TITLE: Evaluating protected area effectiveness using bird lists in the Australian Wet Tropics

Running Title: Evaluating protected area effectiveness using bird lists

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ABSTRACT

Aim:

Protected areas underpin many global conservation efforts. However, it is often unclear whether they are effective in maintaining their biodiversity values, both absolutely, and also relative to other conservation actions or land uses. Longitudinal population data are critical for determining protected area performance robustly, but such data are rare. As such, there is often insufficient information with which to make adequate, informed decisions for policy and management. Conversely, informally collected data, such as species lists, are common, especially for birds, and they are often the only source of historical data. The aim of this study was to use list data to evaluate the contribution of protected areas to the conservation of endemic birds.

Location: Wet Tropics bioregion of Queensland, Australia.

Methods:

We used a List Length Analysis (LLA), a recently developed approach. We estimate trends in species populations with a Bayesian logistic regression to infer bird presence from non-standardised volunteer collected bird surveys from the New Atlas of Australian Birds that were conducted both inside and outside protected areas.

Results:

Overall, the prevalence of the majority of wet tropics endemics (18 of 21) has been stable since 1998. Sixteen species were more likely to be found within protected areas, two were more likely to be recorded outside, and three showed little difference. However, there was no difference in trends in prevalence between protected and unprotected areas for all but one endemic species.

Main Conclusions: Where formal data collection is too expensive or time consuming, it may still be possible to inform decision-making when citizen-collected species list data are available. In the Wet Tropics, our results suggest that for the majority of the species, protected areas may contain better habitat than unprotected areas, but that birds inside protected areas are not significantly better off through time than birds outside protected areas, as long as forest outside protected areas remains intact.

Key Words: *Australian Wet Tropics, birds, citizen science, conservation evaluation, impact evaluation, protected areas*

INTRODUCTION

Current global conservation strategies rely heavily on protected areas (CBD 2010). Currently, protected areas cover 12 -15% of the world's land surface area (WCMC & WDPA, 2012). Under new targets (17% terrestrial coverage by 2020) set at the most recent CBD conference (CBD 2010), they are likely to continue expanding. Despite this, extinctions approach mass extinction rates (Barnosky *et al.*, 2011). In this study we endeavor to evaluate the contribution of protected areas to the conservation of birds.

As a minimum, protected areas are expected to maintain the biodiversity values for which they have been established. Some examples of protected areas with effective management have successfully maintained populations of greater one-horned rhinoceros (*Rhinoceros unicornis*) in Chitwan National Park, Nepal (DNPWC, 2009), and achieved recovery and ongoing persistence of the kakapo (*Strigops habroptilus*) and kiwis (*Apteryx* spp.) in New Zealand (Department of Conservation, 2011). However, many governments, scientists, NGOs and management agencies also expect protected areas to be a conservation panacea, maintaining all of the biodiversity values contained therein, not just specifically targeted species and systems, in the face of substantial threats and competing land uses. Unfortunately, the mere existence of a protected area is far from a guarantee that it will achieve its biodiversity goals (Dudley & Stolton, 1999; McKinney, 2002), and it is unclear whether protected areas are able to retain viable populations of vertebrate fauna (Redford & Feinsinger, 2003). Indeed, some protected areas cannot even maintain targeted species within their boundaries (Craigie *et al.*, 2010). Consequently, there is an urgent need for more comprehensive and systematic impact evaluation in conservation, especially with regard to the effectiveness of protected areas (Ferraro & Pattanayak, 2006).

Long-term systematic population monitoring data are critical for evaluating protected area impact (Lindenmayer & Likens, 2009), but they are uncommon. Collecting high-quality data of sufficient duration and frequency to enable separation of natural fluctuations from ongoing trends requires high levels of monitoring investment, institutional support, and capacity that remains stable over long periods of time (Szabo *et al.*, 2010). Faced with limited resources, managers are often reluctant to invest in monitoring when they could instead allocate resources to management actions (Ferraro & Pattanayak, 2006). Consequently, where monitoring data within protected areas do exist, they often originate from short-term studies or were collected for other purposes (Field *et* *al.*, 2007), and complementary control data are rarely collected. As a result, insufficient data exist with which to determine the return on investment from protected areas, and proving that a protected area delivers outcomes above and beyond no action, or alternative actions, is challenging. Without an understanding of how populations in protected areas change through time relative to control sites, management is problematic, and best-practice management is not possible (e.g. Lindenmayer *et al.*, 2008).

Ideally, protected area performance would be quantified using a standardised BACI (Before After Control Impact) monitoring program (Lindenmayer & Likens, 2010). However, protection has usually been established well before resources were dedicated to biological monitoring. Where only post-establishment data are available, a comparison of temporal change in biodiversity values within and outside of PAs is the best option to determine the impact of protection. Use of an external (preferably matched) control approximates likely conditions in the absence of protection. Studies that evaluate the benefit of protection for vertebrate populations relative to an appropriate control are rare (but for examples see Devictor *et al.*, 2007; Western *et al.*, 2009; Hoffmann *et al.*, 2010). In contrast, studies that compare species richness and/or abundance within and outside PAs at a given time to estimate relative performance are common (e.g. Sinclair *et al.*, 2002; Gardner *et al.*, 2007), but fundamentally flawed as a performance measure, since they only tell us the relative diversity of the sites rather than their capacity to maintain species through time. Without the temporal component, it is impossible to tell whether differences are attributable to initial differences between the two sites (establishment bias), or the result of differential management. There is an urgent need for more comprehensive and systematic impact evaluation in conservation, especially with regard to the effectiveness of protected areas (Bruner *et al.*, 2001; Ferraro and Pattanyak, 2006). Knowing if and when protected areas are effective, conservation strategies will ensure those lessons can be applied to maximise biodiversity outcomes.

