Toward quantification of the impact of 21st-century deforestation on the extinction risk of terrestrial vertebrates

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Abstract

Conservation actions need to be prioritised, often taking into account species' extinction risk. The International Union for Conservation of Nature (IUCN) Red List provides an accepted objective framework for the assessment of extinction risk, but field data to apply the IUCN Red List criteria are often limited. Information collected through remote sensing can inform these assessments, and forests are perhaps the best-studied habitat type for use in this approach. Using an open-access 30 m resolution map of tree cover and its change between 2000 and 2012, the extent of forest cover and loss within the distributions of 11,186 forest-dependent amphibians, birds and mammals worldwide was assessed. Sixteen species have experienced sufficiently high rates of forest loss to be considered at elevated extinction risk under Red List criterion A, owing to inferred rapid population declines. This number would increase to 23 if data deficient species (i.e., those with insufficient information previously to apply the Red List criteria) were included. Some 484 species (855 if data deficient species are included) may be considered at elevated extinction risk under Red List criterion B2, owing to restricted areas of occupancy resulting from little forest cover remaining within their ranges. This would increase the proportion of species of conservation concern by 32.8% for amphibians, 15.1% for birds and 24.7% for mammals. Central America, the Northern Andes, Madagascar, the Eastern Arc forests in Africa and the islands of South-East Asia are hotspots for these species. The analyses illustrate the utility of satellite imagery for global extinction risk assessment and measurement of progress towards international environmental agreement targets. We highlight areas for which subsequent analyses could be performed on satellite image data in order to improve our knowledge of extinction risk of species.

Introduction

The IUCN Red List categorises species according to their risk of extinction (IUCN 2014). It has become a valuable source of information for the conservation planning process, increasingly helping to focus priorities for conservation funding and action (Rodrigues et al. 2006). The Red List data also underpin the Red List Index (RLI), an indicator of temporal trends in extinction risk (Butchart et al. 2004, 2007). The IUCN Red List uses five criteria with quantitative thresholds to assign species to one of seven hierarchical categories, in increasing order of extinction risk from “least concern” to “extinct”.(IUCN 2014). These criteria are based on rates of population decline (A), distribution size, structure and trends (B), population size, structure and trends (C), absolute population or distribution size (D) and modelled extinction probability (E). Species in the three categories of “critically endangered”, “endangered” and “vulnerable” are collectively referred to as “threatened”. These, and those in the category “near threatened” are referred to as being of conservation concern. The remaining categories are “least concern”, “extinct”, “data deficient” and “not evaluated”. The IUCN Red List system is designed to take into account uncertainty and allows the use of inference where appropriate (Akçakaya et al. 2000; IUCN 2014). For example, if quantitative data on population trends are not available from field surveys, it is acceptable to infer them from rates of habitat loss.

Forests hold the highest levels of species diversity (e.g. Hilton-Taylor et al. 2009), and forest loss (principally driven by agriculture and logging) is considered one of the top threats to biodiversity (Pimm et al. 1995; Bailie et al. 2004). Objective estimates of forest loss can be produced through remote sensing, making it possible to compare rates of loss in time and space from local to global scales (e.g. Achard et al. 2002; Hansen et al. 2010; Hansen et al.

2013). Forest loss data derived from remote sensing have previously been used to inform extinction risk assessment at local to regional scales, with rates of forest loss being used as surrogates for population declines under the Red List criterion A (e.g. Buchanan et al. 2008), and the calculation of area of occupancy under criterion B (Hall et al. 2009). Such approaches have generally been restricted to particular taxa, countries, or regions, because the analyses are computationally intensive and appropriate standardised land cover change datasets have not been available at a global scale. Hansen et al. (2013) produced a global map of tree cover change from 2000 to 2012, mapping tree cover loss and gain from remote sensing data across the entire globe at a 30 m resolution.

