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Saving the World's Terrestrial Megafauna

WILLIAM J. RIPPLE, GUILLAUME CHAPRON, JOSÉ VICENTE LÓPEZ-BAO, SARAH M. DURANT, DAVID W. MACDONALD, PETER A. LINDSEY, ELIZABETH L. BENNETT, ROBERT L. BESCHTA, JEREMY T. BRUSKOTTER, AHIMSA CAMPOS-ARCEIZ, RICHARD T. CORLETT, CHRIS T. DARIMONT, AMY J. DICKMAN, RODOLFO DIRZO, HOLLY T. DUBLIN, JAMES A. ESTES, KRISTOFFER T. EVERATT, MAURO GALETTI, VARUN R. GOSWAMI, MATT W. HAYWARD, SIMON HEDGES, MICHAEL HOFFMANN, LUKE T. B. HUNTER, GRAHAM I. H. KERLEY, MIKE LETNIC, TAAL LEVI, FIONA MAISELS, JOHN C. MORRISON, MICHAEL PAUL NELSON, THOMAS M. NEWSOME, LUKE PAINTER, ROBERT M. PRINGLE, CHRISTOPHER J. SANDOM, JOHN TERBORGH, ADRIAN TREVES, BLAIRE VAN VALKENBURGH, JOHN A. VUCETICH, AARON J. WIRSING, ARIAN D. WALLACH, CHRISTOPHER WOLF, ROSIE WOODROFFE, HILLARY YOUNG, AND LI ZHANG

From the late Pleistocene to the Holocene and now the so-called Anthropocene, humans have been driving an ongoing series of species declines and extinctions (Dirzo et al. 2014). Large-bodied mammals are typically at a higher risk of extinction than smaller ones (Cardillo et al. 2005). However, in some circumstances, terrestrial megafauna populations have been able to recover some of their lost numbers because of strong conservation and political commitment, as well as human cultural changes (Chapron et al. 2014). Indeed, many would be in considerably worse predicaments in the absence of conservation action (Hoffmann et al. 2015). Nevertheless, most mammalian megafauna face dramatic range contractions and population declines. In fact, 59% of the world's largest carnivores (more than or equal to 15 kilograms, $n = 27$) and 60% of the world's largest herbivores (more than or equal to 100 kilograms, $n = 74$) are classified as threatened with extinction on the International Union for the Conservation of Nature (IUCN) Red List (supplemental tables S1 and S2). This situation is particularly dire in sub-Saharan Africa and Southeast Asia, home to the greatest diversity of extant megafauna (figure 1). Species at risk of extinction include some of the world's most iconic animals—such as gorillas, rhinos, and big cats (figure 2 top row)—and, unfortunately, they are vanishing just as science is discovering their essential ecological roles (Estes et al. 2011). Here, our objectives are to raise awareness of how these megafauna are imperiled (species in tables S1 and S2) and to stimulate broad interest in developing specific recommendations and concerted action to conserve them.

Megafauna provide a range of distinct ecosystem services through top-down biotic and knock-on abiotic processes (Estes et al. 2011). Many megafauna function as keystone species and ecological engineers, generating strong cascading effects in the ecosystems in which they occur. These species also provide important economic and social services. For example, ecotourism is the fastest growing subsector of tourism in developing countries (UNEP 2013), and megafauna are a major draw for these tourists. Besides contributing considerable revenue to conservation, wildlife-based tourism can contribute significantly to education, economies, job creation, and human livelihoods.

Many of the surviving mammalian megafauna remain beset by long-standing and generally escalating threats of habitat loss, persecution, and exploitation (Ripple et al. 2014, 2015). Large mammals are extremely vulnerable to these threats because of their large area requirements, low densities (particularly for carnivores), and relatively "slow" life-history traits (Wallach et al. 2015). Various anthropogenic forces such as deforestation, agricultural expansion, increasing livestock numbers, and other forms of human encroachment have severely degraded critical habitat for megafauna by increased fragmentation or reduced resource availability. Although some species show resilience by adapting to new scenarios under certain conditions (Chapron et al. 2014), livestock production, human population growth, and cumulative land-use impacts can trigger new conflicts or exacerbate existing ones, leading to additional declines. According to the Food and Agriculture Organization, as of 2014, there were an estimated 3.9 billion ruminant livestock on Earth compared with approximately 8.5 million individuals of 51 of the 74 species of wild megaherbivores for which population estimates are available within their native ranges (table S2), a magnitude difference of approximately 400 times.

