Research

The changing fates of the world's mammals

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A recent complete assessment of the conservation status of 5487 mammal species demonstrated that at least one-fifth are at risk of extinction in the wild. We retrospectively identified genuine changes in extinction risk for mammals between 1996 and 2008 to calculate changes in the International Union for Conservation of Nature (IUCN) Red List Index (RLI). Species-level trends in the conservation status of mammalian diversity reveal that extinction risk in large-bodied species is increasing, and that the rate of deterioration has been most accelerated in the Indomalayan and Australasian realms. Expanding agriculture and hunting have been the main drivers of increased extinction risk in mammals. Site-based protection and management, legislation, and captive-breeding and reintroduction programmes have led to improvements in 24 species. We contextualize these changes, and explain why both deteriorations and improvements may be under-reported. Although this study highlights where conservation actions are leading to improvements, it fails to account for instances where conservation has prevented further deteriorations in the status of the world's mammals. The continued utility of the RLI is dependent on sustained investment to ensure repeated assessments of mammals over time and to facilitate future calculations of the RLI and measurement against global targets.

Keywords: IUCN Red List; extinction risk; threat category; conservation status; biodiversity indicators; conservation action

1. INTRODUCTION

Mammals are a highly versatile group. The most recent taxonomic treatise recognizes 5339 recently extant valid species ([1]; with an additional 82 *sensu* [2]) that have colonized all of the Earth's major habitats, except for the ice massifs in the Arctic and the Antarctic, and display great topographic and bathymetric plasticity, being absent only from the great ocean depths and the highest mountain peaks. The vast majority (98%) of species occupies terrestrial habitats, but some are dependent on freshwater (3%) and marine (2%) systems. They range in size from the

largest mammal to have ever lived, the Blue Whale *Balaenoptera musculus*, to the smallest, Kitti's Hog-nosed Bat *Craseonycteris thonglongyai*, also known as the Bumble-bee Bat, from Thailand and Myanmar. Mammals are widely recognized as playing a key role in numerous ecological functions, including predation [3], grazing [4] and seed dispersal [5], and provide important human benefits such as food [6], recreation [7] and income [8]. Indeed, arguably because they include many charismatic species, mammals have been important flagships for conservation efforts [9].

Notwithstanding their iconic appeal, the overall conservation status of the world's mammals is precarious. Mammalian diversity and abundance have been rapidly depleted in the face of threats such as habitat loss (due mainly to expanding agriculture and logging) and over-exploitation, nowhere more so than in Southeast Asia

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[10,11], where the populations of many large mammal species number less than 100 individuals (and some, such as Kouprey *Bos sauveli*, may already be extinct). The prevalence of certain threats, such as hunting, compounded by the ecological traits of some species (large body size; low density; large home range size; migratory or nomadic movements), means declines are taking place even in protected areas [12,13] and within the great expanses of tropical wilderness [14,15]. Consequently, many mammals have current ranges dramatically reduced from their historical extent [16–18]. For some, the loss has been complete with some 255 species of mammals documented to have gone extinct in the last 10 000 years [19], of which one-third have taken place in the last 500 years [20]. This puts current extinction rates for mammals far higher than the average background extinction rate (1.8 extinctions/million species years) [21].

Here, we describe and demonstrate application of the Red List Index (RLI) to mammals based on retrospective determinations of genuine change. We describe large-scale trends in mammal extinction risk, providing examples of genuine deteriorations and improvements. We also address potential shortcomings or limitations in application of the RLI, and finally preliminarily assess the role of conservation in ameliorating extinction risk in mammals.

2. MAMMALS ON THE IUCN RED LIST
In 1966, the International Union for Conservation of Nature (IUCN) published the Mammal Red Data Book [22], the first volume in what has grown to become the *IUCN Red List of Threatened Species*—the most authoritative reference on the global conservation status of species [23]. The compilation grew out of earlier works published in the 1940s by the American Committee for International Wildlife Protection (now the American Committee for International Conservation), specifically 'Extinct and Vanishing Mammals of the Western Hemisphere' [24] and 'Extinct and Vanishing Mammals of the Old World' [25]. In 1982, portions of Simon [22] were revised in a volume covering some 155 species from the Americas and Australasia [26], but it was not until 1996 that the first global assessment of every known mammal species was completed. At the time, 24 per cent of the world's mammals were documented as threatened (i.e. species listed as Critically Endangered, Endangered and Vulnerable), and 86 species were listed as Extinct [27].

Although the 1996 assessment was a remarkable feat, it provided little supporting data to justify individual species assessments. Furthermore, a new system of categories and criteria was introduced in 2001 [28]. Consequently, in 2004, following a successful initiative to completely assess extinction risk in the world's amphibians [29], IUCN embarked on an ambitious endeavour to reassess the conservation status of the world's mammals. This included collecting a comprehensive suite of documentation to underpin the assessments. This 4 year-long study, which involved the input of more than 1700 experts and covered 5487 species of mammals known at the time (to December 2007), revised the estimate of mammal species threatened down from

24 to 21 per cent [20]. However, this apparent overall 'improvement' in the global conservation status of the world's mammals in the 12 years between 1996 and 2008 was not a genuine one.

3. THE IUCN RED LIST INDEX
A common misuse of the Red List, particularly for monitoring and evaluation purposes, involves directly comparing summary or individual Red List results for one year with those of another [30,31] by mistakenly assuming that a change in Red List category necessarily corresponds to a genuine change in the conservation status. For example, Schipper *et al.* [20] documented 76 mammals as Extinct, 10 fewer than the 86 species in the 1996 assessment. Some of these discrepancies result from changes in accepted taxonomy, as with the Quagga, regarded in 1996 as a distinct species, and now commonly considered an extinct subspecies of the widespread Plains Zebra, *Equus quagga*. Other changes have resulted from improvements in extinction dating, changes in the cut-off date for recent extinctions on the Red List (from AD 1600 to AD 1500), and the 'Lazarus' effect, whereby a species is prematurely declared to be extinct and subsequently proven extant [32].

Overall, even if species assessments are done using the best available knowledge, species may undergo non-genuine changes in categories across assessment periods for several reasons, including: criteria revision; improved knowledge (e.g. better estimates for population size, range size or rate of decline); changes in taxonomy; previously incorrect application of the criteria; or changes in the IUCN guidelines for applying the criteria (e.g. how to deal with risk and uncertainty).

