Long-term assessment of birds' extirpation from a tropical agroecosystem

ABSTRACT. To better understand the processes that may lead to potentially avoidable extinction events, it is important to identify the influence of change in the communities at the local scale. We compiled bird lists from a field station with an artificial wetland system and a history of drastic changes in land use in the Colombian Andes. This data expands from 1974 to 2018. Our assessment uses three criteria to recognize local extinction: looking at the short-term (last 5 years) variation, a comparison between baseline and the most recent data, and the time in between. These criteria also allowed us to quantify substantial colonization and recolonization events. We found that 5.9% of previously recorded species had become extirpated, 5.2% can be considered probably extirpated, and 6.7% are possibly extirpated. Moreover, there was an important turnover in foraging guilds which implies a transition in the community's functional diversity. The loss of artificial wetlands in addition to the local afforestation plan in the mid-90s at the study site likely constitute the leading factors for the observed gains and losses of species in the agroecosystem. We highlight the importance of multicriteria assessment in community-level studies to distinguish between an apparent persistence and an actual extirpation event over the long term. Artificial wetlands and agroecosystems should be better studied as they could complement regional conservation targets.

INTRODUCTION

Rapid extirpation of species at the local scale is a complex phenomenon that enhances the risk of extinction at various larger geographic scales. It can be difficult to trace local extinction events before it is too late to begin effective conservation efforts. It is of high importance, therefore, to describe the historical context associated with actual extirpation events. Concerns about the increasing decline of biodiversity in the Anthropocene are part of the 2020–2030 agenda for sustainable development of the United Nations (IUCN 2020, United Nations 2020). Worldwide, 14% of bird species are considered threatened (United Nations 2018, IUCN 2020). Determining which populations have a high risk of local extinction is especially difficult when the majority of contemporary research is limited in length and typically formed from only a few years of monitoring (Strayer et al. 2006, Gonzalez et al. 2016). The lack of long-term studies in many locations presents a formidable challenge for conservation biology (Sæther et al. 2005, Brooke et al. 2008, Stiles et al. 2017, Bretagnolle et al. 2018). Accurately identifying which species are vulnerable to local extinction is critical because false assessments could result in wasted resources or poor and ineffective conservation efforts at the species level.

Given the difficulty of predicting whether species will persist or become extirpated following habitat alteration and fragmentation, it is clear that long-term studies would provide the necessary
evidence to detect community-level changes (Strayer et al. 2006, Porzig et al. 2011, Blake and Loiselle 2016, Gonzalez et al. 2016, Cardinale et al. 2018, Stouffer 2020). Few long-term studies have been undertaken in Latin America (Blake et al. 2017, Stiles et al. 2017). Those which do exist have concentrated on bird communities in forested habitats (Stratford and Stouffer 1999, Pearson et al. 2010, Blake and Loiselle 2016, Palacio et al. 2020), and only a few have looked at birds in agroecosystems in tropical areas (Johnson et al. 2011, Sica et al. 2018, Sekercioglu et al. 2019).

Currently, a typical methodological approach of long-term studies is to detect species loss through the comparison of community composition between distinct sampling occasions separated in time (i.e., temporal comparison). This approach allows inference into the local disappearance of species (Kattan et al. 1994, Stratford and Stouffer 1999, Johnson et al. 2011, Chouteau et al. 2012, Sica et al. 2018). Usually, these studies lack a proper baseline and instead use the fieldwork of naturalists from the 19th and 20th centuries to examine changes in local assemblages or to detect extirpation (Kattan et al. 1994, Chouteau et al. 2012, Moura et al. 2014). Thus, how to define an extirpation event is crucial for community-level studies. In addition to the temporal comparison approach, alternatives have been developed such as the use of occupancy modeling (Pearson et al. 2010), standardized bird monitoring (Stiles et al. 2017), or, as in our study, implementing a multicriteria approach to define and assess extirpation.

A high risk of local extinction is an expected phenomenon in the context of habitat fragmentation (Feeley et al. 2007, Betts et al. 2017, Kehoe et al. 2017, Stouffer 2020), as occurs in areas of expanding intensive agriculture (Wretenberg et al. 2010), especially in the tropics (Laurance 2013, Betts et al. 2019). Colombia, a country located in the tropical Andes, is one of the richest hotspots for biodiversity in the world. In this Andean country, the loss of 90% of the native tropical dry forest has been driven by landscape conversion to agriculture (Portillo-Quintero and Sánchez-Azofeifa 2010, Pizano and García 2014). In particular, the Cauca River valley (hereafter Cauca Valley, ca. 3509.59 km²) has seen extensive land conversion (Alvarado-Solano and Otero-Ospina 2017) with concomitant impacts on over 24 wetlands linked to the Ramsar site Laguna de Sonso. Land conversion has been mainly driven by demand for growing sugarcane. The total area used for sugarcane crops has increased from 79.58 km² in 1915 to 2303 km² in 2013 (Uribe Castro 2017), and it is still increasing. At present, the Cauca Valley retains less than 5% of the native forest, and what is left is fragmented into small and isolated remnants in a sea of sugarcane (Alvarado-Solano and Otero-Ospina 2015). Despite the Cauca Valley’s tropical dry forest biome being home to approximately 400 bird species (Navarro-Vélez and Sedano-Cruz data unpublished), current conservation policies are insufficient to protect the native biota or the remaining natural wetland habitats. The transformation of the Cauca valley constitutes one of the most aggressive conversions of land use in Latin America and provides an exemplary case for studying the impacts of habitat fragmentation on species persistence and extinction in the Neotropics.

In this study, our main goal was to provide an assessment of changes in avian community composition, including colonization, recolonization, and extirpation of species over the long term (1974–2018, n = 44 years). Additionally, by joining three complementary methods to define extirpation events, we provided estimates of uncertainty in our predictions of species extirpation. We examined the bird community occupying an afforested area with artificial wetlands, including some flooded rice fields (∼ 5.4 km²) dedicated to experimental agriculture in the Cauca valley. For several years the phenology of trees, shrubs, and birds was documented in this experimental study area (Segovia et al. 2000), along with that, we used a collection of bird lists from experts, amateurs, and professional scientists. Besides the availability of lists, birds are good bioindicators, highly diverse, provide key ecological functions, and respond relatively quickly to habitat transformation (Canterbury et al. 2000, Sekercioglu 2012). To our knowledge, this study, spanning 44 years, constitutes the longest-term bird study ever conducted in a Latin American agroecosystem. Studying community turnover, colonization, and extirpation events is critical to advise conservation strategies, especially given the current context where habitat fragmentation and loss are increasing globally.

**METHODS**

**Study site**

Our study site is an agroecosystem in the Cauca Valley, Colombia (3.5026° N, 76.3550° W; 1012 m). This site is part of the tropical dry forest biome. There is a long history of agricultural experimentation in this landscape, including edaphic management (e.g., calcium enrichment, flooded fields) (Howeler 1986, Becerra et al. 2005) and experimental crops transitioning into beans, cassava, legumes, and grasses. Irrigation was originally provided by the local water, but in the 1970s irrigation channels and seven water reservoirs were added throughout the agroecosystem (Díaz-Durán and Narváez 1977), constituting an artificial wetland system (map in Segovia et al. 2000). By 1995, a plan of afforestation started, and 60% of the total trees and shrubs existing today (tropical dry forest flora) were planted (Segovia et al. 2000) alongside the introduction of the sugarcane crop. Approximately 0.16 km² of sugarcane has been planted every year since 1995, and there is currently ca. 2.5 km² of sugarcane. By 2010, all but two water reservoirs were closed and the open irrigation channels were replaced by covered aqueducts. Moreover, the area of flooded rice fields was greatly reduced and most of the adjacent areas surrounding CIAT were widely converted to sugarcane, forming a matrix with a few patches of natural forest.