Meanwhile, protected area policy and management decisions must be made, and conservation practitioners often make decisions without sufficient information (Cook *et al.*, 2010). Where limited or no information is available, ad-hoc volunteer-collected data can be valuable substitute to evaluate biodiversity status and trends, support the identification of monitoring priorities and inform policy and adaptive management (Tulloch *et al.*, 2012). Citizen science is by no means a new innovation (Bock & Lepthien, 1975; Root, 1988), but programs that utilise citizen science are increasingly popular, and many organisations now hold decades-long datasets of amateur observations that can inform estimates of species distributions, abundance and phenology (reviewed in Tulloch *et al.*, 2013).

Species lists are probably the most common form of biodiversity data available (Szabo *et al.*, 2010). List data generally cover greater geographic extent and longer time periods than more systematic surveys, and are relatively inexpensive to collect (Geissler & Noon, 1981; Bart, 2005). Further, historical lists are often available where no other monitoring data exists (Szabo *et al.*, 2010). Thus, list data represent a vast underutilised resource that can help to shed light on the current state of biodiversity, especially for birds (Szabo *et al.*, 2010). Unlike other data, they often encompass areas both within and outside of protected areas. This presents an exciting opportunity to conduct a robust evaluation of the relative performance of protected areas using a control/impact trend evaluation framework.

Until recently, volunteer-collected data have often been considered unreliable and hard to interpret, limiting their use (Breed *et al.*, 2013). List Length Analysis (LLA) is a technique that employs logistic regression to make inferences from species lists using the number of species on a list for a particular visit as the primary proxy for survey effort and detectability (Franklin, 1999; Szabo *et al.*, 2010). In this study, we use the LLA approach to evaluate the impact of protected areas, focusing on the tropical rainforests of the Australian Wet Tropics, and thereby evaluate whether the Wet Tropics protected areas are an effective conservation mechanism for 21 endemic and restricted range species (Table 1), both in absolute terms and relative to unprotected forest.

METHODS

Study Area

The Wet Tropics bioregion of Queensland, Australia (Figure 1) is diverse and threatened (WTMA, 2010). It covers 894,420 ha, which is about 0.1% of Australia's land area. It includes the Australian Wet Tropics World Heritage Area (WHA), designated since 1988, which constitutes most of the forests within the region (UNESCO, 2013). Approximately 40% of the bioregion is within Category I and II National Parks, strictly protected from extractive uses. The WHA is subject to oversight by the Wet Tropics Management Authority (WTMA), which administers the WHA and co-ordinates planning within the WHA. Some areas outside protected area estate are subject to some management actions – often restoration and clearing restrictions, by the WHA, regional councils, community groups, and Nature Refuge agreements on private land. However, there are key differences: protected areas often include larger contiguous patches, are more likely to occur on steeper and less fertile soils, less likely to include lowland rainforest, more difficult to access, and have greater restrictions on development (Joppa & Pfaff, 2009; WTMA 2010).

The Wet Tropics are subject to a wide range of threats and underlying pressures and are likely to be highly susceptible to climate change (Garnett and Franklin 2014) as well as habitat fragmentation, invasive alien plant and animal species, and altered fire and hydrological regimes (WTMA 2010). The WTMA (2010) identify the primary underlying pressures as regional population growth, urban development and pollution, demand for community infrastructure, and farming; while tourism and recreation also threaten the biodiversity values of the region.

The Queensland Wet Tropics are part of a global biodiversity hotspot, in which 60% of Australian butterflies (230 species), 50% Australian birds (over 300 species), 65% of Australian ferns (over 250 species), and 36% of Australian mammals occur (WTMA 2010). For 130 species of birds Wet Tropics closed forests (including mangroves) comprise important habitat; including 23 species that are either endemic or have their Australian distribution restricted to the area, including 13 upland rainforest endemics.

Figure 1 here

Dataset

We used a subset of the data in the New Atlas of Australian Birds (Barrett *et al.*, 2003; Birdlife Australia, 2012; hereafter "the Atlas") from the Wet Tropics bioregion of Queensland, Australia for the period of 1998 – 2010. Data from the Atlas consists of bird survey data collected by volunteers using one of three methods: 2-ha area searches for 20 min, area searches within a radius of either 500 m or 5 km, both for at least 20 min, or incidental sightings, of unquantified area and duration, in which no formal survey was made (for details see Birds Australia, 2012). Data from all three methods were converted to lists of species presence for specific locations. Records with less than 5km accuracy, or missing projection information, were eliminated. All location points were projected in AGD84 according to Australian standards. Monitoring in the Wet Tropics was poor prior to 1998 when the Atlas was established in its current form, so only data from 1998 onwards have been used. Bioregional and protected area boundaries were defined using regional ecosystem mapping data (DERM, 2011). Records in unvegetated areas, including urban areas, were eliminated, and the dataset was restricted to rainforest ecoregions. Spatial analysis was conducted using ArcGIS 10.0 (ESRI, 2010). Lists with less than three species were eliminated, as were species unreliably sampled by the method, such as seabirds and nocturnal species (Szabo et al., 2010). Species with less than five records in the dataset were also removed. LLA was applied, and results examined for the remaining 21 endemic or regionally restricted species. Species were ranked according to their level of endemicity based on Williams (2006; Table 1).