Here, we combined remote sensing data on land cover change with species' distribution ranges derived from IUCN Red List polygon maps (IUCN 2014; BirdLife International & NatureServe 2014), for forest-dependent terrestrial vertebrates: amphibians, birds and mammals. This allowed us to infer rates of habitat loss in a standardised way across >11,000 species worldwide. We applied IUCN Red List criteria to these data to identify the number of species potentially qualifying for 'uplisting' to higher categories of extinction risk. This assessment was based on rates of population decline (criterion A), inferred from forest loss, and areas of occupancy (AOO, criterion B2), inferred from remaining forest cover. We used the extent of forest within species' altitudinal limits and geographical range (i.e. Extent of Suitable Habitat, *sensu* Beresford et al. 2011; Buchanan et al. 2011; Rondinini et al. 2011) as a maximum potential value for AOO. We described the geographical distributions of the species that potentially qualify for uplisting and identified areas holding the largest numbers of species threatened by deforestation. Finally we identified areas in which the analysis could be improved in the future to maximise the benefits derived from remote sensing for species conservation status assessments.

Methods

Species data

Species distribution polygons were extracted for forest-dependent amphibians (3540 species; IUCN 2014), birds (6283 species; BirdLife International & NatureServe 2014), and mammals (1363 species; IUCN 2014; Figure1; Supporting Information). These vector polygons delimitated the current known ranges for each species (either within range or not in range). Forest-dependent bird species were defined as those having high dependency or medium dependency (following Buchanan et al. 2008; Bird et al. 2012). Species with high dependency are characteristic of the interior of undisturbed forest; they may persist in secondary forest and forest patches if their particular ecological requirements are met, but breed almost invariably within forest. Species with medium dependency may occur in undisturbed forest but are also found in forest strips, edges and gaps, and typically breed within forest (BirdLife International 2015). For amphibians and mammals, we considered forest specialists to be those that have a high dependency on forests (Rondinini et al. 2011; Ficetola et al. 2015). These species are characteristic of the interior of undisturbed forest; they may persist in secondary forest and forest patches if their particular ecological requirements are met, but breed almost invariably within forest.

We used distribution polygons with presence coded as “extant” or “probably extant”, and origin coded as “native” or “reintroduced”. We extracted data on altitudinal preferences and generation lengths (Schad 2008; Rondinini et al.2011; Pacifici et al. 2013; IUCN 2014; Ficetola et al. 2015; BirdLife International 2015), where generation length is defined as “the average age of parents of the current cohort (i.e. newborn individuals in the population); ”, generation length therefore reflects the turnover rate of breeding individuals in a population (IUCN 2001). Altitudinal limits were not known for 18% of amphibians, 22% of birds and 50 % of mammals, in these cases we used the minimum and maximum values within the species range (Beresford et al. 2011; Rondinini et al. 2011).

Forest cover data

Tree cover data (hereafter `forest cover`) were extracted from the Hansen et al. (2013) Global Forest Change (GFC) map (Figure 1). This 30 m resolution map was derived from Landsat imagery and made available via the Google Earth Engine (GEE; https://earthengine.google.org/). The "treecover2000" layer representsi the percentage forest cover in the year 2000, and the "lossyear" layer, reports for each pixel the year when a deforestation event occurred (i.e. forest loss of sufficient magnitude to be detected as a loss by the Hansen et al. algorithm), in the period 2001-2012.

The GFC map cannot always distinguish between plantations and natural forest (Tropek et al. 2014). Consequently, we excluded known wood fibre plantations, oil palm plantations and logging areas for which data were available from our analyses. These data, obtained through The World Resources Institute (2014), were limited to Cameroon, Canada, Central African Republic, Democratic Republic of the Congo, Equatorial Guinea, Gabon, Indonesia, Liberia, and Republic of the Congo. They covered 3 million km^2. The plantations covered up to c.20% of tree cover in the countries for which they are available, indicating the area of suitable habitat that we estimated for each species might have been inflated resulting in an underestimated extinction risk.

A comparison of the Hansen et al. (2013) global data with a visual assessment study reported that there was a 4% difference in tree cover estimates globally (Achard et al. 2014). However, there was a 22% difference in Africa, with cover estimated through the Hansen et al. algorithm being lower than the visual assessment in this area (Achard et al. 2014). The accuracy depended upon how forest was defined, highlighting the difficulty of comparisons between data (Achard et al 2014), not to mention uncertainty in the accuracy of both classifications.

