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Deforestation and bird extinctions in the Atlantic forest

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Abstract

The Atlantic forests of South America hold a great concentration of biodiversity, but most of this habitat has been destroyed. We therefore expect many species to become extinct, and yet no bird extinctions have conclusively been recorded. There could be three explanations for this. First, birds may be able to adapt to deforested landscapes. Second, many species may have become extinct before they were known to science. Third, there may be a time-lag following deforestation before extinction occurs. We present the most complete list to date of the endemic birds of the Atlantic forests (124 forest-dependent species), and then use the species–area relationship to predict how many species we expect to become extinct through deforestation (51 species i.e. 41%). We also count how many Atlantic forest endemic birds are independently considered 'threatened' with 'a high risk of extinction in the wild in the medium-term future' (45 species i.e. 36%). We compare these totals and find that they are similar, suggesting that there is a time-lag between deforestation and extinction. We go on to test the robustness of this result by varying the parameters used to make our predictions. The only parameter that varies enough to substantially weaken predictions based on deforestation is the habitat classification of Atlantic 'forest' birds. If we include species that can survive in secondary and non-forest habitats then, unsurprisingly, we find that deforestation overestimates threat. Overall, not only does deforestation accurately predict threat to Atlantic forest endemic birds, but this result is robust enough to accommodate considerable variability within our data.

INTRODUCTION

Very little of the Atlantic rainforest (Fig. 1) of south-east Brazil, north-east Argentina and eastern Paraguay remains (da Fonseca, 1985), and the forests that survive are highly fragmented (Ranta *et al*., 1998). This region has one of the highest concentrations of endemic bird species anywhere in the world (Stattersfield *et al*., 1998), and no less than 68% of all its bird species are considered to be rare (Goerck, 1997). Many ecologists have predicted that such massive deforestation in the tropics and sub-tropics will cause an extinction crisis (Wilson, 1988). However, not a single bird species has become extinct in the Atlantic forests (Brown & Brown, 1992). In this paper we ask why.

One explanation could simply be that deforestation does not cause extinction. Brown & Brown (1992) argue that we have seen no bird extinctions in the Atlantic forests because the region's birds are naturally adapted to fragmented forest. Budiansky (1994) re-iterates this, concluding that 'one would appear to be justified in continuing to take the much-cited global extinction rate with a grain of salt'.

Second, extinctions could have occurred historically, unnoticed by science (Balmford, 1996), as happened on many islands in the Pacific (Pimm, Moulton & Justice, 1994). The Atlantic forests have a long history of deforestation (Dean, 1995), which makes this hypothesis plausible. Teixeira (1986) even notes that a 'curassow was recorded from the northeastern Brazilian forests by

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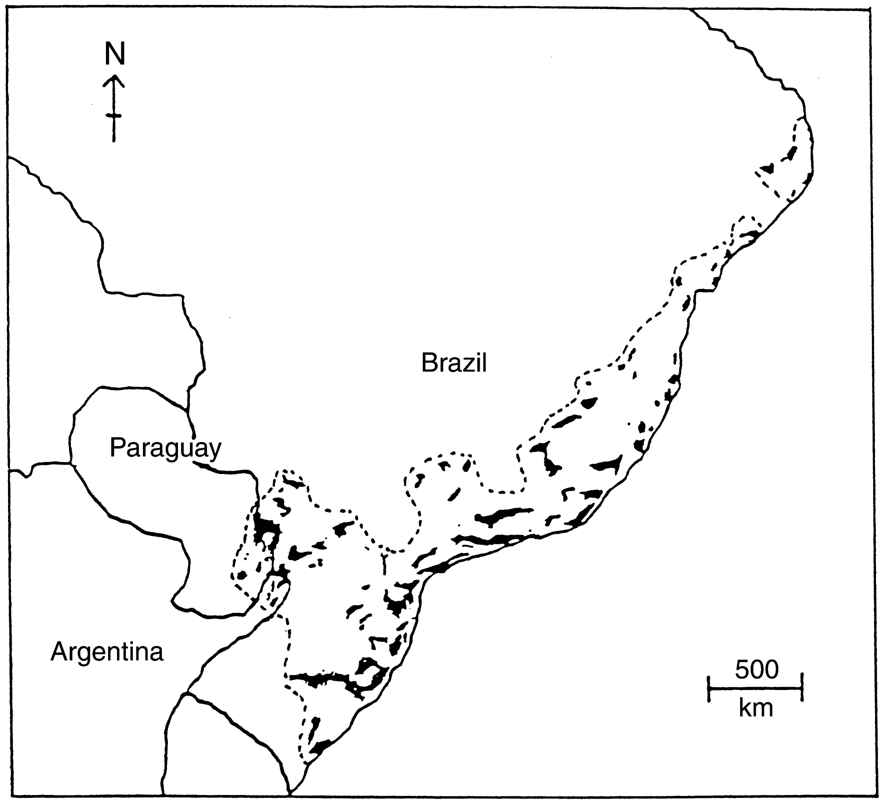

Fig. 1. The current extent of Atlantic forests is shaded in black (Brown & Brown, 1992). The dashed line delimits the approximate historical extent of forest (Dean, 1995).

G. Marcgrave in the seventeenth century and became extinct about the 1930s', although the taxonomic status of this bird is unknown. Such extinctions would have left the region's avifauna depauperate before it was even known. Brown & Brown (1992) suggest this possibility but reject it as 'not subject to any verification'.

Third, there could be a time-lag between deforestation and extinction. Extinctions following habitat loss typically take place over prolonged relaxation times (Diamond, 1972). By extension, in areas of rapid deforestation, many species could even now be in serious danger of extinction (Pimm & Brooks, in press). Although Brown & Brown (1992) do not suggest this possibility, the idea that today's threatened species may well be extinct tomorrow is not new (Heywood & Stuart, 1992). Indeed, the new IUCN criteria (Mace & Stuart, 1994) define a species as 'threatened' if it has 'a high risk of extinction in the wild in the medium-term future'.

We can test these hypotheses by comparing two independently derived predictions of extinctions among endemic Atlantic forest birds. One involves coupling data on deforestation with the relationship between an area and the number of species that it holds (Simberloff, 1992). The second is based on a detailed analysis of the conservation status of the Atlantic forest's endemic birds, published in *Birds to watch 2* (Collar, Crosby & Stattersfield, 1994). There is an obvious worry that comparing such lists is in some way circular. However, we have no *a priori* basis for expecting that the number of extinctions predicted by deforestation should necessarily be similar to the number of species listed as threatened. Indeed, Budiansky's (1994) hypothesis is that the clearance of the Atlantic forests causes no threat to endemic birds. Moreover, *Birds to watch 2* was prepared by treating each species individually (Collar, Crosby *et al.*, 1994), giving a 'bottom-up' prediction of extinction. In contrast, our predictions of extinction based on deforestation are 'top-down' predictions, produced by considering the community as a whole, without regard to individual species. We can thus safely consider our two sets of numbers to be independent of one another.

