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Using citizen-science data to identify declining or recently extinct populations of Bahamian birds

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Abstract Birds restricted to islands are especially vulnerable to extinction. To assess the status of island-specific populations of breeding landbirds in the Bahamas, we analyzed more than 307,000 occurrence records of Bahamian birds from the citizen-science database eBird. We identified populations that have gone unrecorded from 1 January 2012 to 31 May 2018 and which, therefore, may be declining, imperiled, or even extinct. We found 56 island populations, representing 30 species, that have gone unreported during that period. Including eBird records through 31 May 2020 lowered this number to 43 populations representing 25 species. These potentially declining or extinct island populations should be of concern to conservationists and merit follow-up searches by birdwatchers. Citizen-science data in eBird may offer a new way to identify imperiled populations in places that lack systematic, long-term bird surveys.

Keywords Bahamas, conservation, eBird, extinction, island populations, monitoring

Resumen Utilización de los datos de ciencia ciudadana para identificar las poblaciones de aves de las Bahamas en declive o recientemente extintas • Las aves restringidas a islas son especialmente vulnerables a la extinción. Para evaluar el estado de las poblaciones isla-específicas de aves terrestres reproductoras en las Bahamas, analizamos más de 307.000 registros de ocurrencia de aves de las Bahamas de la base de datos de ciencia ciudadana eBird. Identificamos poblaciones que no han sido registradas desde el 1 de enero de 2012 hasta el 31 de mayo de 2018 y que, por lo tanto, pueden estar disminuyendo, en peligro o incluso extintas. Encontramos 56 poblaciones insulares, que representan 30 especies, que no han sido registradas durante ese periodo. Incluir los registros de eBird hasta el 31 de mayo de 2020, redujo este número a 43 poblaciones que representan 25 especies. Estas poblaciones insulares potencialmente en declive o extintas deberían ser motivo de preocupación para los conservacionistas y ameritar búsquedas de seguimiento por parte de observadores de aves. Los datos de ciencia ciudadana en eBird pueden ofrecer una nueva forma de identificar poblaciones en peligro en lugares que carecen de muestreos sistemáticos de aves a largo plazo.

Palabras clave Bahamas, conservación, eBird, extinción, monitoreo, poblaciones insulares

Résumé Utilisation de données de la science citoyenne pour identifier les populations d'oiseaux des Bahamas en déclin ou récemment disparues • Les oiseaux inféodés aux îles sont particulièrement sensibles à l'extinction. Pour évaluer l'état des populations insulaires des oiseaux terrestres nicheurs aux Bahamas, nous avons analysé plus de 307 000 mentions d'oiseaux des Bahamas issues de la base de données de science citoyenne eBird. Nous avons identifié les populations qui n'avaient pas été enregistrées entre le 1er janvier 2012 et le 31 mai 2018 et qui, par conséquent, pourraient être en déclin, en danger ou même éteintes. Nous avons trouvé 56 populations insulaires, représentant 30 espèces, qui n'avaient pas été signalées durant cette période. En incluant les données eBird jusqu'au 31 mai 2020, ce nombre a été ramené à 43 populations représentant 25 espèces. Ces populations insulaires potentiellement en déclin ou éteintes devraient préoccuper les acteurs de la conservation et méritent que les ornithologues amateurs entreprennent des recherches complémentaires. Les données de la science citoyenne enregistrées dans eBird peuvent offrir un nouveau moyen d'identifier les populations menacées là où il n'y a pas de suivis systématiques et à long terme des oiseaux.

Mots clés Bahamas, conservation, eBird, extinction, populations insulaires, suivi

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Hurricane Dorian's destructive path through the northern Bahamas in 2019 raised concern for the survival of several of the region's endemic birds, including the Bahama Nuthatch, a subspecies of the Brown-headed Nuthatch (*Sitta pusilla insularis*, classified as Critically Endangered by BirdLife International), Ba-

hama Oriole (*Icterus northropi*, Critically Endangered), and Bahama Swallow (*Tachycineta cyaneoviridis*, Endangered), among other species (Hayes *et al.* 2004, Chesser *et al.* 2019, Youth 2019, BirdLife International 2020). Hurricane Dorian, however, occurred against a backdrop of deforestation, logging, overhunting, and the spread of invasive species that have eroded populations of a number of Bahamian birds in recent decades (Lloyd and Slater 2011). White (1998) reported six breeding populations of birds, representing five species, that had disappeared from particular Bahamian islands on which they once occurred, although some of these species persist elsewhere in the archipelago.