The IUCN RLI has been developed as an aggregated measure of extinction risk to indicate trends in the status of biodiversity. The RLI is calculated from the change in IUCN Red List categories of all assessed species in a taxon over time [33–35]. To avoid introducing errors owing to non-genuine changes in categories discussed above, the RLI only considers genuine deteriorations (i.e. when a threat drives a species from a lower to a higher category of threat) or genuine improvements (typically, when threat mitigation leads to a change from a higher to a lower category of threat) in conservation status. Species moving categories for non-genuine reasons such as those outlined above are not considered. The RLI has been used to report against the Convention on Biological Diversity 2010 target [36,37] and is an adopted indicator to measure progress towards Target 7b under Millennium Development Goal 7 by providing the information required for indicator 7.7 (i.e. 'proportion of species threatened with extinction').

4. RETROSPECTIVELY IDENTIFYING GENUINE CHANGES
To calculate trends in the RLI for a taxon, all species in a group must have been assessed for the IUCN Red List at least twice. As the RLI is a relatively coarse measure of extinction risk (as a consequence of the broad nature of Red List categories), changes in the RLI may only be manifested over multi-year time-frames. For species

groups currently assessed, this means waiting several years (typically a minimum of four) before undertaking a reassessment for a trend to be recorded. However, an interim approach, where data are sufficient, involves retrospectively assigning or 'back-casting' categories of extinction risk to species at a previous point in time using currently available information and taxonomy (and consistent with the current IUCN Categories and Criteria), and referring to previously published information. In reality, such retrospection is integral to the RLI methodology. For example, a species may not change its published Red List category over time, but if new information indicates it would have qualified for a different category than assigned in an earlier assessment, then the retrospectively adjusted category change needs to be incorporated to calculate the RLI.

Retrospective assessments were also employed on amphibians to estimate trends in extinction risk between 1980 and 2004 [29], and on reef-building corals from 1996 to 2008 [38]. This approach requires the availability of adequate information in order to be confident of correctly identifying all genuine changes in conservation status since the earlier time-point. Such data are often lacking for less well-known groups. Hence, despite expanding coverage of the IUCN Red List to include all species within an increasing suite of taxa, including freshwater crabs [39] and odonates [40], there have been few attempts to use this approach for producing RLIs in these taxonomic groups.

We retrospectively identified genuine changes in extinction risk of the world's mammals between 1996 (when all species were first completely assessed) and 2008 (when they were reassessed). The default 1996 category was assumed to be the same as 2008 unless there was adequate evidence of a change, which means the RLI is conservative (i.e. likely to underestimate rates of change, because it is more likely that we failed to detect genuine deteriorations in status than genuine improvements). Adequate evidence of a change typically includes data or information on the exacerbation or emergence of a threatening process, such as accelerating habitat loss (e.g. [10]), outbreak of disease (e.g. [41]), the introduction of alien invasive predators (e.g. [42]) or data and information on conservation successes.

In effect, we retrospectively 'corrected' the original 1996 categories. In general, three types of reconciliation between 1996 and 2008 were required: (i) species whose 1996 assessments were considered inappropriate, based on current available evidence; (ii) species described post-1996, that needed to be retrospectively assessed; and (iii) species undergoing taxonomic change subsequent to 1996 necessitating correction of former assessments.

As an example of the first type, the Greater Red Musk Shrew *Crocidura flavescens* from southern Africa was classified as Vulnerable in 1996 and as Least Concern in 2008. However, the 1996 determination was considered erroneous (perhaps owing to incorrect application of the criteria), as there is no basis to suggest that the species was anything other than Least Concern also in 1996. Indeed, given the knowledge on the size of the species' range ($>20\,000\,\text{km}^2$) and population size ($>10\,000$ mature individuals), the only Red List criterion under which the species could have been listed as either

Threatened or Near Threatened back in 1996 was under the A criterion (population decline), and there is no adequate evidence that any threatening process was operating at a level that would have resulted in a decline of 30 per cent (or otherwise approximating 30%) over a 10-year time-frame. The species was thus considered Least Concern in both time-periods for purposes of the RLI calculation. In all cases such as these where changes were non-genuine, the reason for change was coded according to whether it was owing to criteria revision, knowledge, taxonomy, a mistake or some other reason.

The rate of new species descriptions continues unabated [2,43] with no fewer than 300 species described in the years between 1996 and end-2007. In the case of new species described since 1996, the same general rule was applied: 1996 categories were presumed to be the same as those in 2008 unless there was evidence of change. Thus, Jenkins' Shrew Tenrec *Microgale jenkinsae*, described in 2004 from the Mikea Forest in southwestern Madagascar [44], was assessed as Endangered in 2008 and retrospectively also in 1996.

The most difficult reconciliations involved some species that have been subject to taxonomic changes. The Clouded Leopard *Neofelis nebulosa*, for example, was considered a single species (classified as Vulnerable in 1996) until a taxonomic revision resolved the species into two: *N. nebulosa* from mainland Southeast Asia, and *Neofelis diardi* from Borneo and Sumatra [45,46]. This necessitated the reassessment of *N. nebulosa* in both time-periods to account for its new circumscription, as well as new assessments for *N. diardi*. In this case, both species were considered Vulnerable in 1996 and 2008 on the basis of their small and declining population sizes.

5. TRENDS IN MAMMALIAN EXTINCTION RISK

A comparison of Red List categories for mammals in 2008 with those retrospectively assigned in 1996 revealed that the percentage of mammals threatened with extinction in 1996 was not 24 per cent (as published by Baillie & Groombridge [27]), but actually 19.7 per cent (table 1). In other words, what at first appeared to be an overall improvement in the status of the world's mammals is shown to be an overall deterioration. Using the revised RLI methodology [35], the change in the RLI for mammals between 1996 (using the corrected categories) and 2008 has been calculated at −0.8 per cent, equivalent to the net deterioration of 156 species by at least one category over the time-period [47]. The proportion of mammals listed as Data Deficient in 2008 is 15 per cent, and with better information (and, in some cases, a less evidentiary approach to listing) many of these may well prove to be threatened and to have undergone serious declines through this period.