Conceptual Approach: List Length Analysis

List data have generally been considered of little use to deduce population trends because the effort expended to compile a list is generally unknown and therefore we cannot control for observation effort (Elphick, 2008). The LLA permits estimation of trends in species relative abundance using presence-only data from lists collected with unknown effort. The method was first used by Franklin (1999) and later by Szabo *et al.* (2010) and Szabo *et al.* (2011). Assuming that list length scales with detectability, this method uses the length of the list to control for factors that affect detectability on a particular day, including survey effort, weather, and observer skill (see Appendix S1 in supporting information). For species where this assumption was not met: i.e. reporting rate decreased with list length - trends could not be estimated.

Analysis

We used LLA to evaluate impacts and examine trends in species prevalence (i.e. the proportion of lists on which a species occurs in a given year) with a logistic regression using Bayesian inference and Markov chain Monte Carlo (MCMC) sampling to estimate the probability of a species occurring on a list as a function of list length and survey year. It would be just as easy to perform LLA using a different statistical model (e.g., probit regression) or fit it using a different technique, such as maximum likelihood or machine learning, but in our opinion the Bayesian approach makes it more intuitive to interpret.

In Model I we included a regression term to account for protected area status (recorded in or out of the protected area) and an interaction term to estimate the impact of protection for each species.

Model 1:

$$\Pr(y_{ij}=1) = \mathrm{logit}^{-1}(\beta_i^{(0)} + \log_{\mathrm{e}}(\mathrm{L}_j)\beta_i^{(1)} + \mathrm{Year}_j\beta_i^{(2)} + \mathrm{PA}_j\beta_i^{(3)} + \mathrm{Year}_j\mathrm{PA}_j\beta_i^{(4)}),$$
$$\text{for } i = 1,\ldots,\mathrm{N}^{\mathrm{species}};\, j = 1,\ldots,\mathrm{N}^{\mathrm{lists}}$$

where Pr(y_{ij} =1) is the probability of observing the i^{th} species on the j^{th} List, L is the list length, and Year is year of observation (centered on 2003). The coefficients, $\beta_i^{(0-4)}$, each have normal prior distributions (see below); $\beta_i^{(0)}$ is the intercept term and reflects the overall prevalence of the species, $\beta_i^{(1)}$ describes the multiplicative effect of increasing list length, $\beta_i^{(2)}$ is the term for change per year, PA is a binary term for protection status (1 for inside, 0 for outside protected area), $\beta_i^{(3)}$ is the effect of protection and $\beta_i^{(4)}$ is the difference in change in prevalence through time (i.e., the relative difference in trends through time, depending upon whether the species is within or outside of a protected area).

We used vague priors (Gelman, 2006) for the regression coefficients (normal distribution with means zero and standard deviation 10,000). List length was centered on the mean list length. We sampled from three MCMC chains for each model and assessed convergence using multiple diagnostics, including trace plots, auto-correlations plots, and the Gelman-Rubin statistic (Zuur *et al.*, 2002), for each species. Convergence was always achieved within 5,000 iterations, but we used a more conservative 10,000 samples as burn-in. We used a subsequent 20,000 iterations from each of the three chains for inference and further analysis.

Analyses were performed in R v2.15.0 (R Development Core Team, 2012) and the program JAGS (Plummer, 2003) via the R package R2jags, using the Liszt package for LLA in R (Barnes *et al.* 2013; available at http://www.edg.org.au/free-tools/listlength.html).

RESULTS

There were 5764 lists available across the Wet Tropics between 1998 and 2009. Of these, 3250 were outside, and 2514 were within protected areas. The maximum list length was 127 species outside, and 94 inside, respectively. Mean list length per year did not change substantially over time ($r_2 = 0.294$), and there was no significant difference in mean list length inside ($\mu_{inside} =$ 18.4) and outside ($\mu_{outside} =$ 19.5) protected areas (W=2834, p =0.655). Sampling effort varied across years – it was highest in 2000 and 2001, driven by increased sampling for a project to map the distribution of birds across all of Australia (Barrett *et al.*, 2003), but the distribution of sampling density across years remained similar within and outside of protected areas across years.

Among the species with sufficient data, 12 are upland endemics, and nine are regionally restricted species or sub-species (based on Williams 2006). No species were preferentially recorded on shorter lists (Table 1). All 21 species reached convergence for all parameter values in all models (Rhat < 1.10).