This loss of island populations is alarming for at least three reasons. First, population losses can be a prelude to the eventual extinction of a species. Indeed, bird species restricted to islands are more vulnerable to extinction than those found on continents (Johnson and Stattersfield 1990). Second, the loss of distinct populations can mean the loss of genetic diversity within a species (Adkison 1995). Third, the loss or decline of populations can disrupt ecosystem functioning or the provisioning of ecosystem services (Ceballos *et al.* 2017). Rathcke (2000), for example, reported that after a hurricane sharply reduced populations of Bananaquits (*Coereba flaveola*) and Bahama Woodstars (*Nesophlox evelynae*) on San Salvador Island, fruit set of the native Bahama swamp-bush (*Pavonia bahamensis*) was severely depressed, which he attributed to pollination limitation caused by the decline of the two birds.

Unfortunately, the disappearance of island populations can go unnoticed, especially in countries lacking systematic, annual monitoring programs for their birds. In the case of the Bahama Nuthatch, a large decline that commenced sometime after the late 1960s was not detected until 2007, when extensive surveys on Grand Bahama resulted in very few sightings (Lloyd and Slater 2011). A concerted search effort on Grand Bahama in 2018 resulted in only 1–2 individuals being seen (Hermes and Sessa-Hawkins 2019).

Over the last few decades, citizen science has become a popular tool in ecology and conservation. It has been successfully used in monitoring population trends of various species (Jiguet *et al.* 2012), identifying images taken by camera traps (Swanson *et al.* 2016), detecting invasive species (Crall *et al.* 2011), and managing wildlife diseases (Lawson *et al.* 2015), amongst others.

Here, we use a popular citizen-science and conservation database, eBird (eBird 2020), to identify island populations of Bahamian birds that have gone undetected in recent years and may therefore be imperiled or even extinct. Our list of recently unreported populations could be useful in identifying species that may be sliding toward endangerment. Moreover, this approach can easily be extended to other archipelagoes, providing early warnings of declines in other avifaunas.

Methods

We first compiled a list of breeding species on each island in the Bahamian archipelago based on the checklist in White (1998). To the best of our knowledge, it is the only readily available compilation of presence/absence data for bird species on each island in the Bahamian archipelago, although we did not independently verify its accuracy. We further narrowed our focus to native, diurnal species that inhabit forests, scrublands, and disturbed terrestrial habitats such as agricultural lands and residential areas. Narrowing our list in this way emphasized species that are likely to be relatively easy to detect by birdwatchers, especially visitors eager to see the Bahamas' endemic species. This resulted in a pool of 52 species in the families Columbidae, Cuculidae, Trochilidae, Cathartidae, Accipitridae, Strigidae (Burrowing Owl [*Athene cunicularia*] only), Picidae, Psittacidae, Tyrannidae, Vireonidae, Corvidae, Hirundinidae, Polioptilidae, Turdidae, Mimidae, Spindalidae, Icteridae, Parulidae, and Thraupidae.

We then obtained all checklists from the Bahamas reported to eBird up through 31 May 2018 from the Cornell Lab of Ornithology (eBird Basic Dataset 2018). This totaled approximately 307,000 occurrence records of species, each including the island on which the sighting was made. The checklists span all months of the year, although visitation is clearly biased toward certain seasons. Dividing the checklists into 3-month blocks shows that the period January–March accounted for ~41% of checklists, April–June for ~24%, July–September for ~12%, and October–December for ~23%. Because any observation of a species on a given island would demonstrate that its population there persists, we included both complete and incomplete checklists in our study. Complete checklists (~82% of total checklists) list all species detected by the observer at the site in question during the time the observer was birdwatching, while incomplete checklists (~18%) list only some of the species the observer saw or heard.