The current depletion of megafauna is also due to overhunting and persecution: shooting, snaring, and poisoning by humans ranging from individuals to governments, as well as by organized criminals and terrorists (Darimont et al. 2015). Megafauna are killed for meat and body parts for traditional medicine and ornaments or because of actual or perceived threats to humans, their crops, or livestock. Meat and body parts are sold locally, sold to urban markets, or traded regionally and internationally. Striking instances include the slaughter of thousands of megafauna, such as African elephants (*Loxodonta africana*) for their ivory, rhinoceroses for their horns, and tigers (*Panthera tigris*) for their body parts. In addition, many lesser-known megafauna species (figure 2, bottom row) are now

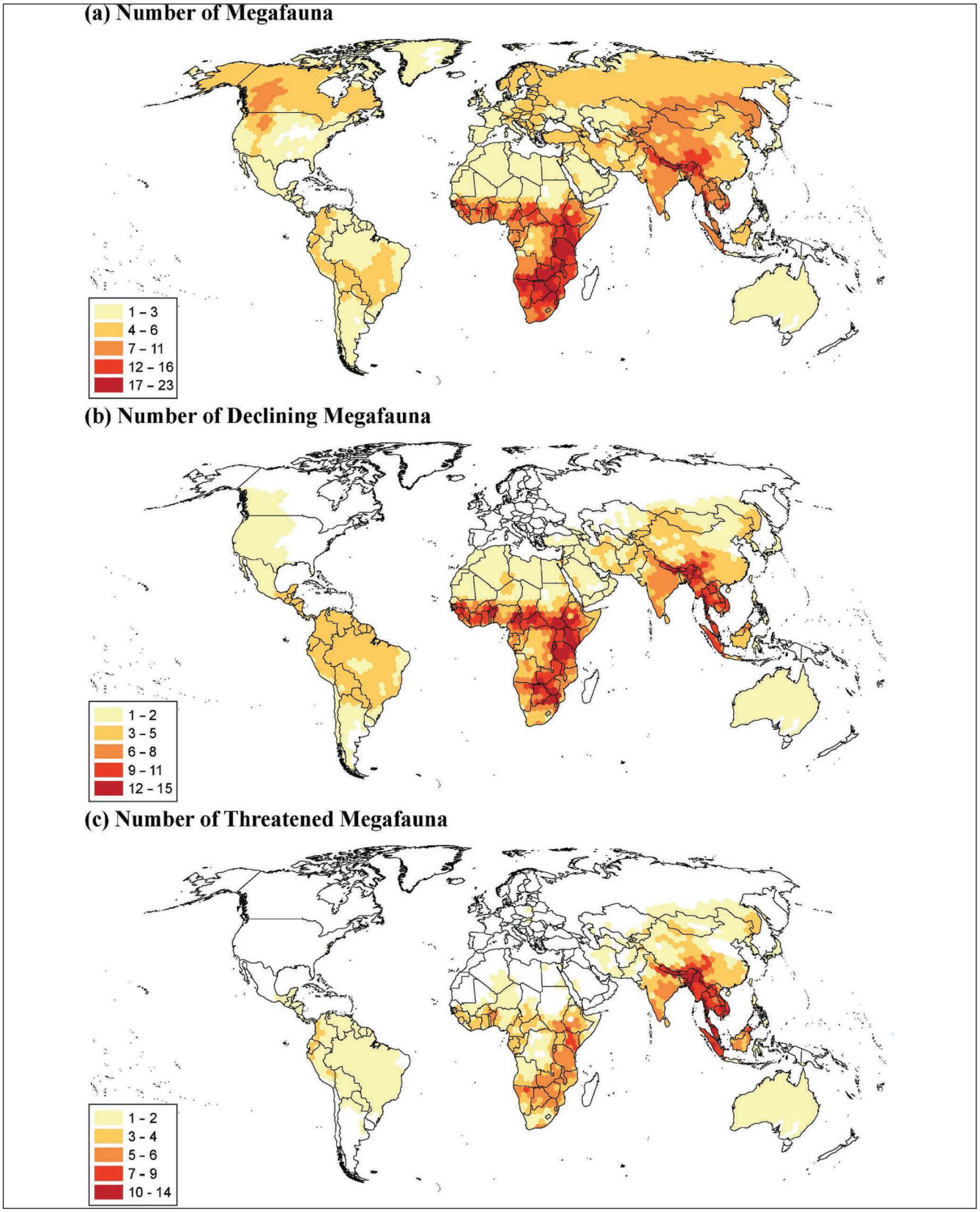

Figure 1. A richness map of (a) the number of megafaunal species, (b) the number of declining megafauna species, and (c) the number of threatened megafaunal species in their native ranges. **Megafauna** ***are defined as terrestrial large carnivores (more than 15 kilograms) and large herbivores (more than 100 kilograms).*** **Threatened** ***includes all species categorized as Vulnerable, Endangered, or Critically Endangered on the IUCN Red List (see supplemental tables).***

Figure 2. Photographic examples of threatened megafauna. Top row left to right: photos of well-known species, including the Western gorilla (*Gorilla gorilla*) (CR), black rhino (*Diceros bicornis*) (CR), and Bengal tiger, (*Panthera tigris tigris*) (EN). Bottom row left to right: photos of lesser-known species, including the African wild ass (*Equus africanus*) (CR), Visayan warty pig (*Sus cebifrons*) (CR), and banteng (*Bos javanicus*) (EN). Photo credits: Julio Yeste, Four Oaks, Dave M. Hunt, Mikhail Blajenov, KMW Photography, and Kajornyot.

imperiled (tables S1 and S2). Most of the world's megaherbivores remain poorly studied, and this knowledge gap makes conserving them even more difficult (Ripple et al. 2015).