Analyses

We used a Python 2.7 programming interface. We imported species distribution polygons into Google Earth Engine as raster images. Taking each species in turn, we used the GTOPO30 digital elevation model with a resolution of 30 arc seconds (approximately 900 m at the equator) to remove areas within each species' distribution that fell outside its altitudinal range. The extent of species ranges was further reduced to only those areas considered to be suitable forest habitat in 2000, using the "treecover2000" layer in the GFC map. This was equivalent to an estimate of the Extent of Suitable Habitat (ESH). Forest loss from 2001 till 2012 was obtained by summing the area of all pixels that indicated loss between 2001 and 2012 (from the "lossyear" layer in the GFC map). This calculation assumed that all the original tree cover (from the "treecover2000" layer) within the pixel was lost. For instance, if the pixel's value in the "treecover2000" layer was 70% and it was marked in the "lossyear" layer in 2005, we assumed 70% loss by 2012.

Forest cover remaining in 2012 was calculated as an estimate of maximum possible AOO (actual AOO would be less than this, because species do not occupy their habitat entirely). The accuracy of ESH maps is likely to vary globally, and the limitations and advantages of such types of spatial layers have been highlighted (e.g. Beresford et al. 2011; Rodrigues 2011). As AOO is recommended to be measured at a 2 km × 2 km spatial resolution for Red List assessments (IUCN 2012), the forest cover and loss maps were first rescaled to match this resolution (i.e. we measured total forest cover and loss in each 4 km^2 pixels). This might result in the loss of spatial detail where distributions are well known, while giving a false accuracy for species whose distributions are less well understood. For migratory birds, we assessed forest loss and remaining forest cover within the resident + breeding distribution and separately within the resident + non-breeding distribution, taking the lower value of forest cover as the maximum possible AOO and the higher value of forest loss. Full code is available through GitHub, a web-based code repository hosting service at https://github.com/RSPB/GFCalculator.

IUCN Red List Assessment

Under the IUCN Red List, each species is assessed against all criteria, and is listed at the highest category met under any of them (IUCN 2001). The implication of the forest loss data for each species' IUCN Red List assessment was evaluated by trained assessors from the designated Red List authorities or assessment coordination units for each of the taxa considered. We applied forest loss estimates to Red List criterion A2, which assesses extinction risk based upon population decline over the past three generations or 10 years (whichever whichever time period is longer [i.e. 30 years for a species with generation time of 10 years or 10 years for a species with generation time of 2 years]. This follows IUCN guidance. We assumed that the rate of population change is equal to that of forest loss (i.e. the loss of 15% cover will result in a 15% decrease in the population as 100*[1 – (forest loss $^{(\text{generation length}/12)}$)] . This approach follows the IUCN criteria, and have been used in previous analyses (Bird et al 2011; Buchanan et al. 2008) although the relationship might be non linear for some species (e.g. Bender et al. 1998).

The Red List category near threatened does not have specified thresholds, but following guidelines from IUCN (2012), we assumed that any species with a decline of >25% over 10 years or three generations would qualify as near threatened. We examined all species with forest loss rates close to a category threshold (10% distance from a given threshold), and identified (from documentation in current Red List assessments or from the literature) those for which hunting pressures or other threats are likely to be sufficiently severe for the overall population decline to exceed the relevant category threshold under criterion A2. Thus, a species facing a forest loss rate of 40% in 3 generations would qualify as vulnerable (category threshold: population decline rate ≥30% AND < 50% over ten years or three generations) owing to forest loss alone, but could qualify as endangered (population decline rate ≥50% AND < 80% over ten years or three generations) if additional factors are likely to be driving severe declines (e.g. intense hunting pressure). For many amphibian species, generation length is unknown, and we therefore assessed extinction risk over 10 years, following IUCN (2012). We also applied the maximum possible AOO estimate (inferred from forest cover data for 2012) to IUCN Red List criterion B2, which assesses extinction risk on the basis of restricted AOO.

To qualify as threatened under criterion B2, species must have an AOO estimate falling below a specified areal threshold (10 km^2 for critically endangered, 500 km^2 for endangered, and 2,000 km^2 for vulnerable), and in addition meet two of three subcriteria (a, b, or c). Subcriterion ‘a’ requires the distribution to be ‘severely fragmented’ or restricted to fewer than a specified number of ‘locations’ (IUCN 2012). Subcriterion ‘b’ requires a ‘continuing decline’ in population or distribution, which we assumed to be the case for those species for which our data showed a decline in forest cover during 2000-2012. Subcriterion ‘c’ requires species to be undergoing extreme fluctuations in population size or distribution. We did not consider subcriterion ‘c’ here as we focussed upon forest cover between 2000 and 2012, a timescale that does not allow rapid fluctuations in cover. We assumed that those species with AOO estimates falling below the relevant category threshold and that are also undergoing a decline would also qualify under subcriterion 'a' on fragmentation. This was supported by a positive relationship between forest loss and fragmentation (Supporting Information).

