

Research Article

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Relationship between age and method of population estimation and the impact of changes in range-size maps on the IUCN Red List assessments of birds

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Summary

Population size is one component of several criteria in the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (Red List). For these criteria, the quality of the population estimate can therefore have significant impact on the assessed status. To evaluate population estimate quality, we selected 473 species of land birds from the Americas considered by the Red List to be “Critically Endangered”, “Endangered”, or “Vulnerable” at the end of 2021, of which 414 (88%) had a population size estimate. For these species, we determined the age of the estimate and how the population estimate was derived, grouped into eight categories. For 87 species (18%) the population estimate was derived by sampling a small area and extrapolating to the entire range of the species; for these, the population size estimate depends on the estimate of range size. For the subset of 22 of these with complete data, we compared range size estimates obtained from maps published by IUCN with maps produced using the methods of Huang et al. (2021) to see how range map differences could affect population size estimates and therefore Red List status. Potentially half of these species (11 of 22) could change status using the new maps. More than one-third of the population size estimates (38%, 161 species with a date of population estimate) were made in 2000 or earlier. A majority of the species, 63% (300 of 473 species), do not have population size estimates made using a scientific sampling method, although the majority since 2010 have been made using a sampling method, reflecting an effort by Red List assessors to include more scientific information. We encourage the ornithological community to work to obtain current, high quality population size and range estimates to improve the quality of Red List status assessments.

Introduction

The International Union for Conservation of Nature (IUCN) Red List of Threatened Species (hereafter Red List) is arguably the most authoritative and widely used tool for assessing the risk of extinction of species (IUCN 2022). Legal protection for species and resources for conservation are often given based on Red List evaluations, both at a global and national level. The Red List uses a set of standard criteria, with quantitative thresholds based on trend, size, and structure of populations and/or geographical range to assign species into one of eight categories of extinction risk (IUCN 2012). Of the five criteria, the one based on geographical range size (criterion B) is the more widely applied (Collen et al. 2016), likely due to the increasing availability of spatial distribution data. On the other hand, criteria C and D (excluding sub-criterion D2) that require population size data (defined by IUCN as number of mature individuals) are less frequently used (Collen et al. 2016) given the scarcity of adequate data. In addition, population estimates have limited temporal validity because populations fluctuate over time (Santini et al. 2022). Nevertheless, the population size criteria are important in the Red List status evaluations of many species.

Among the comprehensively, globally assessed vertebrates, birds are the one group that has been evaluated most frequently using population size data only (39.9% of threatened species), followed by mammals (11.6% of threatened species), amphibians (6.5% of threatened species), and reptiles (1.6% of threatened species). Population estimates of these are usually derived from a variety of sources. In birds, population estimates may be obtained: from direct counts of all individuals (usually of rare species with few individuals, such as Whooping Crane *Grus americana*); from sampling across the entire species range; from extrapolating across the entire range with densities obtained from small sampled areas; or from expert opinion based on various sorts of input data.

In many cases, population estimates for a species being evaluated are made using a density estimate derived using a scientific sampling method, such as a point count or transect method, or by expert opinion, and then extrapolating that value to the estimated range of the species to obtain an overall population estimate. These types of population estimates are dependent on the

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estimate of the range size, proportion of that range that is occupied, and the density estimate used (in cases where average density is used to include both occupied and unoccupied areas of the range), and the population estimate can be significantly affected by an increase or decrease in the estimate of the range size.

Range maps are also often developed using a wide variety of sources, such as specimen records, informal observations, habitat maps, and expert opinion (Brooks et al. 2019; Palacio et al. 2021; Anderson 2023). Recently, Huang et al. (2021) developed a method to produce species distribution maps largely based on eBird data (<https://ebird.org>). Although often based on incomplete data, these maps have a clearly defined method that does not rely on expert opinion, unlike many previous range maps.

The main objective of our work is to review the population size estimates of a set of threatened land birds in the Americas given in the IUCN Red List, focusing on the derivation of the data, year of the estimate, and data quality. We also evaluate how changes in range size estimates may affect population size estimates and thereby affect Red List status. The ultimate goal is to identify issues in the development of population assessments that can be addressed and improved, and to identify geographical areas where additional data on species' density or abundance can be obtained to allow improvements in future Red List assessments.

Methods

Data sources

We focused on species of land birds from the Americas and Caribbean. We excluded seabirds and mainly marine species, such as sea ducks (e.g. Long-tailed Duck *Clangula hyemalis*), and some species that are primarily Eurasian but with small populations or with regular vagrants in the Americas (e.g. Yellow-breasted Bunting *Emberiza aureola*). From this set, our analysis included only species listed at the end of 2021 in the IUCN Red List categories "Critically Endangered" (CR), "Endangered" (EN), and "Vulnerable" (VU), except species listed as CR (Possibly Extinct; seven species) or

species that have not been recorded since 2011 (six "lost species" using the definition of Long and Rodriguez 2022). The assessments and all analysis of the Red List criteria in this paper are based on the *IUCN Red List Categories and Criteria: Version 3.1*. 2nd edn (IUCN 2012). Our final set contained 473 bird species.