**Bird records**

Bird records at this location came from a variety of sources, including records collected by RESC (available in eBird Hotspot: Centro Internacional de Agricultura Tropical), different researchers who visited CIAT, and from two online platforms: eBird (2021), which stores bird lists uploaded by ornithologists and naturalists worldwide; and iSiB Colombia (2020), the Colombian database for biodiversity records from public and private research projects and collections (Appendix 1). The collected database does not provide a continuous time series, since there are some years for which we do not have records. Nevertheless, the compiled database included 3789 bird observations, in 150 bird lists; 61% of the lists included abundance
data and 39% presence/absence data. These records were assigned to three periods (Appendix 2). The first period included scattered bird records between 1974 and 1995. Despite most of these lists providing incomplete records, they are useful to identify colonization, recolonization, and extirpation events during the baseline period and beyond. It gives an insight into community composition before the baseline, enriching the historical bird list at the study site and contributing 13.7% of the total species listed. The second period (1998–2002) was chosen as the baseline because the records come from a consistent sampling methodology and effort by RESC and contribute 61.4% of the total bird species recorded. The third period is the most recent, running from 2003 to 2018, these records are from observations by more than a dozen different birdwatchers who visited the study site and reported their lists on eBird and SiB Colombia (Appendix 1). This period provided 24.9% of the species in the historical record. Although eBird, as well as SiB Colombia, have internal quality control protocols for species records (e.g., Lagoze 2014), we re-examined all bird lists in our database and scrutinized atypical records or extraordinary abundances. On average, there were 5 lists per year. Observers visited CIAT for 2.71 hours on average and had a mean sampling effort of 4.14 km with party sizes ranging from 1 to 6 observers (Appendix 1). Morning and afternoon surveys occurred at a ratio of approximately 1:1. Records that employed less strict sampling protocols, where birding was not the main activity, were excluded from the database.

To determine a bird list’s suitability for analysis, we examined both completeness and species detectability following Meyer et al. (2011). For completeness, we quantified the number of species per list per year and its proportion regarding the average richness during the baseline species inventory. From this, we obtained the Mean Species Inventory Completeness value for all the years excluding the baseline period. For species detectability, we calculated the probability of detecting each species for two continuous lists, and then we took the average of these probabilities as the species-specific detectability.

To determine colonization or recolonization, the bird lists from every period were compared to each other. Colonization events were defined as bird records of species present for the first time in the agroecosystem after the baseline period and subsequent and continuous sightings for two or more years. Recolonization events were defined as records of species that re-appeared in the locality after a prolonged absence of at least five years (buffer period in Methods). We only considered recolonization as a successful event when the novel population remained in the agroecosystem continuously for at least two years (a reasonable time frame to describe a species establishment at the study site). In contrast, we considered a persistent or retained species when its presence in the record was evident and consistent through time.

**Criteria to assess changes in bird communities**

To assess changes in bird communities, we established three criteria as follows. Criterion A is based upon a comparison of the community composition (presence/absence data) of two periods separated over a decade. This offers a long-term data comparison between the oldest high-quality records available (1998–2002) vs. the newest records of the period (2013–2017). A species not recorded in the second period satisfies criterion A (Fig. 1). We adopted this criterion because it is the most common approach in the literature and therefore we can compare its relative contribution to the estimation of local extinction. Criterion B is based on the number of years of local retention for the bird species. It takes into consideration the patterns of appearance and disappearance of the species in the record (Fig. 1), as an indirect estimate of the variability in the frequency of use by the species in the agroecosystem. To us, it is a subsample of the shifts that could happen in a community in 44 years (Si et al. 2014). If the number of years after the last sighting of the species in the agroecosystem was greater than the average of years that the species has been absent from the record (Pearson et al. 2010), then such a species fulfilled criterion B (Fig. 1). This criterion allowed us to examine if the time-lapse between the last sighting and the species’ apparent disappearance from the study site is meaningful.

Criterion C is based upon a buffer period in which the community composition is expected to be stable. A buffer period is instrumental to estimating the appropriate period over which one may expect changes in the stability of the community. In other words, beyond the buffer period, there is an increased possibility of extirpation. If a species is not observed after the buffer period, it fulfills criterion C. To determine the buffer period, we used a Mantel’s correlogram (Mantel 1967) using the package vegan (Oksanen 2017) in R (R Core Team 2020). This test correlates the temporal structure to the species composition amongst bird lists. For each separation time among bird lists in the correlogram, their significance was calculated with a Bonferroni correction by 16,000 permutations ($\alpha = 0.05$). By using the correlogram, we determined the maximum number of years among bird lists with a direct-positive correlation. After this buffer period, we expected more variability in the community composition that might affect the correlation among lists. Overall extirpation events determined under criterion C are conditioned to the buffer estimated from the data.

**Defining extirpation events**

Before we estimated which species have been extirpated from the study site, we excluded unique records, vagrants, and nocturnal species, for which there was not enough data. This step reduced variability within the dataset. Then, we examined the remaining database using the three criteria outlined above for detecting local extinction. Each of the three criteria has a priori the same weight in our classification of local extinction. Thus, we assigned species to different categories if they met one, two, or three of the criteria. This multicriteria classification enables us to assign a species as possibly extirpated if it fulfills one criterion; probably extirpated if it fulfills two criteria; and extirpated if such species fulfills all of the three criteria (adapted from Butchart et al. 2006 and after Fig. 4 of Moura et al. 2014).

**Community analysis**

To determine if there were differences in species richness, we compared the period between the baseline (1998–2002) and the period from 2013 to 2018 which have a comparable representativity. We excluded years with a lower number of lists.
Fig. 1. Scheme of bird extirpation criteria. Dark tracks mean the species was recorded in that period and clear tracks mean that it was not on record. In the columns: Present (P), Absent (A), Years Last Seen (YLS), and Average Gaps (AG).

RESULTSCONCLUSION

Criterion A: Present in 1996-2002 + Absent 2013-2017= Extirped
Present in 1999-2002 + Present 2013-2017= Retained

P + A Extirped
P + P Retained

Criterion B: YLS > AG= Extirped
YLS < AG= Retained
YLS = AG= Undetermined

YLS= 3, AG= 1.8 Extirped
YLS= 3, AG= 4.4 Retained
YLS= 2, AG= 2 Undetermined

Criterion C: YLS ≥ 5 years = Extirped

YLS= 5 Extirped
YLS= 3 Retained

1974 - 1995
Baseline Period before baseline Period after baseline Validation

Analysis of extirpation

Over the 44 years, a total of 189 bird species were recorded at the study site. These species belonged to 43 bird families among which Tyrannidae (11%), Thraupidae (10%), and Scolopacidae (8.9%) were the most frequent in the compiled data set (Appendix 3). Of the 189 species recorded in the agroecosystem, 34.9% of birds were aquatic and 65.1% were terrestrial. 76.7% were resident bird species and 23.3% represented migratory species (both Austral and Nearctic-Neotropical). Also, 5.8% of entries in the data set comprised records of vagrants, whose occurrence constituted a range extension, and as detailed above were excluded from subsequent analyses. There were also a few species with highly irregular records, and 20.6% of entries in the data set were unique species (Appendix 3). The mean species inventory completeness was 0.91, meaning that on average, the bird lists (excluding baseline years) had 91% of the value of richness recorded during the baseline. Species-specific detectability calculated for all the species in the study site ranged from 0.50 to 0.91 with an average of 0.59. Here, 55% of the species have a detection probability above 0.5 (Table 1).

As a proxy for functional diversity within the community, we determined if there was a feeding-guild bias in the pool of extirpated species in comparison to the group of colonizing and re-colonizing species. We classified bird species into feeding guilds following the classification of Segovia and colleagues (2000) and then we applied a Friedman test in R, version 3.6.1 (R Core Team 2020). Nevertheless, we emphasize that a full comparison of many other aspects of functional diversity at the study site is beyond the scope of this study.

RESULTS

Over the 44 years, a total of 189 bird species were recorded at the study site. These species belonged to 43 bird families among which Tyrannidae (11%), Thraupidae (10%), and Scolopacidae (8.9%) were the most frequent in the compiled data set (Appendix 3). Of the 189 species recorded in the agroecosystem, 34.9% of birds were aquatic and 65.1% were terrestrial. 76.7% were resident bird species and 23.3% represented migratory species (both Austral and Nearctic-Neotropical). Also, 5.8% of entries in the data set comprised records of vagrants, whose occurrence constituted a range extension, and as detailed above were excluded from subsequent analyses. There were also a few species with highly irregular records, and 20.6% of entries in the data set were unique species (Appendix 3). The mean species inventory completeness was 0.91, meaning that on average, the bird lists (excluding baseline years) had 91% of the value of richness recorded during the baseline. Species-specific detectability calculated for all the species in the study site ranged from 0.50 to 0.91 with an average of 0.59. Here, 55% of the species have a detection probability above 0.5 (Table 1).

