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ARTICLE

Conducting rigorous avian inventories: Amazonian case studies and a roadmap for improvement

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ABSTRACT: Site-based avian inventories are ubiquitous in Neotropical ornithology but are prone to error if fieldworkers are not familiar with the regional species pool, particularly in species-rich regions such as the Amazon basin. Here, we review recent species lists from the Brazilian Amazon in both the primary ornithological literature and in protected area management plans to assess the level of putative errors in terms of bird species recorded in site-based inventories that are biogeographically unlikely in the sampled region. We found errors to be frequent across all inventory types. Failure to recognize recent taxonomic modifications in a cited taxonomy was a common error in many inventories. We outline a series of steps to follow to improve the utility and accuracy of avian inventories, and stress the importance of both obtaining and archiving documentary material, which should be included in the publications as digital vouchers to facilitate detailed peer review.

KEY-WORDS: Amazonia, avian surveys, checklist, documentation, taxonomy, vouchers.

INTRODUCTION

Comprehensive and accurate site-based species inventories are the backbone of macroecological studies and crucial for understanding multi-scale patterns of species richness, evolutionary processes, natural patterns of environmental heterogeneity, and species-specific responses to environmental change (Blackburn & Gaston 1998). Species lists can function as a baseline to which new ecological and evolutionary studies can be compared in the future (Moritz *et al.* 2008; Coterrill & Foissner, 2010). However, compiling species lists can be a labor-intensive and a rather unrewarding academic task, as high-impact scientific journals typically do not publish species inventories. Despite the clear importance of high-quality baseline inventories in the face of global habitat loss, fragmentation, degradation, and climate change, avian inventories are being published in lower-profile journals, which often do not demand the highest desirable scientific standards for publication. On the other hand, avian inventories are likely to be cited for centuries (e.g., Snethlage 1908), which also means that errors can potentially propagate for decades.

There is little doubt that birds represent the best-known taxonomic group in the Neotropics, yet our knowledge of the avifauna in many regions remains poorly documented, particularly in the vast Amazon basin. In fact, significant knowledge gaps regarding species identification, distribution, and taxonomy still exist in entire Amazonian regions (Aleixo 2009; Barlow *et al.* 2011). These gaps in knowledge, allied to the intrinsic difficulties of surveying birds in highly diverse tropical forests, where researchers are reliant on avian vocalizations to conduct accurate surveys (Remsen 1994; Cohn-Haft *et al.* 1997; Willis 2003) may result in false-positive detections (i.e., species that appear in regional or site-based lists that are unlikely to occur in a given region). Even well-trained ornithologists may make identification errors in these environments, which is unsurprising given the many morphologically and vocally similar species

which occur in sympatry in Amazonia. These errors have been experimentally quantified before, for aural errors in controlled studies of electronically broadcast avian vocalizations (e.g., Simons *et al.* 2007) and for visual errors by releasing trapped birds (of biometrically confirmed individuals) in front of field observers (e.g., Hull *et al.* 2010), or even to test the subjectivity of abundance estimates (Cerqueira *et al.* 2013).

Identification errors that enter the primary ornithological literature (species lists in journals) may rapidly be spread into the secondary literature, leading to incorrect distribution maps in widely used field guides. This leads to further proliferation of identification errors, as ornithologists and birders alike may pay little attention to the identification of 'confusion' species (similar-looking and potentially sympatric species) widely considered to be present in a region (Robbins & Stallcup 1981; Willis 2003; Rojas-Soto & de Ita 2005; McKelvey *et al.* 2008). Given these potential problems, we believe that species inventories should be treated as rigorously as any other scientific enterprise and provide as much supporting documentary evidence as possible (e.g., Cohn-Haft *et al.* 1997; Silveira & D'Horta 2002; Silveira *et al.* 2010; Aleixo *et al.* 2011; Somenzari *et al.* 2011; Lees *et al.* 2012, 2013a) to prevent 'false presences' becoming established in the literature (McKelvey *et al.* 2008; Silveira *et al.* 2010), as well as to facilitate re-evaluations of taxonomic status in the future.

Corrections of previous mistakes have already been published in the recent Amazonian literature. For example: Cohn-Haft *et al.* (1997) removed seven species from the list of Stotz & Bierregaard (1989) of the birds north of Manaus; Naka (2006) removed, or included as hypothetical, 15 species previously reported for the Brazilian state of Roraima; Whittaker et al. (2008) re-identified or removed 30 species from the initial checklist of the birds of the upper Rio Urucú, originally published by Peres & Whittaker (1991); Lopes *et al.* (2009) re-identified and corrected 52 species from the Chapada dos Guimarães; Lees *et al.* (2013a) moved to 'hypothetical species appendix' or removed entirely 10 species from the lists of Sanaiotti & Cintra (2001) and Henriques *et al.* (2003) from around Santarém; and Lees *et al.* (2013b) removed three species from the checklist of Alta Floresta (Zimmer *et al.* 1997) and moved another nine taxa to a 'hypothetical species' appendix. However, we consider this issue likely more widespread and here evaluate the pervasiveness of problems related to bird misidentifications in both the 'primary' and 'grey' Brazilian ornithological literature. In this article, we judge the ubiquity and nature of errors in 63 Amazonian bird inventories (including all of our own) and point out likely cases of misidentification. We then suggest a roadmap for producing less error-prone avian inventories.

