Introduction

The key elements of a comprehensive global mammal conservation strategy

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A global strategy is necessary to achieve the level of coordination, synergy and therefore optimization of resources to achieve the broad goal of conserving mammals worldwide. Key elements for the development of such a strategy include: an institutional subject that owns the strategy; broad conservation goals, quantitative targets derived from them and appropriate indicators; data on the distribution of species, their threats, the cost-effectiveness of conservation actions; and a set of methods for the identification of conservation priorities. Previous global mammal research investigated phylogeny, extinction risk, and the species and areas that should be regarded as global conservation priorities. This theme issue presents new key elements: an updated Red List Index, a new list of evolutionarily distinct and globally endangered species, new high-resolution mammal distribution models, a global connectivity analysis and scenarios of future mammal distribution based on climate and land-cover change. Area prioritization schemes account for mammalian phylogeny, governance and cost–benefit of measures to abate habitat loss. Three discussion papers lay the foundations for the development of a global unifying mammal conservation strategy, which should not be further deterred by the knowledge gaps still existing.

Keywords: biodiversity; conservation goal; conservation planning; conservation priority setting; conservation target; triage

1. THE NEED FOR A GLOBAL (MAMMAL) CONSERVATION STRATEGY

The increasing pressures of human activities continue to surpass biodiversity conservation efforts, and as a result biodiversity loss is accelerating [1]. Stepping-up conservation action is therefore crucial, not only by substantially increasing overall investment [2], but also by ensuring that such investment is as strategic as possible. This requires setting clear goals and priorities [3] and then making the best use of available data to maximize conservation impact with the limited available resources [4].

To optimize the use of conservation resources, these should be spent under an agreed upon strategy to achieve the broad goal of biodiversity conservation. An indication of lack of strategy is provided by conservation spending, which is disproportionately higher for mammals than other taxonomic groups, and for large mammals within mammals [5]. Uncoordinated action by different conservation organizations and governmental agencies is likely to result in duplication and heterogeneity of conservation efforts, which is detrimental given the scarcity of resources [2]. Without a clear global strategy—agreed upon by the policy, scientific and conservation community—the coordination, synergy, and therefore optimization of resources to maximize the benefit of action towards a broad conservation goal is impossible to achieve.

The 5339 currently extant mammals include many charismatic species and important flagships for conservation efforts [6]. A number of (usually large) mammals have been regarded as potential umbrella for the conservation of many other species, owing to their wide habitat and spatial requirements [7]. Yet, the overall conservation status of the world’s mammals is precarious [8]: an estimated one-fourth of the mammals are threatened with extinction, and their overall condition is deteriorating [9]. As of today, there is not yet a comprehensive, widely agreed, global conservation strategy to tackle mammal decline. New datasets on the taxonomy [10], phylogeny [11], life-history traits [12], conservation status, threats, ecology and distribution [8,13] provide now an opportunity to strategically plan for mammal conservation in the coming decades [14].

2. KEY ELEMENTS FOR A COMPREHENSIVE GLOBAL SPECIES CONSERVATION STRATEGY

(a) Owner

A strategy can only be created and implemented if there is a clearly identified ‘owner’, an institutional
subject with recognized authority, accountability and implementation capacity [6]. Strategies that are not directed to, and agreed upon by, one or more owners run the risk of remaining paper strategies. There is no ‘natural’ owner at the global level but a strategy for global mammal conservation can build from the existing international dialogue and cooperation around the Convention for Biological Diversity (as, for example, has been done with the Global Plant Conservation Strategy), by creating a partnership of institutions including governments and non-governmental organizations. By signing a common strategy, these multiple owners would complement rather than duplicate each other’s actions.

(b) Goals and objectives
A global conservation strategy requires (as any other strategy) a clear statement of goals, and the definition of explicit, quantitative objectives. Conservation goals are necessary to allow explicit trade-offs with other, possibly contrasting goals (for example, trade-off between reducing biodiversity loss by setting aside areas for conservation and increasing short-term food availability by expanding agricultural areas) [15]. Goals are typically broad and not immediately operational (for example, the goal ‘to achieve by 2010 a significant reduction of the current rate of biodiversity loss’ set in 2002 by the Conference of Parties of the Convention on Biological Diversity), reflecting societal values and political or institutional intent [16]. Objectives should instead be quantitative and time-specific, making the planning approach transparent and allowing for the measurement of progress towards an achievement [17,18].