Analysis of extirpation

After we cleaned the database (Methods), 135 species were examined using the three extirpation criteria. For criterion C, we defined five years as the minimum buffer time when we expect lower changes in the agroecosystem’s bird composition (Appendix 4) because lists separated by fewer than 4 years had a positive and significant correlation. There was evidence of extirpation for eight species that fulfilled the three criteria (5.9%) over the 44 years (Table 1). Furthermore, seven species were considered probably extirpated, fulfilling two of the three criteria (5.2%), and nine species were considered possibly extirpated, fulfilling at least one of the three criteria (6.7%).

Criterion A was satisfied by 10 species because they were recorded in the baseline data set but not in the most recent period. A total of 18 species satisfied Criterion B because the time since their last sighting is greater than the average of years of absence. Criterion C was satisfied by 19 species that had no records for at least the last five years (buffer period). The functional groups of the 24 species under any category of extirpation were predominated by aquatic species (58.3%), followed by terrestrial species (41.6%); 70.8% were residents, and 29.1% were migrants.
Table 1. List of extirpated bird populations between 1974–2018. It includes the extirpation criteria satisfied by each species (Methods), information on residency status, main feeding guild and habitat, the year of first and last sighting and species-specific detectability. Extirpated species (†), Probable extirpated (‡), and possibly extirpated species (§) (Methods). Feeding guilds after Segovia et al. (2000). INS: insects, IS: insects and seeds, IF: insects and fruits, INV: invertebrates, FIS: fish, LISV: large insects and small vertebrates, NEC: nectar, OMN: omnivore diet, SE: seeds, VEG: vegetal parts different to seeds or fruits.

| Family       | Species                        | Habitat | Residency | Feeding Guild | First Seen | Last Seen | Detectability Index | Criteria |
|--------------|--------------------------------|---------|-----------|---------------|------------|-----------|---------------------|----------|
| Anatidae     | Nomonyx dominicus†             | AQU     | RES       | INV           | 1980       | 2006      | 0.5                 | X        |
| Anatidae     | Denrocygna bicolor§            | AQU     | RES       | INV           | 1982       | 2016      | 0.85                | X        |
| Trochilidae  | Chlorostilbon melanorhynchos†  | TER     | RES       | NEC           | 1998       | 2000      | 0.5                 | X        |
| Cuculidae    | Coccyzus metacephalus§         | TER     | RES       | LISV          | 1989       | 2013      | 0.5                 | X        |
| Cuculidae    | Coccyzus americanus§           | TER     | MIG       | LISV          | 1998       | 1999      | 0.5                 | X        |
| Railiidae    | Pardirallus maculatus§         | AQU     | RES       | LISV          | 1978       | 2010      | 0.5                 | X        |
| Railiidae    | Pardirallus nigricans§         | AQU     | RES       | LISV          | 1979       | 2011      | 0.66                | X        |
| Railiidae    | Fulica americana§              | AQU     | MIG       | INV           | 1978       | 1995      | 0.5                 | X        |
| Charadriidae | Charadrius semipalmatus§        | AQU     | MIG       | INV           | 1989       | 1995      | 0.75                | X        |
| Charadriidae | Charadrius collaris§           | AQU     | MIG       | INV           | 1980       | 2001      | 0.62                | X        |
| Scolopaciida | Calidris bimantupus†           | AQU     | MIG       | INV           | 1978       | 2008      | 0.62                | X        |
| Scolopaciida | Calidris mauri†                | AQU     | MIG       | INV           | 1982       | 2002      | 0.6                 | X        |
| Scolopaciida | Limnodromus griseus§           | AQU     | MIG       | INV           | 1995       | 1998      | 0.5                 | X        |
| Ardeidae     | Bataorides virenses§           | AQU     | MIG       | OMN           | 1995       | 2001      | 0.65                | X        |
| Ardeidae     | Egretta caerulea§              | AQU     | RES       | LISV          | 1995       | 2015      | 0.58                | X        |
| Accipitridae | Elanus leucurus‡               | TER     | RES       | LISV          | 1995       | 2015      | 0.58                | X        |
| Akediniidae  | Chloroceryle americana§        | AQU     | RES       | FIS           | 1998       | 2011      | 0.62                | X        |
| Akediniidae  | Chloroceryle amaurolella‡       | AQU     | RES       | FIS           | 1980       | 2010      | 0.5                 | X        |
| Hirundiniidae| Prope chloryza§                | TER     | RES       | INS           | 1989       | 1999      | 0.5                 | X        |
| Estrildidae  | Lonchura oryzivora§            | TER     | RES       | SE            | 2002       | 2007      | 0.5                 | X        |
| Fringillidae | Spina psaltria§                | TER     | RES       | SE            | 1989       | 2013      | 0.5                 | X        |
| Passerelliida| Anomodramus humeralis§         | TER     | RES       | IS            | 2014       | 2016      | 0.5                 | X        |
| Thraupidae   | Paroaria galarela§             | TER     | RES       | IF            | 2008       | 2011      | 0.5                 | X        |
| Thraupidae   | Taeniorex olivaceus§           | TER     | RES       | SE            | 1974       | 1999      | 0.5                 | X        |

Community analysis

There was evidence of colonization events in the agroecosystem for 10 species across the 44 years (Appendix 3). These colonizers appeared after the baseline data set period and were continuously recorded for three or more years (average = 3.5 yr). We highlight the colonization of the Red-crowned Woodpecker (Melanerpes rubricapillus) which was first seen at CIAT in 2014, after several years of very rapid and successful colonization of the entire Cauca Valley (Sedano-Cruz 2020). Also, the bird record documented the colonization of the Red-crowned Woodpecker (Melanerpes rubricapillus) which was first seen at CIAT in 2014, after several years of very rapid and successful colonization of the entire Cauca Valley (Sedano-Cruz 2020). Also, the bird record documented the colonization after the baseline data set period at CIAT.

Twenty-one species that were absent for an average of 9 years were recorded again for approximately four continuous years at the study site. Despite colonization and recolonization events, there was a uniform distribution of the absolute species richness during the study period in the agroecosystem (Fig. 2). In exchange, there was an increase in feeding guilds on small insects and fruits (Fig. 2). In general, species recently colonizing or re-colonizing the agroecosystem were birds with more terrestrial tendencies at the expense of aquatic bird species.

DISCUSSION

We provide empirical evidence using an integrated approach that demonstrates the extirpation of 5.2% to 18% of species in an agroecosystem embedded in the Andean tropical dry forest biome between 1974 and 2018. We show that despite high levels of extirpation, the colonization and recolonization events have driven turnovers in the functional composition of the community. The species listed at the study site represent roughly 45% of the known tropical dry forest avifauna of the Cauca Valley. Considering how highly transformed this biome is worldwide, which now covers less than 10% of its original extent in Colombia (Portillo-Quintero and Sánchez-Azofeifa 2010, Pizano and Garcia 2014), the role of this agroecosystem for conservation is
intriguing. To our knowledge, this is the first study to examine the extirpation and retention of bird species in a highly transformed agroecosystem in Latin America. Together, these results demonstrate the adaptations of a bird community to the fragmentation and destruction of natural habitats resulting from sugarcane expansion.

Because there are few long-term studies in the neotropics, estimates of local extinction are scarce. In Amazonia, Stouffer et al. (2011) estimated at least 10% of bird communities became locally extinct in 100 ha forest fragments, 25 years after isolation. In a larger area of 2500 km² in the Amazon region, Moura et al. (2014) reported that 14% of the bird community was at risk of extinction. Recently, in the Andean mountains, 19% of bird species were estimated to be extirpated in the last 100-year period (Palacio et al. 2020). These estimates vary notably both spatially and temporally; nevertheless, it suggests that our estimate of local extinction (5.2–18%), which falls among these values for other tropical regions, is feasible. We acknowledge that population decline is a prerequisite to local extinction (Collen et al. 2011, Sekercioglu 2019) and that in the Neotropics, despite having high species richness in lowland forests, species often occur at low abundances (Kikuchi et al. 2018). Nonetheless, we speculate that birds’ extirpation is a persistent phenomenon in the region and might be highly relevant to other transformed ecosystems across tropical regions.

Although both overestimation and underestimation of extirpation events are problematic, our methodological approach offers a range of values in an attempt to include the uncertainty rather than having a single-point estimate. If we consider a species to be extirpated if it met at least one of the framework’s criteria, 18% of the species ever recorded in the locality have gone extinct; being cautious, we say that at least 5.9% (species that met three criteria) of bird populations were extirpated. However, the question remains as to how confident we can be of the extirpation status of a species when all the criteria are met. First, communities are dynamic and recolonization events are expected to occur when we still find some suitable habitats in the landscape that can work as population sources. However, if a species that met all three criteria later reappeared at the study site, it is likely that the prior population had been extirpated from this locality and that the new occurrence is a recolonization attempt or that the species has a very low detectability. Thus, answering this question requires repeated and standardized presence/absence methods that allow for accounting for imperfect detection in the long term.