METHODS

Each Amazonian interfluve has its own unique avian assemblage, with species turnover particularly high across wide rivers and in families or guilds with limited dispersal capacity such as understory suboscines. These biogeographical patterns are now increasingly well understood so that unexpected presences are reasonably easy to spot. We reviewed 32 bird inventories (Appendix 1) in the Brazilian Amazon published between 2000 and 2013 to look for instances of presumed misidentification based on expert opinion of the distribution of allopatric and parapatric Amazonian bird species (see Table 1). These lists were published in international journals ($n = 7$), Brazilian journals ($n = 21$), and book chapters ($n = 4$). In addition, we also reviewed 31 reserve management plans (Appendix 2) from the Brazilian Amazon to compare error rates with those lists in the primary literature. Given the general lack of review of the grey literature, we expected to find a higher rate of errors in unpublished reports.

Our error-checking process applied only to biogeographically extremely unlikely records. When searching these inventories there were many instances of unusual boreal and austral migrants, many of which are difficult to identify, that we do not necessarily infer to be in error despite being presented without supporting information or documentation. Also, some species—such as the White-rumped Swallow *Tachycineta leucorrhoa*—are often reported from Amazonian sites, yet they lack any documentation, and we assume many reports to be in error although we do not highlight them herein. We also reviewed which supporting information was supplied with species' lists—form of documentation listed, digital vouchers included—and whether abundance and habitat type information were incorporated in the data.

RESULTS

We found evidence of presumed misidentifications in 25 inventories (78%) involving 107 records of 82 species (Table 1). The number of assumed misidentifications varied between 0 (none) and 15 ($\bar{X} = 3.3$, $SD = 4.1$, 0-3.7% of the total list). Errors could be broadly divided into two groups: a) misidentification of a species that is not known to occur in the Amazonian interfluve sampled ($n = 74$, 70.4%); and b) confusion with replacement species (taxonomic errors) for which the wrong member of a species pair or super-species complex was listed ($n = 31$, $\bar{X} = 29.0\%$), often because of a failure to account for shifts in nomenclature and 'splits.'

We found that 25% of surveys informed the type of documentation obtained during the survey but only 4% provided links to digital vouchers, although some of these web-based resources have only become

available recently. Nearly 20% of the surveys included qualitative abundance estimates and almost 60% included information of which habitat types species were encountered. Reserve management plans (n = 31) were more heterogeneous in their error rates with the number of assumed misidentifications varying between 0 and 35 (n =84, $\bar{X}$ = 2.71, SD = 6.64) accounting for between 0 and 7.9% of all records.

TABLE 1. A compilation of inferred errors from Amazonian avifaunal inventories between 2000 and 2013. All inferred errors represent apparently undocumented records which are not explicitly discussed in the text, some may of course be genuine, but given their biogeographic significance should be adequately documented before being presented as 'confirmed'. Species denoted with an asterix* indicate taxonomic rather than identification errors. Citations can be found in Appendix 1.

Aguiar *et al.* 2010. Lago Piratuba, Amapá	*Comments*
Sterna hirundinacea	Undocumented north of Bahia, would be a first for the biome.
Synallaxis propinqua	Undocumented from Amapá or anywhere in the eastern half of the Guianan Shield.
Aleixo & Poletto 2007. BX44 Polygon, Mato Grosso/ Amazonas	
Hylophilus hypoxanthus	Replaced by *Hylophilus muscicapinus* in this interfluve (Madeira-Tapajós).
Aleixo *et al.* 2010. Tanguro, Mato Grosso	
*Hypocnemis cantator**	Taxonomy followed unclear but should be *H. striata*.
Lophotriccus galeatus	Undocumented east of the rio Xingu where replaced by *Hemitriccus minor* - as reported nearby by Mestre *et al.* 2011.
Borges & Almeida 2011. Jau National Park, Amazonas	
*Trogon violaceus**	*Trogon ramonianus* south of the rio Amazonas and west of the rio Negro following CBRO (2009).
*Schiffornis turdina**	*Schiffornis amazonum* north of the rio Amazonas and west of the rio Madeira following CBRO (2009).
Dantas *et al.* 2011. FLONA de Pau-Rosa, Amazonas	
Polytmus guainumbi	Unknown in central Brazilian Amazonia, more likely to be *P. theresiae*.
Dendrocolaptes picumnus	Unknown in this interfluve (Madeira-Tapajós) where replaced by *D. hoffmannsi.*
Hylophilus hypoxanthus	Replaced by *Hylophilus muscicapinus* in this interfluve (Madeira-Tapajós).
Favaro & Flores 2009. Terra do Meio, Pará	
*Hylexetastes perrotii**	Does not occur south of the rio Amazonas, based on CBRO (2008) this should be *H. uniformis.*
Automolus infuscatus	Reported here as sympatric with *A. paraensis* but highly unlikely as *infuscatus* is undocumented east of the Madeira.
Pipra aureola	Not expected in the interior of the Tapajós-Xingu interfluve.
Pheugopedius genibarbis	Reported as sympatric with *P. coraya* but the two are replacement species; *genibarbis* unknown north of the Serra do Cachimbo between the Tapajós and Tocantins.