For the purposes of this study, we disregarded the number of individuals of each species reported, thereby simplifying our database to a presence/absence record of each species on each island and avoiding variable accuracy of different observers, as many eBird checklists did not list counts of species, only their presence/absence. Using the programming language R (R Development Core Team 2011) and focusing on the 10-yr period from 2008 to 2018 (chosen to reflect the past decade, during which the use of eBird among birdwatchers has grown explosively), we cross-referenced the eBird sightings with White's (1998) list of breeding species on each Bahamian island. Then, we flagged the breeding species that were listed as occurring on a particular island by White that had not been reported on that island since 2012 according to eBird. We chose 2012–2018 so as to have a multi-year period without sightings in order to account for species that may be difficult to find or which occur on islands that are infrequently visited, but not so long a period of time as to obscure any recent extinctions. Once we identified populations that had not been recorded in the multi-year period since 2012, we then performed a second eBird search for records of undetected populations through 31 May 2020, thus including two additional years of observations. We ultimately included only observations from eBird because we could not ascertain the accuracy of sightings reported elsewhere.

White (1998) combines a few of the smaller Bahamian islands in his checklist, an approach we followed in our analysis. Thus, Cat Cay is included in the Biminis; Joulter Cays in Andros; Little San Salvador in Cat Island; Rum Cay and Conception Island in San Salvador; Samana Cay and Plana Cays in Crooked and Acklins; and Cay Verde, Cay Santo Domingo, and Cay Lobos in Ragged Islands. Notably, eBird divides the large islands of Abaco, Andros, Eleuthera, and Grand Bahama into multiple regions (e.g.,