We highlight that there were noteworthy changes in community composition. Our data suggest a significant turnover in feeding guilds (Fig. 2). This finding coincides with two major changes in the agroecosystem: (i) the loss of most artificial wetland area, including an overall reduction in flooded rice fields and the number of water reservoirs between 1998–2010; (ii) the growth of trees and shrubs that are an important resource for the avifauna 18 years after the beginning of an ambitious afforestation program in CIAT in 1995 (Segovia et al. 2000). It stands to reason that complex processes that took place in the agroecosystems constitute changes that likely had major impacts on this bird community.

The baseline here does not represent an undisturbed community. Instead, the baseline may have been responding to other important changes in the agroecosystem well before; like the newly built artificial wetland habitats in the mid-70s. However, by adopting the baseline dataset and multiple criteria we can comprehensively estimate changes within the community (Table 1). The Baseline data set (1998–2002) is an informative subsample of the long-term study. This type of analysis, using a proper baseline as a condition of reference, is essential in global extinction studies, especially to establish conservation targets (Gonzalez et al. 2016, Vellend et al. 2017, Cardinale et al. 2018, Stouffer 2020).

By combining three criteria we covered, as completely as possible, several aspects of species permanence in the study site. Our criterion A offers a long-term data comparison between subsets of records. Criterion C assesses short-term data (last five years), and Criterion B assesses the time between A and C including all the variance in the species’ patterns of visitation that could happen during this time (Appendix 6). Despite criteria A and C being methodologically different and providing distinct entries to the list of extirpated species (Table 1), our data suggest that both, when used by themselves, underestimate the number of extirpated species. Nonetheless, when joined with the other criteria, the overlap of the three criteria may mitigate statistical error Type I (extirpations as false positives).

Changes in the bird community

The long-term analysis of bird species in the agroecosystem showed that the events of colonization and recolonization (n =
31) are numerically equivalent to the number of extirpated and potentially extirpated species (n = 24). The gains and losses of taxa often resulted in an apparent uniform species richness over the years (Appendix 5), which is consistent with the findings of a variety of studies over different habitats and spatial scales (Vellend et al. 2013, Cardinale et al. 2018, Hillebrand et al. 2018). In this study, population retention is lower for aquatic birds than for terrestrial species, a phenomenon associated with a drastic reduction in artificial wetlands since 1998. It stands to reason that the uniform richness could also be explained by the afforestation plan that increased the availability of trees and shrubs since the program started in 1995. The impacts of such a plan would likely take at least a decade before they become evident and, therefore, could explain differences between the baseline and the recent period 2013–2017.

**Importance of long-term studies**

We can further illustrate the importance of long-term studies in three ways. First, a search within >60,000 eBird records of the Cauca Valley, where the agroecosystem is embedded. This review showed that 67% of the locally extinct and potentially extirpated species at CIAT are rare or uncommon at the regional scale. This implies that our list of 24 extirpated species may reflect the vulnerability of these populations at a broader scale. Second, when comparing a list of a few predicted extirpated bird species from the Cauca valley (Restrepo and Naranjo 1987) with our data and eBird data, we find that seven out of the 11 species on their list re-appeared sporadically in multiple localities after 1987. In addition, those seven species were originally considered rare and uncommon in the region (Hilty and Brown 1986) and were always considered erratic. While our assessment strongly suggests that Restrepo and Naranjo (1987) overestimated the number of extirpated waterfowl in the Cauca valley, which tends to happen with this approach (criterion A in this study) - our review, 31 years later, also highlights that the status of “regionally extinct” remains valid for four species (Appendix 7). Third, the attempted colonization of exotic species into this agroecosystem emphasizes the dynamic aspects of these artificial habitats. After invasive species like the Java Sparrow and the Tricolored Munia were first sighted at CIAT in 2002, there were few subsequent sightings, and they were separated by 15 years in the case of the Tricolored Munia and sporadic records between 2002 and 2007 for the Java Sparrow. These patterns are consistent with the expansion of these exotic genus into other regions of Colombia (Certuche-Cubillos et al. 2010). Because these two introduced species are specialists in rice fields, their failure to colonize the CIAT might be best explained by the severe reduction in rice fields over the study period. These types of population changes are only evident from longer-term studies, and any decision for conservation or agricultural policy based on short-term studies is likely to be biased and has the potential to lead to misguided conservation and management actions.

**Land-use changes associated with changes in the birds’ community**

We acknowledge that we cannot generalize what is happening in the Cauca Valley from the findings of a local study, especially considering how dynamic the agroecosystem is. Even so, we think it is important to appreciate how these results on extirpation may scale up to regional patterns as a cryptic phenomenon and the initial step towards extinction. The widespread adoption of sugarcane cultivation in the areas surrounding the study site and in most of the Cauca Valley is an important factor, since local diversity is subject to changes in larger landscape patterns (Tschurunke et al. 2008, Stouffer 2020), especially when these changes have isolated the remaining wetlands and forest fragments. Our working hypothesis on local extinctions implies that, within a context of both wetland loss and the success of afforestation, an agroecosystem could maintain avian communities without an apparent net loss of richness but with the consequence of a high turnover in functional diversity. In a broader sense, it could affect the supply of ecosystem services provided by birds, namely pollination, seed transfer, and pest control, among others (Sekercioglu 2012, Arias-Arevalo et al. 2018).

Several factors acting at different temporal and spatial scales could have influenced the risk of extirpation in the agroecosystem: (i) isolated events of bird mortality that have been associated with exposure to agrochemicals and the grease for agricultural machinery (Segovia et al. 2000); (ii) the transformation of water reservoirs and irrigation channels into arable areas, which decreases the supply of resources (nesting and foraging grounds) for aquatic birds; (iii) the afforestation program that indicates increasing native plant biodiversity in the agroecosystem has a positive influence on some taxa; (iv) the constant changes in land use according to the research goals of the field station; or (v) the vulnerability of species at the regional scale. Several of these factors played a role in the overall reduction of habitat heterogeneity at the study site. The shift in the mix of crops promoted the simplification and homogenization of the agricultural matrix. While most crops have decreased in area, sugarcane has become extensively cultivated at the study site (Segovia et al. 2000). It stands to reason that the gains and losses of avian diversity are somewhat related to the loss of the artificial wetlands and the maturation of trees and shrubs 18-years after the afforestation effort began.

**CONCLUSION**

Our results suggest that short-term studies comparing just the last five years or studies comparing time-distant lists would not provide enough sensitivity to detect changes in avian communities, leading to under and overestimation. Consequently, we find support for the use of the three criteria framework, applied to long-term monitoring datasets for a better assessment of the conservation status of populations and communities. This framework provides a clear definition for extirpation and a traceable outline to assess meaningful changes at the community level. This is of great interest in the context of climate change and complex trends in land use that are affecting bird populations worldwide. We urge that future studies examining local extinction use additional methods that attempt to mitigate underestimation bias as well as imperfect detection. The long-term evidence in this study demonstrates that bird communities in agroecosystems are vulnerable to changes in land use and cropland management, in particular aquatic birds. Artificial wetlands and agroecosystems in the Cauca Valley should be better studied as they could easily complement protected areas and contribute to the long-term viability of bird communities.
Responses to this article can be read online at: https://www.ace-eco.org/issues/responses.php/2221

Author Contributions:

RESC: conceptualization, funding acquisition, methodology (equal), formal analysis (equal), investigation (equal), and writing (lead), review and editing (supporting). KCNC: data curation, methodology (equal), formal analysis (equal), investigation (equal), visualization, writing (supporting), review, and editing (lead).