Overall, the prevalence of 18 of the 21 species evaluated has remained stable since 1996 (Figure 2a, Table 1). Bower's Shrike Thrush (*Colluricincla boweri*) and Eastern Whipbird (*Psophodes olivaceus)* increased and Satin Bowerbird (*Ptilonorhynchus violaceus*) declined (Figure 2a, Table 1). Not all species were equally likely to be found within and outside of protected areas (Figure 2b). Most wet tropics endemics (*n*=16) were more likely to be recorded within a protected area (credible interval of $\beta_i^{(3)}$ parameter estimate does not overlap zero) (Figure 2b). Two species, Mountain Thornbill (*Acanthiza katherina*) and Atherton Scrubwren (*Sericornis keri*) are more likely to be recorded outside of protected areas. Changes in the prevalence of wet tropics endemics (relative to all species within the community) within protected areas are similar to those in external habitat (Figure 2c). However, Atherton Scrubwren was markedly more prevalent within protected areas, compared to outside protected areas (Figure 2b, Table 1), where they are more likely to be recorded (Figure 2b).

Figure 2 here

DISCUSSION

Since protected areas underpin most global conservation efforts, to ensure that biodiversity outcomes are maximised it is critical to understand how effectively protected areas are able to protect their conservation values relative to alternative management options. Recent evidence suggests that protected areas often constitute important spatial refuges, and contribute to achieving holistic biodiversity conservation goals (Simberloff, 1998; Devictor *et al.*, 2007; Thiollay, 2007), and that species with a greater proportion of their extent within protected area boundaries experienced smaller increases in extinction risk over recent decades (Taylor *et al.* 2011, Butchart *et al.* 2012). However, these studies did not account for establishment (placement) bias in the current protected area network (Joppa & Pfaff, 2009), and are therefore unable to estimate impact (Craigie *et al.* In Press).

Although conservation overall appears to have impacted vertebrate species trends worldwide (Hoffman *et al.* 2010), trends within individual protected areas are variable, and it is often unclear whether they are effective in improving or even maintaining their biodiversity values, both in absolute terms, and also relative to alternative conservation mechanisms or land uses (Ferraro and Pattanyak 2006). Especially in the tropics, few species have sufficient monitoring data to even estimate status and trends (Sodhi *et al.* 2011). Meanwhile, policy and management decisions are made in the absence of sufficient information. In Australia, this is the first study to evaluate the impact of protected areas on wildlife relative to a counterfactual alternative, as opposed to performance in terms of coverage or occurrence. It also includes common species, which are more useful surrogate indicators of ecosystem function and health compared to rare species (Gregory *et al.*, 2005). As a result, the findings of this study are directly applicable to both management and policy in Australia, and application of the approach more broadly could make impact evaluation using citizen science possible worldwide.

Overall Trends

The availability of lists across the Australian Wet Tropics (AWT) region meant that it was possible to evaluate the impact of protection even though systematic monitoring data are unavailable. Our results indicate that the endemic and regionally restricted avifauna evaluated appear to be stable across the Wet Tropics bioregion since 1998 (prevalence through time stable for 18 of the 21 species; Figure 2a), a finding that agrees with the most recent Red List assessment (Garnett *et al.*, 2011). Given dire predictions for a number of Wet Tropics endemic species in the face of climate change (Garnett and Franklin 2014), it is good to know that no major declines are yet evident overall. Further, substantial portions of the Wet Tropics were also adversely affected by two severe tropical cyclones during the study period, and resultant local declines have been reported for some of the species assessed (notably Golden and Tooth-billed Bowerbirds) (Harrington 2011, G. Harrington pers.comm.). Though the confidence intervals for these species are broad (Figure 2a), it is promising that sharp declines have not been noted, especially for Golden Bowerbirds, who are among the most vulnerable species in the Wet Tropics under climate change.

Effect of protected areas

Sixteen species were more likely to be found within protected areas, two more likely to be recorded outside, and three showed no statistically significant difference (Figure 2, Table 1), suggesting that these protected areas include important core habitat for several of these species. This seems likely, as several of these species prefer cooler, higher altitude rainforest, which is more prevalent within protected areas as a result of bias in placement to higher, less arable lands.

There was no difference in trends in prevalence between protected areas and unprotected forests. Based on this finding, simply maintaining habitat may therefore be enough to ensure the survival of most endemic and regionally restricted avian species or sub-species in the Wet Tropics. It is possible that there is insufficient power to detect change, but the consistency of the finding across the selected species is convincing. The finding is true for all study species except for the Atherton Scrubwren, which was more likely to be recorded outside the protected areas network. Overall Atherton Scrubwren is performing well both inside and outside protected areas, but this species appears to be performing better in protected areas. Although the observation sample size is restricted (Table 1), it appears robust. However, species distribution modeling predicts a greater likelihood of occurrence within protected areas for Atherton Scrubwren, which is not supported by our findings (Williams, 2006). Since Atherton Scrubwren is very similar to the more widespread Large-billed Scrubwren, so it may be mis-identified, or not recorded when present, and variation in detectability (e.g. if they are easier to identify on forest edges) may also be influencing results. Alternatively, if sites of high value for Atherton Scrubwren are preferentially targeted, or targeted by more skilled observers, this might also explain the discrepancy, especially if known sites outside the protected area network are more accessible. Either way, further investigation of the causal mechanisms underlying the estimated trends would be worthwhile. Further, we would recommend more systematic monitoring for species with high uncertainty, small sample size, indicated declines and differences between protected and unprotected areas: Golden Bowerbird, Fernwren, Atherton Scrubwren, and Satin Bowerbird.