A range of heuristic and analytical methods has been developed to translate conservation goals into quantitative objectives [16,19,20]. For example, a goal of minimizing species extinctions may translate into species-specific targets, expressed as number of individuals needed to ensure the long-term persistence of populations.

c) Species data
To move from broad goals to the identification of conservation priorities and operational targets, and to measure the success of action, a global conservation strategy requires data on species, including on their distribution, threats, the effectiveness of conservation actions and the economic cost of conservation. Data on species distribution are instrumental to identify where and how to act. Indeed any information on species threat cannot inform conservation action if the place where action is needed remains unknown. The requirements of species spatial data to be useful for a global conservation strategy are reviewed in Boitani et al. [21]. Information on threat is already available for more than 50 000 taxa from the IUCN Red List [13], but the spatial distributions of threats to species are poorly understood [22]. Threat data are necessary to identify priority species, but need to be complemented by data on conservation costs and the probability of success [14]. All data come with some degree of stated or unstated uncertainty attached to them [23], therefore methods to process data while taking uncertainty into account are necessary to obtain robust results in terms of targets, priorities and quantification of success.

(d) Choosing cost-effective action
Knowing on which species, where, and when to act is not sufficient to develop a comprehensive global species conservation strategy. A variety of different conservation actions can be taken on species or their habitat [6], and decisions on which action to take would need further data on the expected cost and benefit of actions. These data are hard to find, and globally only exist at very coarse levels [24], but they are essential to identifying cost-effective conservation priorities [25]. Conservation plans that account explicitly for cost achieve substantially higher benefit than those that ignore it (e.g. [26,27]). The economic costs of conservation include acquisition, management, transaction, damage and opportunity costs (see [28] for a review). The cost of conservation is highly variable in space, but is often smaller in developing countries where also disproportionately high biodiversity levels are found [25], and directing conservation efforts to these areas may therefore make a substantial difference at the global scale [3].

e) Identifying priorities
There have been substantial developments in the past three decades of methods for identifying conservation priorities. These methods aim at optimizing the way in which conservation resources are invested, and often rely on the principles of irreplaceability [29] and vulnerability [17]. Irreplaceability typically corresponds to a measure of options in space: highly irreplaceable areas are those containing biodiversity features with few options for conservation elsewhere, such that the loss of those areas would hinder the likelihood of meeting conservation targets in the future. Vulnerability refers to options in time, the likelihood that an area or a species becomes lost to conservation (converted, or driven to extinction). A third dimension of conservation options refers to evolutionary time, as the loss of species that are more evolutionarily distinct reduces options for the conservation of the overall tree of life [30]. A diversity of approaches bases on these principles has been applied globally, at resolutions varying from the regional (e.g. the biodiversity hotspots [31]) to the site scale (e.g. the key biodiversity areas, KBA [32], and the alliance for zero extinction, AZE [33]). Some of these approaches target species (e.g. evolutionarily distinct and globally endangered species, EDGE [34]), others target sites (e.g. systematic conservation planning [17], and conservation resource allocation [24]). Although these methods give sometimes contrasting results, they can provide complementary insights into a global species conservation strategy (potential ways to reconcile the methods are discussed in Rondinini et al. [14]). Overall, in order to be relevant on the operational level, a global species conservation strategy must rely on prioritization methods based on the best available data in order to steer action. Whereas most effective action takes place at the local scale (and, accordingly,
should be based on higher resolution, higher accuracy, local data, global coordination is needed for a global optimization of conservation action [14].

(f) Biodiversity indicators

Biodiversity indicators are instrumental in a global conservation strategy, to raise awareness among policy makers, to evaluate the effectiveness of conservation action and to inform further policy decisions [35]. Many features can be monitored as part of a multi-species level indicator, including taxonomic, ecological, phylogenetic, compositional and functional diversity [36]. At the species level, indicators include population trends (e.g. the Living Planet Index [37,38]), and changes in overall conservation status (e.g. the Red List Index [9,39], an aggregated measure of trend in species extinction risk). These indicators are not necessarily concordant, and maximizing one of them may not maximize others [36]. For this reason, a global species conservation strategy should identify the set of indicators that are most appropriate to monitor the targets that have been set.