Elsewhere, we have compared these two approaches and shown that the extent of deforestation in the region predicts, remarkably closely, the proportion of its endemics that are threatened (Brooks & Balmford, 1996). However, this important result was based on a single set of parameter values, and so here we explore its robustness by varying the precise values used so as to reflect the uncertainties in both approaches to quantifying threat.

METHODS

Predicting extinctions using the species–area relationship

Large areas hold more species than small areas. The relationship between area and number of species has been widely shown to approximate $S = cA^z$, where S = number of species, A = area, and c and z are constants (Preston, 1962). The value of the constant z in a fragmented system has been widely shown to be ~ 0.25 (Rosenzweig, 1995). The species–area relationship has traditionally been used to predict species numbers in different-sized areas over space, but it is straightforward to manipulate it to predict changing species numbers as a single area changes in size over time (Simberloff, 1992). If habitat area decreases from $A_{original}$ to A_{new}, the proportion of species expected to survive will be given by $S_{new}/S_{original} = (A_{new}/A_{original})^{0.25}$. The proportion of species going extinct through habitat loss will therefore be $1 - (S_{new}/S_{original})$. The species–area relationship will only predict the extinction of species endemic to the area in question, of course, since species with larger ranges could survive elsewhere even if the area was completely destroyed (Pimm & Askins, 1995).

To predict extinctions in the Atlantic forest, we therefore need to know what proportion of the Atlantic forest survives ($A_{new}/A_{original}$). The historical extent of the Atlantic forest is a matter of dispute (Leitão-Filho, 1993), but realistic estimates suggest that 12% of the region's forest cover remains (Viana, Tabanez & Batista, 1997). This figure is derived from the most comprehensive survey of the Atlantic forests available, a compendium of 18 maps compiled by the SOS Mata Atlântica/INPE/IBAMA in 1990 as the '*Atlas dos remanescentes florestais do dominio Mata Atlântica*' (Brown & Brown, 1992) and so we follow this here.

In Brooks & Balmford (1996) we subdivided the Atlantic forests into 'Endemic Bird Areas' (EBAs) following ICBP (1992) and early drafts of Stattersfield *et al*. (1998). The EBAs that we used were the Alagoan Atlantic slope (B47), the Bahian deciduous forest (B48), the Brazilian lowlands (B51/52) and the Araucaria forest (B54). We estimated forest cover in each of these regions using the state-by-state data in Brown & Brown (1992). Alternative approaches are proposed by Dinerstein *et al*. (1995), who subdivide the Atlantic forests into three 'ecoregions', and by Parker, Stotz & Fitzpatrick (1996) who divide it into four 'subregions'. Most recently, Stattersfield *et al*. (1998) have updated ICBP (1992) and their early drafts, and now subdivide the Atlantic forests into only three EBAs: the Atlantic slope of Alagoas and Pernambuco (071), the Atlantic forest lowlands (075) and the Atlantic forest mountains (076) plus the non-forest Fernando de Noronha (069) and the Coastal Paraná marshes (s034). Here, rather than attempting to reconcile forest cover estimates across these subdivisions, we treat the Atlantic forests as a single unit.

Compiling a list of Atlantic forest endemic bird species

We want to compare our deforestation-based prediction of the proportional extinction of Atlantic forest endemics ($1 - (S_{new}/S_{original})$) with $S_{threatened}/S_{original}$, the proportion of endemics considered threatened in *Birds to watch 2* (Collar, Crosby *et al*., 1994). We therefore need to compile two data sets: the total number of Atlantic forest endemic bird species ($S_{original}$); and the number considered threatened ($S_{threatened}$) by Collar, Crosby *et al.* (1994).

Early estimates of the endemic avifauna of the Atlantic forest region varied from 160 species (Haffer, 1974) to 214 species (Scott & Brooke, 1985). We used the latter estimate in Brooks & Balmford (1996). However, these early lists did not make explicit range-, habitat- or taxonomy-based criteria for inclusion. The most recent and comprehensive inventory considers 199 species or putative species to be endemic to the Atlantic forest – 'the humid coastal forest region of eastern Brazil, from Ceará south to the escarpment of central Rio Grande do Sul' (Parker, Stotz *et al.*, 1996). We follow their definition of the range of the Atlantic forest exactly. In Appendices I and II we list all taxa restricted to this region.

Some species endemic to the Atlantic forest region are not dependent on forest habitat. Since we are concerned with the response of avian communities to deforestation, we should consider only species reliant on forested habitats. However, a continuum exists between total reliance on primary forest and occurrence in secondary or even non-forested habitats. Fortunately, Parker, Stotz *et al*. (1996) provide habitat data for every species. We therefore exclude from subsequent analyses all species listed by Parker, Stotz *et al*. (1996) as occurring in (natural or anthropogenic) secondary forest (F15) or non-forest habitats (N or A: see Appendix I for details), even when they occur in primary forest as well. We do include species whose occurrence in secondary forest is dubious (F15?) and those that occur in forest edge (E). Our analyses therefore deal only with those species that would become globally extinct if all primary forest cover (of all types) was cleared in the Atlantic forest region.

In compiling our total list of Atlantic forest endemics, we must follow a taxonomy that is as close as possible to that used in Collar, Crosby *et al*.'s (1994) assessment of threatened species. If we include in $S_{original}$ taxa that Collar, Crosby *et al*. (1994) did not evaluate (and hence could not have included in $S_{threatened}$), our figure for $S_{threatened}/S_{original}$ will inevitably underestimate the true proportion of threatened endemics. On the other hand, we must take care to exclude any taxonomic decision made by Collar, Crosby *et al*. (1994) over and above the original source. This is because Collar, Crosby *et al.* (1994) do not revise non-threatened species (except by omission, in one case), and hence a figure for $S_{threatened}/S_{original}$ which included their revisions would overestimate the real extent of threat. Collar, Crosby *et al*. (1994) largely follow Sibley & Monroe (1990, 1993), and so we strictly follow this source. We exclude four taxa (*Myrmotherula (unicolor) snowi*, *Formicivora (serrana) littoralis*, *Onychorhynchus (coronatus) swainsoni* and *Laniisoma (elegans) elegans*) raised to specific status beyond Sibley & Monroe (1990, 1993) by Collar, Crosby *et al*. (1994). We include the one taxon (*Leptodon (cayenensis) forbesi*) that Sibley & Monroe (1990, 1993) consider a full species but that Collar, Crosby *et al.* (1994) do not, which is evidently threatened (Bierregaard, 1994).