The cause for an apparent lack of difference between protected and unprotected areas could be either because of equally effective, or equally ineffective land management within and outside of protected areas. The forests of the entire wet tropics bioregion are subject to landscape planning and broad-scale threat mitigation actions by the WTMA, which made substantial investments in the last 20 years in restoration, education, engagement and planning across the region (WTMA, 2010). Further, logging of all wet tropics rainforest ceased in 1988 (Kouki & Väänänen, 2000), and ecotourism has become increasingly important in the AWT WHA region, currently generating around 400 million dollars per annum (Prideaux & Falco-Mammone, 2007; Driml *et al.*, 2011). Tourism dollars create an economic incentive for managing private land for biodiversity values. As a result, one might expect the conservation values of habitat outside protected areas to be retained. Active management of protected areas in the Wet Tropics is essentially confined to weed control, visitor management, fire management at boundaries, some feral animal control (primarily pig) and facilities maintenance. More than half of the Queensland Parks and Wildlife Service budget is spent on visitor facilities and management (ID Craigie, pers. comm.). Biodiversity objectives are often sidelined in response to other concerns, and less than 30% of operational budgets are spent on biodiversity management, including monitoring and evaluation (ID Craigie, pers. comm.). Given the relative contiguity of remaining rainforest, and management that includes invasive species control outside protected areas, forests of both protection statuses may be functionally similar, explaining the lack of relative impact of protection.

Alternatively, the trends we identify in this study could be attributed to generally low levels of important threats across the Wet Tropics bioregion in remnant habitat, resulting in no change overall, or equally effective threat mitigation in both protected and unprotected areas. Unprotected areas with remnant habitat may be *de facto* protected as result of being remote, of marginal commercial utility, or both (DeFries *et al.*, 2005; Joppa & Pfaff, 2009). Alternatively, they could be subject to low levels of threat as a result of planning and broad-scale management. The greatest marginal benefit would be expected in the presence of extremely high threat (Evans *et al.*, 2011), and may be close to nil in the absence of threat. For instance, threatened vultures in West Africa, which are subject to direct persecution, are now found only within protected areas, whereas the distribution of smaller birds, which are not targeted or hunted, remain ubiquitous (Thiollay, 2007). Conversely, restriction of access and retention of larger habitat patches are key actions and consequences of formal protection. Another possible influence on bird density is connectivity – given that protected areas appear to represent important habitat, they could be acting as source populations for other areas. In other studies, proximity to rainforest or proportion rainforest cover were the best predictors of population trajectories for several northern Australian birds (Price *et al.*, 1999), and in Finnish protected areas, proximity to contiguous habitat in Russia was the best predictor of woodland bird populations (Virkkala & Rajasärkkä, 2007). Testing this is beyond the scope of this study. It is a logical extension, but would only be possible with longitudinal demographic data, or marking and tracking individual birds (Pavlacky Jr., 2008; Pavlacky Jr *et al.*, 2009; Shanahan & Possingham, 2009). For species with estimated declines and high uncertainty, it is a potentially worthwhile investment.

It is important to note that LLA can only estimate changes in the abundance of a species relative to other species. If all species were increasing or decreasing in abundance at the same rate, then there would be no measured change for any species. In reality, this is exceedingly unlikely, as all species would have to respond in the same direction at the same rate simultaneously, and for the same survey effort lists would become shorter through time (Szabo *et al.*, 2010), which was not the case in this study. Nonetheless, given the absence of monitoring data for many tropical birds (and other taxa), in the absence of standardised monitoring programs, this method is an important tool for conservation managers and decision makers

Advantages of LLA for Impact Evaluation

Using LLA is a simple and cost-effective option for the post-hoc evaluation of policy and management interventions when only list data is available. We used LLA to evaluate the impact of protected areas, but it could easily be used to investigate any comparators (e.g. areas with management action and control areas), or modified to consider continuous or multinomial factors (e.g. different intensities of management actions, such as feral predator control). For instance, LLA has recently been applied to estimate impacts of climate change (Breed *et al.*, 2013), and could be applied to many other spatially or temporally distinct management actions. List Length Analysis therefore has exciting implications for evaluating the impacts of protection elsewhere. Species lists are often the only historical data we have, and in many parts of the world the only existing data. For instance, LLA could be extremely valuable to prioritise monitoring and actions in regions of both high avifaunal diversity and high threat, such as the Brazilian Atlantic Forest or other hotspots (Myers *et al.,* 2000). Further, such evaluation does not need to be restricted to birds. Any taxa with sufficient, reliable, detectability and sampling density are viable candidates for LLA, for example: amphibians (especially frogs), Lepidoptera, and Odonata. More complex analytical techniques, such as occupancy modeling, can also be applied where sufficient list data occurs (e.g. Broms *et al.,* 2013)

Management Implications

Our findings have direct implications for the monitoring and management of the Wet Tropics World Heritage Area and other landscape-scale management approaches. Since the planning and management of the Wet Tropics Management Authority has no detectable marginal benefit within the National Reserve System, it is therefore conceivable that our results reflect the effectiveness of landscape management. Maintaining intact rainforest habitat therefore seems fundamental to ensure the conservation of viable populations of endemic and range-restricted birds in the Queensland wet tropics in the medium term. Stable overall populations over the last 14 years are reassuring from a conservation standpoint, and a positive reflection of the investment in a holistic land management approach in the Wet Tropics (WTMA, 2010, 2012). If this is the case, then arresting further habitat conversion is critical. Clearing between 1970 and 1985 was immense, exceeding 1500 hectares per annum (DERM, 2010). It has since been reduced, but conversion of wooded habitat in the wet tropics bioregion is still estimated at approximately 423 hectares per annum, although the rate of conversion is lower within protected areas (DERM, 2010), indicating that they may be important future refuges. Our findings are supported by recent work on woodland birds in New South Wales, Australia, which indicates protected area effectiveness for vulnerable woodland birds is strongly influenced by the physical characteristics and landscape context of the site, and can diminish with changes in surrounding land use over time (Rayner *et al.*, 2013).