We obtained the data of bird population size estimates from BirdLife International. As BirdLife International is the IUCN Red List Authority for Birds, these are the same data that can be accessed on the Red List website (IUCN 2022). The population assessment data we obtained for each species from this data set are: number of mature individuals (i.e. population size as defined by IUCN); year of estimate; derivation; data quality; population justification.

The data set includes two measures that we did not assess, i.e. derivation and data quality. The definitions of each level of these measures are provided in the Red List criteria guidelines (IUCN Standards and Petitions committee 2022). We did not assess these, however, as it is very unclear how they are applied to most of the population estimates in our data set. For example, for most of the species for which a population estimate is given but with no source or other information (63 of 90 species), the derivation of the population number is classified as "Estimated". We judged that often insufficient information is provided as to the methods and assumptions used in making the estimate. Therefore, we did not use the derivation and data quality data further as we were unable to determine how to assess these measures.

To better understand the impact of mapping method on bird population size estimates, and therefore on Red List assessments, we evaluated the impact of the Huang et al. (2021) maps on the population size estimate.

Determining method by which population estimates were made

For each of the species in our data set, we examined the "Population Justification" text and categorised the population estimate method used into one of eight categories. These categories and how we assigned species to them are shown in Table 1.

Table 1. Definitions of population estimate categories.

Category	Category name	Description
1	Direct Count	The entire population of the species was counted by direct observation. This is usually only carried out on species with very low population size.
2	Sampled* Entire Range	A sampling method was used to survey the species over its entire range, and the population size was estimated from those data.
3	Sampled* Small Area and Extrapolated	A sampling method was used to survey the species in a portion of its range, and the population size was extrapolated over the entire range from the data from the sampled sites.
4	Congener Density Applied to Species' Range	A population density estimate from a congener was used and extrapolated over the entire range of the species.
5	Expert Opinion	Some description of how the value was obtained is given, such as "based on an assessment of known records, descriptions of abundance, and range size", but there is no indication that any sampling method was used.
6	Source Cannot Be Located	One or more citations are given for the source of the estimate, but we cannot locate the source; therefore, the method used to estimate the population cannot be determined. Often, the source cannot be located by us because the source is in unpublished reports.
7	Unknown Source of Estimate	A population size is given, but with no evidence of how it was derived. This includes cases stating "population was estimated at xxx individuals" or "Given its highly restricted range, the population size is likely small", but with no further information.
8	No Population Estimate Given	The data cell is empty.

*We considered many methods to be "sampling methods". These could include territory mapping, point counts, point counts with distance measures, transects, distance sampling, or any of a variety of other scientific sampling methods. We did not distinguish between methods. We did not consider mapping of distribution such as eBird locations as sampling methods because distribution maps cannot readily be converted into density estimates and therefore not into population estimates.

In some cases, the text provided in the Population Justification field is not sufficient to allow assignment to one of the categories. To clarify, we sought the original publication referenced in Population Justification to see what methods had been used. As the category assignments are sometimes subjective, each of the co-authors independently evaluated and assigned categories to the entire list of species, then worked together to resolve any disagreement.

Assessment of potential for change in IUCN Red List status

Species distributions are depicted on maps, which are estimates or models that may be derived from many sources. This section of our analysis relies on maps published by the IUCN as part of its Red List assessment process (BirdLife International 2022) and compared with maps produced following the methods of Huang et al. (2021). The methods by which any of these maps is produced relies on a series of assumptions and often on expert opinion, all of which may affect the maps' reliability. It is beyond the scope of our analysis to evaluate the assumptions on which any of the maps used in our analysis are based, and we therefore accept both the maps published by IUCN and the maps produced by the method of Huang et al. (2021) as best estimates produced by their respective methods.

If a species' population estimate is dependent on its area of distribution, as is the case for species in which the population estimate is based on a population density estimate multiplied by the area of distribution, a change in the estimated area of distribution will change the population estimate. Some IUCN criteria depend on the population size estimate, such as criteria C and D for CR and EN status, and criteria C and D1 for VU status (see summary of Red List criteria in Supplementary material Table S1).

To evaluate whether a change in the estimate of a species' area of distribution, based on a new map, has the potential to affect a species' Red List status, we used data from the S1 Table in Huang et al. (2021). For the area of distribution used in the Red List assessment (i.e. the distributional boundary), we used the "Published Range (km²)" (column R in Table S1; hereafter referred to as the "Published Range"). For the area of distribution based on a new map produced by the method of Huang et al. (2021), we used the "Area of Habitat (km²)" (column Q in Table S1; hereafter referred to as the "AOH").