Under a business-as-usual scenario, conservation scientists will soon be busy writing obituaries for species and subspecies of megafauna as they vanish from the planet. In fact, this process is already underway: eulogies have been written for Africa's western black rhinoceros (*Diceros bicornis longipes*) and the Vietnamese subspecies of the Javan rhinoceros (*Rhinoceros sondaicus annamiticus*, IUCN 2015). Epitaphs will probably soon be needed for the kouprey (*Bos sauveli*), last seen in 1988; and the northern white rhinoceros (*Ceratotherium simum cottoni*), which now numbers three individuals (IUCN 2015). The Sumatran rhino (*Dicerorhinus sumatrensis*) is already extinct in the wild in Malaysia and is very close to extinction in Indonesia, with the population collapsing during the last 30 years from over 800 to fewer than 100 (table S2). The Javan rhino (*Rhinoceros sondaicus*) is down to a single population of approximately 58 in a single reserve (table S2). The Critically Endangered Bactrian camel (*Camelus ferus*) and African wild ass (*Equus africanus*) are not far behind. Even in protected areas, megafauna are increasingly under assault. For example, in West and Central Africa, several large carnivores (including lions, *Panthera leo*; African wild dogs, *Lycaon pictus*; and cheetahs, *Acinonyx jubatus*) have experienced recent severe range contractions and have declined markedly in many protected areas (IUCN 2015).

Although many of the general causes and mechanisms of declines are well identified and recognized, this understanding has not translated into adequate conservation action. Some of the existing mammal-prioritization schemes could be incorporated into a comprehensive global strategy for conserving the largest mammals (Rondinini et al. 2011). Increasing prioritization and political will to conserve megafauna—and actions to restore or reintroduce them in areas where they have declined or been extirpated (such as plans to reintroduce scimitar-horned oryx into Chad and to rehabilitate the entire Gorongosa ecosystem in Mozambique)—are urgently needed. We suggest that the problem has two

Box 1. A declaration to save the world's terrestrial megafauna.