An important aspect of the RLI is that it can be disaggregated according to geography, taxonomy and ecology to show trends at finer scales [33,34]. Disaggregated by biogeographic realm (following the classification of Olson *et al.* [48]), the RLI shows that the rate of deterioration has been most severe in the Indomalayan (−2.0%) and Australasian (−1.4%) realms (figure 1). These accelerating losses reflect the aforementioned impacts of hunting and habitat loss in the former, and
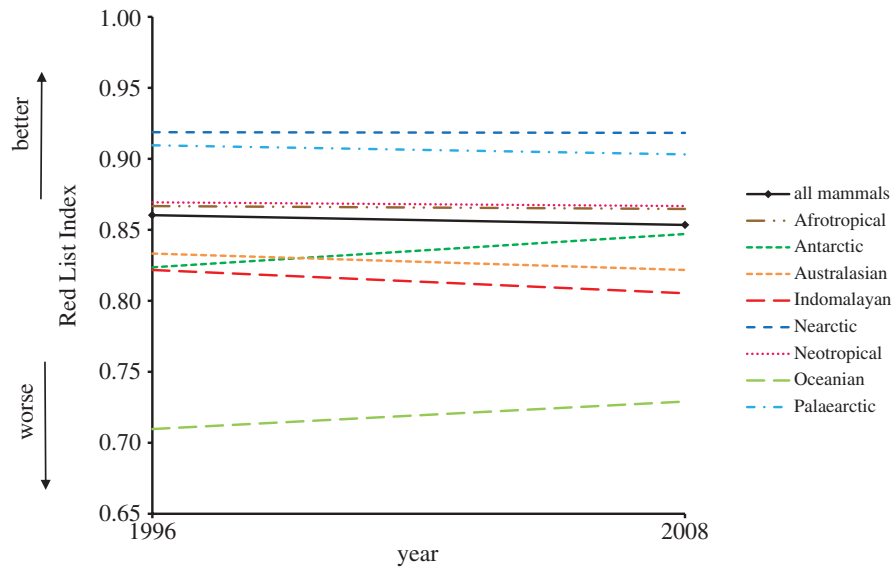
Figure 1. Red List Indices for mammals during 1996–2008 in different biogeographic realms (*sensu* [48]). An RLI value of 1 equates to all species being Least Concern; an RLI value of 0 equates to all species being Extinct. Improvements in species conservation status lead to increases in the RLI; deteriorations lead to declines. A downward trend in the RLI value means that the net expected rate of species extinctions is increasing. Sample sizes: all mammals = 195 genuine status changes/ 4556 non-Data Deficient species (excluding EX and PE in 1996); Afrotropical = 19/1044; Antarctic = 3/17; Australasian = 52/619; Indomalayan = 72/823; Neotropical = 26/1333; Nearctic = 11/470; Oceanian = 4/31; and Palaearctic = 36/776. See Butchart *et al.* [33] for the methodology on disaggregating the RLI.

Table 1. Comparison between IUCN Red List assessments for mammals between 1996 and 2008 showing, in 1996, absolute numbers of species per IUCN Red List category at the time (*sensu* [27]) and absolute number of species according to 'corrected' Red List categories. EX, Extinct; EW, Extinct in the Wild; CR(PE), Critically Endangered (Possibly Extinct); CR, Critically Endangered; EN, Endangered; VU, Vulnerable; NT, Near Threatened; LC, Least Concern; DD, Data Deficient. Proportion of species threatened calculated as all threatened species (CR + EN + VU), including CR(PE), divided by all species (including DD).

	assessment year					
	1996		1996		2008	
	[27]		[47]; this paper		[47]; this paper	
	original[a]		corrected			
RL category	no.	%	no.	%	no.	%
EX	86	1.8	76	1.4	76	1.4
EW	3	0.1	3	0.1	2	0.0
CR(PE)[b]	—	—	21	0.4	24	0.4
CR	169	3.6	138	2.5	164	3.0
EN	315	6.8	435	7.9	449	8.2
VU	612	13.2	485	8.8	492	9.0
NT	598	12.9	340	6.2	326	5.9
LC	2657	57.2	3155	57.5	3120	56.9
DD	209	4.5	834	15.2	834	15.2
Total	4649		5487		5487	
threatened	1096	23.6	1079	19.7	1129	20.6

[a]1996 'original' categories included species listed as LR:cd (here assigned to LC).
[b]The CR(PE) flag was introduced only in 2006.

the contribution of invasive species in the latter [49]. In contrast, trends towards decreasing risk of extinction in the species-poor Antarctic (+2.9%) and Oceania (+2.7%) realms are mainly owing to the improving conservation status of two species with cosmopolitan distributions, Humpback Whale *Megaptera novaeangliae* and Blue Whale *Balaenoptera musculus*, and the Samoan Flying Fox *Pteropus samoensis*. Disaggregation of the RLI for mammals by system has shown that the rate of deterioration has also been more marked among aquatic than among terrestrial species [47], while mammals in developing regions are more threatened and deteriorating at a much faster rate than mammals in developed regions [50].

