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Monitoring an endemic community of terrestrial birds: the Galápagos Islands Breeding Bird Survey (GIBBS).

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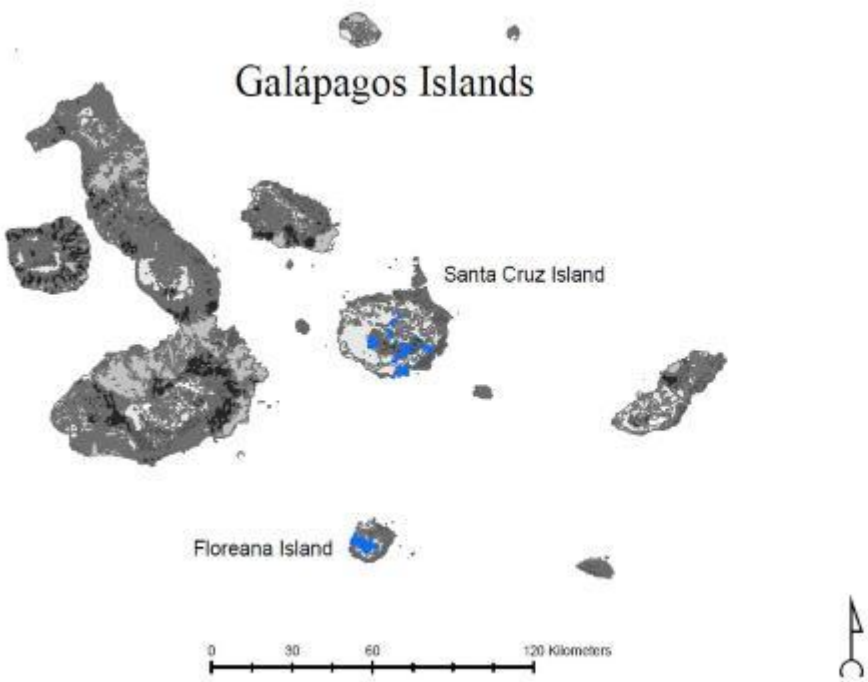
Abstract. Monitoring avifauna on remote island holding numerous endemics needs well-designed and standardize field methods. We tested two field methods to develop a breeding bird survey dedicated to terrestrial birds on the Galapagos Islands, with the help of few volunteer observers. Sampling on count points and along transects have been conducted on Santa Cruz and Floreana islands. By analyzing the survey data, we found that observed abundances varied with field method and observer identity. We therefore advocate for transects surveyed by trained observers to conduct such a BBS. Finally, we report significant variations in abundance among habitats for ten terrestrial species.

Introduction

Bird monitoring is widely used to assess the impacts of human activities and of global environmental changes on biodiversity (Thaxter et al. 2010). From count data, conservationists build indices of trends in population size and community composition. Ideally, these indices should be used for the assessment of management actions and for adaptive conservation planning (Fleishman et al. 2006; Gregory, 2005; Noss 1996).

In the Galapagos Islands, human activities are known to threaten populations of endemic species, mainly through biological invasions and habitat changes. For instance, declines of populations of Warbler Finch (*Certidea olivacea)* and Medium Tree Finch (*Camarhynchus pauper)*, two localized endemic bird species of the humid highlands, are correlated with historical human occupancy and associated habitat loss (Donlan et al. 2007; Grant & Grant 2005). Climate change is also suspected to affect population dynamics; the increasing frequency of El Nino events limited population recovery of some species like Galapagos Penguin (*Spheniscus mendiculus*) and Floreana Mockingbird (*Mimus trifasciatus*) (Grant et al. 2000; Vargas et al. 2006; Vargas et al. 2007; Vargas 1987), whereas some Darwin's finches displayed a two-fold increase in breeding success (Grant & Grant 1987). Though, despite a high terrestrial bird endemism with 18 species out of 29 species, there is currently no integrated longterm monitoring to inform the trends in land bird numbers (apart from species-specific targeted, long-term research schemes; e.g. on finches, (Grant et al. 2000). The Darwin's finches represent the most diverse group (13 species), with three genus: *Geospiza* (four ground finches and two cactus finches), *Camarhynchus* (three tree finches, and Woodpecker, Vegetarian and Mangrove finches), and *Certhidea* (Warbler Finch). The other main group of closely related land birds is the *Nesomimus* mockingbirds (four species).



