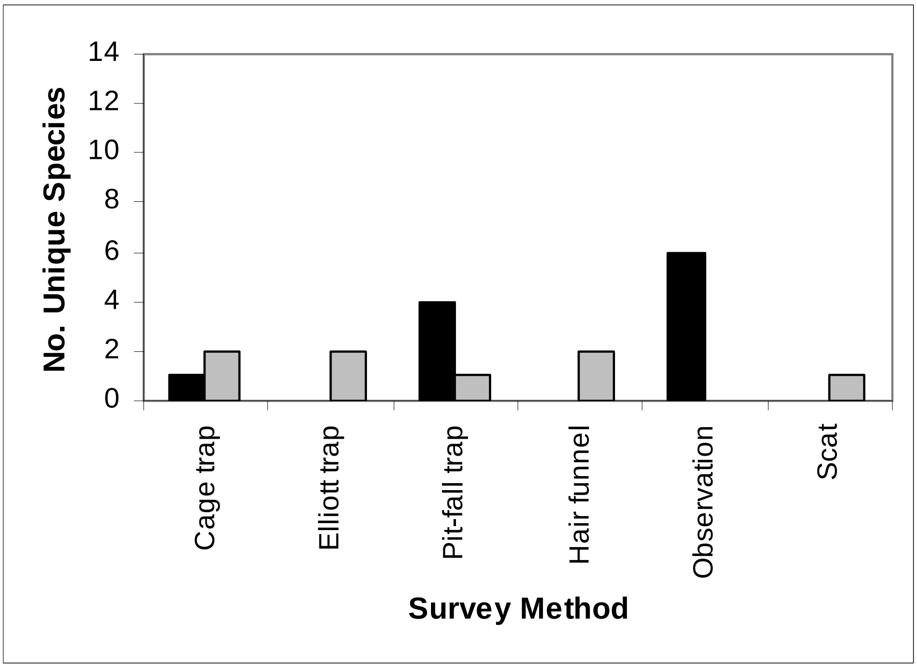


Figure 4.

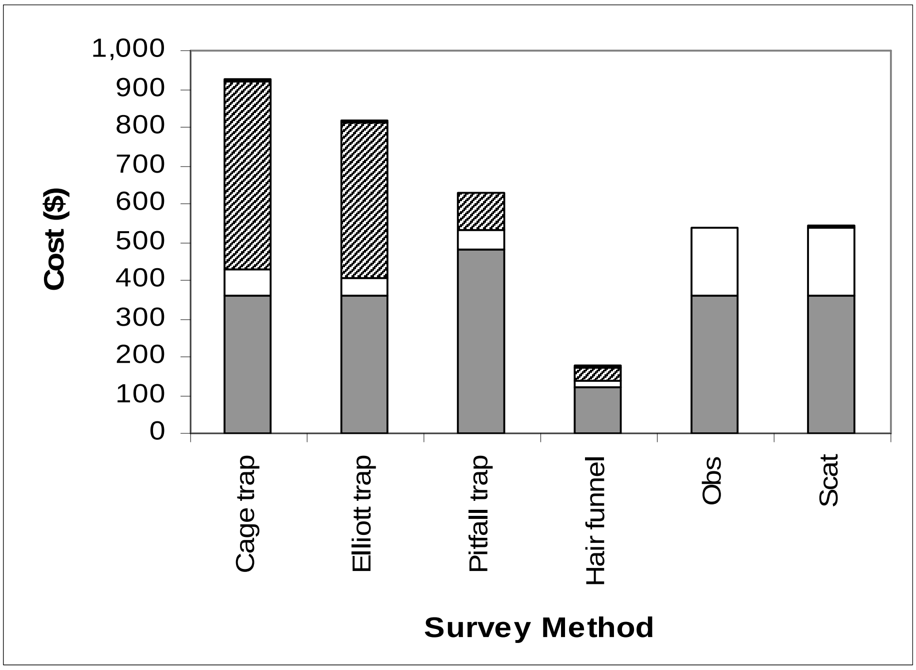

1,000
900
800
700
600
500
400
300
200
100
0
Cost ($)
Cage trap
Elliott trap
Pitfall trap
Hair funnel
Obs
Scat
Survey Method

Figure 5a.