Previous studies have predicted that the risk of extinction is greater than expected for large-bodied mammals [51]. We disaggregated the RLI according to body size by determining the average weight of all species in each mammalian order and then assigning all species in each order to one of four body-class sizes based on this average weight: <1 kg; 1–10 kg; 10–100 kg; and >100 kg. We found that not only does overall conservation status decrease dramatically with each order of magnitude increase in body size, but indeed extinction risk in these classes is increasing over time (figure 2). Mammalian orders including species with an average body size greater than 100 kg—specifically, Perissodactyla (rhinoceroses, equids and tapirs), Proboscidea (elephants) and Sirenia (dugong and manatees)—are not only markedly more threatened than orders in other body size classes (as indicated by their lower RLI value), but collectively have also undergone the steepest deterioration (−3.5%; compared with: −2.2% in class 10–100 kg; −2.0% in class 1–10 kg; −0.4% in class <1 kg).
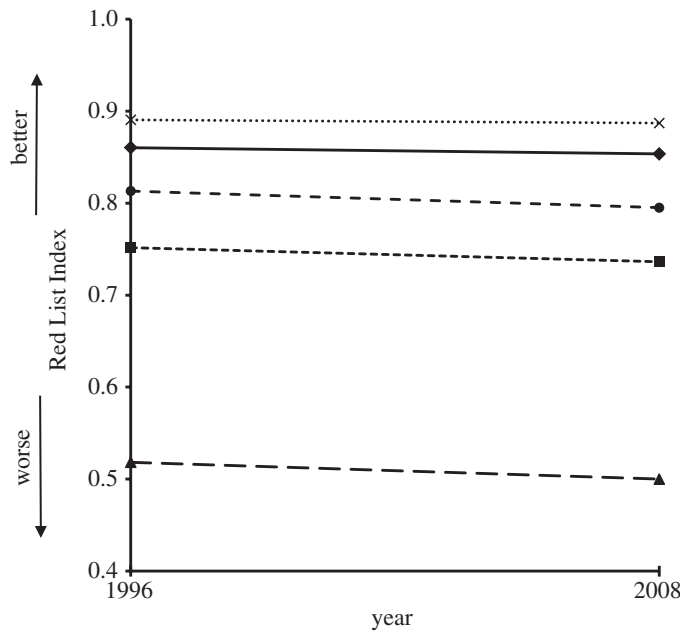
Figure 2. Red List Indices for mammals during 1996–2008 in different body mass classes. Sample sizes: 0–1 kg = 73 genuine status changes/3374 non-Data Deficient species (excluding EX and PE in 1996; dotted line with cross); 1–10 kg = 57/639 (dashed line with square); 10–100 kg = 60/521 (dashed line with circle); more than 100 kg = 5/22 (dashed line with triangle); and all mammals (solid line with diamond).
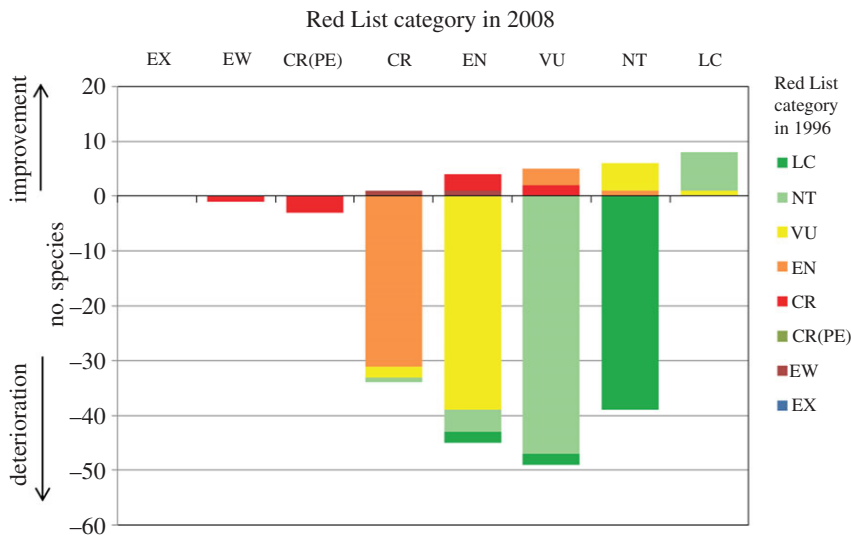

Figure 3. Number of mammal species changing IUCN Red List categories between 1996 and 2008. EX, Extinct; EW, Extinct in the Wild; CR(PE), Critically Endangered (Possibly Extinct); CR, Critically Endangered; EN, Endangered; VU, Vulnerable; NT, Near Threatened; LC, Least Concern. Species undergoing an improvement (i.e. moving from a higher to a lower category of threat) appear above the line; species deteriorating in status (i.e. moving from a lower to a higher category of threat) appear below the line. Species changing categories for non-genuine reasons (improved knowledge, taxonomy) are excluded.

6. DETERIORATIONS

Deteriorations were documented conservatively for 171 species of mammals in the period 1996–2008 (see table S6 in Hoffmann *et al.* [47]). Most (160/171) deteriorations occurred between adjacent categories of threat (figure 3). There may be an order of magnitude difference between the criterion thresholds of adjacent categories. For example, a species listed as Critically Endangered under criterion B1 may have a range size 1/50th the size of a species listed as Endangered under the same criterion [28]. Consequently, even single-category changes can correspond to substantial increases in extinction risk. Thus, one small step

up the Red List hierarchy is one giant leap towards extinction. Deteriorations involved two category steps in eight species and three steps in three species (figure 3).

The rate of change in species like the Tasmanian Devil *Sarcophilus harrisii*, Woodlark Cuscus *Phalanger lullulae* from Papua New Guinea and the Woylie *Bettongia penicillata* from Australia, all of which deteriorated three categories in the 12-year period from 1996 to 2008, puts these species on course to rival some of the most rapidly documented extinctions to have occurred in the last 500 years. Steller's Sea Cow *Hydrodamalis gigas* was hunted to extinction within 27 years of its official discovery in
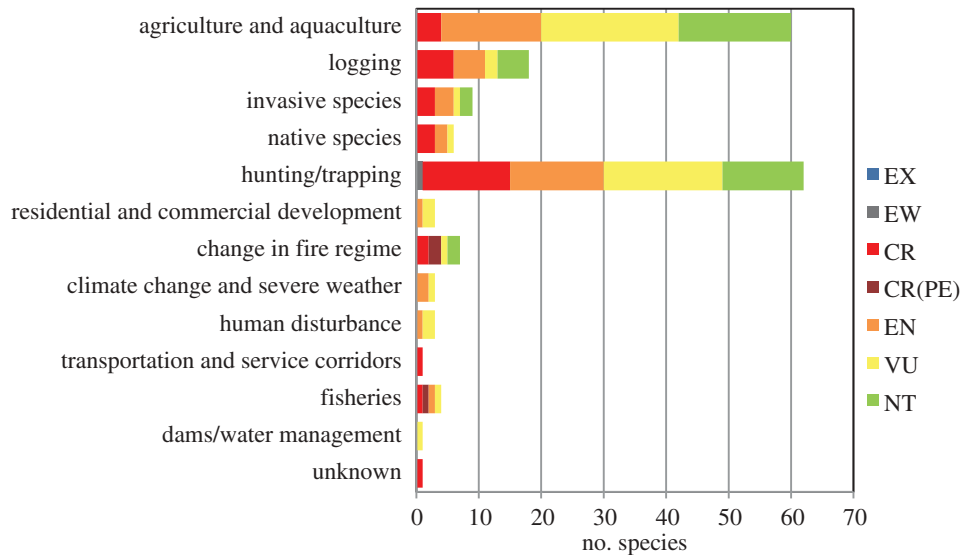
Figure 4. The main drivers for deteriorating mammal species (1996–2008) coded according to the Red List category of the species in 2008. EX, Extinct; EW, Extinct in the Wild; CR(PE), Critically Endangered (Possibly Extinct); CR, Critically Endangered; EN, Endangered; VU, Vulnerable; NT, Near Threatened.