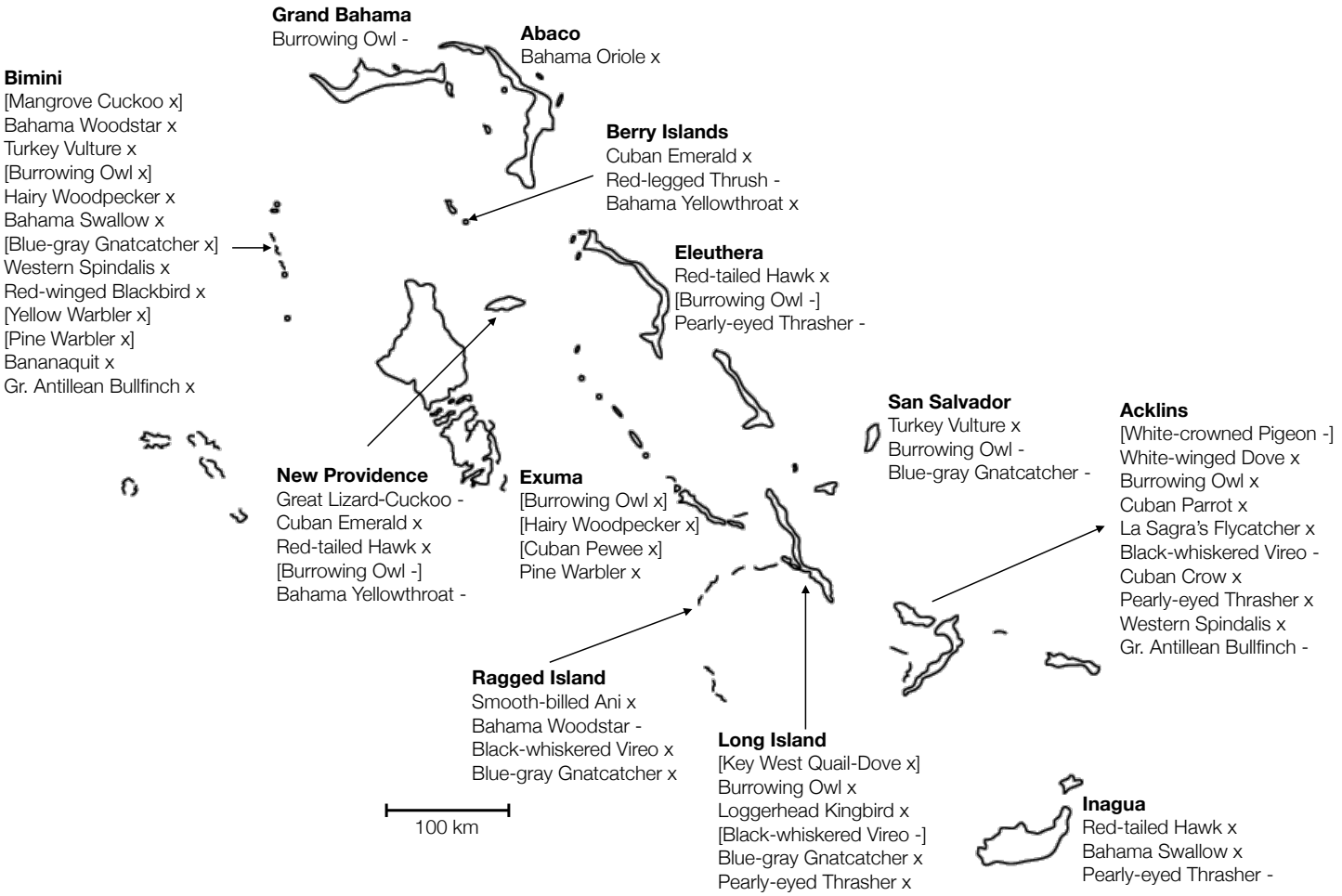

Fig. 1. Breeding populations of Bahamian birds on individual islands that have gone unrecorded in eBird from 1 January 2012 through 31 May 2018. "x" indicates that the population in question was known to occur on that island but was unrecorded in eBird through 31 May 2018; "-" indicates that the population was unrecorded between 1 January 2012 and 31 May 2018. "[]" indicates that the species was subsequently reported in eBird between 1 June 2018 and 31 May 2020. See text for details.

North Abaco, Central Abaco, South Abaco). However, since we were concerned with potential losses of bird populations from each island as a whole, we combined the data from the separate regions so that each of the large islands was analyzed as a single entity.

The likelihood that a species that has not been reported from a particular island since 2012 is actually missing from that island is influenced by the extent to which birdwatchers have covered that island. We therefore generated species accumulation curves for each of the islands or island groups mentioned above. The ~307,000 species occurrence records in our database came from 25,191 checklists posted on eBird. Of these checklists, ~81% indicated how much time the observer(s) had spent in the field on that particular day at that location. Thus, using the checklists that specified time afield, we calculated the average number of hours spent in the field per checklist and applied that average value to the checklists that did not specify time afield. Using the package vegan (Oksanen *et al.* 2019), we then generated species accumulation curves (random order, 100 permutations) as a function of the number of checklists for each island, weighted by the checklist duration, using those species from our pool of 52 that occurred on each island, according to White (1998). Visual inspection of the curves (Appendix 1) indicated that species richness was approaching an asymptotic value for all islands or island groups except Mayaguana (with only 8 cumulative hours of observation). We therefore dropped Mayaguana from our analysis.

Results

We identified 56 populations of Bahamian birds, representing 30 species, that were not reported on eBird between 1 January 2012 and 31 May 2018 (Table 1, Fig. 1). However, when we removed populations that were sighted and reported on eBird after our cutoff date of 31 May 2018, the number of unrecorded Bahamian bird populations dropped to 43 (Table 1). Some of these 43 unreported populations are well known to ornithologists (e.g., Bahama Oriole on Abaco; Price and Hayes 2009, Stonko *et al.* 2018); others, however, especially those involving more widespread species, have attracted little attention to date.

The 43 unreported bird populations include 25 species (nearly half the total number of species included in our study) and span all 19 families represented in our species pool. Thirteen of the

Table 1. Breeding populations of Bahamian birds on individual islands that were unrecorded in eBird from 1 January 2012 through 31 May 2018. The second row contains the total observation hours logged in eBird for each island. A mark in a box indicates that the species was known to occur on that island, but either no records from there exist in eBird as of 31 May 2018 (X), or no records were added during the period 1 January 2012 to 31 May 2018 (—). Brackets [ ] indicate that the population of that species on that island was subsequently reported on eBird after 31 May 2018. Marks without brackets indicate that the population remained unrecorded through the end of the study period (31 May 2020).