This also requires some assumptions about population distributions as range size changes: subpopulations change proportionally; the distribution of habitat within the new range changes proportionally; the population estimate extrapolation was applied to the entire range in all cases.

To calculate a population estimate based on the newly derived area of distribution maps using the method of Huang et al. (2021), we used the following procedure.

1. We calculated the ratio of range sizes of the AOH and Published Range (AOH/Published Range).
2. To calculate the range in population estimates for the AOH maps, we multiplied this ratio by the Minimum Number of Mature Individuals and Maximum Number of Mature Individuals from the IUCN Red List data.
3. We then used two estimates of the population size and independently made two assessments of potential changes to the Red List status. For the first, we calculated the midpoint of the population range (average of the minimum population estimate + maximum population estimate; if only one of these values was given, we used that value). The second estimate used the more precautionary minimum population size. These

estimates were each then used as the population estimate and evaluated separately against the IUCN Red List criteria.

We then selected the subset of species assigned to Category 3 (Sampled Small Area and Extrapolated) for which the Red List assessment is based only on criteria C or D for species with status CR or EN, or only on criteria C or D1 for species with status VU.

For these species we then used the two new population size estimates in re-evaluation of the Red List status against the Red List criteria (IUCN 2012), assuming that all other components of the last Red List assessment, such as the species population trend, threats, distribution of subpopulation sizes, etc., remained the same. Using this method, we determined whether the Red List status of each species could potentially change (uplisting, downlisting, or no change).

Maps

We used the AOH maps from Huang et al. (2021) to identify geographical areas that harbour large numbers of species with old population data (population estimates from 2011 and older). This included 149 species, given that Huang et al. (2021) produced maps only for forest species.

Results

Estimate types

We classified the type of population estimate of 473 species into the eight estimate-type categories (Table 2; definitions of categories are in Table 1). By far, the largest number of species' population estimates was derived from Expert Opinion (Category 5), almost one-third.

Categories 1, 2, and 3 are all based on some method of population counting, although Categories 2 and 3 use a sampling method and calculated population estimate. As a citation is given for the source of the estimate, it is likely that Category 6 estimates are also based on a method of estimation, but because the source of the information could not be found, the method cannot be determined. As it is likely that Category 6 estimates are based on sampling or counting, we assumed they were. (Hereafter, the four Categories 1, 2, 3, and 6 combined will be referred to as the Population Counted or Sampled Categories.) The estimates in the Population Counted or Sampled Categories account for 163 (34%) of all species' population estimates.

Table 2. Number of species in each population estimate category.

Category of estimate	Count	% of total
1: Direct Count	8	2
2: Sampled Entire Range	49	10
3: Sampled Small Area and Extrapolated	87	18
4: Congener Density Applied to Species' Range	10	2
5: Expert Opinion	151	32
6: Source Cannot Be Located	19	4
7: Unknown Source of Estimate	90	19
8: No Population Estimate Given	59	12
TOTAL	473	100

Age of estimate

The year when the most recent population size estimate was made is given by IUCN as “Year of Estimate”. Of the 414 species reviewed that had population estimates, 412 had a Year of Estimate given, and two did not, both in Category 7 (Unknown Source of Estimate).

The number of population size estimates by year is presented in Figure 1. The oldest population size estimate is 1969 (Lava Gull *Larus fuliginosus*). Twelve assessments were made prior to 2000.

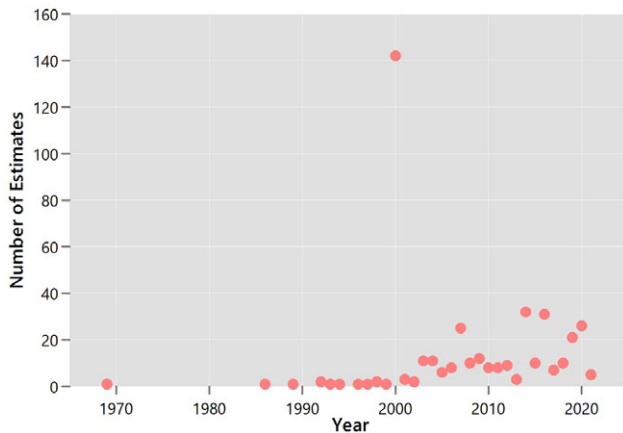


Figure 1. Number of population estimates ($n = 412$) by the “Year of Estimate” as given by IUCN.

The large majority of estimates have been made from 2000 to 2021 (400, or 97%). The year 2000, however, accounts for 142 population size estimates, or 34%. The year 2014 had the highest number, 32 population size estimates, although 2016 was almost the same with 31 estimates, each accounting for about 8% of all population size estimates.

The map in Figure 2 shows areas where two or more species with old population data (i.e. population estimates from 2011 and older) overlap. The highest concentration of species with old population size estimates are in western Ecuador, western and south-western Colombia, and in north-eastern Brazil (see map insets for close-ups of those areas).