Aleixo & Guilherme 2010. Estação Ecológica do Rio Acre, Acre	
Chaetura spinicaudus	Undocumented in SW Amazonia; best treated as hypothetical.
Lees *et al.* 2008. Serra dos Caiabis, Mato Grosso	
Synallaxis cherriei	Listed in error, record pertains to *S. rutilans.*
Lees *et al.* 2012. Paragominas, Pará	
*Phaeothlypis rivularis**	Based on CBRO (2011) this should be *P. mesoleuca.*
Tangara sayaca	Archived digital voucher (a photo) appears to be a juvenile *T. episcopus,* which are very similar to *T. sayaca.* The latter would represent a significant range extension.
Euphonia chrysopasta	Archived digital voucher (a photo) is ambiguous; we consider it better to treat this record and others east of the rio Tocantins as hypothetical until better documentation available.
Lees *et al.* 2013b. Santarém, Pará	
*Phaeothlypis rivularis**	Based on CBRO (2011) this should be *P. mesoleuca.*
Mestre *et al.* 2010 . RESEX Chico Mendes, Acre	
Aulacorhynchus prasinus	This should be *Aulacorhynchus atrogularis* following CBRO (2009).
Mestre *et al.* 2011. Querencia, Mato Grosso	
Poecilotriccus fumifrons	Only *P. latirostris* expected in this region - as reported nearby by Aleixo *et al.* 2010.
Pacheco & Olmos 2005. BR163, Pará	
Hemitriccus minor	Does not occur between the Tapajós and Xingu north of the Teles Pires where replaced by *Lophotriccus galeatus*.
Pacheco *et al.* 2007. Carajas, Pará	
*Phaethornis nattereri**	The taxonomic position of this species in relation to *P. maranhaoensis* is unresolved but only the latter is expected in this region.
Myrmotherula sclateri	Undocumented east of the rio Xingu.
Hyloctistes subulatus	Undocumented east of the rio Xingu, this species was removed from the Carajás list by Aleixo *et al.* 2012.
Lophotriccus galeatus	Does not occur in this interfluve (Xingu-Tocantins) see e.g. Cohn-Haft (2000), Lees *et al.* (2013a).
Pipra aureola	Undocumented as far south as Carajás, where similarly looking *P. fasciicauda* has been documented, this species was removed from the Carajás list by Aleixo *et al.* 2012.
Turdus hauxwelli	As currently mapped this species is not expected in eastern Amazonia where *T. fumigatus* is usually reported.

Hylophilus muscicapinus	Undocumented east of the rio Tapajós, this species was removed from the Carajás list by Aleixo *et al.* 2012.
Portes *et al.* 2011. Belem Centre of Endemism, Pará	
Milvago chimango	Clerical error, should be *M. chimachima*.
Myrmeciza atrothorax	Undocumented east of rio Tocantins.
Thamnophilus schistaceus	Undocumented east of rio Tocantins.
Thamnophilus stictocephalus	Undocumented east of rio Tocantins.
Cranioleuca gutturata	Undocumented east of rio Tocantins.
Furnarius rufus	Undocumented in the Belém centre of endemism.
Hemitriccus minimus	Undocumented east of rio Tocantins, recording likely pertain to a recently discovered and as yet undescribed *Myiornis* taxon.
Hylophilus hypoxanthus	Undocumented east of rio Tocantins.
Tangara chilensis	Undocumented east of rio Tocantins.
*Phaeothlypis rivularis**	Based on CBRO (2011) this should be *P. mesoleuca,* which was recently split from *P. rivularis.*
Euphonia chrysopasta	Undocumented east of rio Tocantins.
Oliveira *et al.* 2011. Cotriguaçu, Mato Grosso	
Leucopternis lacernulatus	This species is restricted to the Atlantic Forest and is not expected in Amazonia, record likely relates to a similar species.
Circus cinereus	This would represent the first record from anywhere in central or north Brazil and would require extensive documentation.
*Pyrrhura picta**	This should be *P. amazonum* or *P. snethlageae* in this region, although the taxonomy followed in this inventory is unclear.
Pionus maximiliani	This species is undocumented from northern Mato Grosso and would represent a significant range extension.
*Notharchus macrorhynchus**	Only *N. hyperrhynchus* occurs south of the Amazon.
Colaptes campestris	Not expected in NW Mato Grosso.
Thamnomanes ardesiacus	Undocumented east of the rio Madeira.
Dysithamnus mentalis	Not expected in NW Mato Grosso, should preferably be documented.
*Schistocichla leucostigma**	This should be *Schistocichla* (formerly *Percnostola*) *rufifacies* in this region, although the taxonomy being followed in this inventory is unclear.
Xiphorhynchus spixii	*X. spixii* does not occur west of the rio Juruena (or Teles Pires), only *X. elegans* is expected.
Automolus infuscatus	*A. infuscatus* is undocumented east of the rio Madeira; this will likely pertain to *A. paraensis*.
Hemitriccus zosterops	Replaced by *H. griseipectus* south of the rio Amazonas.
*Fluvicola pica**	Undocumented and unexpected in southern Amazonia.
Turdus fumigatus	Reported as occurring sympatrically with *T. hauxwelli,* only *T. hauxwelli* expected in this interfluve (Madeira-Juruena).
Olmos *et al.* 2011. Rondônia	
Galbula albirostris	Unknown south of the rio Amazonas, *G. cyanicollis* occurs in this region.
*Notharchus macrorhynchos**	Only *N. hyperrhynchus* occurs south of the Amazon.