Based on these rules, we include 124 forest-dependent endemics in $S_{original}$ (see Appendix I).

Predicting extinctions using the *Red list* of threatened birds

We next need to count the number of these species listed as 'threatened' ($S_{threatened}$) by Collar, Crosby *et al.* (1994); that is, those categorized as 'vulnerable,' 'endangered,' 'critical,' or 'extinct in the wild'. We do not include species considered 'near-threatened' or 'data-deficient', since these are not considered to face a high risk of extinction (Collar, Crosby *et al.*, 1994). Furthermore, since species can be listed as 'threatened' for a number of reasons, we must exclude all species threatened solely by causes other than deforestation to date. These fall into three possible groups.

First, Collar, Crosby *et al.* (1994) include species based on predicted future threat (under their code A2). In principle, including these species in $S_{threatened}/S_{original}$ would overestimate threat in comparison to our predictions of extinction based on current levels of deforestation. However, none of the species that we consider here are listed solely due to future predictions of decline.

Second, species with tiny ranges can be listed as threatened without any evidence of decline (under code D2). Such species are threatened not by current habitat destruction but by biogeographical circumstance. We therefore exclude the one species in this category, *Tijuca condita*, from inclusion in $S_{threatened.}$

Third, direct human persecution (mainly under code A1c) rather than habitat destruction threatens some species (Aleixo & Galetti, 1997). Although the Atlantic forest guans and tinamous are seriously threatened by hunting, and some of its *Amazona* parrots by trapping for the cage-bird trade, all of these species are primarily threatened by deforestation (Collar, Crosby *et al.*, 1994), and so we do not need to exclude any further species.

Following these guidelines, we estimate $S_{threatened}$ to total 45 species (see Appendix I). (Of these, 20 are 'vulnerable,' 17 'endangered,' 7 'critical,' and 1 'extinct in the wild').

RESULTS AND DISCUSSION

We compare the proportion of Atlantic forest endemic birds considered 'threatened' ($S_{threatened}/S_{original}$) with the proportion predicted to become extinct based on the extent of deforestation ($1 - (S_{new}/S_{original})$). Our null hypothesis is that the two proportions are identical. When z is set to 0.25, $A_{new}/A_{original}$ to 0.12, and $S_{original}$ and $S_{threatened}$ to 124 and 45 species, respectively, we fail to reject our null hypothesis: the two proportions are not significantly different ($\chi^2 = 1.21$, d.f. = 1, $P > 0.05$).

This result therefore provides provisional confirmation that deforestation accurately predicts threat to Atlantic forest endemic bird species (Brooks & Balmford, 1996). If Atlantic forest endemics were 'pre-adapted' to deforestation (Brown & Brown, 1992) we would expect predictions based on deforestation to overestimate the true degree of threat. We would similarly expect our deforestation-based prediction to overestimate recorded threat if many Atlantic forest endemics had already been lost (Balmford, 1996). The fact that in practice deforestation closely predicts threat suggests that there is indeed a time-lag between deforestation and bird extinctions (Heywood & Stuart, 1992).

How robust is this initial result to the precise parameter values used? With 1 d.f. and a significance level of $P = 0.05$, we must obtain $\chi^2 > 3.84$ to reject our null hypothesis. If we hold our proportion of threatened endemics ($S_{threatened}/S_{original}$) constant (i.e. at 45/124 = 0.36), our predicted proportion of extinctions ($1 - (S_{new}/S_{original})$) must fall outside the range 0.29–0.45 to reject our null hypothesis. Alternatively if we hold our predicted proportion of extinctions constant (i.e. at 0.41), our proportion of threatened species ($S_{threatened}/S_{original}$) must fall outside the range 0.33–0.49 to reject our null hypothesis. Could these situations occur?

Varying z-values

The first and most obvious test is to vary our value of z, which tends to be smaller in less fragmented systems, and *vice versa* (Rosenzweig, 1995). Reid (1992) predicted global extinction rates using z-values of 0.15, 0.25 and 0.35, and so we use his values of 0.15 and 0.35 to predict extinctions. Using as small a z-value as 0.15 causes deforestation to significantly underestimate threat ($\chi^2 = 5.42$, d.f. = 1, $P = 0.02$), while using as large a value as 0.35 causes deforestation to overestimate threat ($\chi^2 = 12.31$, d.f. = 1, $P < 0.01$). Nevertheless, our analysis is relatively insensitive to the value of z, for we could vary our z-value in the range 0.16–0.28 while remaining within the range of $1 - (S_{new}/S_{original})$ of 0.29–0.45, across which we cannot reject the null hypothesis that deforestation predicts threat. This range of z-values covers most biologically realistic situations in fragmented habitats (Rosenzweig, 1995).

Varying deforestation estimates ($A_{new}/A_{original}$)

Second, what is the effect if we use different values for the proportion of forest surviving ($A_{new}/A_{original}$)? If we use an extreme (and unlikely) value of 1% we find that deforestation significantly overestimates threat ($\chi^2 = 59.04$, d.f. = 1, $P < 0.01$). However, estimates of remaining forest cover varying from 9–26% would all give us values of $1 - (S_{new}/S_{original})$ between 0.29–0.45 where we cannot reject the null hypothesis that deforestation predicts threat. Our analysis is thus relatively insensitive to realistic values of $A_{new}/A_{original}$, although with extremely high estimates of deforestation we will find that deforestation overestimates threat.

Varying habitat definition ($S_{original}/S_{threatened}$)

Third, what will happen if we vary the numbers of endemics considered for inclusion in $S_{original}$ and $S_{threatened}$? If we assume no change in numbers of threatened endemics, our total numbers of endemics can range from 93–136 without $S_{threatened}/S_{original}$ straying beyond the range of 0.33–0.49, within which we cannot reject the null hypothesis. Why might we vary $S_{original}$?