Floreana Island Sampling

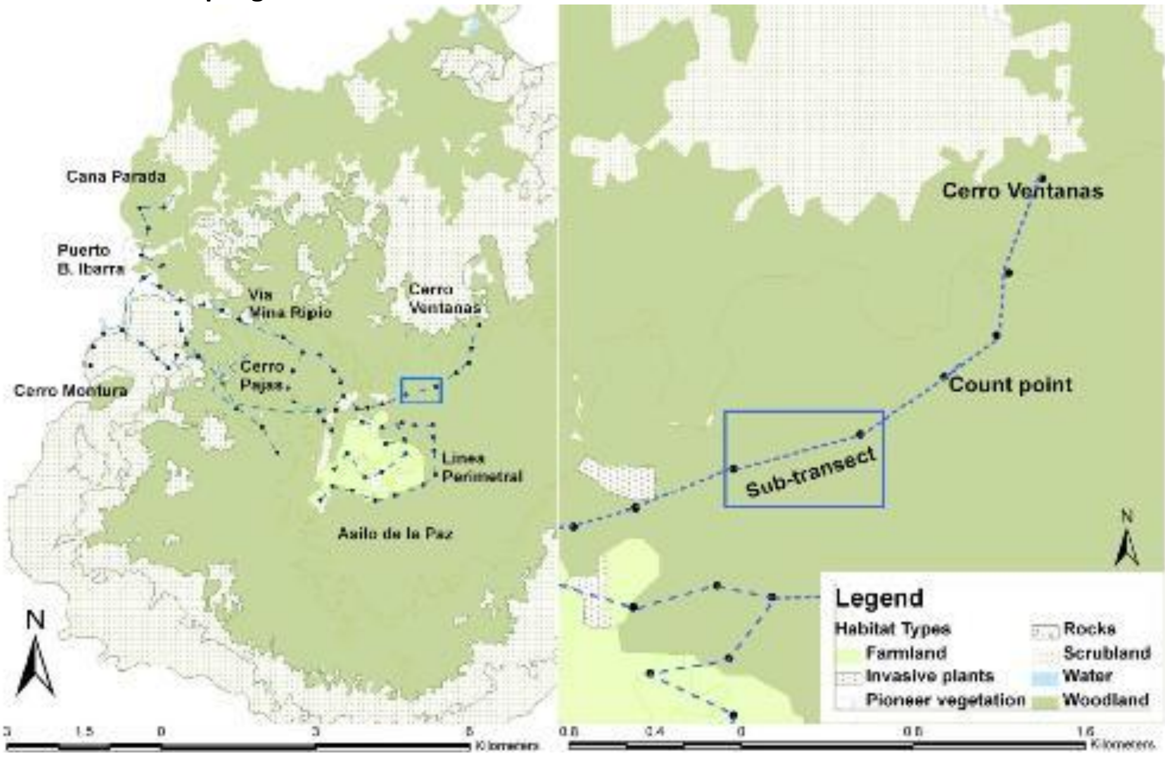


Figure 1. Locations of (upper) the GIBBS transects and point counts (in blue) on the islands of Santa Cruz and Floreana, and (lower) example of the detailed distribution across habitat types on Floreana (right panel is a zoom of the left panel).