Capito niger	*Capito niger* only occurs north of the rio Amazonas; this record should pertain to *C. auratus* based on current taxonomy.
Pteroglossus azara	Unknown south of the rio Amazonas, *P. bitorquatus* occurs east of the Madeira.
Celeus flavescens	Within Amazonia, unknown away from the floodplain forest along the main channel of the lower Amazon River; it would represent a significant range extension requiring documentation.
Dysithamnus mentalis	Documentation would be preferable for such a significant range extension.
*Schistocichla leucostigma**	This should be *Schistocichla* (formerly *Percnostola*) *rufifacies* east of the Madeira and *S. humaythae* west of the Madeira following CBRO (2011).
Dendrocolaptes picumnus	Unknown in this interfluve where replaced by *D. hoffmannsi*.
Hemitriccus griseipectus	Undocumented in the Madeira-Tapajós interfluve.
*Schiffornis turdina**	*Schiffornis amazonum* north of the rio Amazonas and west of the rio Madeira following CBRO (2011).
Hylophilus hypoxanthus	Replaced by *Hylophilus muscicapinus* in this interfluve (Madeira-Tapajós).
Turdus fumigatus	Distribution of this species rather poorly known, but contemporary wisdom suggests that *T. hauxwelli* occurs in this interfluve.
Santos *et al.* 2011a. Juruti, Pará	
*Pyrrhura picta**	Based on CBRO (2011) this should be *P. snethlageae or P. amazonum*.
Neomorphus geoffroyi	By range more likely to be *N. squamiger*.
Capito dayi	A biogeographically extraordinary record given allopatry in *Capito* barbets, suggest should be treated as hypothetical if no photo or specimen.
Picumnus cirratus	Unexpected in sympatry with *P. varzae*, *which* becomes more heavily barred towards the western end of its distribution inviting confusion with *cirratus*.
Automolus infuscatus	*A. infuscatus* does not occur east of the rio Madeira; this will pertain to *A. paraensis*.
Pipra aureola	Sympatry with *P. fasciicauda* unknown from most of Amazonia.
Poecilotriccus fumifrons	Not expected to occur sympatrically with *P. latirostris* in this interfluve (Madeira-Tapajós).
Icterus jamacaii	Replaced by *I. croconotus* in most of Amazonia, including the Madeira-Tapajós interfluve.
Gnorimopsar chopi	An extremely significant range extension not discussed in the text, unknown from central Amazonia.
Santos *et al.* 2011b. Jí-Paraná, Rondônia	
*Megascops watsonii**	Replaced by *M. usta* south of the rio Amazonas.
Phaethornis superciliosus	Based on current taxonomy does not occur west of the Tapajós, *P. malaris* expected in this region.
Hypocnemis subflava	Absent from this interfluve (Madeira-Tapajós) where replaced by *H. ochrogyna* (in this case) and the recently described *H. rondoni*.
*Hylexetastes perrotii**	Does not occur south of the rio Amazonas, based on CBRO (2011) this should be *H. uniformis*.
Automolus infuscatus	*A. infuscatus* is undocumented east of the rio Madeira, this will likely pertain to *A. paraensis*.
*Schiffornis amazona**	*Schiffornis turdina* south of the rio Amazonas and east of the rio Madeira following CBRO (2011).
Turdus fumigatus	Distribution of this species rather poorly known, but contemporary wisdom suggests that *T. hauxwelli* occurs in this interfluve.

