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Short Communication

Predicting extinction of mammals in the Brazilian Amazon

Carlos Eduardo Viveiros Grelle

Abstract Using the species-area correlation I predicted the percentage of endemic Amazonian mammals committed to extinction by 2020 as an outcome of deforestation resulting from the implementation of mega-infrastructure projects in the Brazilian Amazon. Simulations based on optimistic and non-optimistic deforestation scenarios showed a 2-fold and a 3-fold increase, respectively, in Amazonian mammals committed to extinction. The predicted number of threatened species by 2020 was 5–18% of the total number of endemic mammal species, depending on the scenario and equation used. This increase in extinction rates could be catastrophic for ecosystem stability in the Amazon because the loss of functional groups may produce a cascade effect of species extinctions.

Keywords Amazonia, Brazil, frugivores, functional group, habitat loss, neotropics, rainforest, species-area relationship.

Species extinctions have been occurring on a large-scale for millions of years, but human intervention in natural ecosystems is accelerating rates of extinction beyond historical background levels (Pimm *et al*., 1995; Jablonski, 2001). As an evolutionary process, extinction, like speciation, is difficult to estimate. For instance, models based on analysis of ecological characteristics can determine which species are prone to extinction (Purvis *et al*., 2000; Ceballos & Ehrlich, 2002), but it is uncertain how many species will be threatened with extinction based on current deforestation rates (Mendoza & Dirzo, 1999; Pimm & Raven, 2000). This is particularly problematic in natural systems with high biological complexity and for which taxonomic and biogeographical knowledge is limited, such as tropical forests, where vast areas of forest have been cleared (Myers *et al*., 2000).

Despite the long-standing discussion about the relationship between species richness and the stability of natural systems (Fonseca & Ganade, 2001; Loreau *et al*., 2001), it is now widely accepted that the maintenance of natural processes is dependent on the conservation of a large number of species and individuals (Myers & Knoll, 2001; Sechrest *et al*., 2002). For this reason, the conservation of large tracts of tropical forest should have two goals: to reduce extinction rates of extant species, and to facilitate the formation of new species. Therefore, the conservation of large natural areas is needed to maintain natural processes and to guarantee the services and benefits provided by nature (Pimm *et al*., 2001; Balmford *et al*., 2002; Ceballos & Ehrlich, 2002).

Recent reports have criticised the mega-infrastructure programme Avança Brasil for its predicted environmental costs (Laurance *et al*., 2000; Carvalho *et al*., 2001; Kohlhepp, 2001; Laurance *et al*., 2001; Peres, 2001). Projects for the Brazilian Amazon include the construction of highways, railroads, pipelines and hydroelectric reservoirs in undisturbed areas (Laurance *et al*., 2001). Some projections have estimated that by 2020 $>40\%$ of the Brazilian Amazon may be deforested, and considerably larger areas degraded, if the programme is implemented, with incalculable loss of biodiversity (Laurance *et al*., 2001).

Here, I address the possible effects of future deforestation on Amazonian mammals using the species-area relationship ($S = cA^z$, where $S =$ number of species, $A =$ area, and c and z are constants). This well-known relationship has been widely used in conservation biology (Rosenzweig 1995, 2003, and references therein). Studies on Brazilian mammals (Grelle *et al*., 1999) and birds (Brooks & Balmford, 1996; Brooks *et al*., 1999), as well as mammals and birds endemic to global biodiversity hotspots (Brooks *et al*., 2002), have successfully used the species-area relationship to describe the effects of deforestation on the vulnerability of these groups to

Carlos Eduardo Viveiros Grelle Laboratório de Zoologia de Vertebrados, Setor de Zoologia, DBAV, IBRAG, UERJ, Av. São Francisco Xavier, 524 Maracanã, 20559-900 – Rio de Janeiro, RJ, Brazil.
E-mail grellece@biologia.ufrj.br

Current address: Laboratório de Vertebrados, Departamento de Ecologia – UFRJ, CP 68020, 21941-590 Rio de Janeiro, RJ, Brazil.