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Appendix 1. Summary of bird lists sources used in the study. It includes the date, number of records, number of species recorded by list, distance, duration (hours), distance (Kilometers), the name of the main observer, number of observers and notes.

| LIST                                      | YEAR   | RECORDS  | SPECIES | DURATION (h) | DISTANCE (Km) | LEAD OBSERVER | NUMBER OF OBSERVERS | NOTES                                      |
|-------------------------------------------|--------|----------|---------|--------------|---------------|---------------|---------------------|--------------------------------------------|
| Handbook 1998                            | 1998   | 723 (Median) | 72      | 2 per each sample | 4 per each sample | R. Sedano     | 1                   | Multiple lists through the year           |
| Handbook 1999                            | 1999   | 565 (Median) | 77      | 2 per each sample | 4 per each sample | R. Sedano     | 1                   | 10 or more lists through the year         |
| Handbook 2000                            | 2000   | 176 (Median) | 59      | 2 per each sample | 4 per each sample | R. Sedano     | 1                   | 10 or more lists through the year         |
| Handbook 2001                            | 2001   | 102 (Median) | 40      | 2 per each sample | 4 per each sample | R. Sedano     | 1                   | 10 or more lists through the year         |
| Handbook 2002                            | 2002   | 89 (Median) | 61      | 2 per each sample | 4 per each sample | R. Sedano     | 1                   | 10 or more lists through the year         |
| Handbook 2006                            | 2006   | 15       | 15      | 2 per each sample | 4 per each sample | R. Sedano     | 1                   | Multiple lists through the year           |
| Handbook 2008                            | 2008   | 21       | 21      | 2 per each sample | 4 per each sample | R. Sedano     | 1                   | Multiple lists through the year           |
| Handbook Peter Jennings                  | 1977, 1982, 1999 | 25       | 25 | Undetermined (U) | U | P. Jennings | 1 | Handbook |
| Censo Neotropical de Aves Acuáticas en Colombia (CNAa):020216-110731 | 2003, 2006, 2007, 2008, 2009, 2010, 2011 | 305 (Median) | 45 | U | U | U | 3 - 5 |

Zamudio, J., & Cifuentes-Sarmiento, Y. (2013). El Censo Neotropical de Aves Acuáticas en Colombia (CNAa): 2002 - 2011. Biota Colombiana, 14. Recuperado a partir de http://revistas.humboldt.org.co/index.php/biota/article/view/302
| Reference | Years | Sources | Authors | Notes |
|------------|-------|---------|---------|-------|
| Hilty & Brown 1986 | 1975 | 1 1 U U | S. Hilty, D. Zimmerman & J. Abramson | Hilty, S. L. and W. L. Brown. 1986. A guide to the birds of Colombia. Princeton University Press. |
| Instituto Colombiano Agropecuario - ICA 1978-1979 | 35 35 U U | E. Finke, D. Valencia & W. Mckay | Ortiz De Finke-Valencia, D. and McKay, W. (n.d). Evaluación de pérdidas debidas al ataque de pájaros en zonas arroceras de Colombia. [Unpublished Report 1978-1979]. Instituto Colombiano Agropecuario (ICA), Palmira, Colombia. 140 pp. |
| Instituto para la Investigación y la Preservación del Patrimonio Cultural y Natural del Valle del Cauca (INCIVA) 1974-1975 | 3 3 U U | S. Curniss | Bird Collection- INCIVA |
| Informe CIAT-CVC 1999 | 60 60 U U | M. Reyes & W. Bolivar-G | Technical Report [unpublished] |
| Libro CIAT, 2000 | 2000 | 45 45 U U | R. Sedano | Segovia, R. J., R. E. Sedano, G. Reina, and G. López. 2000. Arboles, arbustos y aves en el agrosistema del CIAT. Centro Internacional de Agricultura Tropical, Palmira. |
| S16010971 | 2013 | 82 82 4 4 | M. Gable | eBird |
| S16997280 | 2014 | 40 40 4.25 5 | Calidris | eBird |
| S17910149 | 2014 | 71 71 5 10 | M. Gable | eBird |
| S18040910 | 1989 | 58 58 4.58 5 | L.G. Naranjo | eBird |
| S18659472 | 2014 | 18 18 1 2 | M. Strimas-Mackey | eBird |
| S22056858 | 2015 | 16 16 4 U | Y. Cifuentes | eBird |
| S24990933 | 1989 | 30 30 2 1 | F. Estela | eBird |
| Project ID  | Year  | Latitude | Longitude | Mean Horizon | Standard Deviation | Author(s)                          | Database |
|-------------|-------|----------|-----------|--------------|--------------------|------------------------------------|----------|
| S25343690  | 2015  | 41       | 41        | 2            | 1                  | J. van der Hout                     | eBird    |
| S25499228  | 2015  | 41       | 41        | 1.25         | 1                  | J. van der Hout                     | eBird    |
| S25729439  | 2006  | 41       | 41        | 3            | 3                  | F. Estela                          | eBird    |
| S25771774  | 2007  | 44       | 44        | 3            | 3                  | F. Estela                          | eBird    |
| S26426546  | 2015  | 57       | 57        | 2            | 3                  | J. van der Hout                     | eBird    |
| S27477703  | 2016  | 45       | 45        | 3.5          | 5                  | R. D. Palacios                     | eBird    |
| S27638550  | 2016  | 34       | 34        | 0.5          | 2                  | J. van der Hout                     | eBird    |
| S30890738  | 2016  | 25       | 25        | U            | U                  | J. van der Hout                     | eBird    |
| S33884639  | 2017  | 34       | 34        | 0.75         | 3                  | J. van der Hout                     | eBird    |
| S34338341  | 2017  | 29       | 29        | 3.5          | 5                  | Calidris                           | eBird    |
| S36081983  | 2017  | 32       | 32        | 0.5          | 1                  | J. van der Hout                     | eBird    |
| S38189408  | 2017  | 35       | 35        | 3.5          | 10                 | E. Fierro-Calderón, R. Steiner & Y. Cifuentes | eBird    |
| S38444464  | 2017  | 33       | 33        | 2            | U                  | J. Mogollón                        | eBird    |
| S40057449  | 2017  | 34       | 34        | 5            | 5                  | R. Sedano                          | eBird    |
| S40630328  | 2017  | 31       | 20        | U            | U                  | A.M. Cuervo                        | eBird    |
| S51514373  | 2018  | 305      | 24        | 4.06         | 15                 | L. C. Lugo Quesada                  | eBird    |
| S50442028  | 2018  | 949      | 55        | 3.91         | 3.63               | R. Sedano & L. Calvert              | eBird    |
Appendix 2. Descriptive patterns of the records among periods. A. Number of lists per month in each of the three periods of the database. B. Number of records in each period of study. C. Number of observers per period. D. Total number of lists per period.
Appendix 3. List of bird species recorded at CIAT (1974-2018) with notes on residency status, the last year on record and observations.

Observations on their status of permanence at the study site, including extirpated taxa, candidates to extirpation, retained species, colonizers, re-colonizers, vagrants, unique records and exotic or invasive. Candidates to extirpation are those taxa that may fulfill one, two or three criteria in coming years (see methods in main text).