One such possibility arises if we relax our habitat definition to include species not restricted to primary forest. Many species occur in secondary regrowth (Parker, Stotz *et al*., 1996) and gallery forest along rivers (da Silva, 1996). Including all of these gives us an additional 57 Atlantic forest endemics of which only six are threatened (we would not count *Vireo gracilirostris* as threatened, because Collar, Crosby *et al*. (1994) list this only under criterion D2). Indeed, of the six additional threatened endemics, three (*Myrmotherula unicolor*, *Formicivora erythronotus* and *Tangara peruviana*) are not classified as 'strict' endemics because they occur in restinga, itself a highly threatened habitat (Tobias & Williams, 1996). Added to our totals of strict endemics (45 threatened and 124 total), these species would give us a value for $S_{threatened}/S_{original}$ of 51/181 = 0.28. Since this value is less than our critical value for $S_{threatened}/S_{original}$ of 0.33, deforestation would overestimate threat in this case ($\chi^2 = 12.09$, d.f. = 1, $P < 0.01$). We can therefore see that our analysis is quite sensitive to our definition of Atlantic 'forest'. This result is entirely unsurprising – by definition, we do not expect non-forest species to be harmed by deforestation. In fact, many of these species may actually have benefitted as the extent of secondary habitat has increased at the expense of primary Atlantic forest.

Varying range definition ($S_{original}/S_{threatened}$)

$S_{original}$ could also vary if we use a broader definition of the extent of the Atlantic forests, for example, to include migrants. Three austral migrants – *Elaenia mesoleuca*, *Attila phoenicurus* and *Tangara preciosa* – spend part of the year restricted to the Atlantic forest (Ridgely & Tudor, 1989, 1994). However only one, *A. phoenicurus*, is a strict forest inhabitant (Parker, Stotz *et al*., 1996), and none are threatened. Thus $S_{threatened}/S_{original}$ becomes 45/125, suggesting that our analysis is insensitive to whether migrants are included ($\chi^2 = 1.19$, d.f. = 1, $P > 0.05$).

An additional argument could be made to include species with ranges largely, but not entirely, within the region, e.g. *Streptoprocne biscutata*, *Lophornis magnificus*, *Xiphocolaptes albicollis*, *Synallaxis cinerascens*, *Phyllomyias fasciatus*, *Pachyramphus validus*, *Thryothorus longirostris* and *Schistochlamys ruficapillus* (Scott & Brooke, 1985), in dry forest very close to the region, e.g. *Formicivora iheringi* and *Rhopornis ardesiaca* (ICBP, 1992), or in arid montane scrub extending from the region, e.g. *Polystictus superciliaris* (Stattersfield *et al*., 1998). However, as we broaden our definition of the range of the Atlantic forest, we will include more and more species that are found in forest edge or non-forest habitats (Parker, Stotz *et al*., 1996). Only four of the species mentioned above (*P. fasciatus*, *X. albicollis*, *F. iheringi* and *R. ardesiaca*) are strict forest species, and only the latter two are threatened, so again our analysis is insensitive to broadening the geographical range of the 'Atlantic forest' ($\chi^2 = 1.16$, d.f. = 1, $P > 0.05$).

The converse of these possibilities would be to subdivide our region into smaller units, as we did in Brooks & Balmford (1996), which would reduce our total number of endemics. As we consider smaller centres of endemism, we tend to find higher proportions of threatened endemics and hence higher values of $S_{threatened}/S_{original}$ (Brooks & Balmford, 1996). Consider, for example, northern coastal Brazil in the state of Alagoas, the region's most distinctive sub-unit (Parker, Stotz *et al*., 1996). Alagoas holds seven (*Leptodon forbesi*, *Crax mitu*, *Synallaxis infuscata*, *Philydor novaesi*, *Terenura sicki*, *Phylloscartes ceciliae* and *Hemitriccus mirandae*) endemic forest species, of which all are threatened. A further endemic (*Tangara fastuosa*) that is not confined to primary forest is also threatened, as, presumably, would be another three (*Pyrrhura (leucotis) leucotis*, *Myrmotherula (unicolor) snowi* and *Conopophaga (lineata) cearae*) of uncertain taxonomic status (see Appendix II). Even though only 2% of the Alagoan Atlantic forest remains (Brown & Brown, 1992), the species–area relationship predicts that 38% (= $0.02^{0.25}$) of its endemics should survive. This is significantly different from 0%, the proportion of unthreatened Alagoas endemics ($\chi^2 = 5.25$, d.f. = 1, $P = 0.02$). At progressively finer scales, then, deforestation-based estimates increasingly underestimate threat (Brooks, Pimm & Collar, 1997).

Varying threat definition ($S_{threatened}$)

What will be the effect of varying our counts of threatened species ($S_{threatened}$)? This could occur as our knowledge of conservation status improves. For example, Volume 7 of *Cotinga* dramatically reported the rediscoveries in 1996 of three of the rarest Atlantic forest endemics, *Calyptura cristata* (Gonzaga, 1997), *Myrmotherula fluminensis* (Knapp, 1997) and *Nemosia rourei* (Scott, 1997). In Table 1 we illustrate differences in the numbers of strict Atlantic forest endemics considered threatened by Collar, Crosby *et al*. (1994) and by three other major assessments (Collar & Andrew, 1988; Collar, Gonzaga *et al*., 1992; Parker, Stotz *et al*., 1996).

Of the sources in Table 1, Collar & Andrew (1988) and Parker, Stotz *et al*. (1996) both consider a number of species to be threatened that have been shown to be not uncommon in the southern part of their ranges, e.g. *Tinamus solitarius*, *Phylloscartes eximius*, *Polioptila lactea* and *Euphonia chalybea* (Brooks, Barnes *et al*., 1993). Conversely, Collar & Andrew (1988) and Collar, Gonzaga *et al*. (1992) do not list the *Myrmotherula*

Table 1. Changing knowledge of threat to 'strict' Atlantic forest endemics, with primary sources for species not considered threatened by assessments preceeding Collar, Crosby *et al.* (1994)

Source	Details	Number	
		Threatened	Relative to Collar, Crosby *et al.* (1994)
Collar, Crosby *et al.* (1994)	We include *Leptodon forbesi* in all threatened lists (Sibley & Monroe, 1990)	45	–
Parker, Stotz *et al.* (1996)	*Crypturellus noctivagus*, *Clibanornis dendrocolaptoides*, Cercomacra *brasiliana*, *Phylloscartes eximius*, *Tijuca atra*, *Polioptila lactea* and *Amaurospiza moesta*: conservation priority 1 or 2		52 +7
Collar, Gonzaga *et al.* (1992)	*Myrmotherula minor* and *Myrmotherula urosticta* (Whitney & Pacheco, 1995)	43	–2
Collar & Andrew (1988)	*Myrmotherula fluminensis* (Gonzaga, 1988), *Myrmotherula urosticta* (Whitney & Pacheco, 1995), *Scytalopus psychopompus* (Teixeira & Carnevalli, 1989) and *Hemitriccus mirandae* (Fitzpatrick, 1976)	–	–4
	Tinamus solitarius, *Crypturellus noctivagus*, *Macropsalis creagra*, *Clibanornis dendrocolaptoides*, *Cercomacra brasiliana*, *Amaurospiza moesta* and *Euphonia chalybea*.	–	+7

antwrens shown to be threatened by Whitney & Pacheco (1995). There have also been several taxonomic changes since the publication of Collar & Andrew (1988), which have added threatened species. Overall, however, it is clear that the conservation status of the Atlantic forest endemics is relatively well-known.