1741, when the species was confined largely to the Bering Sea and numbered perhaps 1500–2000 individuals [52]. Two endemic rats of Christmas Island, Maclear's Rat *Rattus macleari* and the Bulldog Rat *R. nativitatis*, were described as numerous or even 'abundant' when first collected in 1887, but are thought to have become extinct by 1908, within a quarter-century of discovery [53].

Although no mammal species was recorded as having gone extinct between 1996 and 2008, three species were flagged as 'Possibly Extinct'. These flags are applied to Critically Endangered species that are likely to be (but not confirmed as being) already extinct [54,55], and hence for RLI purposes are regarded as a step-wise change from Critically Endangered [33]. The most famous of these is the Baiji or Yangtze River Dolphin *Lipotes vexillifer* for which the last authenticated records date back to a stranded pregnant female found in 2001 and a live animal photographed in 2002. Extensive subsequent survey work has failed to record any individuals [56]. The second Possibly Extinct species is the Telefomin Cuscus *Phalanger matanim* from Papua New Guinea: its only known location was destroyed by fire in 1998, although it is possible that it may persist in an adjacent under-surveyed area. Finally, the Central Rock Rat *Zyzomys pedunculatus* had disappeared in 2002 following drought and wildfire. However, it was recently (mid-2010) rediscovered and consequently the Possibly Extinct flag will be removed from future iterations of the mammal RLI.

For each species that underwent a genuine change in IUCN Red List category, we recorded the primary driver (using the classification scheme developed by Salafsky *et al.* [57]) of the change in category (the main threat for deteriorating species, or threats mitigated by conservation actions in the case of improving species). Primary drivers are those causing greater than or equal to 50 per cent of the change. Overwhelmingly, expanding agriculture and hunting have been the main drivers of increased extinction risk in mammals (figure 4).

Hunting has been the primary driver of deterioration in 62 species of mammal and drives a high proportion of

these changes to the highest threatened category 40 per cent of deteriorating species currently listed as Critically Endangered are impacted by hunting, compared with only 11 per cent affected by agriculture. For example, the Saiga *Saiga tatarica*, an antelope inhabiting the steppes and semi-desert regions in Russia, Kazakhstan, Uzbekistan and Western Mongolia, deteriorated from Vulnerable in 1996 to Critically Endangered in 2008. This followed a greater than 95 per cent decline in population size from approximately one million in the early 1990s to an estimated 50 000 by 2008, primarily owing to poaching [58], concomitant with the dissolution of the Soviet Union.

Habitat loss, owing to expanding agriculture and logging, has been primarily responsible for the deterioration of 78 species of mammal. As noted already, these deteriorations have been particularly evident among species in Southeast Asia due, in particular, to commercial logging (e.g. three species in the genus *Solomys* in Papua New Guinea and the Solomon Islands) and agricultural conversion of land to rice paddies, coffee, oil palm and other crops.

Disease can be a major driver of population declines in mammals; for instance, mortality in Lowland Gorillas *Gorilla gorilla* owing to Ebola (exceeding 90% in some areas; [59]) precipitated a change in category from Endangered to Critically Endangered [60]. Disease has also emerged as a novel catalyst of rapid deteriorations in status for some species. The Tasmanian Devil experienced local population declines of up to 89 per cent following the emergence of devil facial tumour disease, an infectious cancer that first appeared in 1996 [41]. Listed as Least Concern in 1996, the Tasmanian Devil qualified for listing as Endangered in 2008 [60]. Similar rapid declines have been observed in other taxa, particularly amphibians where the emergence of the pathogenic chytrid fungus *Batrachochytrium dendrobatadis* [61,62] is the likely driver of the deteriorations of 40 amphibians by at least three IUCN Red List categories between 1980 and 2004 [29,47].
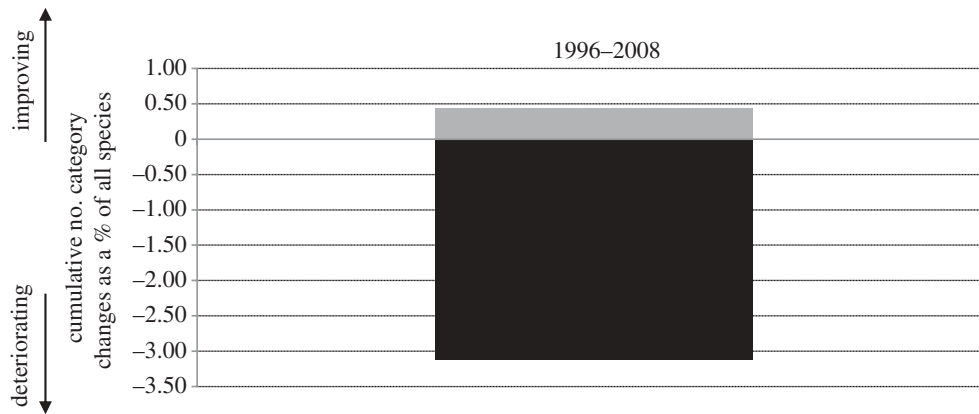
Figure 5. Cumulative proportion of species undergoing Red List category changes. Non-Data Deficient extant species at start of the period ($n = 4556$).
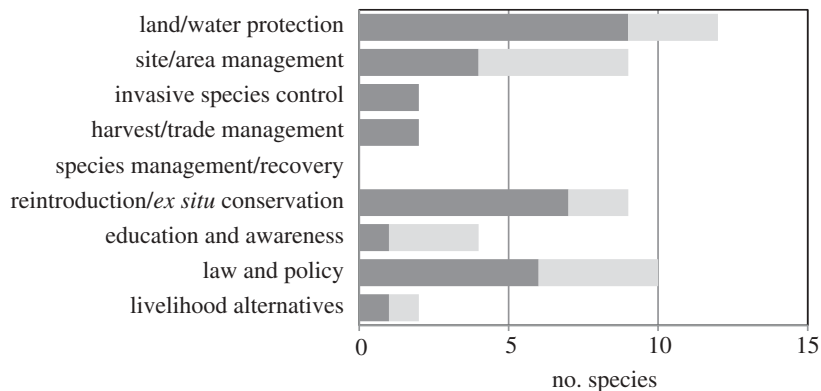

Figure 6. Conservation actions implemented that led to improvements in IUCN Red List Status for mammals (figure reproduced from Hoffmann *et al.* [47], with permission from *AAAS/Science*). Dark grey, major conservation actions; light grey, minor conservation actions.

