# Appendix 1: Study sites, bird assemblages and trait selections

## Complementary information about study areas

For the placement of the 23 focal landscapes with different forest covers, we also evaluated if forest cover varied within radii of 1, 2 or 3 km based on each landscape’s centroid. Landscape-level forest cover did not vary more than 5% within those radii, avoiding the influence of any outside larger patch on colonization processes (Pasher et al. 2013).

Sampling sites inside forest patches were spaced a minimum of 800 m apart (1591 ± 621 m) and they were placed within the forest patch at the end of a 100 m transect, always oriented to the center of the forest patch.

## Bird assemblages

We restricted our analysis to forest specialist and forest generalist species, excluding open area species eventually detected inside smaller forest patches. We recorded 180 bird species in both regions: 93 specialists and 87 generalists. **Specialist species richness** was higher in the low-quality than in the high-quality matrix region (82 and 68 species respectively), with 57 species common to both regions. However, the median of specialist species richness per landscape and site in the high-quality matrix was higher than in the low-quality matrix (Table S1). There were 11 specialist species (16% of total richness) in the high-quality matrix detected only once (singletons), and 15 singletons (18% of total richness) in the low-quality matrix.

**Generalist species richness** was quite similar between regions, with 77 and 74 species in the high and low-quality matrix, respectively (64 common species). Accordingly, generalist species richness per landscape and site did not varied much between high-quality and low-quality matrix region (Table S1). There were 9 singleton generalist species in the high-quality matrix (12% of total richness) and 12 in the low-quality matrix (16% of total richness). For more details in biodiversity metrics of both regions see Boesing et al. (2018).

**Table S1:** Species richness for the assemblages in the high and low-quality matrices across spatial scales.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Assemblage | | Total richness | Landscape | | Site |
| Median (min – max) | | Median (min – max) |
| Specialists | | 93 | |  |  |
|  | Low-quality matrix | 82 | | 32 (17 – 61) | 16 (4 – 42) |
|  | High-quality matrix | 68 | | 40 (29 – 48) | 24 (12 – 40) |
| Generalists | | 87 | |  |  |
|  | Low-quality matrix | 74 | | 38 (34 – 44) | 19 (10 – 31) |
|  | High-quality matrix | 77 | | 44.5 (38 – 49) | 22.5 (15 – 31) |
| Total | | 180 | |  |  |

## Species traits selection

The bird traits selected and the associated hypothesis of how species may respond to habitat loss according to its traits are summarized in Table S2 and described in detail in the following paragraphs.

**Table S2:** Bird traits selected, the operational variables, the sources of data, and the hypothesis of species habitat loss filtering according to trait values.

|  |  |  |  |
| --- | --- | --- | --- |
| Trait | Operational variable | Hypothesis | Data source |
| Body size | Log of mean body mass in grams. | Abundance decreases more intensely with habitat loss for larger species. | Ramirez et al. 2008; Rodrigues et al. 2019 |
| Nest type | Nest in cavities; open or semi-open nest; closed nest. | Abundance of species with open/semi-open decreases more intensely with habitat loss than other nest types. | Del Hoyo et al. 2014 |
| Diet | Main diet: omnivorous, frugivorous, nectarivorous, insectivorous, granivorous. | Abundance of frugivorous and insectivorous species decrease more intensely with habitat loss than other diets. | Sick 1997, Del Hoyo et al. 2014; Willman et al. 2014 |
| % of fruits in the diet. |
| % of invertebrates in the diet. |
| Foraging stratum | Main foraging stratum: ground and/or understory, midstory and/or canopy and all strata. | Abundance of species in the ground and understory strata decrease more intensely than species using midstory, canopy or all strata. | Sick 1997, Del Hoyo et al. 2014; Willman et al. 2014 |
| % of lower strata (ground and understory) use. |