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extinction. The assumption here is that deforestation will commit species to eventual extinction, rather than bring about their immediate extinction. In addition, the species-area relationship can be used to estimate how many species will eventually become extinct due to deforestation (Mendoza & Dirzo, 1999; Pimm & Raven, 2000) and habitat reduction due to climate change (Thomas *et al*., 2004) within a certain time span. My results, as expected, reveal an increase in the number of species that will become extinct or highly threatened by 2020 as a consequence of habitat reduction.

As has already been shown (Pimm *et al*., 1995; Brooks & Balmford, 1996; Brooks *et al*., 1999; Grelle *et al*., 1999; Pimm & Raven, 2000; Brooks *et al*., 2002), if the original area A_0 is reduced to A_n, the number of species S_0 should drop to S_n. Thus, the number of remaining species can be determined by the equation $S_n/S_0 = (A_0/A_n)^z$. The proportion of species predicted to become extinct when there is a reduction in habitat from A_0 to A_n is given by $1-(S_n/S_0)$. I used this equation to simulate how the number of mammals committed to extinction in the Brazilian Amazonian would change under future deforestation scenarios. The most comprehensive species list of mammals for the area was used (Silva *et al*., 2001), with additions from van Roosmalen *et al*. (2002) and Voss *et al*. (2001). In the analysis I used only the 78 endemic species because they are more likely to be affected by habitat reduction than non-restricted species (Pimm *et al*., 1995; Brooks *et al*., 1999; Grelle *et al*., 1999; Brooks *et al*., 2002). In general, information on the ranges of endemic species is better than for non-endemic species, which typically have larger ranges and a lower degree of habitat specificity.

The extent of habitat loss by 2020 in the Brazilian Amazon due to the Avança Brasil programme was based on the predictions of Laurance *et al*. (2001). I considered as habitat loss the projections of deforested or heavily degraded areas in both optimistic and non-optimistic scenarios (Laurance *et al*., 2001) that predict, respectively, 28 and 42% of habitat loss by 2020 for the entire Brazilian Amazon. Estimates of habitat reduction from a detailed, spatially explicit analysis would be desirable, but unfortunately only small-scales studies on historical deforestation (e.g. Alves, 2002) are available. Estimates of habitat loss for the Amazon are approximate and should be used with caution because they may include natural non-forest areas such as Campinarana and Cerrado, mainly in south-eastern Amazonia and Roraima State (Vale, 2002) and it is known that deforestation is also greater in seasonal than in evergreen forest, and near highways (Alves, 2002; Laurance *et al*., 2002).

My assumptions in this analysis were that (1) the deforestation rate will occur randomly from the present to 2020, (2) deforestation will be evenly distributed throughout the Brazilian Amazon, and (3) all endemic mammal species in the Brazilian Amazon may be potentially and equally affected by habitat loss. Simulations were performed with the three *z*-values most commonly found in empirical studies: 0.15, 0.25 and 0.35 (Rosenzweig, 1995). The value of *z* is known to depend on variables such as degree of isolation of the area and vagility of the organism considered (Rosenzweig, 1995).

As expected, both optimistic and non-optimistic predictions of future deforestation increased the extinction of endemic Amazonian mammals, and the highest *z*-value showed the strongest relationship between time and extinction rates in both scenarios (Fig. 1). The non-optimistic simulations predicted a more dire future, with a 3-fold increase in extinction rates at all *z*-values (Fig. 1b). Optimistic scenarios produced a 2-fold increase in extinction rates (Fig. 1a).

Species loss due to deforestation in the Amazon will not be restricted to the endemic mammals. A recent species-specific study of passerine birds throughout the Amazon identified species that would become extinct as an outcome of deforestation due to the Avança Brasil programme (Vale, 2002). The ecological consequences of such species loss to the natural processes in the Amazon are hard to discern.