Santos *et al.* 2011c. Serra do Cachimbo, Pará	
Ortalis superciliaris	Endemic to north-east Brazil, the *Ortalis* occurring in this region is *O. motmot*.
*Psophia viridis**	Based on CBRO (2011) this should be *P. dextralis*.
*Pyrrhura picta**	Based on CBRO (2011) this should be *P. amazonum* or *P. snethlageae*.
Brotogeris cyanoptera	Unknown east of the Tapajós and would represent a significant range extension, better documentation is desirable.
Polytmus guainumbi	Unknown in central Brazilian Amazonia, more likely to be *P. theresiae* which is common on the Serra do Cachimbo and in other Amazonian savannah regions (*e.g.* Pacheco & Olmos 2005).
*Pteroglossus viridis**	An old record that pertains to *P. inscriptus* pre-split.
Thamnophilus murinus	Undocumented east of the rio Tapajós.
Hypocnemoides melanopogon	Unexpected in sympatry with *H. maculicauda* and is unrecorded on the Tapajós south of the mouth.
Synallaxis albigularis	Undocumented east of the rio Madeira.
Hemitriccus minor	Does not occur between the Tapajós and Xingu north of the Teles Pires where replaced by *Lophotriccus galeatus*.
Corythopis delalandi	Listed in error because of a mislabelled specimen collected by Hidasi, which was likely taken in Goias given the date (but not the locality) on the specimen label. The specimen was collected within a day of a series taken at the 'Rio Araguaia, margem direita, Aragarças (15°55'S, 52°15'W)'.
*Fluvicola pica**	An old record that pertains to *F. albiventer* pre-split.
Hylophilus brunneiceps	A clerical error only occurs in NW Amazonia.
Schunck *et al.* 2011. two localities Amapá	
Venilliornis affinis	Undocumented north of the rio Amazonas and east of the rio Branco, where replaced by *V. cassini*.
Silveira & D'Horta 2002. Vila Bela da Santíssima Trindade, Mato Grosso	
Neopelma sulphureiventer	Not expected in this interfluve, presumably a mislabelled or misidentified historical specimen.
Hylophilus thoracicus	Not expected in this interfluve, old specimen likely *H. pectoralis*, with which this species was historically lumped, see Pacheco *et al.* (2011).
Somenzari *et al.* 2011. Amazonia-Cerrado ecotone, Mato Grosso/Pará	
*Trogon violaceus**	Based on CBRO (2011) this should be *Trogon ramonianus, T. violaceus* only occurs north of the rio Amazonas and east of the rio Negro.
Serpophaga nigricans	This species was listed in error; the record pertains to *S. hypoleuca,* which is expected in this region.
Pheugopedius genibarbis	*P. genibarbis* and *P. coraya* are not expected to occur sympatrically in this region, an undocumented audio record is insufficient evidence for an important range extension.
*Phaeothlypis rivularis**	Based on CBRO (2011) this should be *P. mesoleuca.*
Caryothraustes canadensis	Undocumented south of the rio Amazonas between the rios Tapajós and Tocantins.

Vasconcelos *et al.* 2011. Monte Alegre, Pará	
Notharchus ordii	Questions over specimen provenance, likely taken on the south bank as discussed in Lees *et al.* 2013a.
Pteroglossus bitorquatus	Unknown on north bank of the Amazon.
Whittaker 2009. Rio Roosevelt, Amazonas	
Phaethornis superciliosus	Based on current taxonomy does not occur west of the Tapajós, *P. malaris* expected in this region.

DISCUSSION

Our analysis indicates that errors are near ubiquitous, albeit at a low frequency in Amazonian avian inventories in peer-reviewed papers, book chapters, and reserve management plans. Many errors may reflect a lack of prior knowledge of a recent split—in which case the parent species was listed (despite the authors referring to a contemporary taxonomic arrangement that acknowledges the split) or to assignment of the wrong member of a species complex. In some cases, errors have been propagated by authors who included historical data, but failed to adjust for subsequent changes in taxonomy split (e.g., Lopes *et al.* 2009). In many cases, inaccurate distributional maps, frequently seen in field guides and some online sites, proliferate errors. For example the tyrant flycatchers Helmeted Pygmy-Tyrant *Lophotriccus galeatus* and Snethlage's Tody-Tyrant *Hemitriccus minor* are erroneously mapped as occurring sympatrically in southern Amazonia by some authors (e.g., Ridgely & Tudor 1994; Van Perlo 2009; Sigrist 2009) when no such instances of sympatry have been confirmed (Cohn-Haft 2000).