Breeding Birds Survey (GIBBS) is to set up a cost-efficient, citizen-based, long-lasting monitoring scheme of terrestrial birds to be used for tracking spatial and temporal changes in population size and for informing policy makers and managers about the response of the bird community to their actions. This project was initiated in July 2009 with the support of the Charles Darwin Foundation (Ecuador) and the Museum National d'Histoire Naturelle (France). The first step was to define, test and optimize a monitoring protocol suitable for this largely endemic island avifauna (Vořišek et al. 2008). Specific objectives were: (i) to test the two widely-used monitoring methods, transects and point counts, in the major habitats of two test islands, and (ii) to statistically evaluate the influence of methodological components of the protocol (effects of the counting method, the observer and the date) on observed relative abundances.

Methods

Study area: island characteristics

The GIBBS protocol was tested on two islands with contrasted land management but similar avifauna: Santa Cruz (989 km2, 1°N 89°W) and Floreana (173 km2, 2°S 92°W; Fig. 1a). Santa Cruz is characterized by a higher extension of human-impacted habitats, with 8.1% of farmlands, 4.9% of invasive plants, and 0.4% of urban habitat, the rest of the island being mainly covered by forests 61.6%, 21.5**%** of scrubs, 3.2% shrubland. Floreana is less influenced by human activities, with only 1.2% of farmland, 0.9% of invasive plants, and 0.1% of urban habitat, and is equally covered by forests (48.7%) and scrubs (47.9%). Santa Cruz is twice higher in elevation (800 m a.s.n.) than Floreana (450 m).

Monitoring design and protocols

Birds were counted along 22 transects, which were subdivided into individual sub-transects units (300m). Transects were defined to be less than 3.5 km. At the start of each subtransect (and the end of the last one), we realized a 5-min point count (Bibby et al. 1992; Gregory 2004). We covered all the dominant habitats of the islands (> 10% coverage): woodland, scrubland, farmland and lands dominated by invasive plants (according to Clirsen 2006). Counts were distributed along domestic roads and tracks rather than at random, because of the lack of existing tracks in the forest habitats, and because of restricted access to cores of protected areas. A transect and associated point counts were implemented in half a day (6-10 a.m. or 4-6 p.m.) by one observer. Every individual bird that was heard or seen within a range of 150 meters from the observer was counted. Its distance from the observer (for both transects and point counts) and angle to the transect (for transects only) were measured, respectively, with a telemeter and a compass. Precise locations were taken with a GPS. Three different observers took part to the censuses. Observers were trained at visual and auditory bird identification (particularly for Darwin's finches) during eight hours prior to running GIBBS counts. This survey was conducted in 2010 during the breeding season (February 27 - April 25).

Statistical analyses

Sample size

The statistical unit considered in the analyses were the sub-transect and the corresponding point count. However we did not have such paired data for all sub-transects, what reduced the dataset to 90 sub-transects and 104 point counts. The sampling coverage per habitat type was 37% for woodland (n=72 sampling units), 29% for scrubland (n=56), 23% for farmland (n=46) and 10% for invasive plant habitat (n=20).

Species grouped

In a first approach we grouped the species in three categories based on physical traits: characteristics of sound (intensity, pitch and frequency), plumage coloration, body length and local abundance; the values were obtained from the literature (see Table 1). We created an Index of species recognition (IR) to better interpret further results on species relative abundances. This was necessary as field records were largely obtained by visual contacts (64%), and as the field work was carried out by local observers with little training.