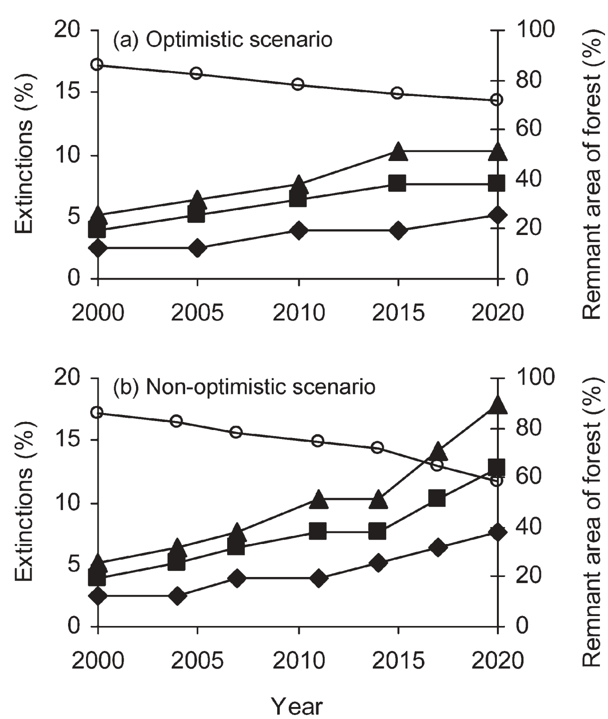

Fig. 1 Predicted extinction of Amazonian mammals in (a) optimistic and (b) non-optimistic scenarios (see text for details) using the species-area relationship ($S = cA^z$). Values of *z* used in the simulations were 0.15 (◆), 0.25 (■), and 0.35 (▲). Circles show forest cover loss by 2020 in the two scenarios (see text for details).

One possible consequence would be the loss of functional groups, causing a cascade of species extinctions. This can be particularly harmful in tropical forests, which are characterized by strong, complex interspecific interactions. For example, about 80% of tropical trees depend on vertebrates for seed dispersal (Gentry, 1982; Howe & Westley, 1997), and the extirpation of birds may terminate dispersal and pollination syndromes, leading many tree populations in forest fragments to die out within a few decades (Silva & Tabarelli, 2000; Cordeiro & Howe, 2003; Martinez-Garza & Howe, 2003). Without dispersal and pollinating agents, many fragments tend to become 'empty forests' (*sensu* Redford, 1992). There is evidence that frugivorous species quickly disappear after deforestation, thus revealing the vulnerability of this functional group (Lovejoy *et al*., 1986; Moegenburg & Levey, 2002). Considering the large number of frugivorous mammals (Fonseca *et al*., 1996) and birds (Sick, 1985) in the Amazon, the extirpation of such species may compromise the future of many Amazonian tree species. About 14% of the Amazon has been deforested to date and the region already harbours many threatened mammals (Grelle *et al*., 1999), mainly frugivorous primates (Fonseca *et al*., 1994). The negative impacts of species loss may be further enhanced by other factors associated with deforestation such as hunting pressure (Peres, 2000) and the spread of invasive species.

The results presented here should be interpreted carefully, as I had to assume random deforestation. When spatially explicit data become available, the scenarios should be rexamined, possibly using non-random patterns of deforestation and species-specific effects of habitat loss. The projected deforestation that will occur if the Avança Brasil programme is implemented will considerably increase the number of threatened Amazonian mammals over the next two decades. The assessment of the species-specific threats of the programme will be paramount to targeting species and areas for protection.

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Biographical sketch

Carlos Eduardo Viveiros Grelle has an interest in the ecology and conservation biology of neotropical mammals, in particular large-scale studies on the distribution of species and the effects of habitat reduction and fragmentation on the persistence of populations.