Islands		**Grand Bahama**	**Abaco**	**New Providence**	**Inagua**	**San Salvador**	**Eleuthera**	**Exuma**	**Berry Islands**	**Long Island**	**Bimini**	**Acklins**	**Ragged Island**
eBird Observation Hours		9,435	6,908	5,238	1,377	1,008	767	642	425	158	145	81	52
Species	*Conservation Status*												
White-crowned Pigeon (*Patagioenas leucocephala*)	NT											[—]	
Key West Quail-Dove (*Geotrygon chrysia*)	LC									[x]			
White-winged Dove (*Zenaida asiatica*)	LC											x	
Smooth-billed Ani (*Crotophaga ani*)	LC												x
Mangrove Cuckoo (*Coccyzus minor*)	LC										[x]		
Great Lizard-Cuckoo (*C. merlini*)	LC			—[a]									
Bahama Woodstar (*Nesophlox evelynae*)	LC										x		—
Cuban Emerald (*Chlorostilbon ricordii*)	LC			x					x				
Turkey Vulture (*Cathartes aura*)	LC					x					x		
Red-tailed Hawk (*Buteo jamaicensis*)	LC			x	x		x						
Burrowing Owl (*Athene cunicularia*)	LC	—		[—]		—	[—]	[x]		x	[x]	x	
Hairy Woodpecker (*Dryobates villosus*)	LC							[x[a]]			x		
Cuban Parrot (*Amazona leucocephala*)	NT											x[a]	
La Sagra's Flycatcher (*Myiarchus sagrae*)	LC											x	
Loggerhead Kingbird (*Tyrannus caudifasciatus*)	LC									x			
Cuban Pewee (*Contopus caribaeus*)	LC							[x[a]]					
Black-whiskered Vireo (*Vireo altiloquus*)	LC									[—]		—	x
Cuban Crow (*Corvus nasicus*)	LC											x	
Bahama Swallow (*Tachycineta cyaneoviridis*)	EN				x						x		
Blue-gray Gnatcatcher (*Polioptila caerulea*)	LC					—				x	[x]		x
Red-legged Thrush (*Turdus plumbeus*)	LC								—[a]				
Pearly-eyed Thrasher (*Margarops fuscatus*)	LC				—		—			x		x	
Western Spindalis (*Spindalis zena*)	LC										x	x	
Bahama Oriole (*Icterus northropi*)	CR		x										
Red-winged Blackbird (*Agelaius phoeniceus*)	LC										x		
Bahama Yellowthroat (*Geothlypis rostrata*)	LC			—					x				
Yellow Warbler (*Setophaga petechia*)	LC										[x]		
Pine Warbler (*S. pinus*)	LC							x			[x[a]]		
Bananaquit (*Coereba flaveola*)	LC										x[a]		
Greater Antillean Bullfinch (*Melopyrrha violacea*)	LC										x[a]	—[a]	

Symbols and Notations
X: no records of population in eBird through 31 May 2018
—: population not reported in eBird between 1 January 2012 and 31 May 2018
[]: population reported in eBird between 1 June 2018 and 31 May 2020
LC: species listed as Least Concern by IUCN Red List
NT: species listed as Near Threatened by IUCN Red List
EN: species listed as Endangered by IUCN Red List
CR: species listed as Critically Endangered by IUCN Red List
Species in boldface are endemic to the Bahamas
[a]: denotes a population belonging to a subspecies endemic to the Bahamas

43 species are unreported from single islands; 8 are unreported from 2 islands each, 2 are unreported from 3 islands, and 2 (Burrowing Owl, Pearly-eyed Thrasher [*Margarops fuscatus*]) are unreported from 4 islands each.

Of the 25 unreported species, islands ranged from having no unreported species to having nine. Specifically, two islands (Andros, Cat) have no unreported species; Grand Bahama, Abaco, and Exuma each have one unreported species (though the Bahama Nuthatch may have disappeared from Grand Bahama since our cutoff date of May 2018; Youth 2019); Eleuthera has two; Inagua, San Salvador, and Berry each have three; New Providence, Long, and Ragged each have four; Bimini has eight; and Acklins has nine.

Discussion

Our analysis of eBird data from 15 islands or island clusters in the Bahamas revealed 43 island populations, encompassing 25 species, that have gone unrecorded since at least 2012. These unrecorded populations defy easy categorization by life-history traits often associated with vulnerability to extinction (e.g., high trophic level, large body size, habitat specialization; Terborgh 1974, Purvis *et al.* 2000). Nor are they disproportionately from avian families with high proportions of threatened species (Bennett and Owens 1997). Four species are endemic to the Bahamas (Bahama Woodstar, Bahama Swallow, Bahama Oriole, Bahama Yellowthroat [*Geothlypis rostrata*]), making the lack of recent observations from some of the islands they inhabit especially troubling. Twelve of the unrecorded populations constitute subspecies endemic to the Bahamas, representing 10 species. Two unrecorded species, Western Spindalis (*Spindalis zena*) and Greater Antillean Bullfinch (*Melopyrrha violacea*), each have two unrecorded populations of an endemic subspecies (in the case of the Western Spindalis, both populations are of *S. z. zena*). Because Chesser *et al.* (2019) does not include subspecies, we relied on the Cornell Lab of Ornithology's database, Birds of the World, for information on subspecies (Billerman *et al.* 2020). Also, we do not include La Sagra's Flycatcher (*Myiarchus sagrae*) in this tally because the unrecorded population on Bimini may not be the endemic subspecies *lucaysiensis*.