Scientific names	Status	SC	FL	Length	Size	LO	CP	Song	Index (IR)	Level Identification
Geospiza fuliginosa	RE	O	O	11	0	1	0	0	1	Difficult
Geospiza fortis	RE	O	O	12.5	0.5	1	0	0	1.5	Difficult
Geospiza magnirostris	RE	O	NO	16	1	0.5	0	0	1.5	Difficult
Geospiza scandens	RE	O	O	14	0.5	1	0	0	1.5	Difficult
Camarhynchus parvulus	RE	O	O	11	0	1	0.5	0.5	2	Difficult
Camarhynchus psittacula	RE	O	O	13	0.5	0.5	0.5	0.5	2	Difficult
Camarhynchus pauper	RE	A	O	13	0.5	1	0.5	0.5	2.5	Difficult
Pyrocephalus rubinus	RE	O	NO	14	0	0	2	0.5	2.5	Easy
Certhidea olivacea	RE	O	NO	10	0	1	1	1	3	Easy
Crotophaga ani	I	O	O	35	1	1	0	1	3	Easy
Laterallus spilonotus	RE	O	A	15-16	1	0.5	1	0.5	3	Easy
Neocrex erythrops	R	O	O	18-20	1	0.5	1	0.5	3	Easy
Platyspiza crassirostris	RE	O	NO	16	1	0.5	0.5	1	3	Easy
Camarhynchus pallidus	RE	O	A	15	1	1	1	0.5	3.5	Easy
Myiarchus magnirostris	RE	O	O	16	1	1	1	1	4	Easy
Coccyzus melacoryphus	R	O	O	27	1	0	2	1	4	Easy
Dendroica petechia aureola	R	O	O	12	0	1	2	1	4	Easy
Nesomimus parvulus	RE	O	A	25	1	1	1	1	4	Easy
Zenaida galapagoensis	RE	O	O	18-23	1	0	2	1	4	Easy
Asio flammeus galapagoensis	RE	O	O	34-42	1	0.5	2	1	4.5	Easy
Bubulcus ibis	RE	O	O	50	1	1	2	1	5	Easy

Table 1. Observation of land birds during the GIBBS census in Galápagos Islands and the Species Recognition Index, estimated as explained in the Methods (IR<2.5= difficult; IR>2.5= easy). Other columns report the global status (RE: resident endemism; R: regional endemism; I: introduced); SC= Santa Cruz Island, FL= Floreana Island, O=observed, A=absent, NO=not observed. Data on songs have been found in (Bowman 2009; Podos & Nowicki 2001); data on CP=colours and body size come from (Swash & Still 2005) LO=local abundance from (Dvorak et al. 2011; Grant et al. 2005; O'Connor et al. 2010a); (Shriver et al. 2011); (Rosenberg et al. 1990).

Aquatic birds (*Anas bahamensis*, *Gallinula chloropus)* were discarded from the analyses because the field protocol was not appropriate for this group. Other species were also discarded because we obtained very few records: Short-eared Owl (*Asio flammeus*) (n=3), Galapagos Rail (*Laterallus spilonotus*) (n=8), and Paint-billed Crake (*Neocrex erythrops*) (n=10).

Statistical analysis

We based the analyses presented here on morning counts only. The dependent variable estimating the relative abundance was the total number of observed individuals (all species grouped), or the number of observed individuals per species for species-specific analyses. When a species had not been observed on a sub-transect or point, whereas it occurred in at least another sub-transect or point of the same transect, a value of 0 individual was given for each visit per counting unit of the transect where it was not detected. Variables that were examined for their effect on the relative abundance were the counting method (point *vs* transect), the identity of the observer (three observers), the date of survey (in days since 1st January), the island (Santa Cruz *vs* Floreana) and the habitat type (woodland, scrubland, farmland, land dominated by invasive plants), and two interactions between variables including habitat that were *a priori* expected to be of importance (habitat x method and habitat x observer; Table 2).

The variation in relative abundance between species, and between habitats within species, were analysed using the number of individuals per specie as dependant variable. The models also included the effects of the observer identity and the counting method to account for these potential confounding factors. The statistical effects were tested using nested generalized linear models (‘glm’) with *quasi- Poisson* distribution (O'Hara & Kotze 2010). We used the R Statistical computing environment (R Foundation for Statistical Computing (R 2008).

Response	Df	Res. Df	Deviance	F	P<0.05
Method: Habitat	185	450.19	-17.587	3.385	0.036
Method: Observer	183	432.61	-7.456	1.459	0.235
Date	184	441.7	-9.099	3.503	0.063
Island	185	443.42	-1.711	0.640	0.425
Observer	187	462.12	-18.709	3.496	0.032
Method	188	637.31	-193.89	24.155	<10 ^{8}

Table 2. Statistical dependence of the total number of birds counted per monitoring unit on the counting method (transect *vs.* point count), the habitat (four categories), the observer identity (three persons), the date (linear effect), the island (Santa Cruz *vs.* Floreana), and bivariate interactions. Tests were performed with comparisons of nested generalized linear model with quasi-Poisson distribution

Results

Global number of birds

21 species were detected on transects and 22 at point counts. Discarding aquatic species, sixteen terrestrial species remained for analyses.