We conservation scientists

1. Acknowledge that most of the terrestrial megafauna species are threatened with extinction and have declining populations. Some megafauna species that are not globally threatened nonetheless face local extinctions or have Critically Endangered subspecies.
2. Appreciate that "business as usual" will result in the loss of many of the Earth's most iconic species.
3. Understand that megafauna have ecological roles that directly and indirectly affect ecosystem processes and other species throughout the food web; failure to reverse megafaunal declines will disrupt species interactions, with negative consequences for ecosystem function; biological diversity; and the ecological, economic, and social services that these species provide.
4. Realize that megafauna are epitomized as a symbol of the wilderness, exemplifying the public's engagement in nature, and that this is a driving force behind efforts to maintain the ecosystem services they can provide.
5. Recognize the importance of integrating and better aligning human development and biodiversity conservation needs through the engagement and support of local communities in developing countries.
6. Propose that funding agencies and scientists increase conservation research efforts in developing countries, where most threatened megafauna occur. Specifically, there is a need to increase the amount of research directed at finding solutions for the conservation of megafauna, especially for lesser-known species.
7. Request the help of individuals, governments, corporations, and nongovernmental organizations to stop practices that are harmful to these species and to actively engage in helping to reverse declines in megafauna.
8. Strive for increased awareness among the global public of the current megafauna crisis using traditional media as well as social media and other networking approaches.
9. Seek a new and comprehensive global commitment and framework for conserving megafauna. The international community should take necessary action to prevent mass extinction of the world's megafauna and other species.
10. Urge the development of new funding mechanisms to transfer the current benefits accrued through the existence values of megafauna into tangible payments to support research, conservation actions, and local people who bear the cost of living with wildlife in the places where highly valued megafauna must be preserved.
11. Advocate for interdisciplinary scientific interchange between nations to improve the social and ecological understanding of the drivers of the decline of megafauna and to increase the capacity for megafauna science and conservation.
12. Recommend the reintroduction and rehabilitation, following accepted IUCN guidelines, of degraded megafauna populations whenever possible, the ecological and economic importance of which is evidenced by a growing number of success stories, from Yellowstone's wolves (*Canis lupus*) and the Père David's deer (*Elaphurus davidianus*) in China to the various megafauna species of Gorongosa National Park in Mozambique.
13. Affirm an abiding moral obligation to protect the Earth's megafauna.

parts: (1) a need to further and more effectively implement, expand, and refine current interventions at relevant scales and (2) a need for large-scale policy shifts and global increases in funding for conservation to alter the framework and ways in which people interact with wildlife.

In order to save declining species, there is a need to increase global conservation funding by at least an order of magnitude (McCarthy et al. 2012). Without such a transformation, there is a risk that many of the world's most iconic species may not survive to the twenty-second century. We must not go quietly into this impoverished future. Rather, we believe it is our collective responsibility as scientists who study megafauna to act to prevent their decline. We therefore present a call to the broader international community to join together in conserving the remaining terrestrial megafauna (see declaration in box 1).

From declaration to action

Social and political commitment to provide sufficient protection across the vast landscapes needed for the conservation of the world's megafauna is increasingly required. International frameworks and conventions such as the Convention on Biological Diversity (CBD), the Convention on the Conservation of Migratory Species of Wild Animals (CMS), and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) have had some success in safeguarding species. However, the decisions of these conventions are not always binding, and they will require substantially increased political will and financial support if they are to be effective in the critical task of securing the survival of the world's megafauna. Some regional instruments such as the CMS Gorilla Agreement and the Global Tiger Initiative incorporate environmental or biodiversity commitments and are playing a growing role in protecting biodiversity. International agreements are often well placed for enforcing regional frameworks for megafauna; examples include the

African Elephant Action Plan and the regional conservation strategy for cheetahs and African wild dogs. However, the implementation of such initiatives requires financial resources and capacity that are seldom available at those locations where the highest diversity of megafauna remains (figure 1). Therefore, the onus is on developed countries, which have long ago lost most of their megafauna, to not only embark on conservation and restoration programs on their own lands but also support conservation initiatives in those nations where diverse megafauna still persist. For conservation efforts to be successful, actions should be taken at all levels by authorities who have the public interest in mind and who work to secure the continued existence of these species.