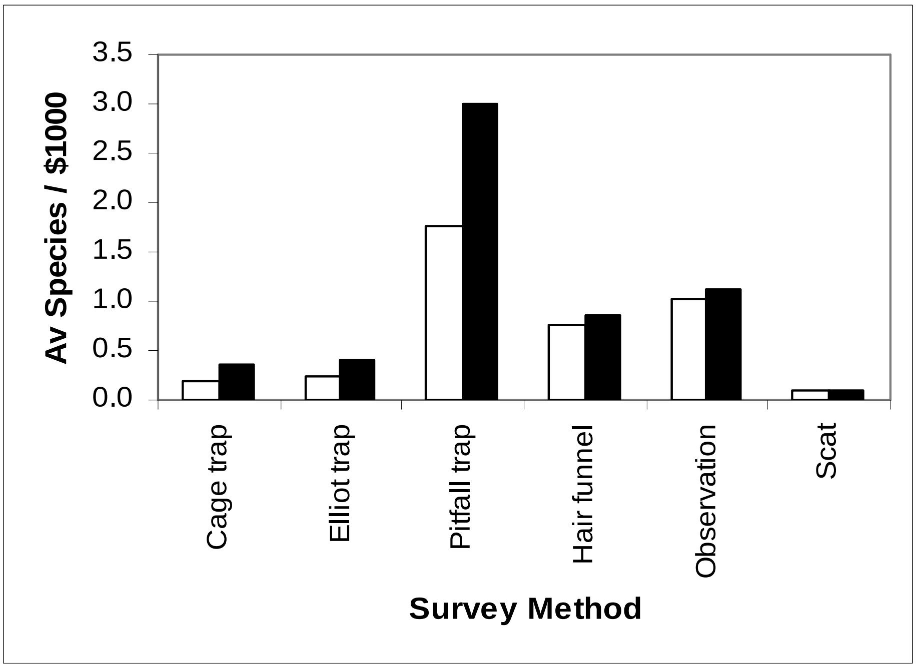


Figure 5b.

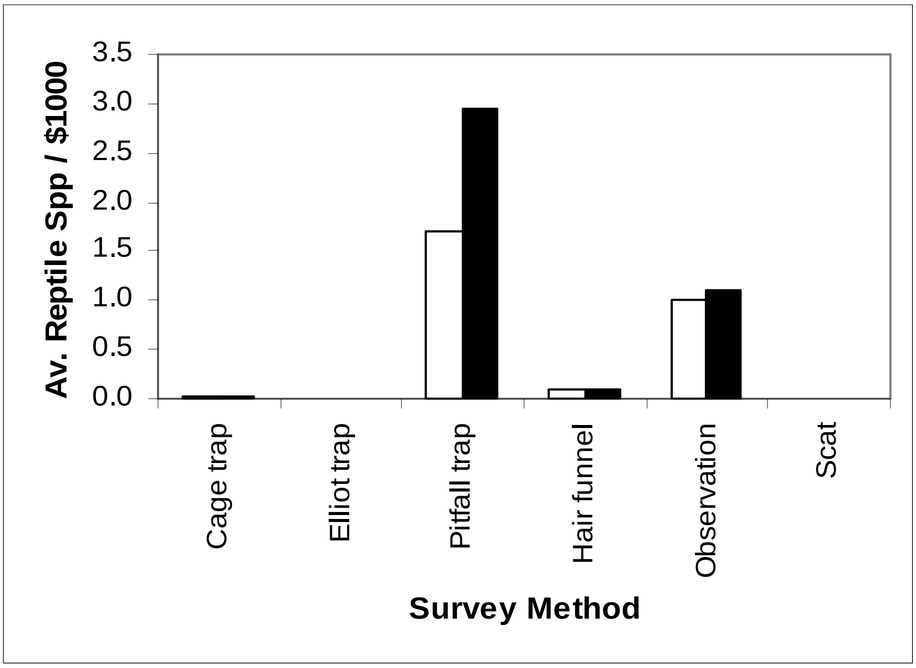
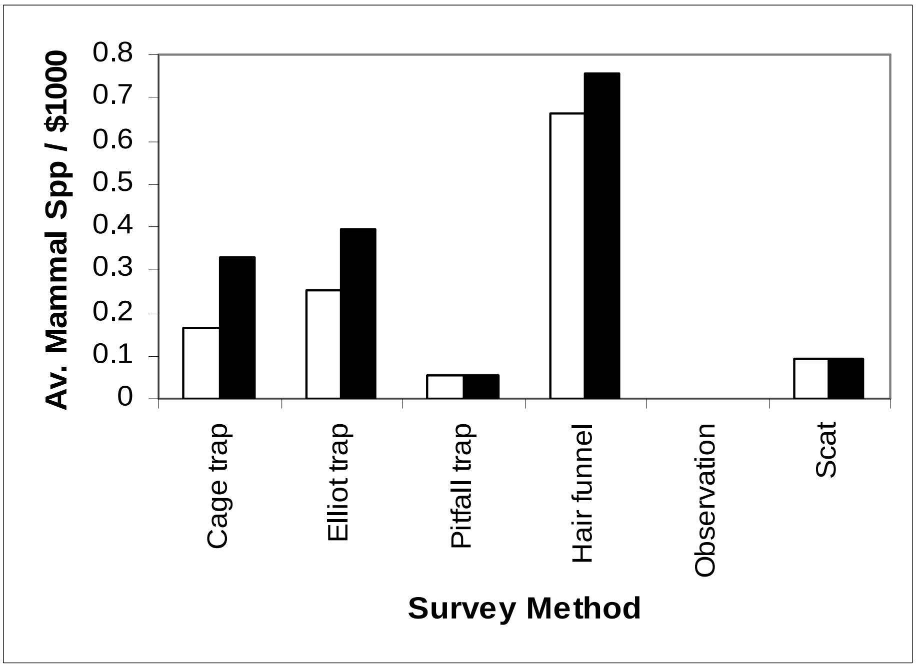


Figure 5c.


Av. Mammal Spp / $1000
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Cage trap
Elliot trap
Pitfall trap
Hair funnel
Observation
Scat
Survey Method