**Body size** is one of the key attributes of vertebrates in respect of extinction risk, reproduction, and dispersal (Owens and Bennett 2000, Ripple et al. 2017). In birds, species with large mean body sizes are often considered more vulnerable to extinction given their low population densities, large home ranges, slow growth rates, high energetic requirements, and high sensitivity to anthropogenic overexploitation (Cardillo et al. 2005). The risk of local extinction in altered and smaller habitats correlates with mean body size (e.g. Barbaro and Halder 2009, Flynn et al. 2009, Newbold et al. 2013, Bregman et al. 2016, Bovo et al. 2018). However, sometimes this trait is not a good predictor of community changes (e.g. Tscharntke et al. 2008, Angert et al. 2011), probably because large species may also benefit from having higher mobility (Tscharntke et al. 2012). We compiled information on avian body mass in Boesing et al. (2018a), which followed Ramirez et al. (2008) and Rodrigues et al. (2019). Body mass was log-transformed before modeling.

**Nest type** is often associated with reproduction effort and is most likely to affect recruitment (Bennett and Owens 2002). For example, species that make nests in cavities have higher growth rates (Bellier et al. 2018) probably because it is a safer nest against parasitism and predation (Sibly et al. 2012). Nest predation and parasitism are among the most impacting factors of bird populations’ decline in fragmented landscapes (Cavitt and Martin 2002). In addition, the lack of suitable nesting habitats in disturbed environments can have a strong effect on the reproductive success of certain bird species, such as those from Picidae and Psittacidae families, which require old or dead trees to build their nests (Sick 1997). We assigned the species to 3 nesting categories: closed, cavity and open/semi-open. We collapsed open and semi-open nest types because of the low proportion of specialist species with open nests in our datasets. Nest type information was collected in Del Hoyo et al. (2014).

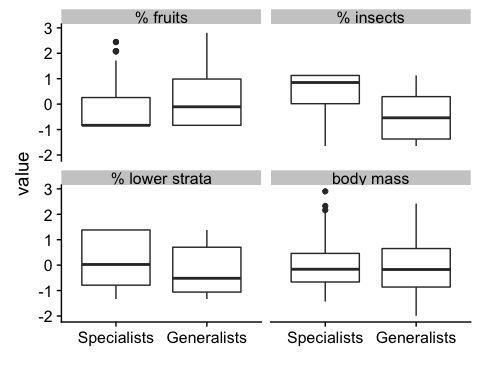
Habitat loss, fragmentation, and land-use change affect the structure of the habitat by altering differently the provision of food for birds. For example, nectarivorous, frugivorous, and insectivorous species seem to be more sensitive to habitat loss and fragmentation than omnivorous and granivorous (Şekercioğlu et al. 2004, Newbold et al. 2013, Bovo et al. 2018, Chatterjee and Basu 2018). We assigned species to five **main diet** categories according to information available in the literature (Sick 1997, Del Hoyo 2014): omnivorous, insectivorous, frugivorous, nectarivorous, granivorous. Because of the special relationship found for frugivorous and insectivorous species in land-use change (Newbold et al. 2014), we also assigned the proportion of each of these components in species’ diet as trait variables. The percentages of fruits and insects in the species’ diet were extracted from the EltonTrait database (Wilman et al. 2014). For the analysis, we excluded the single granivorous forest specialist species in the high-quality matrix region and two omnivorous forest specialist species in the low-quality matrix region because of problems during models fit.

**Foraging stratum** is of most importance for birds in fragmented landscapes. Ground and understory species are more prone to extinction (Laurance and Gomez 2005), mostly because of higher dispersal limitation and avoidance of open areas (gaps, matrix, and forest edges). We assigned each species to 3 foraging strata categories: ground-understory strata, midstory-canopy strata, and all strata. We also used the percentage of use of lower foraging strata (ground and understory) as an alternative variable extracted from EltonTrait database (Wilman et al. 2014).

## Comparing traits between forest specialists and generalists

All traits were compared between forest specialists and generalists using graphical and multi- variate analysis to ensure that the selected traits are comparable between groups, i.e. there was not a single trait that could separate specialist from and generalist species. The only noticeable difference between forest generalists and specialists was in the main diet variable, where there were nectarivorous birds only for generalists and insectivorous were more common among specialists.