The total number of detected birds was primarily affected by the counting method (Table 1): we counted twice more birds on transects than on points counts (Fig. 2; respectively 10.86□} 1.03 [S.E.] and 5.55 □} 1.04 birds, when computed from raw data). This methodological effect was similar for the three observers (see Table 2, interaction Method x Observer not significant). It was however variable among the different surveyed habitats (Table 2, *P*=0.036). The total number of birds was similar in all habitats but farmland where it was lower (Fig. 2a). The total number of detected birds did not differ significantly between islands (*P*>0.4) and displayed no significant linear trend throughout the study period (*P*>0.06).The observer effect was significant (Table2): the two assistant observers (2 and 3) detected less birds (respectively, -21.4%, *P*=0.003 for observer 2; -20.5%, *P*=0.067 so not significant for observer 3*)* than the main observer (1, N. Luzuriaga).

Number of individuals per species

When analysing data at the species level (Table 3), counts were significantly higher on transects than on point counts for Woodpecker Finch (*Camarhynchus pallidus)*, Yellow Warbler *(Dendroica petechia),* Galapagos Flycatcher (*Myiarchus magnirostris)*, Galapagos Mockingbird *(Nesomimus parvulus)* and for the group of Darwin’s finches (*Ps*<0.05). There was no significant difference for the remaining six species.

The relative abundance averaged across species was similar between woodland, scrubland and farmland habitats (*Ps*>0.20), but was significantly higher in habitats dominated by invasive plants (+9.14%, *P*=0.026) in comparison to woodland. The range of variation between habitat types was of similar importance than the range of variation between observers. Eventually, there was a small difference in relative abundance between the two islands, higher abundances occurring on Santa Cruz (slope = 1.455 □} 0.636) without obvious differences at the habitat level (habitat x island interaction not significant).

When we was analyzed the observer effect on the number of individuals detected by species, we found a reduced number of Galapagos Mockingbird (-9%, *P*<0.001), Vegetarian Finch (-20%, *P*<0.001) and Smooth-billed Ani (-14%, *P*=0.02) for Observer 2 and of Yellow Warbler (-40%, *P*=0.003*)* for observer3. The observer effects for the finch group and other remaining species was not significant.

The average number of individuals per species differed between habitats (species x habitat interaction) for six species and the finch group: Galapagos Flycatcher (*F3,190*= 3.11, *P*=0.02), Warbler Finch (*F3,190*=3.203*, P*=0.030)

Species		*Transects*			*Point Count*			
		estimate	**SD**	**N(log)**	**estimate**	**SD**	**N(log)**	**P<0.05**
Finch group	*Geospiza* & *Camarhynchus*	1.810	6.111	0.08	0.845	0.12	2.327	<0.000
Medium Tree Finch	*Camarhynchus pauper*	-1.658	0.421	0.190	-3.258	0.038	0.841	0.057
Vegetarian Finch	*Platyspiza crassirostris*	-2.420	0.595	0.089	-3.035	0.048	0.752	0.355
Woodpecker Finch	*Camarhynchus pallidus*	-1.409	0.359	0.244	-3.258	0.038	0.841	0.001
Warbler finch	*Certhidea olivacea*	-1.609	0.397	0.200	-2.005	0.135	0.450	0.518
Cattle Egret	*Bubulcus ibis*	-2.015	0.486	0.133	-1.118	0.327	0.289	0.355
Dark-billed Cuckoo	*Coccyzus melacoryphus*	-3.114	0.841	0.044	-2.698	0.067	0.636	0.550
Galápagos Flycatcher	*Myiarchus magnirostris*	-0.530	0.231	0.589	-0.375	0.688	0.293	0.031
Galápagos Mockingbird	*Nesomimus parvulus*	-0.650	0.245	0.522	-1.509	0.221	0.351	0.037
Smooth-billed Ani	*Crotophaga ani*	0.075	0.171	1.078	-0.340	0.712	0.196	0.203
Yellow Warbler	*Dendroica petechial aureola*	0.582	0.133	1.789	0.253	1.288	0.145	0.023