We did not assess the number of species potentially qualifying for 'downlisting' to lower categories of threat. Species may be listed under a particular category as a result of factors other than habitat loss. Similarly, species may have an AOO that is considerably smaller than our maximum estimate owing to highly specific habitat requirements (e.g. caves within forested areas) that we could not map, or owing to extirpations in some areas owing to over-exploitation. Finally, field based assessments of threat may be more accurate than our inferred assessments.

Results

One amphibian species (*Dendropsophus coffees*) from Bolivia appears to qualify for uplisting under criterion A2, moving from least concern to vulnerable. *Ambystoma talpoideum*, (USA) suffered 24% forest loss over 12 years, and may qualify as vulnerable as additional threatening factors (invasive species) are present, potentially contributing to a rapid decline exceeding 30% over ten years (Table 1 and 2). Our analysis indicates that 196 species of amphibians have a smaller maximum AOO value than previously assessed, and as such may qualify for uplisting under criterion B2. This would potentially result in12 species becoming near threatened, 107 vulnerable, 75 endangered and two critically endangered (Table 3). Inclusion of data deficient species would mean the number of species uplisted might increase to seven under criterion A2 and 483 under criterion B2 (Tables 1-3). The distributions of many of these data deficient species are so poorly known that our assessment of forest loss, and maximum AOO may be unreliable. Amphibian species potentially qualifying for uplisting occurred mainly in the Northern Andes, Brazil's Atlantic Forest, Central America, New Guinea, Madagascar and the Eastern Arc forests of East Africa (Figure 2a).

Fourteen bird species qualified for potential uplifting under criterion A2 owing to rates of forest loss alone, with one moving to endangered, three to vulnerable and ten to near threatened (Tables 1 and 2). Seven may qualify as near threatened owing to forest loss in combination with other factors driving moderately rapid declines, while *Rhinoplax vigil* (Malaysia and Indonesia) may qualify for uplisting to endangered from near threatened, given rates of forest loss in combination with intense hunting pressure. A total of 237 species potentially qualified for uplisting under criterion B2 (33 to near threatened, 131 to vulnerable, and 73 to endangered; Table 3). *Columba trocaz* (Madeira, Portugal) was potentially near threatened owing to a combination of forest loss and hunting (A2) but potentially endangered under B2. The species affected occurred mainly in Central America, the Andes and South-East Asia (Figure 2b). An additional two species that are currently data deficient may qualify as vulnerable under criterion B2 (Table 3).

No mammal species qualified for uplisting under criterion A2, while 51 species potentially qualified for uplisting under criterion B2 (eight to near threatened, 24 to vulnerable, 18 to endangered and one to critically endangered; Table 3). These species were concentrated in the Andes and the islands of South-East Asia (Figure 2c). Inclusion of data deficient species results in two additional species potentially qualifying as threatened under criterion A2 (one as vulnerable and one as endangered; Tables 1 and 2), while for criterion B2, there were an additional eight species potentially near threatened, 33 as vulnerable, 39 as endangered and two as critically endangered (Table 3) Our analysis identified about a third of all species that currently qualify as globally threatened under B2, and 41% of those which are of conservation concern., but failed to detect many more species currently qualifying under A2 (Supporting Information).

The potential uplistings, and reclassification of data deficient species would increase the percentage of threatened forest species by 37.9% for amphibians, 22.1% for birds and 26.6% for mammals, compared with the numbers on the 2014 IUCN Red List. Species potentially qualifying for uplisting were concentrated in the Andes, Central America, Madagascar, the Eastern Arc forests of Africa and the islands of South-East Asia (Figure 2d). The increases in the percentages of species considered at elevated conservation concern (i.e. near threatened, vulnerable, endangered, and critically endangered) were 32.8% for amphibians, 15.1% for birds and 24.9% for mammals, including data deficient species. Details of current and potential revised Red List categories for all species are given in Supporting Information.