Successfully conserving megafauna requires bold social, political, and financial commitments from nations around the world. Through understanding the value and importance of local human needs and by combining international financial support with a coordinated multilateral approach to conservation, it may be possible to rescue megafauna from the brink of extinction. As biologists, ecologists, and conservation scientists, we are mindful that none of our arguments are new and that our prescriptions are far easier to write out than to accomplish. However, our objective in presenting them together here is to demonstrate a consensus of opinion amongst the global community of scientists who study and conserve these animals, thereby emphasizing to the wider world the gravity of the problem. Our hope is that this declaration, with the proposed actions and list of signatories, will attract the public and media attention that this issue requires to galvanize opinion, catalyze action, and establish new funding mechanisms. Comprehensive actions to save these iconic wildlife species will help to curb an extinction process that appears to have begun with our ancestors in the late Pleistocene.

In the supplemental material for this article, this entire paper is available in six other languages: Spanish, Chinese, French, Portuguese, Malay (Bahasa Malaysia), and Thai.

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Supplemental material

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References cited

Cardillo RN, Mace GM, Jones KE, Bielby J, Bininda-Emonds ORP, Sechrest W, Orme DL, Purvis A. 2005. Multiple causes of high extinction risk in large mammal species. Science 309: 1239–1241.

Chapron G, et al. 2014. Recovery of large carnivores in Europe's modern human-dominated landscapes. Science 346: 1518–1519.

Darimont CT, Fox CH, Bryan HM, and Reimchen TE. 2015. The unique ecology of human predators. Science 349: 858–860.

Dirzo R, Young HS, Galetti M, Ceballos G, Isaac NJB, Collen B. 2014. Defaunation in the Anthropocene. Science 345: 401–406.

Estes JA, et al. 2011. Trophic downgrading of planet Earth. Science 333: 301–306.

Hoffmann M, Duckworth JW, Holmes K, Mallon DP, Rodrigues ASL, Stuart SN. 2015. The difference conservation makes to extinction risk of the world's ungulates. Conservation Biology 29: 1303–1313.

[IUCN] International Union for Conservation of Nature. 2015. The IUCN Red List of Threatened Species. IUCN. (17 March 2016; *www.iucnRedList.org*)

McCarthy DP, et al. 2012. Financial costs of meeting global biodiversity conservation targets: Current spending and unmet needs. Science 338: 946–949.

Ripple WJ, et al. 2014. Status and ecological effects of the world's largest carnivores. Science 343 (art. 1241484).

Ripple WJ, et al. 2015. Collapse of the world's largest herbivores. Science Advances 1 (art. e1400103).

Rondinini C, et al. 2011. Reconciling global mammal prioritization schemes into a strategy. Philosophical Transactions of the Royal Society B 366: 2722–2728.

UNEP [United Nations Environment Programme]. 2013. Green Economy and Trade: Trends, Challenges, and Opportunities. UNEP. (17 March 2016; *http://web.unep.org/greeneconomy/sites/unep.org.greeneconomy/files/field/image/fullreport.pdf*).

Wallach AD, Izhaki I, Toms JD, Ripple WJ, Shanas U. 2015. What is an apex predator? Oikos 124: 1453–1461.