However, we hasten to add that the lack of recent records in eBird does not constitute proof that these populations have actually disappeared from the islands in question. Indeed, the fact that our initial list of 56 unrecorded populations as of 31 May 2018 dropped to 43 when we expanded our search to include eBird records through 31 May 2020 suggests some or even many of these populations persist. Nonetheless, the absence of recent records should be seen as a warning sign that some or all of these populations may be in decline, and the species identified should be actively searched for by birdwatchers in the Bahamas. In particular, we encourage birdwatching and conservation organizations in the Caribbean to publicize this list of "missing-in-action" populations so as to encourage both resident and visiting birdwatchers to look for them. The islands with the largest number of unreported populations (e.g., Acklins, Bimini, New Providence, Long, and Ragged) merit particular attention. So, too, does Mayaguana, where the paucity of eBird records made it impossible for us to identify populations that may be at risk. In the long term, bird conservation in the Bahamas would benefit greatly from a standardized annual survey of breeding birds across the archipelago that can detect population declines (as opposed to population extirpations) more accurately and rapidly than eBird.

We note that any errors in White (1998) with respect to which species occur on which islands would have carried over into our study in terms of either inaccurately reporting an island extirpation if the species, in fact, never occurred on that island, or failing to detect an actual loss if White did not list a species as breeding on a particular island from which it has, indeed, recently vanished.

Seasonality affects how likely a given species is to be detected by birdwatchers. If many landbirds are easiest to detect during the breeding season when males are singing, then a tendency for birdwatchers to be most active during the non-breeding season would reduce the chances of detecting uncommon species. Birdwatching activity in the Bahamas, as measured by the eBird checklists, is clearly more intense during the winter and spring months (see Methods). Fortunately, heavy coverage in the spring overlaps with the breeding periods of many (but surely not all) Bahamian birds, reducing the impact of this seasonal bias in coverage on our results.

Our study design does not allow us to determine why particular species may have declined or disappeared from particular islands. Doing so would require additional analyses of the habitat relationships of resident birds combined with island-specific data on anthropogenic land-use change, storm damage, and other potential threats. Lloyd and Slater (2011) thought that a recent decline in the Hairy Woodpecker (*Dryobates villosus*) population on Grand Bahama might be due to forest damage caused by hurricanes; however, we do not know whether its possible disappearance from Bimini (Table 1) is due to storms or other factors. Allen (1996) identified habitat loss due to commercial logging and commercial development, plus competition for nesting cavities from non-native birds, as likely threats to the Bahama Swallow on Grand Bahama Island. This could also be true on Inagua and Bimini, as our data show that the Bahama Swallow appears to be unrecorded on these islands in recent years. Logging and commercial development were also cited as factors in the decline of the Bahama Nuthatch (Hayes *et al.* 2004). Lloyd and Slater (2010) considered the loss of coconut palms (*Cocos nucifera*) in residential areas to be a threat to the Bahama Oriole, while Stonko *et al.* (2018), reporting the discovery of orioles nesting within native pine forests, listed logging as an additional concern. Other species with potentially missing populations (e.g., Bahama Yellowthroat on New Providence and Berry) have been shown to utilize a wide variety of habitats elsewhere in the archipelago (Currie *et al.* 2005), which cautions against assuming habitat destruction is a driver in all cases.

The heightened vulnerability of island birds to extinction is well documented (Johnson and Stattersfield 1990). Although > 80% of bird species live on continents, 92% of avian extinctions since 1500 have involved insular species (BirdLife International 2017). Sadly, the Bahamas have not been immune to this trend, with at least one species (Brace's Emerald, *Chlorostilbon bracei*) now considered extinct and another (Bahama Nuthatch) that is nearly, if not completely, gone as well. Our hope is that

future extinctions can be prevented if the observational power of birdwatchers can be harnessed to provide timely notice of declining or missing populations of birds on particular islands within the archipelago.