If we included the 10 additional strict Atlantic forest species listed as threatened by Collar & Andrew (1988), or by the Parker, Stotz *et al.* (1996) list, our value of $S_{\text{threatened}}/S_{\text{original}}$ would only increase to 55/124 = 0.44, still within the range 0.33–0.49 where deforestation predicts threat ($\chi^2 = 0.53$, d.f. = 1, $P > 0.05$). Conversely, if we did not consider *Myrmotherula minor* and *M. urosticta* as being threatened (Collar, Gonzaga *et al.*, 1992), our value of $S_{\text{threatened}}/S_{\text{original}}$ would only decrease to 43/124 = 0.33, again within the range where deforestation predicts threat ($\chi^2 = 2.13$, d.f. = 1, $P > 0.05$). Our analysis is thus insensitive to the few probable changes in conservation status.

Varying taxonomy ($S_{\text{original}}/S_{\text{threatened}}$)

The final reason for $S_{\text{threatened}}/S_{\text{original}}$ to vary is through taxonomic change. We do not know how this might alter the number of species considered threatened, but taxa that are newly discovered or raised to specific status generally have very small populations, and are therefore likely to be threatened (Blackburn & Gaston, 1995; Whitney, Pacheco & Parrini, 1995). There have been 25 changes to the taxonomic status of birds in our region after the publication of Sibley & Monroe (1993), all of which have involved the 'splitting' of existing taxa (Gonzaga & Pacheco, 1990; Collar, Gonzaga *et al.*, 1992; Willis, 1992; Howell & Robbins, 1995; Whitney, Pacheco & Parrini, 1995; Whitney, Pacheco, Isler *et al.*, 1995; Parker, Stotz *et al.*, 1996; Isler, Isler & Whitney, 1997), or the discovery of new ones (Willis & Oniki, 1992; Gonzaga & Pacheco, 1995; Pacheco & Gonzaga, 1995; Pacheco, Whitney & Gonzaga, 1996). Two non-forest species have also been discovered (Bornschein, Reinert & Teixeira, 1995; Bornschein, Reinert & Pichorim, 1998). We list these in Appendix II.

Even if all of these new forest species were threatened, our value of $S_{\text{threatened}}/S_{\text{original}}$ would only increase to 0.47, still within the range 0.33–0.49 where deforestation predicts threat ($\chi^2 = 2.25$, d.f. = 1, $P > 0.05$). For deforestation to underestimate threat we would have to revise our taxonomy to add 29 species, all of them threatened. Alternatively, we would have to 'lump' eight threatened species to cause deforestation to overestimate threat. Our analysis is therefore quite insensitive to changing taxonomy.

CONCLUSIONS

Our result that the extent of deforestation predicts the numbers of threatened endemic birds in the Atlantic forests (Brooks & Balmford, 1996) is robust. Varying most of the parameters that we used in the analysis across ecologically sensible ranges produces the same result. The one exception occurs when we use a broad definition of the habitat of an Atlantic 'forest' endemic, in which case we find that deforestation overestimates threat. Most of the species in this category survive in secondary forest (F15) rather than non-forested habitats (Parker, Stotz *et al.*, 1996). Nevertheless, by definition, we do not expect species that can persist in secondary forest to become extinct following the loss of primary forest – as long as the secondary forest is not cleared as well.

So what proportion of the endemic Atlantic forest avifauna is in danger of being lost? We know that 36% are already threatened with a 'high risk of extinction in the wild in the medium-term future' (Collar, Crosby *et al.*, 1994). Varying our predictions of extinction based on deforestation across ecologically plausible ranges produces estimates in the range of 30–50%. We stand to lose between a third and a half of the Atlantic forest's endemic birds as a consequence of the deforestation that has already been carried out.

How long is the 'medium-term' over which we expect these extinctions to take place? We can estimate this using the new IUCN categories of threat, which assign probabilities of extinction of 50% in 5 years to 'critical' species, 20% in 20 years to 'endangered' species, and 10% in 100 years to 'vulnerable' species (Collar, Crosby *et al.*, 1994). Applying these probabilities of extinction to the number of Atlantic forest-dependent endemic birds in each category of threat gives a crude estimate of 21 global extinctions within a century, that is, a sixth of the avifauna. This prediction is conservative: it does not include species that survive in secondary forest nor those forest species that may become threatened through deforestation in the future.

That Atlantic forest endemic species become extinct following the loss of their habitat has been widely demonstrated on small scales (e.g. Willis, 1979; Aleixo & Vielliard, 1995; Christiansen & Pitter, 1997; dos Anjos, 1998). Our analysis clearly shows that deforestation is also leading to mass bird extinctions over the scale of the entire Atlantic forest, but that these have not yet occurred. We conclude that 'one would appear to be justified in continuing to take the much-cited extinction rate' (Budiansky, 1994) very seriously indeed. Without immediate and comprehensive conservation action (Parker & Goerck, 1997), many species of Atlantic forest endemic birds (and untold numbers of other taxa) threatened with extinction today will become extinct in the medium-term future.

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Appendix I. Atlantic forest endemics

Our taxonomy and nomenclature follows Sibley & Monroe (1990, 1993), our systematic order follows Parker, Stotz *et al*. (1996). Threat status follows Collar, Crosby *et al*. (1994), with 'threatened' species marked T (EW, 'extinct in the wild'; CR, 'critical'; EN, 'endangered'; VU, 'vulnerable') and 'near-threatened' marked NT, except where marked † because we include *Leptodon forbesi* as a full, threatened species (Bierregaard, 1994) and do not count *Tijuca condita* or *Vireo gracilirostris*, threatened under criteria D2 by their tiny ranges (Collar, Crosby *et al*., 1994). Habitat classification follows Parker, Stotz *et al*. (1996): F1, tropical lowland evergreen forest; F3, river-edge forest; F4, montane evergreen forest; F5, elfin forest; F7, tropical deciduous forest; F8, gallery forest; F9, southern temperate forest; F12, white sand forest; F15, secondary forest; N3, semi-humid/humid montane scrub; N7, southern temperate grassland; N11, riparian thickets; N13, pastures/agricultural lands; N14, second-growth srcub; A1, freshwater marshes; A9, streams; E, edge; ?, uncertain habitat. We mark species that we do not consider 'strict' Atlantic forest endemics with‡.