Age of estimate by category

To determine if there was a pattern to category of population size estimate over time, we used the same 412 estimates as in the age of estimate, above, and then grouped the estimates into five-year bins, except for all estimates before 2000 which were grouped as one bin, and 2020 and 2021 as another bin. The results can be seen in Figure 3.

In 2000–2004, a large number of estimates (103) were made using Expert Opinion (Category 5). The second largest group was Category 7 (Unknown Source of Estimate; 40 estimates). These two categories account for 85% (143 of 169 estimates) made during that period. Since 2004, the estimates have been more evenly distributed across all categories, with no one category

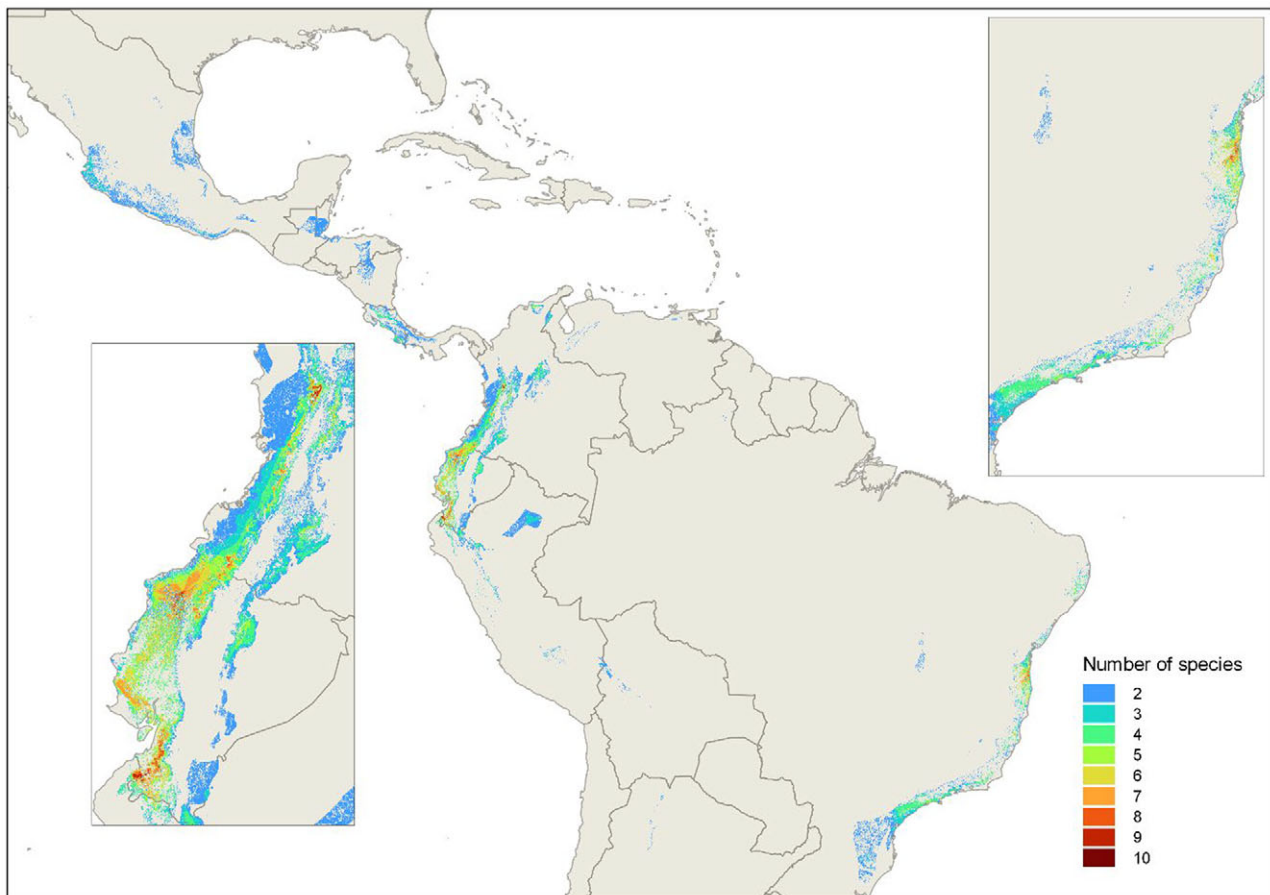


Figure 2. Areas of overlap of at least two species having population estimates from 2011 or earlier.