7. IMPROVEMENTS

We identified only 24 species of mammals that improved in conservation status. In other words, approximately one species of mammal improved in status for every seven that deteriorated (figure 5). Nevertheless, the impacts of conservation are noticeable—not only can we prevent extinctions but we can engineer recoveries. Five species improved by two categories, of which the flagship conservation recovery story is the return of the Black-footed Ferret *Mustela nigripes* to the wild, which by the late-1980s survived only in captive-breeding programmes. Since 1991, more than 3000 individuals have been reintroduced into the wild to 18 sites in the Western USA, one site in Mexico and one site in Canada [63–65]. The overall population size is large enough to warrant listing as Endangered, an improvement of two categories from its status as Extinct in the Wild in 1996.

For improving species, we recorded details of the conservation actions that played major and minor roles in recoveries (using the conservation actions schema developed by Salafsky *et al.* [57]). Improvements have come about mainly through a combination of area-based protection and management, legislation, and captive-breeding and reintroduction programmes (figure 6). The largest number of species has improved through site-based protection, including Przewalski's Horse *Equus ferus* and Gray Myotis *Myotis grisescens* (the latter largely owing to strict protection of cave-roosting sites). Several species confined to the Wet Tropics of northeastern Australia, including the Daintree River

Ringtail Possum *Pseudochirulus cinereus*, Herbert River Ringtail Possum *P. herbertensis* and Lumholtz's Tree Kangaroo *Dendrolagus lumholtzi*, have benefited from the designation of the area as a World Heritage Site, and subsequently the establishment of the Wet Tropics World Heritage Protection and Management Act of 1993 and the 1998 Wet Tropics Management Plan, which regulates land use activities in the World Heritage Area through a zoning and permit system. In another example, the Greater One-horned Rhinoceros *Rhinoceros unicornis* has, like its counterpart in southern Africa, recovered mainly owing to strict protection from Indian and Nepalese wildlife authorities from a total population of fewer than 200 in the early 1900s to more than 2500 individuals today [66]. However, with more than 70 per cent of the global population in just one protected area—Kaziranga National Park—the need for sustained management and protection is evident, especially given the evidence of recent increases in poaching within the protected area [67].

Captive-breeding and reintroduction programmes are largely responsible for the recovery of icons such as the European Bison *Bison bonasus*, Przewalski's Horse, Golden Lion Tamarin *Leontopithecus rosalia* and the Black-footed Ferret. The European Bison, Europe's largest land mammal and last surviving large grazer, was Extinct in the Wild after the First World War. A few animals survived in zoos and systematic breeding was quickly initiated. Starting in the 1950s, European Bison were reintroduced in several areas of Central and Eastern

Europe. Today, wild bison number about 2500 animals, occurring in about 35 herds [68]. Similarly, Przewalski's Horse of Central Asia was Extinct in the Wild in the late 1960s. Reintroductions began in the 1990s and animals have since been introduced within and outside their former Mongolian range [69]. This makes Przewalski's Horse the second Extinct in the Wild mammal after the Black-footed Ferret to be reintroduced successfully in the 1996–2008 time-period, and only the fourth in the history of conservation (in addition to European Bison and Arabian Oryx *Oryx leucoryx*). Meanwhile, populations of the Golden Lion Tamarin in Brazil have been augmented with captive-bred animals and have dramatically improved the status of this species *in situ* [70].

Legislation is almost single-handedly responsible for the improvements of Humpback Whale. Humpbacks have been protected from commercial harvesting in the North Atlantic by the International Whaling Commission since 1955, in the Southern Hemisphere since 1963 (although spatial and temporal regulation of catches in the Antarctic occurred prior to this) and in the North Pacific since 1966. Despite having been severely depleted to a world population in the low thousands, Humpbacks have recovered to an estimated global population exceeding 60 000 and increasing [71]. Several populations remain small and without a detected increase (such as the population in the Arabian Sea), but the species no longer meets any criteria for listing in a threatened category. International legislation also seems to have benefitted the Samoan Flying Fox. Populations underwent drastic declines in the 1980s, owing to commercial hunting that supplied fruit bats as a luxury food item in Guam and the Northern Marianas. The species was listed on appendix A of the Convention on Trade in International Fauna and Flora (CITES) in 1990, and since that time the conservation status of the species appears to have stabilized, although hunting of bats for the domestic market remains a concern [72].

8. INTERPRETING THE RED LIST INDEX FOR MAMMALS

Although the RLI serves as an important tool for monitoring the changing extinction risk of species over time, there are some important considerations that should be borne in mind. The 171 species that underwent genuine deteriorations represent only 3 per cent of total mammalian diversity in terms of species, and so it could be construed that the world's mammals are not doing too badly. However, as noted earlier, the RLI is a relatively coarse measure of change and does not measure reductions taking place among slowly declining species. In this regard, it is complemented by the population-based Living Planet Index, which tracks trends in vertebrate species populations in the wild by calculating the annual rate of change for each species population based on time-series data [73]. Aggregated trends for 1307 populations of 360 terrestrial mammal species demonstrate an average decline of 25 per cent for the period 1970–2005 [74].

Aggregated trends of the RLI are based on changes in IUCN Red List categories over time, and are dependent on extinction risk having been reliably estimated using the quantitative categories and criteria [28]. Depending on an assessor's attitude towards uncertainty, it is possible to overestimate (by being overly precautionary) or underestimate (by being too evidentiary) true extinction risk [75,76]. Although IUCN guidelines on application of the criteria indicate that assessors should adopt a precautionary, but realistic attitude [55], the risk assessment process contains uncertainty that can hinder making an accurate estimate of true extinction risk.