Our review highlights apparent knowledge gaps in our collective understanding of the distribution of many difficult-to-separate Amazonian species pairs e.g., in the swifts *Chaetura chapmani/viridipennis*, the thrushes *Turdus fumigatus/hauxwelli*, and the manakins *Pipra aureola/fasciicauda* which are inadequately mapped in the literature and require more robust surveys (preferably with voucher specimens) to ascertain their actual distributional limits and zones of contact within the basin (e.g., O'Neill *et al.* 2011). In the case of the swifts we have not listed their occurrences in Table 1 as most inventories have followed the 'expected' pattern of occurrence in Amazonia based on a few specimen records, as published by Marin (1997). However we note that *Chaetura chapmani/viridipennis* are not separable in the field, nor readily diagnosable by genetic analysis (Vaseghi & Chesser 2011), so the accepted pattern of occurrence universally followed since 1997 appears to be very tenuous. In fact, reliable field identification of most species of swifts requires a highly trained observer to obtain very good, preferably prolonged, views. We must also recognize that our taxonomy of some groups such as swifts may suffer far more serious identification problems than "use of outdated taxonomy" if our working knowledge is not based on identification of topotypical material, a step rarely acknowledged as a requirement for accurate taxon identification.

The way forward—a road-map for writing species inventories.

That all inventories published in peer-reviewed journals fall within the 95% confidence interval of accuracy is an obviously satisfying statistic to report, but we believe that reducing error rates in species inventories still further is an easily achievable goal. Such reductions increase the utility of such lists for macroecologists and taxonomists studying variation in Neotropical birds, and to increase transparency, we suggest a series of guidelines that may improve the accuracy and utility of species lists.

1. Obtain good documentation

While in the field, ornithologists should make every effort to collect as much documentary evidence to prove the presence of a given species. Obviously it is not always feasible, nor strictly necessary to provide voucher material for widespread common species such as Great Kiskadee *Pitangus sulphuratus* and House Wren *Troglodytes musculus* in every inventory (although the effort to obtain documentation for these species should be negligible and is certainly welcomed). However, evidence must certainly be obtained and presented for any rarer species or poorly known species, particularly any that are not anticipated in the region. These species would typically be afforded a separate species account in the body of the text in which details of these important observations can be amplified. Evidence is ideally a combination of specimens

(including tissue samples), photographs, and sound-recordings (e.g., Carlos *et al.* 2010). Detailed field notes are obviously useful (particularly in the absence of other evidence), but do not represent unquestionable proof and cannot be accepted as hard evidence. The accumulation of evidentiary information of these types can essentially eliminate pre-publication errors of identification as they become available for evaluation by outside experts. If such expert review is not obtained, then at least it will be possible for future review to correct errors. Obtaining highly accurate GPS coordinates (not coordinates taken from a map or *Google Earth*) at all inventory sites that will be listed separately in the published paper is also extremely important. These coordinates should be taken in decimal degrees, with all decimals provided by unit recorded, and include the datum and an error estimate (Chapman & Wieczorek 2006). Great care should be taken to identify which riverbanks were surveyed. If both banks of rivers are surveyed, they should have separate coordinates and indications in the list (B. M. Whitney *in litt.*).

2. Present documentation hierarchically and transparently

Once documentary evidence has been obtained, the level of documentation for each species should be listed for each species and ranked hierarchically, with permanent archived voucher material: 1) specimens, 2) video, preferably with commentary; 3) still photographs and/or sound recordings (ranked over sight records). If supporting documentation is not available, authors should indicate the identity of the observers involved in the record, and whether the record is auditory, visual, or both (Willis 2003). On some occasions video may be the most unambiguous, complete form of documentation for a rare species (B. M. Whitney *in litt.*). If a record is undocumented and of significant biogeographic interest, then authors can include morphological descriptions that lead to the species identification. If in doubt, a record should be considered as hypothetical, pending future confirmation, and excluded from the main list, or identified to the genus or species complex level. Accession numbers should be provided for important specimen records, and if possible, images of important specimens should be included as photo figures within manuscripts or as supplementary online material (SOM), which should be permanently archived at a stable URL. Museums should be encouraged to provide digital space to facilitate this archiving (F. Olmos *in litt.*). It should be noted that the highest quality evidence for different species may vary—a sound recording of an *Elaenia* may be of more value than a photograph or a prepared specimen, whereas sound recordings of many species may not be diagnosable from closely related heterospecifics.

3. If in doubt, leave it out

If doubt remains over an identification of a difficult-to-identify species pair or species complex, then a record can be either excluded or included as hypothetical, ideally with some discussion of the potential record. Future fieldwork will likely result in confirmed records. Over-confidence may lead to future identification error cascades and should be avoided.

4. Include as much supporting life history data as space allows

As highlighted above, many inventories include supporting life history information such as a) a qualitative (or better quantitative) abundance estimate or calculation, b) (micro)habitat usage, c) seasonality, d) breeding behavior (e.g., nest records, brood patches, gonadal data). These types of data add scientific value to a paper and make it more citable.