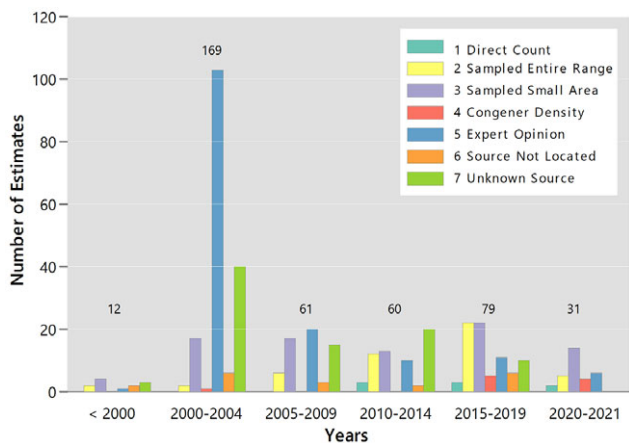


Figure 3. Number of population estimates ($n = 412$) grouped by five-year bin by the “Year of Estimate” as given by IUCN, with all estimates prior to 2000 and for 2020–2021 grouped as single bins. Bars indicate number of estimates by category. Total number of estimates in the year bin is given above the bars.

exceeding 22 estimates in one 5-year time period. In the 2015–2019 bin, Categories 2 (Sampled Entire Range) and 3 (Sampled Small Area and Extrapolated) each had 22 estimates, each accounting for 28% of the total number of estimates made during that time period (79 estimates).

The estimates in the Population Counted or Sampled Categories (1, 2, 3, and 6 combined) accounted for only 15% (25 of 169) of all population size estimates made from 2000 to 2004, but increased to 67% (53 of 79) of the estimates from 2015 to 2019 (Figure 4). They accounted for 68% (21 of 31) in 2020–2021 (an incomplete set of five years).

Species Red List status and how estimate was made

To determine if there is a pattern to how population size estimates were made in relation to species’ Red List status, we categorised the 473 species by their status category. Three-quarters of the species (six of eight) whose estimates were made by Direct Counts (Category 1; Table 3) are listed as CR, and no VU species’ estimates were made in this way. This is as would be expected, because only species with small or very low numbers are appropriate for direct counting, and those species will also likely be CR. In contrast, the

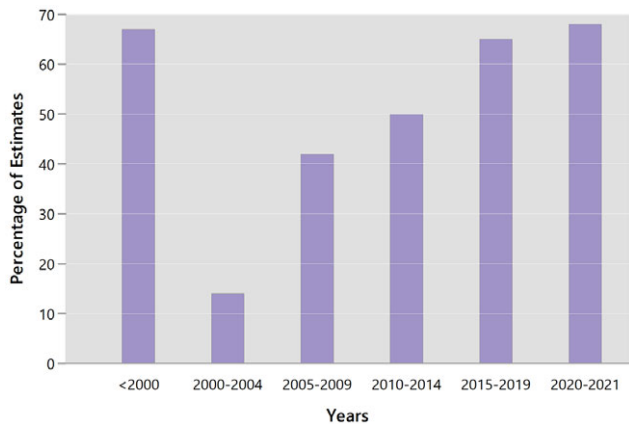


Figure 4. Proportion of all population estimates classified in the four Population Counted or Sampled Categories (1, 2, 3, and 6; $n = 163$) grouped by five-year bin by the “Year of Estimate” as given by IUCN, with all estimates prior to 2000 as a single bin.

Table 3. Number of species in this analysis ($n = 473$) in each of the IUCN Red List categories CR, EN, and VU by category of population estimate. CR = Critically Endangered; EN = Endangered; VU = Vulnerable.

Category of estimate	CR	EN	VU
1: Direct Count	6	2	0
2: Sampled Entire Range	16	14	19
3: Sampled Small Area and Extrapolated	9	40	38
4: Congener Density Applied to Species’ Range	1	2	7
5: Expert Opinion	9	49	93
6: Source Cannot Be Located	1	10	8
7: Unknown Source of Estimate	10	25	55
8: No Population Estimate Given	0	15	44
TOTAL	52	157	264

majority of species for which a population size estimate is given but with no source (Category 7, Unknown Source of Estimate, 55 of 90) are classified on the Red List as VU. An estimate is provided for all species that are CR (that is, no species are in Category 8, No Population Estimate Given), but 44 of 59 species with no estimate given are VU. Of species for which an estimate is based on Expert Opinion (Category 5), 93 (62%) of 151 species are VU, and 9 (6%) are classified as CR.

Table 4 shows the percentage of estimates in each of the IUCN Red List categories for the Population Counted or Sampled Categories (1, 2, 3, and 6). These methods were used in more than half (62%) of the CR species’ population estimates, and 42% of EN species’ estimates. Category 7 (Unknown Source of Estimate), however, accounts for 19% of CR species’ estimates. For VU species more than half (56% = 35% + 21%) had estimates based on a non-sampling method (Categories 5, Expert Opinion or 7, Unknown Source of Estimate), while an additional 17% lacked any estimate (Category 8, No Population Estimate Given).