| Family             | English name           | Scientific name       | Residency | Last record | Observations          |
|--------------------|------------------------|-----------------------|-----------|-------------|-----------------------|
| Anatidae           | Fulvous Whistling-Duck | Dendrocygna bicolor   | Resident  | 2017        | Candidate to extirpation |
| Anatidae           | White-faced Whistling-Duck | Dendrocygna viduata   | Resident  | 2018        | Retained              |
| Anatidae           | Black-bellied Whistling-Duck | Dendrocygna autumnalis | Resident  | 2020        | Retained              |
| Anatidae           | Muscovy Duck           | Cairina moschata      | Resident  | 2020        | Retained              |
| Anatidae           | Comb Duck              | Sarkidiornis sylvicola | Resident  | 1989        | Unique                |
| Anatidae           | Blue-winged Teal       | Spatula discors       | Migratory | 2020        | Retained              |
| Anatidae           | Cinnamon Teal          | Spatula cyanoptera    | Migratory | 2020        | Retained              |
| Anatidae           | Masked Duck            | Nomonyx dominicus     | Resident  | 2006        | Candidate to extirpation |
| Anatidae           | Ruddy Duck             | Oxyura jamaicensis    | Resident  | 2017        | Unique                |
| Odontophoridae     | Crested Bobwhite       | Colinus cristatus     | Resident  | 2017        | Retained              |
| Podicipedidae      | Least Grebe            | Tachybaptus dominicus | Resident  | 2020        | Retained              |
| Podicipedidae      | Pied-billed Grebe      | Podilymbus podiceps   | Resident  | 2018        | Retained              |
| Columbidae         | Rock Pigeon            | Columba livia         | Resident  | 2017        | Retained              |
| Columbidae         | Pale-vented Pigeon     | Patagioenas cayennensis | Resident  | 2014        | Retained              |
| Columbidae         | White-tipped Dove      | Leptotila verreauxii  | Resident  | 2017        | Unique                |
| Columbidae         | Gray-headed Dove       | Leptotila plumbeiceps | Resident  | 1989        | Unique                |
| Columbidae         | Eared Dove             | Zenaida auriculata    | Resident  | 2020        | Retained              |
| Columbidae         | Ruddy Ground-Dove      | Columbina talpacoti   | Resident  | 2020        | Retained              |
| Cuculidae          | Smooth-billed Ani      | Crotophaga ani        | Resident  | 2020        | Retained              |
| Cuculidae          | Striped Cuckoo         | Tapera naevia         | Resident  | 2020        | Recolonizer           |
| Family            | Species                           | Status            | Year    | Reason               |
|-------------------|-----------------------------------|-------------------|---------|----------------------|
| Cuculidae         | Dwarf Cuckoo                      | Coccycua pumila   | Resident| 2020                 | Recolonizer |
| Cuculidae         | Dark-billed Cuckoo                | Coccyzus melacoryphus | Resident| 2013                 | Candidate to extirpation |
| Cuculidae         | Yellow-billed Cuckoo              | Coccyzus americanus | Migratory| 1999                 | Candidate to extirpation |
| Nyctibiidae       | Common Potoo                      | Nyctibius griseus | Resident| 2016                 | Retained    |
| Apodidae          | Chestnut-collared Swift           | Streptoprocne rutila | Migratory| 1989                 | Unique      |
| Apodidae          | White-collared Swift              | Streptoprocne zonaris | Migratory| 2018                 | Recolonizer |
| Trochilidae       | Ruby-topaz Hummingbird            | Chrysolampis mosquitus | Resident| 2020                 | Retained    |
| Trochilidae       | Black-throated Mango              | Anthracothorax nigricollis | Resident| 2020                 | Retained    |
| Trochilidae       | White-bellied woodstar            | Chaetocercus multus | Resident| 1977                 | Unique      |
| Trochilidae       | Western Emerald                   | Chlorostilbon melanorhynchus | Resident| 2017                 | Extirpated |
| Trochilidae       | Steely-vented Hummingbird         | Saucerotita saucerottei | Resident| 2018                 | Retained    |
| Trochilidae       | Rufous-tailed Hummingbird         | Amazilia tzacati | Resident| 2020                 | Retained    |
| Aramidae          | Limpkin                           | Aramus guarauna   | Resident| 2018                 | Retained    |
| Rallidae          | Purple Gallinule                  | Porphyrio martinica | Resident| 2020                 | Retained    |
| Rallidae          | Gray-breasted Crake               | Laterallus exilis | Resident| 2010                 | Unique      |
| Rallidae          | Ash-throated Crake                | Mustelirallus albicollis | Resident| 1975                 | Vagrant     |
| Rallidae          | Spotted Rail                      | Pardirallus maculatus | Resident| 2010                 | Candidate to extirpation |
| Rallidae          | Blackish Rail                     | Pardirallus nigricans | Resident| 2011                 | Candidate to extirpation |
| Rallidae          | Gray-cowled Wood-Rail             | Aramides cajaneus | Resident| 2018                 | Recolonizer |
| Rallidae          | Yellow-breasted Crake             | Porzana flaviventer | Resident| 1980                 | Vagrant     |
| Rallidae          | Sora                              | Porzana carolina  | Resident| 1982                 | Unique      |
| Rallidae          | Common Gallinule                  | Gallinula galeata | Resident| 2020                 | Retained    |
| Rallidae          | American Coot                     | Fulica americana  | Resident| 2020                 | Candidate to extirpation |
| Charadriiidae     | American Golden-Plover            | Pluvialis dominica | Migratory| 1978                 | Vagrant     |
| Charadriiidae     | Southern Lapwing                  | Vanellus chilensis | Resident| 2020                 | Retained    |
| Charadriiidae     | semipalmated Plover               | Charadrius semipalmatus | Migratory| 1995                 | Candidate to extirpation |
| Charadriiidae     | Wilson's Plover                   | Charadrius wilsonia | Migratory| 1995                 | Vagrant     |
| Charadriiidae     | Collared Plover                   | Charadrius collaris | Resident| 1995                 | Candidate to extirpation |
| Recurvirostridae  | Black-necked Stilt                | Himantopus mexicanus | Resident| 2020                 | Retained    |
| Scolopacidae      | Upland Sandpiper                  | Bartramia longicauda | Migratory| 1998                 | Unique      |
| Family         | Species                          | Scientific Name      | Status     | Year  | Extinction Status         |
|---------------|----------------------------------|----------------------|------------|-------|---------------------------|
| Scolopacidae  | Whimbrel                         | Numenius phaeopus    | Migratory  | 1995  | Vagrant                   |
| Scolopacidae  | Hudsonian Godwit                 | Limosa haemastica    | Migratory  | 1998  | Unique                    |
| Scolopacidae  | Stilt Sandpiper                  | Calidris himantopus  | Migratory  | 2001  | Extirpated                |
| Scolopacidae  | Least Sandpiper                  | Calidris minitula    | Migratory  | 2020  | Retained                  |
| Scolopacidae  | Pectoral Sandpiper               | Calidris melanotos   | Migratory  | 2020  | Retained                  |
| Scolopacidae  | Semipalmented Sandpiper          | Calidris pusilla     | Migratory  | 1982  | Vagrant                   |
| Scolopacidae  | Western Sandpiper                | Calidris mauri       | Migratory  | 2008  | Extirpated                |
| Scolopacidae  | Short-billed Dowitcher           | Limnodromus griseus  | Migratory  | 2020  | Vagrant                   |
| Scolopacidae  | Long-billed Dowitcher            | Limnodromus scolopaceus | Migratory  | 2002  | Vagrant                   |
| Scolopacidae  | Noble Snipe                      | Gallinago nobilis    | Migratory  | 1995  | Unique                    |
| Scolopacidae  | Wilson's Snipe                   | Gallinago delicata   | Migratory  | 2010  | Unique                    |
| Scolopacidae  | Wilson's Phalarope               | Phalaropus tricolor  | Migratory  | 1998  | Vagrant                   |
| Scolopacidae  | Spotted Sandpiper                | Actitis macularius   | Migratory  | 2020  | Retained                  |
| Scolopacidae  | Solitary Sandpiper               | Tringa solitaria     | Migratory  | 2018  | Retained                  |
| Scolopacidae  | Greater Yellowlegs               | Tringa melanoleuca   | Migratory  | 2018  | Retained                  |
| Scolopacidae  | Lesser Yellowlegs                | Tringa flavipes      | Migratory  | 2020  | Retained                  |
| Jacanidae     | Wattled Jacana                   | Jacana jacana        | Resident   | 2020  | Retained                  |
| Laridae       | Laughing Gull                    | Leucophaeus atricilla | Migratory  | 1980  | Vagrant                   |
| Anhingidae    | Anhinga                          | Anhinga anhinga      | Resident   | 2020  | Retained                  |
| Phalacrocoracidae | Neotropic Cormorant         | Phalacrocorax brasilianus | Resident   | 2020  | Retained                  |
| Ardeidae      | Black-crowned Night-Heron        | Nycticorax nycticorax | Resident   | 2020  | Retained                  |
| Ardeidae      | Green Heron                      | Butorides virescens  | Migratory  | 1998  | Candidate to extirpation  |
| Ardeidae      | Striated Heron                   | Butorides striata    | Resident   | 2020  | Retained                  |
| Ardeidae      | Cattle Egret                     | Bubulcus ibis        | Resident   | 2020  | Exotic/ Invasive          |
| Ardeidae      | Great Blue Heron                 | Ardea herodias       | Migratory  | 2007  | Unique                    |
| Ardeidae      | Cooi Heron                       | Ardea coco           | Resident   | 2020  | Retained                  |
| Ardeidae      | Great Egret                      | Ardea alba           | Resident   | 2020  | Retained                  |
| Ardeidae      | Tricolored Heron                 | Egretta tricolor     | Resident   | 2006  | Unique                    |
| Ardeidae      | Snowy Egret                      | Egretta thula        | Resident   | 2020  | Retained                  |
| Ardeidae      | Little Blue Heron                | Egretta caerulea     | Resident   | 2020  | Candidate to extirpation  |
| Family             | Common Name                        | Scientific Name                | Status       | Year  | Notes                      |
|--------------------|------------------------------------|--------------------------------|--------------|-------|----------------------------|
| Threskiornithidae  | Glossy Ibis                        | Plegadis falcinellus           | Migratory    | 2020  | Retained                  |
| Threskiornithidae  | Bare-faced Ibis                    | Phimosus infuscatus            | Resident     | 2020  | Retained                  |
| Threskiornithidae  | Buff-necked Ibis                   | Theristicus caudatus           | Resident     | 2020  | Recolonizer               |
| Catartidae         | Black Vulture                      | Coragyps atratus               | Resident     | 2020  | Retained                  |
| Catartidae         | Turkey Vulture                     | Cathartes aura                 | Resident     | 2015  | Retained                  |
| Pandionidae        | Osprey                             | Pandion haliaetus              | Migratory    | 2015  | Recolonizer               |
| Accipitridae       | White-tailed Kite                  | Elanus leucurus                | Resident     | 2020  | Candidate to extirpation   |
| Accipitridae       | Pearl Kite                         | Gampsonyx swainsonii           | Resident     | 2015  | Recolonizer               |
| Accipitridae       | Snail Kite                         | Rostrhamus sociabilis          | Resident     | 2010  | Unique                     |
| Accipitridae       | Roadside Hawk                      | Rupornis magnirostris          | Resident     | 2018  | Retained                  |
| Accipitridae       | Broad-winged Hawk                  | Buteo platypterus              | Migratory    | 2013  | Unique                     |
| Accipitridae       | Short-tailed Hawk                  | Buteo brachyurus               | Migratory    | 2008  | Unique                     |
| Tytonidae          | Barn Owl                           | Tyto alba                      | Resident     | 1999  | Retained                  |
| Strigidae          | Tropical Screech-Owl               | Megascoptes choliba            | Resident     | 1999  | Unique                     |
| Alcedinidae        | Ringed Kingfisher                  | Megaceryle torquata            | Resident     | 2018  | Retained                  |
| Alcedinidae        | Amazon Kingfisher                  | Chloroceryle amazona           | Resident     | 2010  | Extirpated                 |