Discussion

Forest loss between 2000 and 2012 appears to have resulted in the extinction risk of 16 (23 including currently data deficient) species of amphibians, birds and mammals increasing to a sufficient extent to uplist them to a higher extinction risk category on the IUCN Red List (IUCN 2001). Many additional species experienced rapid rates of forest loss that were nevertheless consistent with their current extinction risk category (i.e. loss rates did not exceed the relevant category threshold). Amphibians accounted for 40.5% of the potential uplistings (56.5% if currently data deficient species are included), re-iterating the previously reported importance of habitat loss as a major threat to amphibians (Stuart et al. 2004). Our approach allows estimates of forest loss and cover within forest-dependent species' distributions, and thereby species' Red List categories, to be updated rapidly when new satellite-derived change data become available. It demonstrates the potential benefits from using these data to assess extinction risk in the future, and is a major step to the delivery of a system to assessing the impact of forest loss on species. Annually updated estimates of tree cover and tree cover loss are planned (Hansen et al. 2013), with the first two updates already released (Global Forest Change 2000–2014 Data Download 2015). Knowing the distribution of threatened species and their associated threats could help target allocating resources to areas of particular conservation concern, for example (e.g. hotspots where forest loss has impacted large numbers of threatened species, or locations where forest conservation would benefit help achieving multiple biodiversity targets (Di Marco et al. 2016).

We assumed that those species with AOO estimates falling below the relevant category threshold (under criterion B2) and that are also undergoing a decline would also qualify under subcriterion 'b2a', owing to a restricted number of locations or a severely fragmented distribution. Based on a test on randomly-selected areas, we confirmed a strong relationship between forest loss and forest fragmentation. These results support our experience of carrying out IUCN Red List assessments for these taxa over recent years. However, case-by-case examination of each species through ongoing efforts to reassess the status of all three taxonomic groups will be required.

There are known limitations associated with the Hansen et al. data. Firstly, forest cover may be underestimated in dry forest habitats (Achard et al. 2014). This would not affect our results relating to criterion A2, but could inflate our estimates of the number of species potentially qualifying for uplifting under criterion B2. The underestimate of forest cover was most notable in Africa (Achard et al. 2014). However, uplisted species are concentrated in humid rather than dry regions (Figure 2), with very few species from Africa. Consequently, we suggest that this potential issue did not have a major effect on our results.. Secondly, the Hansen et al. data have been criticised for mapping the cover of all trees, and not just natural forest (Tropek et al. 2014). We attempted to control for this by masking out known plantations, but these data come from only a few parts of the world. Consequently, a significant number of plantations will not have been masked out. Additionally, in some situations, forest might have been degraded or have a structure/composition that is not suitable for all species, especially those that are highly dependent on intact primary forest, especially those that are highly dependent on intact primary forest. Refining our results to account for fine-scale habitat composition is not currently possible from current global satellite data, but could become available in the future. The retention of these areas as suitable habitat in our analysis could have led to an over-estimation of the extent of forest in species ranges and / or an underestimation of forest habitat loss. Therefore, our results likely are conservative; we may have underestimated the number of species potentially qualifying for uplisting under criterion B2. We may have also underestimated the number of species potentially qualifying for uplisting under criterion A2 if natural forest is lost at a faster rate than plantation forest, or natural forest is replaced by plantations. Finally, the map of Hansen et al. (2013) does not cover all areas of the planet, and omits some areas of Oceania. Consequently, the assessment of forest loss and AOO for some species in this area might be incomplete. Expansion of the forest map to cover these areas, or use of other data, could fill these gaps.

The distribution maps that our analyses were based upon represent the best available data, but have some limitations, in particular because they are maps of range boundaries rather than of occupancy. Therefore they are susceptible commission errors. Removal of unsuitable areas of land cover and altitude from these range polygons reduces the commission errors (Beresford et al. 2011), but some will remain. For poorly known species, particularly among amphibians and small mammals and in many tropical regions, they may also underestimate the actual distributional limits (Ficetola et al. 2014), although the converse may also be true in some cases. Assessing the likely accuracy of the distributional information will be an important component of the task of assessing each species potentially qualifying for uplisting before these re-categorisations are implemented on the IUCN Red List. These and other factors will be considered, and expert information and input solicited through ongoing processes coordinated by the relevant IUCN Red List Authority for each group (including BirdLife International for birds and Sapienza University of Rome for mammals). Species distribution maps showing probability of occurrence are becoming available based on point locality datasets (e.g. Jetz et al. 2012). The use of these maps could potentially result in more accurate estimates of occupancy, and consequently more accurate estimates of extinction risk. However, the accuracy of these maps remains unclear, especially for less well-known species and in particular because of the likely high proportion of errors in the underlying point locality datasets.