Comparison of new maps with published ranges

In this comparison, we used the “Area of Habitat (km²)” and “Published Range (km²)” data from Huang et al. (2021), copied in columns K and J in Table S2 of this paper. The AOH is the

Table 4. Percentage of species in each population estimate category by IUCN Red List category. The Population Counted or Sampled Categories (1, 2, 3, and 6) are those with estimates that were made, or likely made, using a sampling method. Values are percentages of values in Table 3, with data for Categories 1, 2, 3, and 6 combined. Columns may not sum to 100% because of rounding error. CR = Critically Endangered; EN = Endangered; VU = Vulnerable.

Category of estimate	CR	EN	VU
Population Counted or Sampled Categories (1, 2, 3, and 6)	62%	42%	25%
4: Congener Density Applied to Species’ Range	2%	1%	3%
5: Expert Opinion	17%	31%	35%
7: Unknown Source of Estimate	19%	16%	21%
8: No Population Estimate Given	0%	10%	17%
TOTAL	100%	100%	100%

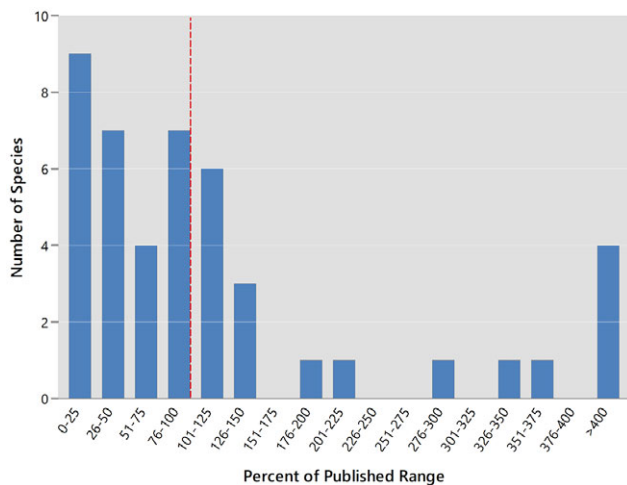


Figure 5. AOH percentage of Published Range for 45 species in Category 3 (Sampled Small Area and Extrapolated), grouped into bins of 25% difference width. The red line indicates 100%; that is, the AOH and Published Range areas are exactly the same. AOH = Area of Habitat.

species' distribution area using the method developed by Huang et al. (2021). The Published Range is the species' distribution area from the range maps published by BirdLife International.

In the current analysis, we included only species for which the population size estimate is dependent on the estimated range size (Category 3, Sampled Small Area and Extrapolated). As described in the Methods, we assumed that as range size changed, that population, subpopulation, and habitat distribution within the range changed proportionally. That is, within the distribution, population characteristics remained the same.

To evaluate how the differences in species' distribution area estimates from AOH and Published Ranges can affect the population size estimates, we used the 45 species in our Category 3 for which both areas are available from Huang et al. (2021) and which also have a population size estimate. We calculated the percentage difference of AOH and Published Range, and grouped these by bins of 25% difference (Figure 5).

Of the 45 species, 27 (60%) had AOH areas smaller than their Published Ranges. Nine species had AOH areas smaller than 25% of the Published Range (left-most bar in Figure 5). Four of these (Urroa Antpitta *Grallaria fenwickorum*, Rufous Flycatcher *Myiarchus semirufus*, Forbes's Blackbird *Anumara forbesi*, and Belding's Yellowthroat *Geothlypis beldingi*) had AOH areas less than 5% of the Published Range. The method of Huang et al. (2021) focuses on forested habitats, and except for Urroa Antpitta, these species are birds of open habitats, not forests. Therefore, the much smaller AOH maps than the Published Ranges may be an artefact of the methods of Huang et al. (2021). Eight of the 45 species (18%) had AOH areas that were more than twice as large as the Published Range, including two species (Thick-billed Parrot *Rhynchopsitta pachyrhyncha* and Mountain Grackle *Macroagelaius subalaris*) with AOH area more than five times as large as the Published Range.

The use of AOH maps may also affect the population size estimate for species in Category 6 (Source Cannot Be Located), and perhaps also for species in Categories 2 (Sampled Entire Range), 4 (Congener Density Applied to Species' Range), and 5 (Expert Opinion), although that is less certain. We did not evaluate the potential changes in those categories.

Determining whether species' Red List status would change depending on a new estimate of area of distribution

To determine the impact of a change in range size alone for the species for which the Red List status depends on population size (those CR and EN species on which the status assessment is based on Red List criteria C or D, or the VU species on which the assessment is based on criteria C or D1), we re-evaluated the Red List category assuming all other aspects of the assessment remained the same, but used the estimates for population size based on the area of distribution (AOH) derived from the maps produced using the method described by Huang et al. (2021).

Species for which the population size estimate is most dependent on the species' area of distribution are those in our Category 3 (Sampled Small Area and Extrapolated). Of 45 species in this category with maps and population estimates, the Red List evaluation depended on population size criteria for 22 species. Using the midpoint of the population size estimates derived from the Huang et al. (2021) maps, 11 may have the potential for a change in Red List status, either uplisting (five species) or downlisting (six species) (Table 5). Using the more precautionary minimum population size, nine species could potentially change status, with seven species potentially uplisted and two species potentially downlisted (Table 5).