Table 3. Effect of the counting method on the number of observed individuals per species. Estimates of relative abundance (after exponential transformation to be expressed in number of individuals) are given for transects and point counts. Slope estimates quantify the difference in log-transformed number of individuals between the point count method (used as intercept value) and the transect method. They were obtained with generalized linear models, with quasi-Poisson distribution, and adjusted for the significant effects reported in Table 1. Species with a significantly higher number of contacts on transects than on point counts are in bold.

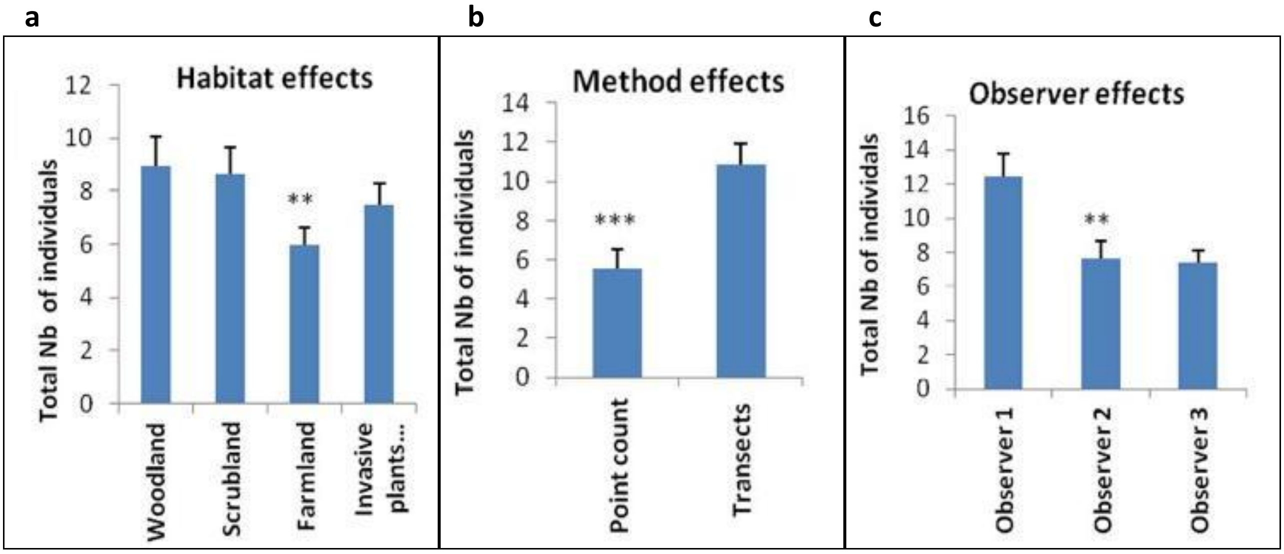


Figure 2. Mean (±SD) number of birds per counting according to (a) habitat type, (b) counting method, and (c) observer. Estimates were obtained with the statistical model described in Table 1.

Smooth-billed Ani (*F3,190*= 6.34*, P*<0.001), Galapagos Mockingbird (*F3,190*=10.36*, P*<0.001), Vegetarian Finch (*F3,190*=9.99*, P*<0.001), Cattle Egret (*F3,190*=5.27*, P*<0.001) and finch group (*F3,190*=20.05*, P*<0.001).