Scientific name	English name	Threat	Habitat
Tinamus solitarius	Solitary tinamou	NT	F1
Crypturellus noctivagus	Yellow-legged tinamou	NT	F1, F15‡
Leptodon forbesi	White-collared kite	T†	F1
Leucopternis lacernulata	White-necked hawk	T-VU	F1
Leucopternis polionota	Mantled hawk	NT	F1
Aburria jacutinga	Black-fronted piping-guan	T-VU	F1, F3
Crax blumenbachii	Red-billed curassow	T-CR	F1
Crax mitu	Alagoas curassow	T-EW	F1
Odontophorus capueira	Spot-winged woodquail	–	F4, F1
Aramides saracura	Slaty-breasted wood-rail	–	F1, F4, A9, F9‡
Claravis godefrida	Purple-winged ground-dove	T-CR	F4, F1
Pyrrhura cruentata	Blue-throated parakeet	T-VU	F1, F15?
Pyrrhura frontalis	Reddish-bellied parakeet	–	F4, F9, F1
Brotogeris tirica	Plain parakeet	–	F1, F4, F15‡
Touit melanonota	Brown-backed parrotlet	T-EN	F1, F4
Touit surda	Golden-tailed parrotlet	T-EN	F1
Pionopsitta pileata	Pileated parrot	NT	F4, F1
Amazona brasiliensis	Red-tailed parrot	T-EN	F1, F12
Amazona pretrei	Red-spectacled parrot	T-EN	F9
Amazona rhodocorytha	Red-browed parrot	T-EN	F1
Amazona vinacea	Vinaceous parrot	T-EN	F9, F1
Triclaria malachitacea	Blue-bellied parrot	T-EN	F1, F4
Otus atricapillus	Long-tufted screech-owl	–	F1, F15, F9‡
Pulsatrix koeniswaldiana	Tawny-browed owl	–	F4, F1
Strix hylophila	Rusty-barred owl	–	F4, F1, F9
Macropsalis creagra	Long-trained nightjar	NT	F4E
Ramphodon naevius	Saw-billed hermit	NT	F1, F15‡
Ramphodon dohrnii	Hook-billed hermit	T-CR	F1
Phaethornis eurynome	Scale-throated hermit	–	F4, F1
Phaethornis idaliae	Minute hermit	–	F1
Melanotrochilus fuscus	Black jacobin	–	F1, F4, F15‡
Stephanoxis lalandi	Plovercrest	–	N14, F15, F4‡
Thalurania glaucopis	Violet-capped woodnymph	–	F1, F4, F15‡
Leucochloris albicollis	White-throated hummingbird	–	F4E, F1E, F15, F9‡
Aphantochroa cirrhochloris	Sombre hummingbird	–	F15, F1E, N14‡
Clytolaema rubricauda	Brazilian ruby	–	F4, F15, F1‡
Trogon surrucura	Surucua trogon	–	F1, F4
Baryphthengus ruficapillus	Rufous-capped motmot	–	F1, F4, F15‡
Jacamaralcyon tridactyla	Three-toed jacamar	T-EN	F1E, F8, F15‡
Malacoptila striata	Crescent-chested puffbird	–	F1, F4
Selenidera maculirostris	Spot-billed toucanet	–	F1, F4
Baillonius bailloni	Saffron toucanet	NT	F4, F1
Ramphastos dicolorus	Red-breasted toucan	–	F1, F4
Picumnus temminckii	Ochre-collared piculet	–	F1, F15, F12‡
Melanerpes flavifrons	Yellow-fronted woodpecker	–	F1, F15‡
Veniliornis maculifrons	Yellow-eared woodpecker	–	F1, F15‡
Veniliornis spilogaster	White-spotted woodpecker	–	F4, F1, F15‡
Piculus aurulentus	Yellow-browed woodpecker	NT	F4, F1, F9
Dryocopus galeatus	Helmeted woodpecker	T-EN	F1
Campephilus robustus	Robust woodpecker	–	F1, F4
Dendrocincla turdina	Plain-winged woodcreeper	–	F1, F4
Lepidocolaptes fuscus	Lesser woodcreeper	–	F1, F4
Lepidocolaptes squamatus	Scaled woodcreeper	–	F4, F1
Campylorhamphus falcularius	Black-billed scythebill	–	F4, F1
Cinclodes pabsti	Long-tailed cinclodes	–	N7, N13‡
Clibanornis dendrocolaptoides	Canebrake groundcreeper	NT	F1
Leptasthenura setaria	Araucaria tit-spinetail	NT	F9, F15‡
Leptasthenura striolata	Striolated tit-spinetail	–	F9, N11‡