We have identified a number of ways in which our estimates could be improved. Consequently, we see this as a first step in the process of using global scale land cover and land cover change maps to assess species extinction risks. Species range maps are constantly being refined and updated (e.g. Joppa et al 2015), while spatial resolution of all datasets is increasing. The relationship between loss of land cover and population decline is a complex one, unlikely to be solved with a "one size fit all" approach could also be explored in more detail. The relationship between shape of the function linking land cover change and population change may be non-linear, being convex for some species and concave for others (Bender et al 1998). Furthermore, the size and context of each patch will strongly affect how many individuals it can support, and the shape of the function between population and patch configuration can vary greatly (e.g. Fahrig 2001). In this paper we did not aim at resolving this complex issue, but we rather followed the IUCN guidance on this topic: states "Under criterion A, a reduction in population size may be based on a decline in area of occupancy, extent of occurrence and/or quality of habitat. The assumptions made about the relationship between habitat loss and population reduction have an important effect on the outcome of an assessment….The sensible use of inference and projection is encouraged when estimating population reductions from changes in habitat…In all cases, an understanding of the taxon and its relationship to its habitat, and the threats facing the habitat is central to making the most appropriate assumptions about habitat loss and subsequent population reduction." (IUCN Standards and Petitions Subcommittee 2014). We deliberately restricted our analysis to species that are known to have a high degree of forest dependence and low tolerance for non-forest habitats, and therefore assumed a linear relationship between habitat loss and population decline. Nevertheless, Red List assessors should consider explicitly consider theis validity of this assumption on a case by case basis with respect to in their assessment of our results forthe characteristic of each individual each species.

The IUCN Red List is the primary means of assessing species' extinction risk. However, the effort and expense involved in collecting data for Red List assessments is a burden (Rondinini et al. 2014). Rapid and cheap methods to estimate some of the relevant parameters are needed. The potential role of remote sensing data in this respect has been highlighted (Buchanan et al. 2009; Rose et al. 2015), but not previously demonstrated at the global scale. While the increased availability of data has enabled production of the tree cover and loss map (Hansen et al. 2013), with a spatial resolution that is ideal for mapping land cover change (Mayaux et al. 2008), and a thematic resolution that can be converted directly to 'forest' in the IUCN Habitats Classification Scheme, it is the presentation of these data on an open-access cloud-processing platform that makes them particularly valuable to conservation. It enables the regular recalculation of forest loss by conservationists who no longer have to process and classify images themselves on desktops or central servers.

Our analyses and future annual updates based on updated data will help to improve the accuracy of the IUCN Red List, providing up to date assessments for large numbers of poorly known species. This in turn contributes to improving the Red List Index: an indicator showing aggregated trends in species' extinction risk over time (Butchart et al. 2004, 2007), which is used to track progress toward the CDB's Aichi Targets, UN Sustainable Development Goals, and the strategic objectives of a number of other international agreements (Butchart et al. 2010; Tittensor et al. 2014; Secretariat of the Convention on Biological Diversity 2014; United Nations 2014).

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Supporting Information

The relationship between forest and fragmentation change (Appendix S1), comparison of the agreement between current red list status of birds (2014 assessment) and status proposed from analysis of forest cover data (Appendix S2), and summary of forest cover in 2012, forest loss between 2000 and 2012 and proposed Red List Categories for all species considered in the analysis. (Appendix S3) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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Table 1. Species that potentially qualify for uplisting to a higher Red List category based on forest loss in their ranges between 2000 and 2012. Species for which forest loss in 3 generations or 10 years was <10% lower than a given Red List category threshold, and for which the rate of population decline was inferred to exceed the threshold owing to hunting# or predation by invasive alien species* are annotated next to the species name.