3. KEY ELEMENTS AVAILABLE FOR MAMMALS

(a) Previous global mammal assessments

Several global analyses have been published in the last decade that can contribute to a global mammal conservation strategy [8,19,34,40–45]. Two of the existing global mammal analyses deal with current species extinction risk. Schipper et al. [8] report on the assessment of extinction risk for all terrestrial and marine mammals under the International Union for Conservation of Nature (IUCN) Red List, which also identifies the main threats to each mammal. They found that between 21 and 36 per cent of the mammals are threatened with extinction, with habitat loss (affecting 40% of species) and hunting (17%) as the most pervasive threats, and Southeast Asia as the region with the highest concentration of threatened species. These results provide, therefore, broad indications on the main drivers of mammal decline, and where their impact is currently felt more strongly. This assessment contributed to a subsequent analysis of extinction risk trend in vertebrates [45] based on the Red List Index. This study found that the overall conservation status of mammals (and of other vertebrates) is deteriorating, particularly in Southeast Asia, but that losses would have been even worse in the absence of conservation action.

Data on species extinction risk have been used in combination with phylogeny [34] and life-history traits [43] to identify mammal species that should be prioritized for conservation. Isaac et al. [34] measured the evolutionary distinctiveness (ED) of each mammal species (their relative contribution to overall mammalian phylogenetic diversity) and combined it with species extinction risk according to the IUCN Red List [13] to obtain an EDGE score, used to prioritize species that should receive conservation action. Cardillo et al. [43,44], on the other hand, correlated the extinction risk of mammals, according to the IUCN Red List [13], with ecological and life-history traits, finding that traits such as small geographical ranges, large body mass and ‘slow’ life-history traits correlate with species’ extinction risk. From these variables, they then calculated a predicted extinction risk for each mammal, prioritizing species for conservation on the basis of their latent extinction risk, defined as the difference between predicted and observed (Red List) risk. The Red List categories, EDGE scores, and latent extinction risk produce different results in terms of species priorities, but this is natural given that each metric has been developed to tackle different conservation issues: to prevent species extinctions; to minimize loss of mammalian evolutionary history; and to proactively conserve mammals that could be potentially threatened in the future. Each of them has, therefore, a potential role to play in meeting different, complementary, targets of a future global conservation strategy [14].

Four other previously published global mammal analyses identified spatial priorities for meeting explicit, quantitative, species representation targets. In a set of two studies, Rodrigues et al. [19,40] evaluated the degree to which the existing global network of protected areas represents vertebrate species, including mammals. In the first study [40], the target was simple representation, with species considered covered if any portion of their geographical range overlapped any protected area. They found that 5.5 per cent of the mammals were not included in any protected area (and 13.5% were included only in protected areas smaller than 10 km²). In the second study [19], a continuous set of species representation targets was defined as a fraction of each species’ distribution range, ranging between 10 per cent for widespread species and 100 per cent for very narrowly distributed species. Priorities for expanding the global network of protected areas were then identified as those with simultaneously high irreplaceability (the extent to which they were needed to complement the existing network in order to meet the species representation targets) and high vulnerability (with substantial concentrations of threatened species). In two complementary studies based on the same data, Ceballos et al. [41] and Carwardine et al. [42] identified priority areas that should be protected to conserve 10 per cent of the geographical range of each of the world’s mammals, finding that 11–13% land surface was required to meet this target. When the prioritization was carried out without accounting for costs, half of the area selected overlapped with important areas for crop production [41] whereas if agricultural opportunity cost was incorporated in the analysis, the potential conflict could be reduced by one-third and the target hit while enlarging only slightly (2%) the amount of area prioritized for protection [42].

(b) New contributions from this Theme Issue

This Theme Issue presents new key elements for a global mammal conservation strategy. Given that all analyses share a common taxonomy ([10], with some modifications as described in Hoffmann et al. [43]) and the same species distribution data were applicable [13,46], inter-comparison is possible among papers.
Some contributions in this Theme Issue provide an advancement in the current knowledge of mammalian conservation status, threats and distribution [9, 46–48]. Hoffmann et al. [9] present an updated Red List Index for mammals, discussing deteriorations and improvements in conservation status between 1996 and 2008 (i.e. species evaluated at higher risk of extinction in 2008 than in 1996, or the reverse). They find that many more mammals have deteriorated (3%) than improved (0.4%) in conservation status, and that although habitat loss threatens a much larger proportion of mammals than hunting, the latter is more likely to trigger a deterioration. Improvements have been due to a combination of protected areas, legislation and other conservation actions.