5. Archive digital vouchers

We believe it is not simply enough to indicate that documentation is archived in the author's private collections and we urge journals not to accept manuscripts that state that documentary material will be archived "at some point in the future." On many occasions we have solicited documentary evidence and it has not been forthcoming. If documentary evidence in the form of images and sound recordings is placed online in the public domain, then peer-review is immediate and the whole process becomes more transparent (*e.g.,* Lees *et al.* 2012, 2013a, 2013b). Such digital vouchers are not intended to supplant traditional specimen vouchers but instead provide an opportunity for peer review of unusual records, which is not possible if material is inaccessible. Field photographs can be archived on the Brazilian avian database *Wikiaves* (WA: www.wikiaves.com.br) where they are searchable by accession number (which can be provided in appendices), whereas both field and in-hand photographs can be archived on the *Internet Bird Collection* (IBC: ibc.lynxeds.com/). Although both of these sites are not currently institutionally hosted and therefore their existence cannot be guaranteed in perpetuity, they seem to represent long-term projects that will remain active for many years. Sound recordings can be archived in several collections, including a) *Wikiaves*; b) the global avian sound library *Xeno-canto* (XC: www.xeno-canto.org), where multiple 'background' species can be listed to reduce workload for documenting common species; c) the *Macaulay Library* (ML: http://macaulaylibrary.org/) and d) the *Avian Vocalizations Center* (AVoCet: avocet.zoology.msu.edu/) where online peer-review is also possible. Many other sound archives are available, and

all of them should be able to provide accession numbers and be readily searchable on the internet. For a digital voucher to be functional, the diagnostic field marks and vocal traits need to be visible in photographs or audible in sound recordings. Presentation of undiagnosable and ambiguous material should be avoided (*e.g.,* Jackson 2006). Digitalization of specimen skins is also a highly desirable future prospect (*e.g.,* Monk & Baker 2001) that will allow for general web-based peer review and museums should ideally include their holdings on an online database.

6. Conduct rigorous searches for historical records

Incorporating old specimen records is extremely important to add historical depth and may function as reference point to quantify shifting baselines. Authors should make efforts to solicit specimen records from both domestic and foreign museums (Alberch 1993). Currently, ornithological data from 42 institutions can be searched using the digital database *Ornithology Information System* (ORNIS: www.ornisnet.org/) and more collections will be available for online search in the near future. Collecting localities can be roughly located using Paynter & Traylor (1991), which are freely available online from the *Biodiversity Heritage Library* (BHL: www.biodiversitylibrary.org/), which is itself an essential resource in searching for historic records along with the *Searchable Ornithological Research Archive* (SORA: sora.unm.edu/). However, care should be taken in the interpretation of historical data. Although it has frequently been argued that physical specimens provide the most reliable evidence for assessing species presence (*e.g.,* McKelvey *et al.* 2008), there are numerous studies indicating that specimen data are only as reliable as the associated collection details (Knox 2003; Boessenkool *et al.* 2010). We encourage compilers of inventories to check any biogeographically unusual historical record by visiting the collection to physically check specimens and their labels. If this is not possible, then curatorial staff could provide images of the specimens in question (see examples in Silveira & D'Horta 2002; Lees *et al.* 2013a). In the event that the identification is deemed secure then it may be worth double-checking collectors' itineraries and conferring against the data to make sure that no mistake was made—see the example of Southern Antpipit *Corythopis delalandi* discussed in Table 1.

7. Take care in citing digital vouchers of third parties

In addition to providing digital archives of the authors' own records, some inventories also include data and/or digital vouchers of other observers' sightings, including those of amateur ornithologists. At temperate latitudes knowledge of spatio-temporal patterns of bird distribution is collated principally by amateur ornithologists, and data is increasingly being compiled using the internet (*e.g.,* Sullivan *et al.* 2009). Similarly, the submission of digital vouchers (photographs or recordings) by amateur ornithologists using sites such as *Wikiaves* and *Xeno-canto*, or through the use of online checklist sites such as *eBird* (ebird.org/content/ebird/) promises to increase our knowledge of tropical avifaunas as long as expert ornithologists maintain a close scrutiny to filter out probable erroneous submissions. We recommend that compilers of lists use data from third parties, but we suggest that authors carry out a thorough prior error-checking, particularly if the record is unusual. This error-checking should include: 1) verifying that the image/recording is identifiable and similar species can be eliminated; and 2) checking to see if there are any grounds to doubt whether the voucher was taken in the locality to which it is attributed. This can be achieved by verifying that the other images and/or recordings taken by the same author around the same time are in complete agreement and have undoctored Exif files, *i.e.*, confirm that there is no evidence of image tampering (see *e.g.,* Harrop *et al.* 2012). Such error-checking should not be restricted to web-based resources to which members of the general public upload vouchers; errors may remain undetected or uncorrected for years in institutional-based archives, particularly those that do not carefully follow current taxonomies. Many new digital cameras come with inbuilt GPS that further reduce the possibility of fraudulent photographic evidence; one such camera was recently used in documenting the first Brazilian record of Corncrake *Crex crex* (Burgos & Olmos 2013).