Below, we present the comparisons of trait values between specialists and generalists. Continuous variables were Z-scores scaled and are presented in Figure S1, Categorical variables are summarized in Table S3.



**Figure S1:** Boxplots of values for the traits measured as continuous variables for the specialists and generalists. The species from both matrix type regions were grouped.

**Table S3:** Percentage of the species in each trait category for specialists and generalists. Numbers inside brackets are the number of species. The species from both regions were grouped.

|  |  |  |
| --- | --- | --- |
| **Traits** | **Specialists** | **Generalists** |
| **Nest type** |  |  |
| Cavities | 25% (23) | 22% (19) |
| Closed | 27% (25) | 21% (18) |
| Open\_semi | 48% (45) | 57% (50) |
| **Main diet** |  |  |
| Frugivorous | 17% (16) | 23% (20) |
| Granivorous | 2% (2) | 6% (5) |
| Insectivorous | 77% (72) | 40% (35) |
| Nectarivorous | 0% (0) | 15% (13) |
| Onivorous | 3% (3) | 16% (14) |
| **Foraging stratum** |  |  |
| All | 5% (5) | 20% (17) |
| Ground/Understory | 58% (54) | 32% (28) |
| Midstory/Canopy | 37% (34) | 48% (42) |

## References on bird traits and environmental change

Below, we list the consulted references of bird traits that could be related to extinction- proneness due to habitat loss, land use or environmental change.

Barbaro, L. & Halder, I.V. (2009). Linking bird, carabid beetle and butterfly life-history traits to habitat fragmentation in mosaic landscapes. Ecography 32, 321–333.

Barros, F.M., Martello, F., Peres, C.A., Pizo, M.A. & Ribeiro, M.C. (2019). Matrix type and landscape attributes modulate avian taxonomic and functional spillover across habitat boundaries in the Brazilian Atlantic Forest. *Oikos* **128**, 1600–1612.

Bellier, E., Kéry, M. & Schaub, M. (2018). Relationships between vital rates and ecological traits in an avian community. Journal of Animal Ecology 87, 1172–1181.

Boesing, A.L., Nichols, E. & Metzger, J.P. (2018). Biodiversity extinction thresholds are modulated by matrix type. Ecography 41, 1520–1533.

Bovo, A.A.A., Ferraz, K.M.P.M.B., Magioli, M., Alexandrino, E.R., Hasui, É., Ribeiro, M.C. & Tobias, J.A. (2018). Habitat fragmentation narrows the distribution of avian functional traits associated with seed dispersal in tropical forest. Perspectives in Ecology and Conservation 16, 90–96.

Bregman, T.P., Lees, A.C., MacGregor, H.E.A., Darski, B., Moura, N.G. de, Aleixo, A., Barlow, J. & Tobias, J.A. (2016). Using avian functional traits to assess the impact of land-cover change on ecosystem processes linked to resilience in tropical forests. *Proc. R. Soc. B* **283**, 20161289.

Bregman, T.P., Sekercioglu, C.H. & Tobias, J.A. (2014). Global patterns and predictors of bird species responses to forest fragmentation: Implications for ecosystem function and conservation. *Biological Conservation* **169**, 372–383.

Chatterjee, S. & Basu, P. (2018). Food preferences determine habitat selection at multiple scales: Implication for bird conservation in tropical forests. *Animal Conservation* **21**, 332–342.

Cleary, D.F.R., Boyle, T.J.B., Setyawati, T., Anggraeni, C.D., Loon, E.E.V. & Menken, S.B.J. (2007). Bird species and traits associated with logged and unlogged forest in borneo. *Ecological Applications* **17**, 1184–1197.

Cormont, A., Vos, C., Turnhout, C. van, Foppen, R. & Braak, C. ter. (2011). Using life-history traits to explain bird population responses to changing weather variability. *Climate Research* **49**, 59–71.

De Coster, G., Banks-Leite, C. & Metzger, J.P. (2015). Atlantic forest bird communities provide different but not fewer functions after habitat loss. *Proceedings of the Royal Society B: Biological Sciences* **282**, 20142844.