Unfortunately, recent relaxation of land clearing laws that were intended to prevent broad-scale vegetation clearing in Queensland (Queensland Government, 2013) are likely to result in increased land use conversion. If the persistence of birds in Australia can be achieved with simple protection of habitat, Category I – IV protected areas are therefore likely to become more important: legally, they are currently the only areas in Australia that are protected from mining and logging in perpetuity (*Nature Conservation Act 1992, Qld*), at least in most jurisdictions. However, even when protected areas are successful in maintaining species populations, gap analysis based on biodiversity hot spots and threatened species coverage has concluded that protected areas alone are not adequate for nature conservation in the long term (Rodrigues *et al.*, 2004; Virkkala & Rajasärkkä, 2007; Watson *et al.*, 2010). Both protected areas and off-reserve conservation schemes have important roles to play in securing species populations (Rayner *et al.*, 2013), and the actions of the WTMA and local landholders in the face of these challenges will therefore be vital for ongoing maintenance of rainforest avifauna.

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Table 1. List of species included in this analysis with common and scientific names, identification code and level of endemicity (1 = upland endemics, only found above 700m, 2 = regionally restricted species or sub-species, only found in the AWT, 3 = regionally restricted species or subspecies only found in rainforest within Queensland (after Williams 2006 and WTMA 2010). Sample size shows the number of occurrences of each species on all lists, only lists within protected areas, and only lists outside protected areas. The relative impact column describes the estimated impact of protection: 1 = detected relative impact, 0 = no difference in detected impact between treatments.

Common Name	**Scientific Name (Chrisitidis & Boles, 2008)**	**ID Code**	**Endemicity**	**Number of Records**			**Relative Impact**
				All	**In PAs**	**Outside PAs**	
Atherton Scrubwren	*Sericornis keri*	ATSC	3	158	57	101	1
Australian King-Parrot	*Alisterus scapularis*	AKPA	1	209	133	76	0
Bower's Shrike-thrush	*Colluricincla boweri*	BOST	1	228	126	102	0
Bridled Honeyeater	*Lichenostomus frenatus*	BRIH	3	437	272	165	0
Brown Gerygone	*Gerygone mouki*	BRGG	2	426	318	108	0
Chowchilla	*Orthonyx spaldingii*	CHOW	3	290	170	120	0
Double-eyed Fig-Parrot	*Cyclopsitta diophthalma*	DEFP	3	336	175	161	0
Eastern Whipbird	*Psophodes olivaceus*	EAWH	3	644	444	200	0
Fernwren	*Oreoscopus gutturalis*	FEWR	1	138	63	75	0
Golden Bowerbird	*Amblyornis newtonianus*	GOBB	1	81	44	37	0
Grey Fantail	*Rhipidura albiscapa*	GRFA	3	893	564	329	0
Grey-headed Robin	*Heteromyias cinereifrons*	GHRO	1	513	341	172	0
Macleay's Honeyeater	*Xanthotis macleayanus*	MAHE	2	526	360	166	0
Mountain Thornbill	*Acanthiza katherina*	MOTB	1	190	71	119	0
Pale-yellow Robin	*Tregellasia capito*	PYRO	3	624	421	203	0
Pied Monarch	*Arses kaupi*	PIMO	2	213	153	60	0
Satin Bowerbird	*Ptilonorhynchus violaceus*	SABB	1	136	99	37	0
Spotted Catbird	*Ailuroedus melanotis*	SPCB	3	598	403	195	0
Tooth-billed Bowerbird	*Scenopoeetes dentirostris*	TBBB	1	192	118	74	0
Victoria's Riflebird	*Ptiloris victoriae*	VIRI	2	514	345	169	0
Yellow-breasted Boatbill	*Machaerirhynchus flaviventer*	YBBB	3	297	204	93	0