Consider the Thomson's Gazelle *Eudorcas thomsonii*, a species confined to a small range in northern Tanzania and southern Kenya, with growing evidence of declines in key populations [77,78]. Key to determining whether the species may be threatened is its status in Serengeti National Park, estimated to hold three-quarters of the global population [79]. Borner *et al.* [80] estimated the population at 250 000 in 1985 (roughly half that in 1980). The next available estimate is 342 000 in 1996 [79]. Subsequently, the only other reliable estimate for the Serengeti population is 174 000 individuals in 2003 [81]. Based on a generation length of 6 years, the question is what the rate of decline was in the Serengeti between approximately 1990 and 2008. Since the population was presumably increasing between 1985 and 1996, the population trajectory post-2003 becomes all important. If it remained stable or increased, then the species may qualify as either Vulnerable or Near Threatened (where it is currently listed); if it decreased, then a higher listing may be warranted. Obtaining a reliable current estimate of the population size in the Serengeti is crucial to establishing whether this species may in fact be threatened. Although current evidence suggests that Thomson's Gazelle was likely Vulnerable in 1996 (based on a 40% decline in the population between 1978 and 1996), the uncertainty around the 2008 listing of Near Threatened makes it difficult to ascertain whether the latter category represents a genuine improvement or simply a conservative estimate of extinction risk. Consequently, it is unclear whether the species has experienced no change, improved or even deteriorated. For the purposes of the RLI, our default assumption is to assume no change.

There may be uncertainty in correctly back-casting the 1996 assessment for some species. The Kouprey, for example, was flagged as Possibly Extinct in 2008. The last published record dates back to the 1960s, and based on estimated habitat loss, long-term overharvesting and that the most likely remaining areas have been well surveyed, applying a possibly extinct marker was deemed appropriate. Less certain is whether this should also have applied in 1996, but it is likely that extinction occurred sometime between the 1960s and 1990s, and hence the species would have qualified as Possibly Extinct in 1996 also. If information becomes available demonstrating that Kouprey persisted into the late 1990s, the Possibly Extinct flag in 1996 would be retrospectively removed and the species would be treated as a genuine deterioration during 1996–2008.

We have not incorporated information that has come to light since 2008, which in some cases may modify the 2008 data-point. For example, declines observed in mammals in Kakadu National Park in Northern

Australia between 2001 and 2009 [82] suggest that species such as the Fawn Antechinus *Antechinus bellus* (currently Least Concern) may perhaps have been eligible for listing in a higher category of threat in 2008. In addition, we are already aware of some status changes that have occurred since 2008 and that will feed into the next mammal RLI data-point. For example, the Christmas Island Pipistrelle *Pipistrellus murrayi* (classified as Critically Endangered in 2008) has almost certainly now gone extinct. As recently as January 2009, there were thought to be as few as 20 remaining individuals. In August 2009, authorities returned to the island to capture some of the remaining individuals for captive breeding, but only a single individual was detected and it evaded capture before disappearing entirely [83]. The species was flagged as Possibly Extinct on the IUCN Red List in 2009. In North America, white-nose syndrome is causing population collapses in colonies of the hibernating Little Brown Myotis *Myotis lucifugus* (currently listed as Least Concern). This infectious disease is associated with the non-native, psychrophilic fungus *Geomyces destructans*, first recorded in North America in 2006. Little Brown Myotis is the most common and widespread of nine bat species that have tested positive for *G. destructans*, including species already at risk such as Indiana Myotis *Myotis sodalis* (Endangered). Models predict that this will lead to a decline in the regional population of Little Brown Myotis from an estimated 6.5 million bats to fewer than 65 000 in less than 20 years [84], suggesting that the current status of the species needs urgent reassessment.

Conversely, some species have undergone recent improvements in conservation status, and are awaiting formal downlisting from a higher to lower category of threat. IUCN guidelines stipulate that 'a taxon may be moved from a category of higher threat to a category of lower threat if none of the criteria of the higher category has been met for five years or more' (obviously, this 'five-year' rule does not apply to species flagged as Possibly Extinct) [55]. One example is Przewalski's Horse, herein highlighted as a conservation success story having been downlisted from Extinct in the Wild to Critically Endangered. Currently, the reintroduced population has numbered more than 50 'mature' individuals (i.e. those capable of reproduction) for 4 years. Provided that the status of the species remains the same or continues to improve for at least another year, Przewalski's Horse potentially could be reassessed as Endangered (P. Moehlman 2010, personal communication); concomitantly, the 2008 category would also need to be retrospectively corrected to Endangered.

Some improvements will take time to be reflected in the RLI, especially for long-lived species assessed under Criterion A that currently have stable or even increasing populations. The pre-eminent example is the African Elephant *Loxodonta africana* (still considered a single species on the IUCN Red List). The species is listed as Vulnerable, narrowly meeting the 30 per cent population decline threshold under A2 (where the time-frame spans the period 1931–2006, based on an IUCN-defined generation length of 25 years). The current global population trend is increasing, with sub-populations in southern and East Africa outweighing the magnitude of declines elsewhere on the continent. Assuming that the global population continues to increase or remains stable, the species should eventually be eligible for downlisting to Near Threatened.

Finally, there are species that might not improve beyond the Near Threatened category so long as they remain conservation-reliant [85]. White Rhinoceros *Ceratotherium simum*—arguably the biggest conservation success story in history—serves as a case in point. At risk of extinction at the start of the last century, today the species numbers almost 17 500 individuals with populations in seven countries [66]. According to the IUCN guidelines, 'a taxon may also qualify for the Near Threatened category if it is the focus of a continuing taxon-specific or habitat-specific conservation programme targeted towards the taxon in question, the cessation of which would result in the taxon qualifying for one of the threatened categories above within a period of five years' [55]. Although currently increasing, in the absence of conservation measures for the White Rhinoceros, within 5 years the species would quickly meet the threshold for C1 under Vulnerable, and potentially also criterion A3 if poaching were to increase markedly in all range states. Indeed, there have been many recent reports that poaching levels in southern Africa have increased dramatically in the past few years, much of it driven by demand from outside the region [66].

9. CONSERVATION

The 24 mammal species that improved in status did so owing to conservation action (although it is possible for species to undergo an improvement in status for reasons unrelated to conservation action). However, species undergoing deteriorations in status often also receive conservation action, although these actions may not lead to improvements or stabilizing of population trends. Among the 171 mammals that deteriorated in status, we used information from the IUCN conservation actions classification schemes to determine which had received some conservation action. There were 18 mammal species for which apparently no obvious conservation action had been implemented (appendix A). Examples include Bolano's Woodrat *Neotoma palatina* from Mexico, where the main threat is the construction of El Cajón hydroelectric dam on the Rio Grande de Santiago, and the Ili Pika *Ochotona iliensis* from China, for which the main driving threat is agricultural expansion. We classified the remaining species according to two types: (i) species that received at least some conservation action, but where that action is considered inadequate to offset, or poorly targeted towards, the primary driver; and (ii) species that received some conservation action, but for which the primary drivers were enigmatic and consequently we were unclear whether the actions implemented were relevant.