Flynn, D.F.B., Gogol-Prokurat, M., Nogeire, T., Molinari, N., Richers, B.T., Lin, B.B., Simpson, N., Mayfield, M.M. & DeClerck, F. (2009). Loss of functional diversity under land use intensification across multiple taxa. *Ecology Letters* **12**, 22–33.

Kupsch, D., Vendras, E., Ocampo-Ariza, C., Batáry, P., Motombi, F.N., Bobo, K.S. & Waltert, M. (2019). High critical forest habitat thresholds of native bird communities in Afrotropical agroforestry landscapes. *Biological Conservation* **230**, 20–28.

Luck, G.W., Carter, A. & Smallbone, L. (2013). Changes in Bird Functional Diversity across Multiple Land Uses: Interpretations of Functional Redundancy Depend on Functional Group Identity. *PLOS ONE* **8**, e63671.

Luck, G.W., Lavorel, S., McIntyre, S. & Lumb, K. (2012). Improving the application of vertebrate trait-based frameworks to the study of ecosystem services. *Journal of Animal Ecology* **81**, 1065–1076.

Macchi, L., Baumann, M., Bluhm, H., Baker, M., Levers, C., Grau, H.R. & Kuemmerle, T. (2019). Thresholds in forest bird communities along woody vegetation gradients in the South American Dry Chaco. *Journal of Applied Ecology* **56**, 629–639.

Martin, A.E., Desrochers, A. & Fahrig, L. (2017). Homogenization of dispersal ability across bird species in response to landscape change. *Oikos* **126**, 996–1003.

Martin, C.A. & Proulx, R. (2016). Habitat geometry, a step toward general bird community assembly rules in mature forests. *Forest Ecology and Management* **361**, 163–169.

Morante-Filho, J.C., Faria, D., Mariano-Neto, E. & Rhodes, J. (2015). Birds in Anthropogenic Land scapes: The Responses of Ecological Groups to Forest Loss in the Brazilian Atlantic Forest. *PLOS ONE* **10**, e0128923.

Newbold, T., Scharlemann, J.P.W., Butchart, S.H.M., Şekercioğlu, Ç.H., Alkemade, R., Booth, H. & Purves, D.W. (2013). Ecological traits affect the response of tropical forest bird species to land-use intensity. *Proceedings of the Royal Society B: Biological Sciences* **280**.

Owens, I.P.F. & Bennett, P.M. (2000). Ecological basis of extinction risk in birds: Habitat loss versus human persecution and introduced predators. *Proceedings of the National Academy of Sciences* **97**, 12144–12148.

Ripple, W.J., Wolf, C., Newsome, T.M., Hoffmann, M., Wirsing, A.J. & McCauley, D.J. (2017). Ex- tinction risk is most acute for the world’s largest and smallest vertebrates. *Proceedings of the National Academy of Sciences* **114**, 10678–10683.

Smith, Y.C.E., Smith, D.A.E., Seymour, C.L., Thébault, E. & Veen, F.J.F. van. (2015). Response of avian diversity to habitat modification can be predicted from life-history traits and ecological attributes. *Landscape Ecology* **30**, 1225–1239.

Şekercioğlu, Ç.H., Daily, G.C. & Ehrlich, P.R. (2004). Ecosystem consequences of bird declines. *Pro- ceedings of the National Academy of Sciences* **101**, 18042–18047.

Tscharntke, T., Sekercioglu, C.H., Dietsch, T.V., Sodhi, N.S., Hoehn, P. & Tylianakis, J.M. (2008). Landscape constraints on functional diversity of birds and insects in tropical agroecosystems. *Ecology* **89**, 944–951.

Vance, M.D., Fahrig, L. & Flather, C.H. (2003). Effect of reproductive rate on minimum habitat requirements of forest-breeding birds. *Ecology* **84**, 2643–2653.

White, H.J., Montgomery, I.W. & Lennon, J.J. (2018). Contribution of local rarity and climatic suitability to local extinction and colonization varies with species traits. *Journal of Animal Ecology* **87**, 1560–1572.