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Title Page Illustration

Bahama Oriole (*Icterus northropi*) on Andros, The Bahamas, photographed by David Wilcove on 4 January 2018.

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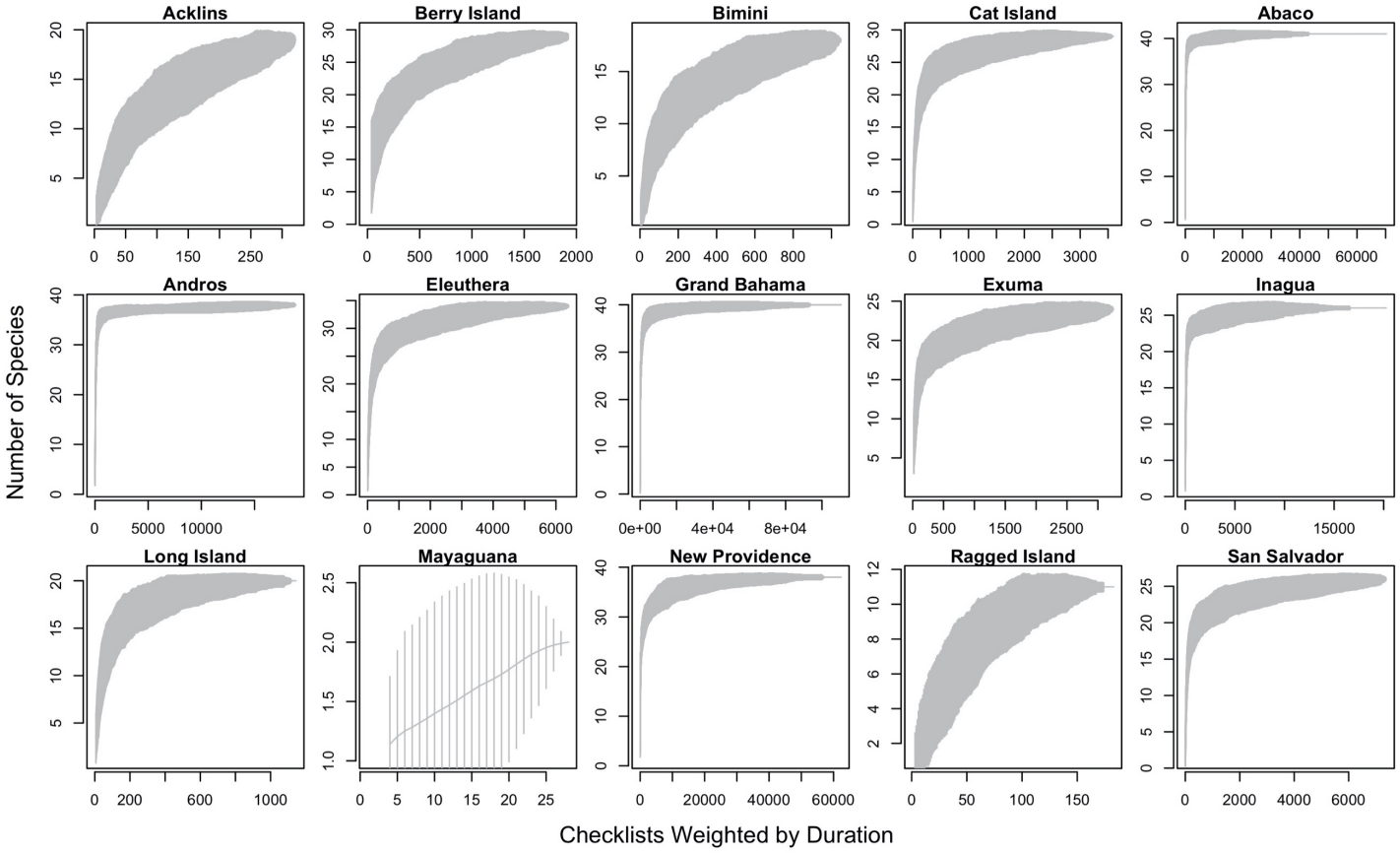
Appendix 1. Species accumulation curves as a function of the number of checklists recorded on each island, weighted by the checklist duration. We only used the 52 species in our species pool in the construction of these curves.



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