In most cases (146 species), conservation action has simply been inadequate to offset the main drivers or is not targeting the primary driver. For example, several species of North African antelope, notably the Addax *Addax nasomaculatus* and Dama Gazelle *Nanger dama* (both Critically Endangered), are present in large conservation areas, have established captive-breeding (and reintroduction) programmes and feature

in international legislation (appendix A of both CITES and the Convention on Migratory Species). And yet, without adequate measures in place to mitigate the primary driving threat—hunting—both species remain on a trajectory to extinction.

In the remaining seven cases of species that deteriorated, conservation action is proceeding without adequate understanding of the drivers of deterioration. A lack of clarity on the causes of decline has stymied conservation efforts for the Woylie, Eastern Quoll *Dasyurus viverrinus*, Hawaiian Monk Seal *Monachus schauinslandi*, Numbat *Myrmecobius fasciatus*, Christmas Island Pipistrelle, Sandstone Pseudantechinus *Pseudantechinus bilarni* and Galápagos Sea Lion *Zalophus wollebaeki*. In the case of the pipistrelle, for example, one suggested possibility is that increased numbers of introduced Yellow Crazy Ants *Anoplolepis gracilipes* led to a decrease in the numbers of Christmas Island Red Crabs *Gecarcoidea natalis*, and a corresponding increase in the number of Giant Centipedes *Scolapendra morsitans* (also introduced), which could have preyed on roosting pipistrelles [83]. Meanwhile, the Woylie is an interesting example of a species that initially recovered owing to conservation efforts (having been removed from both State and national threatened species lists in the 1990s following implementation of a recovery plan), only to then experience an unexplained 75 per cent decline in its population between 2001 and 2006 [86].

Among species that deteriorated, and received some form of conservation, it is difficult to elucidate whether those conservation efforts prevented the species deteriorating even further. Might, for example, the Addax or Dama Gazelle now be extinct if it had not been for the measures (inadequate as they are) put in place above? This dilemma extends to the many species that did not deteriorate in status, but may have done so in the absence of conservation.

The counterfactual scenario of what would have happened in the absence of conservation action is necessary to answer to compare with the observation of what actually happened, and thereby determine whether conservation makes a difference to trends in species extinction risk [87]. The question can be partially addressed by assuming that all species that underwent an improvement in status owing to conservation would have undergone no change without conservation; such species that undergo no change do not affect trends in the RLI, and consequently the slope of the resulting RLI would be steeper [47].

However, to more fully assess what would have happened in the absence of conservation, an analysis similar to that undertaken by Butchart *et al.* [88], who determined which Critically Endangered birds would have gone extinct without conservation, would need to be undertaken for all mammals across each threat category. In effect, this would require updating the current 2008 categories with projected or 'forecast' changes from 1996 onwards based on the cessation of conservation efforts in that year. Such an exercise introduces complexities associated with determining whether (and by how much) a species would have deteriorated in status in the absence of conservation. Nonetheless, an analysis of this sort is a high priority because it would

likely yield a vastly improved understanding of the contribution of global conservation efforts to the trends in mammal conservation status.

10. CONCLUSIONS

We retrospectively assigned categories of threat to determine trends in conservation status of the world's mammals for the period 1996–2008. Our study highlights those species moving most rapidly towards extinction, the threat drivers that must be mitigated and where conservation actions are successful or falling short. Although several important considerations should be borne in mind when interpreting RLIs, we suggest the methodology for retrospectively assessing species could be more widely applied to other completely assessed taxa (provided sufficient data exist to be confident of identifying the great majority of genuine changes in status), hence producing an indication of trends in conservation status in these groups.

However, for the Red List to fulfil its function as the 'barometer of life', resources are needed to ensure repeat assessments of mammal diversity [89]. We estimate that maintaining and improving the mammal dataset on the Red List costs less than US$400 000 per annum (*ca* US$70/species). Such an investment would facilitate future RLI readings and measurement against global targets, such as the recently agreed 2011–2020 Strategic Plan for Biodiversity [90]. It would also provide conservation practitioners and decision-makers with the information necessary to implement reactive and proactive conservation actions to secure positive outcomes for the world's mammals.

APPENDIX A

Deteriorating mammals not recorded as having received any conservation actions on the IUCN Red List. EX, Extinct; EW, Extinct in the Wild; CR(PE), Critically Endangered (Possibly Extinct); CR, Critically Endangered; EN, Endangered; VU, Vulnerable; NT, Near Threatened; LC, Least Concern.

family	species	1996 category	2008 category	country
Cricetidae	*Neotoma palatina*	NT	VU	Mexico
Furipteridae	*Amorphochilus schnablii*	VU	EN	Peru; Ecuador; Chile
Geomyidae	*Pappogeomys alcorni*	EN	CR	Mexico
Muridae	*Gerbillus hesperinus*	VU	EN	Morocco
Muridae	*Solomys ponceleti*	EN	CR	Papua New Guinea; Solomon Islands
Muridae	*Solomys salebrosus*	VU	EN	Papua New Guinea; Solomon Islands
Muridae	*Solomys sapientis*	VU	EN	Solomon Islands
Muridae	*Tokudaia muenninki*	EN	CR	Japan
Muridae	*Uromys neobritannicus*	LC	NT	Papua New Guinea
Muridae	*Uromys rex*	VU	EN	Solomon Islands
Ochotonidae	*Ochotona iliensis*	VU	EN	China
Peramelidae	*Peroryctes broadbenti*	VU	EN	Papua New Guinea
Phalangeridae	*Phalanger lullulae*	LC	EN	Papua New Guinea
Phalangeridae	*Phalanger matanim*	CR	CR(PE)	Papua New Guinea
Phalangeridae	*Spilocuscus kraemeri*	LC	NT	Papua New Guinea
Pteropodidae	*Pteropus lylei*	NT	VU	Cambodia; China; Thailand; Viet Nam
Pteropodidae	*Pteropus melanopogon*	VU	EN	Indonesia
Vespertilionidae	*Rhogeessa minutilla*	NT	VU	Colombia; Venezuela

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