Scientific name	English name	Threat	Habitat
Oreophylax moreirae	Itatiaia spinetail	–	N3
Synallaxis ruficapilla	Rufous-capped spinetail	–	F4, F1, F15‡
Synallaxis infuscata	Pinto's spinetail	T-EN	F1
Cranioleuca obsoleta	Olive spinetail	–	F1, F9
Cranioleuca pallida	Pallid spinetail	–	F4
Thripophaga macroura	Striated softtail	T-VU	F1
Phacellodomus erythrophthalmus	Red-eyed thornbird	–	F4, F1, F15, A1, N11, F8‡
Anabazenops fuscus	White-collared foliage-gleaner	–	F4
Anabacerthia amaurotis	White-browed foliage-gleaner	NT	F4
Philydor atricapillus	Black-capped foliage-gleaner	–	F1
Philydor lichtensteinii	Ochre-breasted foliage-gleaner	–	F1
Philydor novaesi	Alagoas foliage-gleaner	T-CR	F1
Automolus leucophthalmus	White-eyed foliage-gleaner	–	F1
Cichlocolaptes leucophrys	Pale-browed treehunter	–	F1, F4
Heliobletus contaminatus	Sharp-billed treehunter	–	F4, F1
Sclerurus scansor	Rufous-breasted leaftosser	–	F1, F4
Hypoedaleus guttatus	Spot-backed antshrike	–	F1
Mackenziaena leachii	Large-tailed antshrike	–	F4, F1
Mackenziaena severa	Tufted antshrike	–	F4, F1, F15‡
Biatas nigropectus	White-bearded antshrike	T-VU	F4, F1
Dysithamnus stictothorax	Spot-breasted antvireo	NT	F1, F4
Dysithamnus xanthopterus	Rufous-backed antvireo	–	F4
Myrmotherula fluminensis	Rio de Janeiro antwren	T-VU	F1
Myrmotherula gularis	Star-throated antwren	–	F4, F1
Myrmotherula minor	Salvadori's antwren	T-VU	F1
Myrmotherula unicolor	Unicolored antwren	T-VU	F1, F12, F15‡
Myrmotherula urosticta	Band-tailed antwren	T-VU	F1
Formicivora serrana	Serra antwren	NT	F1E, N14, F12‡
Formicivora erythronota	Black-hooded antwren	T-CR	F15‡
Drymophila ferruginea	Ferruginous antbird	–	F1, F4
Drymophila genei	Rufous-tailed antbird	NT	F4
Drymophila malura	Dusky-tailed antbird	–	F1
Drymophila ochropygia	Ochre-rumped antbird	NT	F1, F4
Drymophila rubricollis	Bertoni's antbird	–	F4, F1
Drymophila squamata	Scaled antbird	–	F1, F15‡
Terenura maculata	Streak-capped antwren	–	F1, F4
Terenura sicki	Orange-bellied antwren	T-VU	F1
Cercomacra brasiliana	Rio de Janiero antbird	NT	F1E
Pyriglena atra	Fringe-backed fire-eye	T-EN	F1E
Pyriglena leucoptera	White-shouldered fire-eye	–	F1E, F4E
Myrmeciza loricata	White-bibbed antbird	–	F1, F4
Myrmeciza ruficauda	Scalloped antbird	T-VU	F1
Myrmeciza squamosa	Squamate antbird	–	F4, F1
Chamaeza meruloides	Cryptic antthrush	–	F4, F1
Conopophaga lineata	Rufous gnateater	–	F4, F1, F15, F7?‡
Conopophaga melanops	Black-cheeked gnateater	–	F1
Psilorhamphus guttatus	Spotted bamboowren	NT	F1
Merulaxis ater	Slaty bristlefront	NT	F4
Merulaxis stresemanni	Stresemann's bristlefront	T-CR	F1
Scytalopus speluncae	Mouse-colored tapaculo	–	F4, F1
Scytalopus indigoticus	White-breasted tapaculo	–	F1
Scytalopus psychopompus	Bahia tapaculo	T-EN	F1
Phyllomyias griseocapilla	Grey-capped tyrannulet	NT	F4, F1
Phyllomyias virescens	Greenish tyrannulet	–	F1, F4, F9
Elaenia ridleyana	Noronha elaenia	–	F7, N14‡
Mionectes rufiventris	Grey-hooded flycatcher	–	F1, F4
Phylloscartes ceciliae	Alagoas tyrannulet	T-EN	F1
Phylloscartes difficilis	Serra do Mar tyrannulet	NT	F4
Phylloscartes eximius	Southern bristle-tyrant	NT	F1, F4
Phylloscartes oustaleti	Oustalet's tyrannulet	NT	F1
Phylloscartes paulistus	São Paulo tyrannulet	T-VU	F1
Phylloscartes sylviolus	Bay-ringed tyrannulet	NT	F1
Myiornis auricularis	Eared pygmy-tyrant	–	F1, F15‡
Hemitriccus diops	Drab-breasted bamboo-tyrant	–	F1, F4
Hemitriccus furcatus	Fork-tailed tody-tyrant	T-VU	F1
Hemitriccus kaempferi	Kaempfer's tody-tyrant	T-EN	F1
Hemitriccus mirandae	Buff-breasted tody-tyrant	T-VU	F1
Hemitriccus nidipendulus	Hangnest tody-tyrant	NT	F1E, F15‡
Hemitriccus obsoletus	Brown-breasted bamboo-tyrant	–	F4
Hemitriccus orbitatus	Eye-ringed tody-tyrant	NT	F1
Todirostrum poliocephalum	Yellow-lored tody-flycatcher	–	F1E, F15‡
Platyrinchus leucoryphus	Russet-winged spadebill	T-VU	F1
Knipolegus nigerrimus	Velvety black tyrant	–	F4E, F9, N3‡
Muscipipra vetula	Shear-tailed grey-tyrant	NT	F4E, F1E, F15‡