For the Galapagos Mockingbird, the relative abundance was maximal in woodland and scrubland, and significantly lower in farmland (*P*=0.015, woodland intercept) and in habitats dominated by invasive plants (where it was not observed; Fig. 3). The relative abundance of the finch group was maximal on woodland (intercept=1.70�}0.09 SE) and reduce on farmland 20% (*P*=0.010) and 16% on invasive plant habitat (*P*=0.004); within the other species, the Warbler Finch showed a higher abundance in invasive plants habitat (*P*=0.010).

In woodland, the relative abundance was highest for the finches (6.47�}8.46) individuals per counting unit), Yellow Warbler (1.63�}1.83), followed by Galapagos Mockingbird (0.46�}0.60) and Galapagos flycatcher (0.38�}0.52). In scrubland, the highest relative abundance was for finches (5.83±8.42), Yellow Warbler (1.37±1.58), followed by Galapagos Flycatcher (0.92±1.12) and Smooth-billed Ani (0.80±1.09). In farmland, the finch group (3.1±4.6) and Smooth-billed Ani (1.54±1.97) were the most abundant species, followed by Yellow Warbler (1.28±1.55). In habitats dominated by invasive plants, the commonest species were Yellow Warbler (2.04±2.49), Smooth-billed Ani (1.59±2.39) and Galapagos Flycatcher (1.63±1.83; Fig. 3).

and 1 introduced species (Smoot-billed Ani) on both islands.We did not observe any migrant or vagrant species. The species that we did not observe on Santa Cruz were the Galapagos Hawk (*Buteo galapagoensis*), a resident endemic species, and the Barn Owl (*Tyto alba punctatissima*), a resident endemic subspecies. On Floreana, we did not observe the following species: Barn Owl*,* Warbler Finch *(Certhidea fusca ridgway),* Large Tree Finch, Large Ground Finch and Vegetarian Finch (*Platyspiza crassirostris*) (Grant et al. 2005).

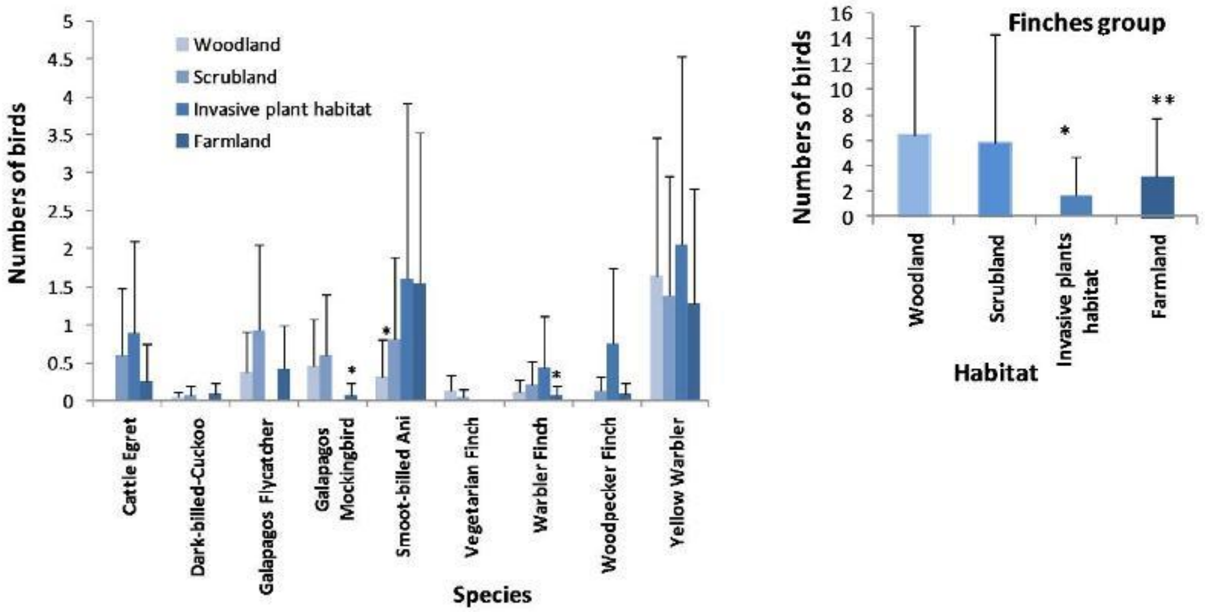


Figure 3. Variation in abundance per species among habitats, (Means ±SD) 95% (categories significantly differing from others marked with an asterisk). The model (glm) was adjusted for method and observer factors.