Figures

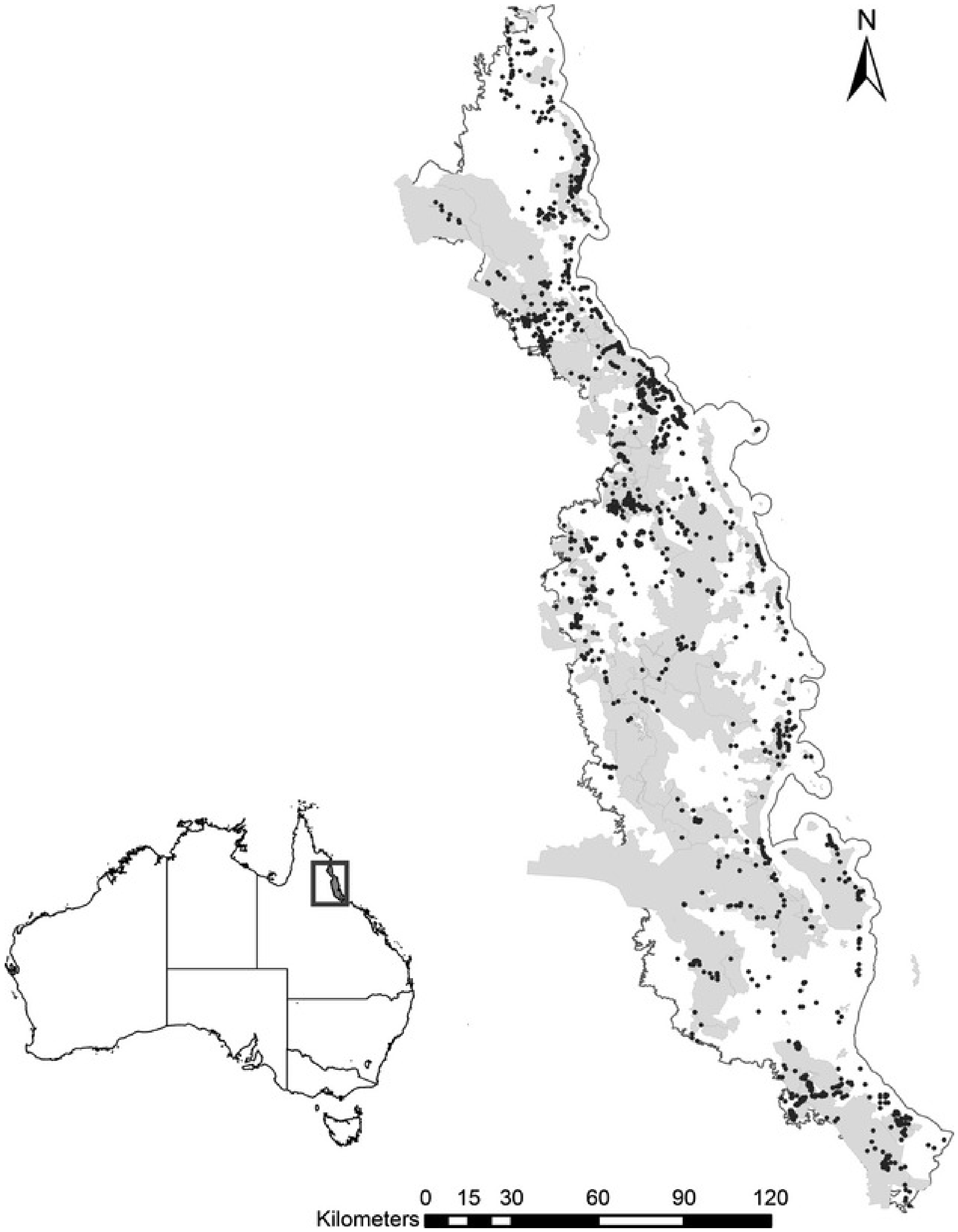

Figure 1. Protected area polygons (grey polygons) and distribution of lists included (grey circles) both within and outside of protected areas in the Australian Wet Tropics, and location of the bioregion in Australia (inset).....5