William J. Ripple (bill.ripple@oregonstate.edu), Robert L. Beschta, Michael Paul Nelson, Luke Painter Christopher Wolf, and Thomas M. Newsome are affiliated with the Global Trophic Cascades Program of the Department of Forest Ecosystems and Society at Oregon State University, in Corvallis; TMN is also with the Desert Ecology Research Group of the School of Biological Sciences at the University of Sydney, in Australia; the Centre for Integrative Ecology at the School of Life and Environmental Sciences at Deakin University, in Geelong, Australia; and the School of Environmental and Forest Sciences, at the University of Washington, in Seattle. Guillaume Chapron is affiliated with the Department of Ecology at the Swedish University of Agricultural Sciences, in Riddarhyttan. José Vicente López-Bao is with the Research Unit of Biodiversity at Oviedo University, in Mieres, Spain. Sarah M. Durant and Rosie Woodroffe are with the Institute of Zoology at the Zoological Society of London, Regents Park. David W. Macdonald and Amy J. Dickman are with the Wildlife Conservation Research Unit of the Department of Zoology at the University of Oxford and the Recanati-Kaplan Centre, in Abingdon, United Kingdom. Peter A. Lindsey and Luke T. B. Hunter are affiliated with Panthera, in New York. PAL is also affiliated with the Mammal Research Institute of the Department of Zoology and Entomology at the University of Pretoria, in Gauteng, South Africa ; and LTBH is also affiliated with the School of Life Sciences at the University of KwaZulu-Natal in Durban, South Africa. Elizabeth L. Bennett, Simon Hedges, and Fiona Maisels are affiliated with the Wildlife Conservation Society, in New York; FM is also with the School of Natural Sciences at the University of Stirling, in the United Kingdom. Holly T. Dublin is affiliated with IUCN Species Survival Commission's African Elephant Specialist Group at the IUCN Eastern and Southern African Regional Office in Nairobi, Kenya. Jeremy T. Bruskotter is affiliated with the School of Environment and Natural Resources at The Ohio State University, in Columbus. Ahimsa Campos-Arceiz is with the School of Geography at the University of Nottingham Malaysia Campus. Richard T. Corlett is affiliated with the Center for Integrative Conservation of the Xishuangbanna Tropical Botanical Garden at the Chinese Academy of Sciences, in Menglun, Yunnan, China. Chris T. Darimont is with the Department of Geography at the University of Victoria and the Raincoast Conservation Foundation, in British Columbia, Canada. Rodolfo Dirzo is affiliated with the Department of Biology at Stanford University, in California. James A. Estes is with the Department of Ecology and Evolutionary Biology at the University of California, in Santa Cruz. Kristoffer T. Everatt, Matt W. Hayward, and Graham I. H. Kerley are affiliated with the Centre for African Conservation Ecology at Nelson Mandela University, in Port Elizabeth, South Africa; MWH is also with the School of Biological

Science and the School of Environment, Natural Resources, and Geography at Bangor University, in Gwynedd, United Kingdom, and the Centre for Wildlife Management at the University of Pretoria, in South Africa. Mauro Galetti is affiliated with the Departamento de Ecologia at the Universidade Estadual Paulista, in Rio Claro, Brazil. Varun R. Goswami is with the Wildlife Conservation Society, India Program, in Bangalore, India. Michael Hoffmann is with the International Union for Conservation of Nature (IUCN) Species Survival Commission, in Gland, Switzerland. Mike Letnic is affiliated with the Centre for Ecosystem Science at the University of New South Wales, in Sydney, Australia. Taal Levi is affiliated with the Department of Fisheries and Wildlife at Oregon State University, in Corvallis. John C. Morrison is affiliated with the World Wildlife Fund–US, in Hope, Maine. Robert M. Pringle is affiliated with the Department of Ecology and Evolutionary Biology at Princeton University, in New Jersey. Christopher J. Sandom is with the School of Life Sciences at the University of Sussex, in Brighton, United Kingdom. John Terborgh is affiliated with the Nicholas School of the Environment and Earth Sciences at Duke University, in Durham, North Carolina. Adrian Treves is with the Nelson Institute for Environmental Studies at the University of Wisconsin, in Madison. Blaire Van Valkenburgh is affiliated with the Department of Ecology and Evolutionary Biology at the University of California, Los Angeles. John A. Vucetich is with the School of Forest Resources and Environmental Science at Michigan Technological University, in Houghton. Aaron J. Wirsing is with the School of Environmental and Forest Sciences at the University of Washington, in Seattle. Arian D. Wallach is with the Centre for Compassionate Conservation in the School of Life Sciences at the University of Technology, in Sydney, Australia. Hillary Young is affiliated with the Department of Ecology and Evolutionary Biology at the University of California, Santa Barbara. Li Zhang is affiliated with the Institute of Ecology at the Beijing Normal University, in PR China.

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