Discussion

This study shows the variability in the source, age, and quality of population size data used in the Red List assessments. It is not our objective to criticise Red List evaluations or the evaluation process, but rather to identify species needing study to provide updated, quantitative population data that can be used to improve the Red List evaluations and ensure that those estimates are as correct as possible (for individual species, see Table S2). Especially outside Europe and North America, significant conservation resources are directed towards species based on their Red List category. For greatest conservation impact, it is therefore important that the Red List assessments be accurate. With our analysis, we have identified several issues that are pertinent to Red List assessments, and the species affected by those issues.

Species lacking population estimates based on sampling

In our sample of 473 species from the Americas, no population size estimate at all is given for 59 species (Category 8; Table 2). For an additional 90 species an estimate is provided (Category 7), but no source is given for that estimate. These two categories account for 32% of the 473 species in our analysis.

The population size estimate for an additional 151 species is derived from Expert Opinion (Category 5). These estimates are not based on a scientific sampling method, but do have some rationale provided for their derivation. Most are probably made using descriptions of abundance (such as "common" or "rare") or review of records from museum specimens and sources such as eBird. Although these sources can provide very useful distribution and occurrence information, because they are not based on a systematic sampling method, it can be very difficult to use them to estimate population sizes or densities.

With the increasing availability of citizen science data and land cover products, significant developments have occurred in the past few years to derive population size and trend estimates (Santini et al. 2019, 2022; Callaghan et al. 2021). However, some of these

Table 5. Potential changes in IUCN Red List status. Only species for which the IUCN Red List status depends on population size were included (species whose population was estimated from a Sampled Small Area and Extrapolated, Category 3) and with full data (original and new maps and population estimate from the Red List). The total was 22 species. “Potential Uplist” are species that could be placed in a more threatened status category based on a change in their population estimate from a change in their area of distribution between the Published Range and AOH; “Potential Downlist” are those that could be placed in a less threatened status. Species already listed as CR cannot be further uplisted, and that cell is therefore not applicable (na). We made two assessments, one using the midpoint of population estimates, and a second using the more precautionary minimum population estimate. CR = Critically Endangered; EN = Endangered; VU = Vulnerable.

Species' current status	Using midpoint of population estimates			Using minimum population estimate		
	Potential Uplist	Potential Downlist	No change	Potential Uplist	Potential Downlist	No change
CR species	na	0	2	na	0	2
EN species	1	5	7	3	2	8
VU species	4	1	2	4	0	3
TOTAL	5	6	11	7	2	13

modelling methods have been criticised, as they are prone to yield extremely uncertain and biased population size estimates for many species (Robinson et al. 2022). These estimates may not be useful in ecology, evolution, or conservation. Currently, no method exists that addresses the gap in population size data across species while accounting for variations in eBird reporting rates (Robinson et al. 2022).

Age of estimate

In a push to complete the Red List assessments of birds, a large number of population size estimates (142) were made in 2000 (Figure 1). Combined with the 12 population size estimates made prior to 2000, these account for 154 estimates, or 33% of all estimates. Although there has been a consistent effort to update estimates since 2000, the fact remains that one-third of our sample have estimates older than 20 years. In those 20 years (2000–2020), deforestation in Latin America and the Caribbean has been 8.3% of total cover (Quiroga et al. 2021), very likely significantly affecting the populations of many forest species. Grasslands and other habitats have been diminished and degraded as well. It is likely that a significant number of the 2000 and earlier population estimates are no longer valid.

Efforts to update population estimates should be directed to those areas identified here as harbouring higher number of species with old population data. Bird surveys targeted at areas where multiple species needing updated population estimates co-occur in western Ecuador, north-western Colombia, or north-eastern Brazil (see Figure 2) could help provide data from one location to improve the population estimates for several species.

Category of estimates by year

In recent years, assessments have been more likely to include quantitative information based on a scientific sampling method rather than unsourced numbers (Unknown Source of Estimate, Category 7) or Expert Opinion (Category 5). The higher quality estimates using complete counts or scientific sampling (Population Counted or Sampled Categories 1, 2, 3, and likely 6) have been used in 50% or more of assessments in each five-year period since 2010 (Figure 4). These assessments are likely replacing some of those made previously using Expert Opinion (Category 5). This reflects an important effort being made by Red List assessors to include more scientific information in assessments.

Comparison of new range maps and published range maps

The species whose population assessments are most likely to be affected by a difference in area of distribution estimate are those in our Category 3 (Sampled Small Area and Extrapolated). As the population estimate for these species is calculated from a density estimate multiplied by the area of distribution, if all else remains the same (factors such as the population density estimate and habitat availability), a change in the value used for the area of distribution can cause large differences in the population estimate.