In the first pantropical community study on forest terrestrial mammals, based on a camera trap network, Ahumada et al. [47] compare mammal communities living in areas with different levels of fragmentation. They conclude that the levels of fragmentation are inversely correlated with species richness, species diversity and functional diversity. This study has broader relevance by presenting a cost-effective standardized approach for the long-term monitoring of mammals, currently being set up in tropical forests worldwide, but which could be extended to other key habitat types as part of a global monitoring strategy.

An updated list of EDGE species is presented by Collen et al. [48], building on the methodology of Isaac et al. [34] and taking advantage of an updated phylogeny. They find that although taxonomy (and consequently phylogeny) has significantly changed between the original and new version of the EDGE list (with number of species described increasing from ca 4300 to ca 5400), the old and new EDGE values are highly correlated. Relatively bigger differences are found owing to species changes in Red List status (ca 200), therefore, the metric appears robust to changes in phylogeny.

Rondinini et al. [46] present a new high-resolution (0.09 km²) dataset of the global distribution of terrestrial mammals, which refines the coarse species geographical ranges compiled under the IUCN Red List assessments [8, 13] by integrating information on modelled habitat suitability. Mammal richness estimated using the refined species data is on average one-third lower than that estimated using coarse geographical ranges, with a more substantial difference in non-forested tropical areas where species are likely to have suffered local extinction owing to habitat loss within their former ranges. They also found that the amount of habitat unsuitable within each species' geographical range increases with the extinction risk according to the Red List [49]. Based on the same habitat suitability models, Crooks et al. [50] analysed the fragmentation of geographical ranges among the world's carnivores, concluding that low habitat fragmentation correlates with larger range sizes, with a higher proportion of suitable habitat within ranges, with higher spatial connectivity and with lower species extinction risk. These two studies suggest that threatened, restricted-range mammals may be more subject to habitat loss and fragmentation than non-threatened, large-range ones.

Two papers present projections of future mammal distributions under several scenarios of climate and land-cover changes. Visconti et al. [51] use a global land-cover change model, coupled with the fine-scale habitat suitability models of Rondinini et al. [46], to assess projected future changes in suitable habitat for terrestrial mammals according to four global scenarios of human development. They find that most of the countries with the largest predicted losses of suitable habitat for mammals are in Africa and central Asia, and have little or no overlap with present global conservation priorities. Maiorano et al. [52] use an ensemble forecasting approach to model the future (2100) potential geographical ranges of 181 Mediterranean mammals under several climate change forecasts, finding that some north-Mediterranean areas will gain mammalian species, while most south-Mediterranean areas will lose species. These two studies highlight the need for proactive conservation strategies in the areas concentrating predicted future losses, to complement reactive conservation action in areas of current high levels of threat.

Three area prioritization analyses account for different variables that are highly relevant to the development of a species conservation strategy. Rodrigues et al. [53] investigate whether conservation planning based on datasets of variable levels of quality and/or quantity provides a good approximation to the representation of overall mammalian phylogenetic diversity. Their results indicate that conservation plans that use phylogenetic information improve only slightly the representation of phylogenetic diversity over conservation plans that ignore it and that, furthermore, taxonomic diversity is a good surrogate of phylogenetic diversity. Eklund et al. [54] investigate the independent and combined effects of information on the distribution of mammals, the costs of conservation and country corruption (as an indicator of governance quality) on the identification of priority areas for the conservation of mammals globally. They find that the outcomes of spatial prioritization using the three factors independently differ markedly, with many areas in Africa chosen primarily because of low cost of conservation action, and areas in South America chosen for a combination of mammalian diversity and low cost, but avoided when governance is accounted for. By contrast, areas in Europe and Australia are chosen when considering governance and mammalian diversity, but avoided when cost is accounted for. When all three factors are considered, mammalian endemism guides the selection of priority areas even, in some cases, in the absence of good governance, because there are few spatial options for the conservation of restricted-range species. In the last area, prioritization analysis, in this Theme Issue, Wilson et al. [55] present a fine-resolution prioritization analysis for mammals at a global scale that accounts for the risk of habitat loss, the actions required to abate this risk, the costs of these actions and the likelihood of investment success. They show that the spatial distribution of investments at a country level does not change regardless of whether investments are prioritized at a global or country scale.