8. Ensure a consistent taxonomy is followed

As our literature trawl revealed, incorrect taxonomy is a major source and propagator of errors in biodiversity inventories (see also Bortolus 2008). Some inventories do not state which taxonomy is being followed, which can make interpretation of the results difficult. We recommend that authors use the most recent version of the checklist prepared by the *Comitê Brasileiro de Registros Ornitológicos* (CBRO 2014: www.cbro.org.br/CBRO/listabr.htm) if focusing only on Brazil, or the *South American Classification Committee*'s checklist (Remsen 2013; SACC: www.museum.lsu.edu/~Remsen/SACCBaseline.html) for the wider South American region, although it should be noted that these currently diverge significantly, with SACC retaining a more conservative taxonomy. Many errors in the Amazonian inventories reflected a lack of knowledge of the most recent definitions on species limits, or a failure to cross-reference current taxonomy against older species lists. Fortunately, and as our evaluations for this paper have

shown, it is usually not difficult to correctly re-identify errors of this type by simply invoking the contemporary taxonomy. When in doubt as to whether a recently split species should be included in a list for a particular area, authors should make sure that the list of the relevant committee is consulted.

9. Conduct rigorous error-checks prior to submission

Do not assume that errors will be detected during the official peer-review process. Depending on the scope of the journal, reviewers may have little experience with the biogeographic region or the taxonomic group in question, and the process is at the mercy of the rigor of the individual reviewer. Distributional error-checking should thus be conducted extensively pre-peer review, using a combination of existing field guides—such as the maps in Van Perlo (2009) or major reference works such as the *Handbook of the Birds of the World* series and online databases such as *Wikiaves, InfoNatura* (www.natureserve.org/infonatura/), and HBW Alive (www.hbw.com/). Circulate lists amongst regional experts; even if they do not have time to make a thorough review, many professional ornithologists can spot biogeographic 'outliers' in seconds. We also suggest that editors of journals allow for 'errata' within manuscripts of this type, such that mistakes can be corrected after publishing on archived PDFs.

Conclusions

Modern avian inventories are a cornerstone of ornithology for which utility, credibility, and transparency can easily be increased by some relatively simple measures highlighted herein and without a prohibitive extra investment in effort. Increasing the robustness of such surveys will reduce error rates and hence guard against error cascades into the secondary ornithological literature.

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APPENDIX 1:

Amazonian avifaunal inventories (published between 2000 and 2013) subject to the meta-analysis.

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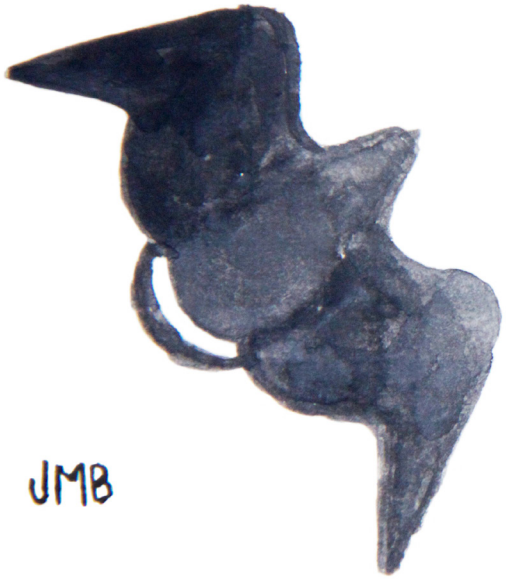
APPENDIX 2:

Reserve management plans with bird lists subject to analysis.

ESEC Rio Acre, FLONA de Carajás, FLONA de Crepori, FLONA do Amaná, FLONA do Jamanxim, FLONA do Purus, FLONA do Trairão, FLONA Macauã, FLONA Mapiá-Inauini, FLONA Tapajós, FLONA Tapirape-aquiri, PARNA Campos Amazônicos, PARNA da Serra da Cutia, PARNA da Serra do Divisor, PARNA de Anavilhanas, PARNA de Juruena, PARNA do Araguaia, PARNA do Cabo Orange, PARNA do Monte Roraima, PARNA Montanhas do Tumucumaque, PARNA Pacaás Novos, REBIO de Uatumã, REBIO do Gurupi, REBIO do Jaru, REBIO do Rio Trombetas, REBIO do Tapirapé, REBIO Guaporé, REBIO Nascentes da Serra do Cachimbo, RESEX Arapixi, RESEX Baixo Juruá, RESEX, Capanã Grande, RESEX do Cazumbá-Iracema, RESEX Rio Iriri, RESEX Riozinho do Anfrísio & RESEX Tapajós-Arapiuns.



Harpyhaliaetus solitarius