| Alcedinidae        | Green Kingfisher                   | Chloroceryle americana         | Resident     | 2017  | Extirpated                 |
| Picidae            | Grayish Piculet                    | Picumnus granadensis           | Resident     | 2014  | Retained                  |
| Picidae            | Red-crowned Woodpecker             | Melanerpes rubricapillus       | Resident     | 2018  | New Colonizer             |
| Picidae            | Crimson-crested Woodpecker         | Campephilus melanolaeucos      | Resident     | 2017  | Retained                  |
| Picidae            | Lineated Woodpecker                | Dryocopus lineatus             | Resident     | 2020  | Retained                  |
| Picidae            | Spot-breasted Woodpecker           | Colaptes punctigula            | Resident     | 2020  | Retained                  |
| Falconidae         | Crested caracara                   | Caracara cheriway              | Resident     | 2020  | Retained                  |
| Falconidae         | Yellow-headed Caracara             | Milvago chimachima             | Resident     | 2020  | Retained                  |
| Falconidae         | American Kestrel                   | Falco sparverius               | Resident     | 2017  | Recolonizer               |
| Falconidae         | Aplomado Falcon                    | Falco femoralis                | Resident     | 2020  | Retained                  |
| Psittacidae        | Orange-chinned Parakeet            | Brotogeris jugularis           | Resident     | 2018  | Unique                     |
| Psittacidae        | Blue-headed Parrot                 | Pionus menstruus               | Resident     | 2018  | New Colonizer             |
| Psittacidae        | Yellow-crowned Amazon              | Amazona ochrocephala           | Resident     | 2020  | New Colonizer             |
| Psittacidae        | Spetacled Parrotlet                | Forpus conspicillatus          | Resident     | 2018  | Retained                  |
| Family               | Species Name                          | Scientific Name       | Status          | Year  | Type           |
|---------------------|--------------------------------------|-----------------------|-----------------|-------|----------------|
| Psittacidae         | Chestnut-fronted Macaw               | *Ara severus*         | Resident        | 2020  | New Colonizer |
| Psittacidae         | Scarlet-fronted Parakeet             | *Psittacula wagleri*  | Resident        | 2018  | Retained      |
| Thamnophilidae      | Bar-crested Antshrike                | *Thamnophilus multistriatus* | Resident      | 2018  | Retained      |
| Thamnophilidae      | Jet Antbird                          | *Cercomacra nigricans* | Resident        | 2018  | Retained      |
| Furnariidae         | Uniform Treehunter                   | *Thripadectes ignobilis* | Resident    | 1989  | Unique        |
| Furnariidae         | Red-faced Spinetail                  | *Craniola eurythrops* | Resident       | 2017  | Unique        |
| Furnariidae         | Slaty Spinetail                      | *Synallaxis brachyura* | Resident       | 2013  | Unique        |
| Furnariidae         | Pale-breasted Spinetail              | *Synallaxis albescens* | Resident       | 2020  | Recolonizer   |
| Tityridae           | Cinereous Becard                     | *Pachyramphus rufus*  | Resident        | 2014  | Retained      |
| Tyriidiidae         | Yellow-olive Flycatcher              | *Tolmomyias sulphurescens* | Resident    | 2020  | Retained      |
| Tyriidiidae         | Slate-headed Tody-Flycatcher         | *Poecliotriccus sylvia* | Resident     | 2016  | Unique        |
| Tyriidiidae         | Common Tody-Flycatcher               | *Todirostrum cinereum* | Resident      | 2018  | Retained      |
| Tyriidiidae         | Golden-faced Tyrannulet              | *Zimmerius chrysops*  | Resident       | 2013  | Unique        |
| Tyriidiidae         | Southern Beardless Tyrannulet        | *Camptostoma obsoletum* | Resident   | 2018  | Retained      |
| Tyriidiidae         | Yellow-bellied Elaenia               | *Elaenia flavogaster* | Resident       | 2018  | Retained      |
| Tyriidiidae         | Mountain Elaenia                     | *Elaenia frantzii*    | Resident       | 1998  | Unique        |
| Tyriidiidae         | Yellow-crowned Tyrannulet            | *Tyrannulus elatus*   | Resident       | 2017  | New Colonizer |
| Tyriidiidae         | Mouse-colored Tyrannulet             | *Phaeomyzetetes murina* | Resident   | 2018  | New Colonizer |
| Tyriidiidae         | Great Kiskadee                       | *Pitangus sulphuratus* | Resident      | 2020  | Retained      |
| Tyriidiidae         | Cattle Tyrant                        | *Macetornis rixosa*   | Resident       | 2020  | Recolonizer   |
| Tyriidiidae         | Streaked Flycatcher                  | *Myiodynastes maculatus* | Resident | 2018  | New Colonizer |
| Tyriidiidae         | Rusty-margined Flycatcher            | *Myiometes cayanensis* | Resident     | 2020  | Retained      |
| Tyriidiidae         | Social Flycatcher                    | *Myiometes similis*   | Resident       | 2017  | Vagrant       |
| Tyriidiidae         | Tropical Kingbird                    | *Tyrannus melancholicus* | Resident | 2020  | Retained      |
| Tyriidiidae         | Fork-tailed Flycatcher               | *Tyrannus savana*     | Migratory      | 2020  | Retained      |
| Tyriidiidae         | Eastern Kingbird                     | *Tyrannus tyrannus*   | Migratory      | 2014  | Retained      |
| Tyriidiidae         | Bran-colored flycatcher              | *Myiophobus fasciatus* | Resident      | 1999  | Unique        |
| Tyriidiidae         | Vermilion Flycatcher                 | *Pyrocephalus rubinus* | Resident      | 2020  | Retained      |
| Tyriidiidae         | Pied Water-Tyrant                    | *Fluvicola pica*      | Resident       | 2020  | Retained      |
| Tyriidiidae         | Western Wood-Pewee                   | *Contopus sordidulus* | Migratory      | 2014  | Unique        |
| Order       | Family            | Species                          | Status    | Year   | Notes                      |
|-------------|-------------------|----------------------------------|-----------|--------|----------------------------|
| Hirundinidae| Blue-and-white Swallow | Pygochelidon cyanoleuca          | Resident  | 2020   | Recolonizer                |
| Hirundinidae| Southern Rough-winged Swallow | Stelgidopteryx ruficollis       | Resident  | 2020   | Retained                   |
| Hirundinidae| Brown-chested Martin  | Progne tapera                   | Migratory | 2017   | Unique                     |
| Hirundinidae| Purple Martin      | Progne subis                    | Migratory | 1981   | Unique                     |
| Hirundinidae| Gray-breasted Martin | Progne chalybea                | Resident  | 1999   | Extirpated                 |
| Hirundinidae| Barn Swallow      | Hirundo rustica                 | Migratory | 2017   | Retained                   |
| Hirundinidae| House Wren         | Troglodytes aedon               | Resident  | 2008   | Unique                     |
| Hirundinidae| Swainson's Thrush  | Catharus ustulatus              | Migratory | 2018   | Retained                   |
| Hirundinidae| Black-billed Thrush | Turdus ignobilis               | Resident  | 2018   | Retained                   |
| Mimidae     | Tropical Mockingbird | Mimus gilvus                  | Resident  | 2020   | Recolonizer                |
| Estrildidae | Java Sparrow      | Lonchura oryzivora             | Resident  | 2007   | Exotic/ Candidate to extirpation |
| Estrildidae | Chestnut Munia    | Lonchura atricapilla           | Resident  | 2002   | Exotic/ Unique             |
| Fringillidae | Lesser Goldfinch | Spinus psaltria               | Resident  | 2015   | Candidate to extirpation    |
| Fringillidae | Thick-billed Euphonia | Euphonia lanirostris       | Resident  | 2020   | Recolonizer                |
| Passerinellida | Grassland Sparrow | Ammodramus humeralis         | Resident  | 2020   | Candidate to extirpation    |
| Passerinellida | Rufous-collared Sparrow | Zonotrichia capensis    | Resident  | 2015   | Unique                     |
| Icteridae   | Red-breasted Blackbird | Leistes militaris          | Resident  | 2018   | Retained                   |
| Icteridae   | Yellow-tailed Oriole | Icterus mesomelas           | Resident  | 2017   | Retained                   |
| Icteridae   | Yellow-backed Oriole | Icterus chrysater            | Resident  | 2017   | New Colonizer              |
| Icteridae   | Yellow Oriole      | Icterus nigrogularis          | Resident  | 2020   | Retained                   |
| Icteridae   | Shiny Cowbird      | Molothrus bonariensis         | Resident  | 2020   | Retained                   |
| Icteridae   | Oriole Blackbird   | Gymnomystax mexicanus        | Resident  | 2018   | Retained                   |
| Icteridae   | Yellow-hooded Blackbird | Chrysomus icteroccephalus  | Resident  | 2017   | Retained                   |
| Parulidae   | Northern Waterthrush | Parkesia noveboracensis     | Migratory | 2014   | Unique                     |
| Parulidae   | Mourning Warbler   | Geothlypis philadelphia      | Migratory | 2014   | Unique                     |
| Parulidae   | Tropical Parula    | Setophaga pitiayumi          | Resident  | 2018   | Recolonizer                |
| Parulidae   | Yellow Warbler     | Setophaga petechia           | Migratory | 2020   | Retained                   |
| Cardinalidae | Summer Tanager  | Piranga rubra                | Migratory | 2013   | Unique                     |
| Order            | Species                        | Scientific Name         | Status     | Year | Notes            |
|------------------|--------------------------------|-------------------------|------------|------|------------------|
| Cardinalidae     | Rose-breasted Grosbeak         | *Pheucticus ludovicianus* | Migratory  | 2015 | Unique           |
| Cardinalidae     | Ultramarine Grosbeak           | *Cyanoloxia brissonii*  | Resident   | 1989 | Unique           |
| Thraupidae       | Guira tanager                  | *Hemithraupis guira*    | Resident   | 2014 | Unique           |
| Thraupidae       | Saffron Finch                  | *Sicalis flaveola*      | Resident   | 2018 | Retained         |
| Thraupidae       | Grassland Yellow-finch         | *Sicalis lutenea*       | Resident   | 2017 | New Colonizer    |
| Thraupidae       | Blue-black Grassquit           | *Volatinia jacarina*    | Resident   | 2020 | Retained         |
| Thraupidae       | Ruddy-breasted Seedeater       | *Sporophila minuta*     | Resident   | 2018 | Retained         |
| Thraupidae       | Thick-billed Seed-Finch        | *Sporophila funerea*    | Resident   | 2017 | New Colonizer    |
| Thraupidae       | Gray Seedeater                 | *Sporophila intermedia* | Resident   | 2015 | Recolonizer      |
| Thraupidae       | Yellow-bellied Seedeater       | *Sporophila nigricollis*| Resident   | 2018 | Retained         |
| Thraupidae       | Slate-colored Seedeater        | *Sporophila schistacea* | Resident   | 2014 | Vagrant          |
| Thraupidae       | Streaked Saltator              | *Saltator striatipectus*| Resident   | 2017 | Recolonizer      |
| Thraupidae       | Bananaquit                     | *Coereba flaveola*      | Resident   | 2018 | Recolonizer      |
| Thraupidae       | Yellow-faced Grassquit         | *Tiaris olivaceus*      | Resident   | 1999 | Extirpated       |
| Thraupidae       | Dull-colored Grassquit         | *Asemospiza obscura*    | Resident   | 1998 | Unique           |
| Thraupidae       | Masked Cardinal                | *Paroaria nigrogenis*   | Resident   | 2014 | Vagrant          |
| Thraupidae       | Red-capped Cardinal            | *Paroaria gularis*      | Resident   | 2011 | Candidate to extirpation |
| Thraupidae       | Scrub Tanager                  | *Stilpnia vitriolina*   | Resident   | 2017 | Recolonizer      |
| Thraupidae       | Blue-gray Tanager              | *Thraupis episcopus*    | Resident   | 2018 | Retained         |
| Thraupidae       | Palm Tanager                   | *Thraupis palmarum*     | Resident   | 2018 | Recolonizer      |
Appendix 4. Mantel’s test correlogram relates the temporal structure of the 44-year period with the correlation of the species composition among bird lists. For the X-axis the temporal distance between lists has units of years. By using the correlogram, we determined the maximum number of years among bird lists with a direct-positive correlation. In order to implement the correlogram we use the Vegan package (Oksanen 2017) in the software R (R Core Team 2020). For each separation time among bird lists in the correlogram, their significance (dark squares) was approximated using a Bonferroni correction by 16,000 permutations (α= 0.05).
Appendix 5. Boxplot of species richness for years with the highest representation on data.
Appendix 6. Multicriteria framework to define extirpation. Criterion A compares two datasets spaced in time. Criterion C assesses the presence/absence of species in the buffer period. Criterion B examines the pattern of appearance and disappearance of the species between the baseline and present.
**Appendix 7.** Long-term assessment of a published hypothesis of 11 extirpated bird species in the Cauca valley, using additional records after Restrepo and Naranjo (1987).