Table 2. Number of forest-dependent species qualifying for uplisting to higher IUCN Red List Categories under criterion A2, based on species listed in Table 1. LC - least concern, NT - near threatened, VU - vulnerable, EN – endangered, CR - critically endangered. Figures in brackets include those species currently listed as data deficient.

Table 3. Number of forest-dependent species qualifying for uplisting to higher IUCN Red List categories under criterion B2. LC - least concern, NT - near threatened, VU - vulnerable, EN – endangered, CR - critically endangered. Figures in brackets include those species currently listed as data deficient.

Table 1. Species that potentially qualify for uplisting to a higher Red List category based on forest loss in their ranges between 2000 and 2012. Species for which forest loss in 3 generations or 10 years was <10% lower than a given Red List category threshold, and for which the rate of population decline was inferred to exceed the threshold owing to hunting# or predation by invasive alien species* are annotated next to the species name.

Class	Species	Current Red List Category	Current Red List Criteria	Potential category under A2	Forest cover 2000 (km^2)	Forest loss 2000 – 2012 (km^2)	Trend period (3 gen. or 10 years)	% forest loss in 3 gen. or 10 years
Amp.	*Bufo wolongensis*	DD		VU	19.4	10	10	46.88
Amp.	*Dendropsophus coffeus*	LC		VU	10.1	4	10	30.26
Amp.	*Eupsophus septentrionalis*	DD		VU	197.2	83	10	36.75

Amp.	*Meristogenys macrophthalmus*	DD		VU	526.6	241	10	40
Amp.	*Ambystoma talpoideum* *	LC		VU	383168.2	56121.5	10	24.21
Amp.	*Atelopus sanjosei*	DD		NT	302.5	53	18	25.25
Amp.	*Rhacophorus gadingensis*	DD		NT	31.9	11	10	28.51
Bird	*Rhinoplax vigil* [#]	NT	A2,3,4	EN	643050.9	78256	19.8	24.59
Bird	*Malurus pulcherrimus*	LC		VU	28011.9	5736	21	33.03
Bird	*Psittacula longicauda*	NT	A2,3,4	VU	410509.2	71411	24.6	32.41

Bird	*Rhabdotor-rhinus corru-gates*	NT	A2,3,4	VU	119211.5	21796	26.1	35.54
Bird	*Bubo suma-tranus*	LC		NT	765808.4	93446	27.9	26.11
Bird	*Columba trocaz* #	LC		NT	17.2	3.52	5.6	20.96
Bird	*Rhaphidura leucopygialis* #	LC		NT	616329.3	88721.8	7.2	21.1
Bird	*Strix chacoen-sis* #	LC		NT	199451.1	24498.8	9.6	22.8
Bird	*Anorrhinus galeritus* #	LC		NT	783758.9	94214.5	9.8	23.83
Bird	*Anthracoceros malayanus* #	LC		NT	293183.2	52919.8	9.2	21.64

Bird	*Micrastur mintoni* #	LC	NT	1536539	126286	8.6	21.85
Bird	*Amazona xan-tholora* #	LC	NT	72538.6	6119.7	12.3	23.91
Bird	*Climacteris rufus* #	LC	NT	37655.7	5222.1	7.1	20.95
Bird	*Macronous ptilosus* #	LC	NT	221215.4	41898.9	3.9	20.21
Mam.	*Petinomys ha-geni*	DD	EN	5.5	4	11.4	67.15
Mam.	*Diomys crum-pi*	DD	VU	5.6	3	10	43.88

Table 2. Number of forest-dependent species qualifying for uplisting to higher IUCN Red List Categories under criterion A2, based on species listed in Table 1. LC - least concern, NT - near threatened, VU - vulnerable, EN – endangered, CR - critically endangered. Figures in brackets include those species currently listed as data deficient.

	Proposed														
	Amphibian					Bird					Mammal				
Current	CR	EN	VU	NT	*Current total*	CR	EN	VU	NT	*Current total*	CR	EN	VU	NT	*Current Total*
CR					*241*					*137*					*86*
EN					*511*					*293*					*192*
VU					*455*					*519*					*1144*
NT					*285*		1	2		*714*					*98*

LC	2		*1350*		1	10	*4592*			*532*
DD	(3)	(2)	*(698)*				*(28)*	(1)	(1)	*(285)*
Up-listed	2(5)	(2)		1	3	10		(1)	(1)	

Table 3. Number of forest-dependent species qualifying for uplisting to higher IUCN Red List categories under criterion B2. LC - least concern, NT - near threatened, VU - vulnerable, EN – endangered, CR - critically endangered. Figures in brackets include those species currently listed as data deficient.