Discussion

We achieved to collect count data for 22 terrestrial bird species, which corresponds to 88% and 92% of the terrestrial breeding bird species listed respectively for the islands of Santa Cruz (n = 18) and Floreana (n=15).

Considering the species coverage per status category, we obtained counts for 14 resident endemic species (RE in Table 1) on Santa Cruz (77% of the island total) and 9 on Floreana (60%), 3 species with regional endemism (R) on Santa Cruz (60%) and 3 on Floreana (75%),

Transects produced on average twice more contacts with birds than point counts, a robust difference that was found for a majority of species. This is consistent with former comparative tests between the two methods (Alldredge et al. 2008). An interpretation is that during point counts, the observer has a restricted detection range (visual and auditory), contrary to transects where observers move and can more easily detect active birds (Brewster & Simons 2009). This is especially true in habitats or regions with relatively low bird density.

The finch group was the most commonly detected, 45% the data consisted of finches, 37% was for Medium Ground Finch. We justify the group-level analysis because observers were not highly experienced and because many observations related to finches were not identified to the species level. Also many finch species do share similar traits making their specific identification difficult (see Table 1), for example Large, Medium and Small ground finches. The variability in song, calls or plumage poses a major challenge in such counting procedures, where the observer does not have time to track individuals until he/she achieves to identify them with certainty. In the Galapagos Islands, this problem is essentially due to the high similarity (both vocal and visual) of finches of genus *Geospiza* and *Camarhynchus* (Podos 2004; Podos & Nowicki 2001; Ratcliffe & Grant 1985; Christensen et al. 2006; Dvorak et al. 2011). Our ability to identify birds to the species level was actually much higher in transect lines than in point counts ; respectively, 1.2% and 4.1% of unidentified records out of all records. Hence, implementing transects provides more counts, what secures a higher statistical power for detecting differences in relative abundance, but also lowers the risk of misidentification.

Our analyses revealed an obvious but expected variability among observers, possibly linked to varying individual experience in survey methods and species detection/identification. Differences between observers can introduce biases and reduce the precision of abundance estimates. Alldredge et al. (2007) used distance sampling approaches to conclude to a big difference between the density estimates obtained from data collected by experienced and by inexperienced observers (Alldredge et al. 2008; Alldredge et al. 2007).

Relying just on our data, we achieved to characterize some species-specific patterns of variation of relative abundance between habitats that are described in the literature. Among the island avifauna, Yellow Warbler, Galapagos Flycatcher and the invasive Smooth-billed Ani (Grant & de Vries 1993; Rosenberg et al. 1990) were identified as the more generalist species, occurring in all habitats and always ranking among the most observed species (O'Connor et al. 2010b), while the other species are more specialized: here Vegetarian and Woodpecker finches, as well as mockingbirds (Dvorak et al. 2011; Fessl et al. 2006; Tebbich et al. 2002). Among rare and localized species, we should mention that Galapagos Dove (*Zenaida galapagoensis*) and Vermillion Flycatcher (*Pyrocephalus rubinus)* have been detected on Santa Cruz, and also Medium Tree Finch which is endemic to Floreana.

Our results suggest that a sampling method based on transects would provide a representative sample of bird observations to study the spatial variations of the relative abundance of such terrestrial breeding birds. Further developments should also consider the study of variations in detection probability, probably using distance sampling approaches. We also recommend that if a long-term breeding bird survey was to be started on the Galapagos Island, observers should first be trained to counting methods and to the identification of finches, in order to minimize observer variability and reduce error on parameters estimation.

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