| Family      | Species                  | Number of Records | Records                  | Long-Term Diagnostic after 1987 |
|-------------|--------------------------|-------------------|--------------------------|---------------------------------|
| Anatidae    | *Cairina moschata*       | 7                 | 1995, 2004, 2006, 2008, 2011, 2018, 2019 | Not extirpated                  |
| Anatidae    | *Spatula clypeata*       | 3                 | 1995, 2017, 2020         | Sporadic                        |
| Anatidae    | *Mareca americana*       | 1                 | 2014                     | Rare, Erratic                   |
| Anatidae    | *Anas acuta*             | 3                 | 2012, 2013, 2017, 2018   | Local, Erratic                  |
| Anatidae    | *Anas georgica*          | 5                 | 2012, 2013, 2014, 2015, 2017, 2019 | Recolonizer                     |
| Anatidae    | *Aythya affinis*         | 1                 | 2016                     | Rare, Sporadic                  |
| Anatidae    | *Netta erythrophthalma*  | 0                 | NA                       | Extirpated                      |
| Ciconiidae  | *Jabiru mycteria*        | 0                 | NA                       | Extirpated                      |
| Ciconiidae  | *Mycteria americana*     | 2                 | 2005, 2012               | Extirpated                      |
| Ardeidae    | *Tigrisoma lineatum*     | 3                 | 1992, 2018, 2019         | Recolonizer                     |
| Threskiornithidae | *Eudocimus albus* | 0 | NA | Extirpated |

Restrepo, C. and L. G. Naranjo. 1987. Recuento histórico de la disminución de humedales y la desaparición de aves acuáticas en el valle geográfico del Río Cauca, Colombia. In: Memorias III Congreso de Ornitología Neotropical, Cali, Colombia, pp. 43–45.