For the Category 3 (Sampled Small Area and Extrapolated) species alone, the new maps produced by Huang et al. (2021) in some cases indicate an AOH much smaller or larger than the previously used range (Published Range), with nine species having areas of distribution less than 25% of the Published Range, and in some cases, more than twice as large (Figure 5). In cases where the population estimate depends on the size of the estimated area of distribution – because the population estimate is calculated from a density determined for a small area then applied to the entire estimated area of distribution – the different estimates of area of distribution lead to very large differences in the population estimate.

Although the population estimate is not as directly tied to the area of distribution for species whose population estimates are derived by other methods, large changes in their estimated area of distribution may also have significant impact on the population estimate for a number of species. The estimated area of distribution is therefore a key element in the Red List status for many species.

Potential changes to IUCN Red List status

Species population estimates are derived in many ways, but a common method is to estimate a species' population density and estimate its range size and then to estimate the total population by multiplying the population density by the area of distribution. Some version of this is the method by which about 37% of population estimates in this study were derived in the Population Counted or Sampled Categories (1, 2, 3, and 6) and including Congener Density Applied to a Species' Range (Category 4; Table 2). This method often provides the best population estimate available for many species, but as it is a multiplication of its two components, density and area, it is sensitive to errors or changes in those two components.

The method for making range maps described in Huang et al. (2021) produces new estimates for the area of distribution, which could affect the estimate of population size and therefore affect the

Red List status for some species for which the status assessment depends on population size. As significant conservation effort – or lack of conservation effort – can depend on the Red List status of species, the area of distribution estimate can be an important parameter. However, given that AOH maps (also referred to as Extent of Suitable Habitat maps) are based on deductive models, different approaches have been proposed for their estimation (e.g. Beresford et al. 2011; Rondinini et al. 2011; Ficetola et al. 2015; Brooks et al. 2019; Huang et al. 2021; Palacio et al. 2021; Lumbierres et al. 2022), which may result in assessments of areas of distribution of varying accuracy. Note that our analysis here is not specifically oriented to evaluating the maps produced by Huang et al. (2021), but rather any maps that produce a different area of distribution from those published by the IUCN Red List. We used the maps by the Huang et al. (2021) methods because they have been recently produced.

Although the assumptions in our analysis of Category 3 species used in this part of the analysis (mainly, that differences in range maps are only in the area and that subpopulations and habitat proportions remain the same) are unlikely to have been met in all cases, especially with regard to proportions of the population in each subpopulation, our purpose here is not to carry out a complete IUCN status assessment, but rather to determine if range size changes could potentially affect the IUCN status for some species. The comparison of population estimates derived from area of distribution between the Published Ranges of species in the Red List and those produced from maps made using the methods of Huang et al. (2021) suggests that a significant number of species whose Red List status depends on their population size could potentially be uplisted or downlisted using the new areas of distribution, following a full Red List status assessment. Table 5 shows that, of the sample of 22 species for which the status assessment depended on the population estimate and had complete data, about half could potentially change Red List status categories (11 of 22 using the midpoint of the new population estimate, or 9 of 22 using the more precautionary minimum population estimate), if no other factors change other than their estimated area of distribution. The production of new, potentially more accurate maps offers an opportunity to identify species that may need review and update of their Red List status.

Conclusions

Improvements in methods such as the production of range maps highlights the need for status reviews of species for which the status depends on population estimates, especially when those estimates themselves depend on area of distribution. Analysis of the 22 species in our set whose status depends only on range size and that have complete data (Table 5) suggested that about half of the species could potentially change status, either uplisting or downlisting, based on a change in the area of distribution. This is an important finding, and indicates that improved data quality is needed in general, and for those cases where assessments depend on range size, proper evaluation of range size needs to be included. The 22 species that may need an updated status review are indicated in columns P and Q of Table S2.

Red List status assessments require the best data possible. For land birds in the Americas and Caribbean, this paper points out the need for recent population estimates and for using the best methods. Of the VU, EN, and CR birds in the current analysis, 66% do not have population estimates made using a scientific

sampling method, but rather have No Population Estimate Given, a number provided but Unknown Source of Estimate, or an estimate derived only from Expert Opinion (categories 8, 7, or 5; Table 2). Of the total sample of 473 species, 38% do not have any population estimates made since 2004 (Figure 3). All of these, with older estimates or estimates based on non-sampling methods, should be the focus of efforts to obtain higher quality up-to-date and scientific population estimates. Obtaining information on populations with outdated information could be made more efficiently by working on more than one species in an area, focusing on areas with two or more species needing up-to-date information as shown in the map in Figure 2.

As a large number of birds do not have recent population estimates or estimates made using a scientific sampling method, and because the Red List status assessment for some species depends on the range estimate of the species, we encourage the ornithological community to work to obtain better quality estimates of both population size and range. This will ensure that Red List assessments more accurately reflect the status of the species, and that conservation planning and actions can have the greatest impact.

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