Scientific name	English name	Threat	Habitat
Attila rufus	Grey-hooded attila	–	F1, F4
Schiffornis virescens	Greenish schiffornis	–	F1, F4, F15‡
Piprites pileatus	Black-capped piprites	T-VU	F9, F4
Neopelma aurifrons	Wied's tyrant-manakin	–	F4, F1, F15‡
Ilicura militaris	Pin-tailed manakin	–	F4, F1
Chiroxiphia caudata	Blue manakin	–	F1, F4, F15‡
Tijuca atra	Black-and-gold cotinga	NT	F4
Tijuca condita	Grey-winged cotinga	T-VU†	F5
Carpornis cucullatus	Hooded berryeater	NT	F4, F1
Carpornis melanocephalus	Black-headed berryeater	T-VU	F1
Iodopleura pipra	Buff-throated purpletuft	T-VU	F1
Calyptura cristata	Kinglet calyptura	T-CR	F1
Lipaugus lanioides	Cinnamon-vented piha	T-VU	F1
Cotinga maculata	Banded cotinga	T-EN	F1
Xipholena atropurpurea	White-winged cotinga	T-VU	F1
Procnias nudicollis	Bare-throated bellbird	NT	F1, F4
Turdus subalaris	Eastern slaty thrush	–	F1, F15, F9‡
Polioptila lactea	Creamy-bellied gnatcatcher	NT	F1, F15‡
Haplospiza unicolor	Uniform finch	–	F4, F1
Poospiza thoracica	Bay-chested warbling-finch	–	F4, F9
Sporophila ardesica	Dubois's seedeater	–	N11, A1, N14‡
Sporophila frontalis	Buffy-fronted seedeater	T-EN	F1
Sporophila falcirostris	Temminck's seedeater	T-EN	F4, F1
Sporophila melanogaster	Black-bellied seedeater	NT	A1, N7‡
Amaurospiza moesta	Blackish-blue seedeater	NT	F4, F1
Pitylus fuliginosus	Black-throated grosbeak	–	F1
Saltator maxillosus	Thick-billed saltator	NT	F4E, F1E, F15‡
Orchesticus abeillei	Brown tanager	NT	F4
Pyrrhocoma ruficeps	Chestnut-headed tanager	–	F1, F4, F15‡
Hemithraupis ruficapilla	Rufous-headed tanager	–	F4, F1, F15‡
Nemosia rourei	Cherry-throated tanager	T-CR	F1?
Orthogonys chloricterus	Olive-green tanager	–	F4, F15‡
Tachyphonus coronatus	Ruby-crowned tanager	–	F1E, F4E, F15‡
Ramphocelus bresilius	Brazilian tanager	–	F15, F8, F3, F12‡
Thraupis cyanoptera	Azure-shouldered tanager	NT	F1, F4, F15?
Thraupis ornata	Golden-chevroned tanager	–	F1E, F4, F15‡
Euphonia chalybea	Green-chinned euphonia	NT	F1
Euphonia pectoralis	Chestnut-bellied euphonia	–	F1, F4
Tangara cyanocephala	Red-necked tanager	–	F1, F15‡
Tangara cyanoventris	Gilt-edged tanager	–	F1, F4, F15‡
Tangara desmaresti	Brassy-breasted tanager	–	F4
Tangara fastuosa	Seven-colored tanager	T-EN	F1, F15‡
Tangara peruviana	Black-backed tanager	T-EN	F12, F1E, F15‡
Tangara seledon	Green-headed tanager	–	F1, F4, F15‡
Dacnis nigripes	Black-legged dacnis	T-VU	F1
Basileuterus leucoblepharus	White-rimmed warbler	–	F4, F1, N11, F15‡
Vireo gracilirostris	Noronha vireo	T-VU†	F7, N14, F15‡
Curaeus forbesi	Forbes's blackbird	T-CR	F1E, A1‡
Cyanocorax caeruleus	Azure jay	NT	F1, F9, F12, F15‡

Appendix II. Atlantic forest endemics newly considered species since Sibley & Monroe (1990, 1993)

Sources first give the reference for the revision, and second, where relevant, Collar, Crosby *et al*. (1994) and Parker, Stotz *et al*. (1996) where these adopted the revision. Four taxa (marked †) were already Atlantic forest endemics (see Appendix I) before taxonomic subdivision. Habitat classifications follow Parker, Stotz *et al*. (1996), as described in Appendix I, except for taxa described in publications post-dating that source; those in brackets are for the superspecies of taxa not separated by Parker, Stotz *et al*. (1996).

Scientific name	Source	Habitat
Ortalis (motmot) araucuan	Parker, Stotz *et al*. (1996)	F1E, F7, F8
Pyrrhura (leucotis) leucotis	Parker, Stotz *et al*. (1996)	F1, F15
Pyrrhura (leucotis) griseipectus	Parker, Stotz *et al*. (1996)	F1
Glaucidium (minutissimum) minutissimum	Howell & Robbins (1995)	F1, F7, F4, F11
Phaethornis (superciliosus) margarettae	Parker, Stotz *et al*. (1996)	F1
Synallaxis whitneyi	Pacheco & Gonzaga (1995)	–
Acrabatornis fonsecai	Pacheco, Whitney *et al*. (1996)	–
Phacellodomus (erythrophthalmus) erythrophthalmus†	Parker, Stotz *et al*. (1996)	F4, F1, F15
Phacellodromus (erythrophthalmus) ferrugineigula†	Parker, Stotz *et al*. (1996)	A1, N11, F8
Thamnophilus (punctatus) ambiguus	Isler *et al*. (1997)	(F7, F15, F1E, F12, F8)
Dysithamnus (plumbeus) plumbeus	Collar, Gonzaga *et al*. (1992), Collar, Crosby *et al*., (1994), Parker, Stotz *et al*. (1996)	F1
Myrmotherula (unicolor) snowi	Collar, Gonzaga *et al*. (1992), Collar, Crosby *et al*., (1994), Whitney & Pacheco (1995)	(F1, F12, F15)
Stymphalornis acutirostris	Bornschein, Reinert & Texeira (1995)	–
Formicivora (serrana) serrana†	Gonzaga & Pacheco (1990), Parker, Stotz *et al*. (1996)	F1E, N14
Formicivora (serrana) littoralis†	Gonzaga & Pacheco (1990), Collar, Gonzaga *et al*. (1992), Collar, Crosby *et al*., (1994), Parker, Stotz *et al*. (1996)	F12
Chamaeza (ruficauda) ruficauda	Willis (1992), Parker, Stotz *et al*. (1996)	F4
Hylopezus (ochroleucus) nattereri	Whitney, Pacheco, Isler *et al*., (1995), Parker, Stotz *et al*. (1996)	F4, F1
Conopophaga (lineata) lineata†	Parker, Stotz *et al*. (1996)	F4, F1, F15
Conopophaga (lineata) cearae†	Parker, Stotz *et al*. (1996)	F7?
Scytalopus iraiensis	Bornschein, Reinert & Pichorim (1998)	–
Phylloscartes beckeri	Gonzaga & Pacheco (1995)	–
Phylloscartes kronei	Willis & Oniki (1992), Collar, Crosby *et al*. (1994), Parker, Stotz *et al*. (1996)	F12, F15
Onychorhynchus (coronatus) swainsoni	Collar, Crosby *et al*. (1994), Parker, Stotz *et al*. (1996)	F1
Neopelma (aurifrons) aurifrons†	Whitney, Pacheco & Parrini (1995), Parker, Stotz *et al*. (1996)	F1?
Neopelma (aurifrons) chrysolophum†	Whitney, Pacheco & Parrini (1995), Parker, Stotz *et al*. (1996)	F4, F1, F15
Laniisoma (elegans) elegans	Collar, Gonzago *et al*., (1992), Collar, Crosby *et al*. (1994)	F4, F1
Pyroderus (scutatus) scutatus	Parker, Stotz *et al*. (1996)	F1, F4
Arremon (taciturnus) semitorquatus	Parker, Stotz *et al*. (1996)	F1, F15?
Tangara (mexicana) brasiliensis	Parker, Stotz *et al*. (1996)	F1E, F15
Tangara (velia) cyanomelaena	Parker, Stotz *et al*. (1996)	F1, F15?
Hylophilus (poicilotis) poicilotis	Parker, Stotz *et al*. (1996)	F1, F4, F15