						Proposed									
	Amphibian					Bird					Mammal				
Current	CR	EN	VU	NT	*Current total*	CR	EN	VU	NT	*Current total*	CR	EN	VU	NT	*Current total*

CR					*241*				*137*					*86*
EN	1				*511*				*293*	1				*192*
VU		41			*455*	18			*519*		11			*170*
NT		17	44		*285*	22	62		*714*		2	7		*98*
LC	1	17	63	12	*1350*	33	69	33	*4592*		5	17	8	*532*
DD	(2)	(149)	(117)	(19)	*(698)*		(2)		*(28)*	(2)	(39)	(33)	(8)	*(285)*
Up-listed	2(4)	75(224)	107(224)	12(31)		73	131(133)	33		1(3)	18(57)	24(57)	8(16)	

Figure 1. Bivariate plots showing richness (number) of forest species and percent loss of forest during 2000-2012. Both axes are divided into quintiles.

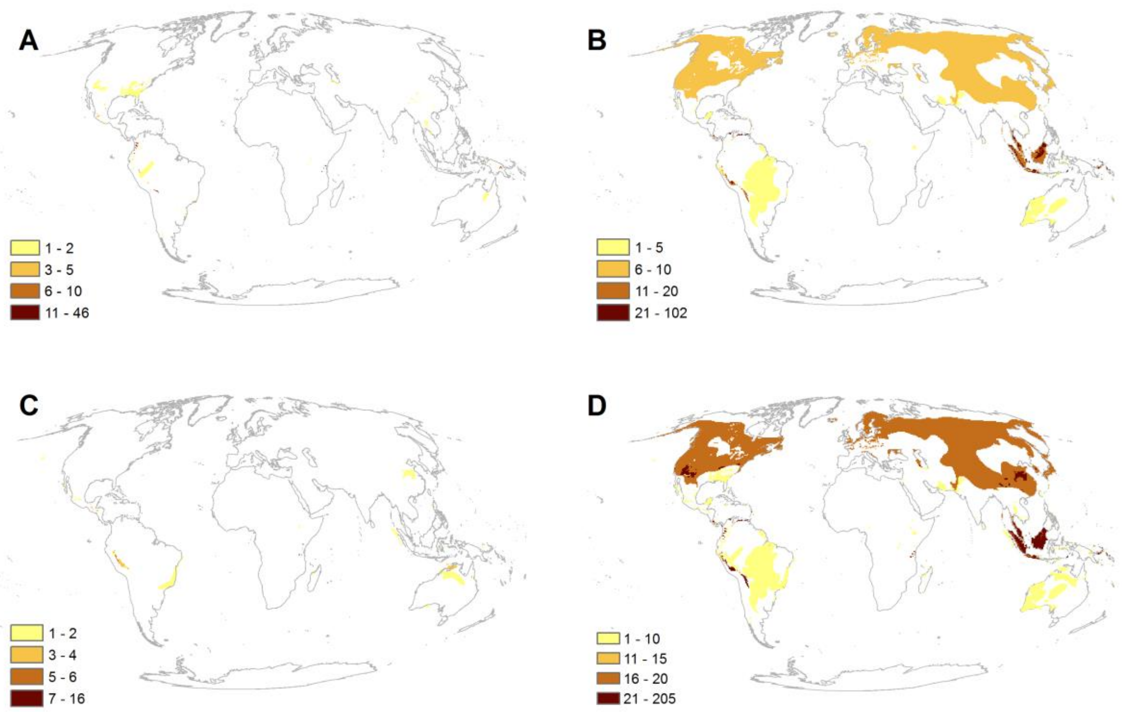

Figure 2. The number of species potentially qualifying for uplisting to higher categories of extinction risk on the IUCN Red List. Species currently qualifying as data deficient are excluded. (A) amphibians, (B) birds, (C) mammals and (D) all species combined.