Finally, three discussion papers lay the foundations for the development of a comprehensive global
Introduction. Global mammal conservation strategy C. Rondinini et al.

Global mammal conservation strategy. Boitani et al. [21] focus on the requirements of species spatial data for a global strategy, in terms of spatial coverage, bias, accuracy, scale, time relevance, reliability, biological significance and availability. They assess the existing datasets against these requirements to identify the facets requiring most urgent improvement. Redford et al. [6] review the criteria that have been used to value mammals, and the many approaches that have been proposed for conserving these species—from protected areas to matrix management, from preservation to sustainable use, from complete protection to triage—outlining the steps necessary to fill the gap between planning and action. In the final paper, Rondinini et al. [14] (including contributors from all the papers presented in the Theme Issue) highlight the potential roles of the different approaches to mammalian conservation presented here, and propose ways to reconcile them under the umbrella of a harmonized, comprehensive global mammal conservation strategy.

4. OUTSTANDING GAPS

The development of a comprehensive global mammal conservation strategy requires further light on some key elements for mammal conservation prioritization. Assuming that a consensual goal would be the persistence of mammal species into the future, what would be the appropriate population and/or area targets to translate this goal into numbers? The targets that have been used so far for mammals have been at best only loosely related to species persistence. Fixed targets, e.g. 10 per cent of the species distribution, have no relationship with the species biology [15], and may or may not ensure persistence depending on the size of the species’ geographical range. Variable targets, as those proposed by Rodrigues et al. [19], can direct efforts to more vulnerable species (e.g. those with smaller range sizes) but are still not directly connected with the concept of a viable population. The difficulty, of course, resides in the fact that in order to set biologically meaningful, species-specific targets, much more detailed information is needed on species that are currently available. A possible way forward has been recently proposed by Wilson et al. [24], whereby species-specific targets based on a minimum viable population are estimated from species’ weight. Further work is required to refine and test this approach for application to mammals at a global level. Simply preventing species extinctions is not a sufficient goal for ensuring the continued persistence of the roles mammals play in ecosystems and of the benefits we obtain from them. An additional, more challenging goal would be that all mammals be listed in a non-threat category in the Red List in the future (e.g. by year 2050 or 2100). This would require not only defining species-specific targets, but also the definition of an overall conservation strategy that coordinates the conservation actions required across all species based on the knowledge of the threats affecting them.

Other unresolved issues are related to data on threats, conservation actions and their cost. Comprehensive threat data are available at the species level [13], but an operational global strategy would require finer detail on the spatial distribution of threats across species’ ranges. Indeed, for widespread species in particular, different processes may be threatening different populations, affecting decisions of where and when to act [56]. For example, legal and illegal hunting is the second threat to mammals in terms of number of species affected, but no global model of the intensity of hunting exists. Also, the effectiveness of conservation actions in abating threats has so far only been roughly estimated [24], hampering attempts to develop conservation strategies that aim to articulate an array of conservation actions across space and time. Finally, data on the spatial distribution of conservation cost are still very scarce. Balmford et al. [25] estimated broad (using countries as the spatial unit) variation in protected area acquisition and management, and Naiddoo & Iwamura [57] mapped agriculture opportunity costs (at a 5’ resolution). Other types of opportunity costs (e.g. associated with livestock breeding, aquaculture, tourism or industry) remain unmapped. Given that different opportunity costs vary in their spatial patterns, using one map of opportunity cost or another can benefit or affect particular interest groups (or countries) in relation to others [58]. In spite of obvious gaps and weaknesses in the available data, however, a global mammal strategy is urgent. We believe that although all best efforts should be applied to reduce the gaps in our knowledge of species distribution, status, threats and conservation costs, missing data should not be used as an impediment to further delay working towards a global strategy.

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