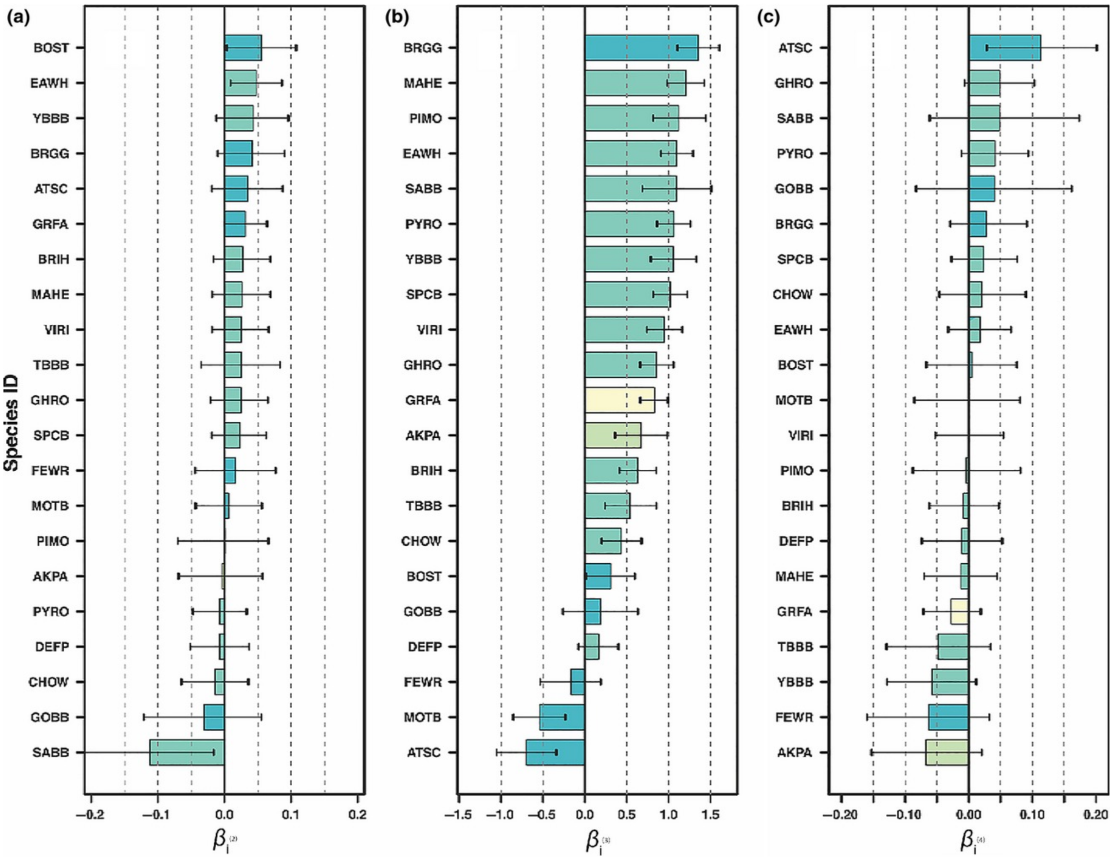

Figure 2. Median parameter estimates with upper and lower 95% credibility intervals for all selected species (n=21). (a) Overall annual change in median prevalence between 1998 and 2012, where credible intervals overlap zero no significant change in prevalence has been detected. (b) Likelihood of occurrence in a protected area. Species with estimates significantly greater than zero are more likely to be recorded within protected areas, species with estimates significantly less than zero are more likely to be recorded outside of protected areas, where credible intervals overlap zero, species exhibit no significant difference in likelihood of being recorded. (c) Impact of protection: species with significantly positive parameter estimates exhibit a relatively greater increase in prevalence within protected areas. Significantly negative parameter estimates indicate a relatively greater increase in prevalence outside of protected areas. Species for which credible intervals overlap zero exhibit no difference in change in prevalence between protected and unprotected areas. Full species names are listed in Table 1. Colours indicate the degree of rainforest specialisation as defined by Williams (2006). Yellow = Rainforest obligate, Green = Rainforest is core habitat, but also found in wet schlerophyll and Teal= Rainforest is a main habitat, but the species is also common in other forested habitat......................7

Supporting Information

APPENDIX S1: Conceptual Approach: List Length Analysis

Lists are species data that, at a minimum, constitute a list of species identified during a survey, from which the number of species encountered (list length) can be calculated. List Length Analysis (LLA) is a technique developed to estimate population trends from lists using logistic regression in a Bayesian framework.

The technique was first developed by Franklin (1999) to deal with the problem of unknown effort while quantifying long-term declines in granivorous birds in Northern Australia. Franklin (1999) used change in relative likelihood of occurrence on species lists to estimate trends. Standard LLA fits a three-parameter logistic regression and makes the simple assumption that the more species that are reported during a given survey, the greater the observation effort. The method also assumes a stable community size through time, so that any change through time is assumed to be a result of change in detectability. Adding the list-length parameter to the regression acts as a complex proxy for observer effort and detectability. Use of virtual data (Baxter *et al*. in prep) indicates that list length analysis is superior to reporting rate analysis (i.e. LLA without list-lengths) in predicting trends.

Szabo *et al.* (2010) extended Franklin's methods by examining the relative performance of various modifications of Franklin's equation in both Bayesian and frequentist frameworks. They found the simple List Length corrected model in a Bayesian framework to be more robust compared to a frequentist framework. In a subsequent publication the technique was validated in comparison to more robust population survey methods (Szabo *et al.* 2011).

The probability of observing a given species tends to be low on the shortest lists, and reaches 1.0 as the list length reaches the total number of species in all lists combined (i.e. the whole community). List Length Analysis monitors the relationship between the probability of the presence of a species and the length of the lists it occurred on through time. Rare species have a low probability of detection that remains close to zero as list length increases, reaching 1.0 only on the longest lists. Common species have a higher probability of occurrence and detection and compared to rare species are more likely to be recorded on short lists. Therefore, when the relative abundance of a given species changes over time, the curve of the probability of its observation versus list length will change correspondingly. The reporting rate (i.e. the proportion of lists on which a species occurs, or the probability of occurrence of a particular species on a list of a given length) will decrease as a species becomes less abundant and increase as it becomes more abundant. Since data are relative, as one species becomes more common and its curve shifts up and towards the left, the remaining species become relatively less common and their curves shift down and towards the right. The larger the species pool, the smaller the effect of any one species on the others.

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BioSketch:

Megan Barnes is a postdoctoral fellow at the NERP Environmental Decisions Hub in the Centre for Biodiversity and Conservation at the University of Queensland. She is actively engaged in research pushing the boundaries of evaluation in protected areas management, and optimal conservation decision making more broadly. She is also engaged in research focused on adaptive monitoring and management and passionate about integrating unstructured data into formal decision science, as well as an active citizen scientist herself.

All authors are current or past members of the Centre for Excellence in Environmental Decisions (www.ceed.org), and the project was condcuted as part of the National Environmental Research Program Environmental Decisions Hub. The authors focus on developing tools for working with citizen science data using Bayesian inference, especially for birds (http://www.edg.org.au/free-tools/listlength.html). All four authors work on different aspects of applied decision science to inform conservation decisions and to prioritise monitoring and management in Australia and worldwide.