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# Conserving Mammals

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“In pushing other species to extinction, humanity is busy sawing the limb on which it perches.”

—*Paul Ehlrich*

There are 5,850 known species of living mammals across the world (IUCN 2020a). Their diversity in size and form, from tiny bats to deep-diving whales, has enabled them to conquer all ecosystems on Earth. Alongside birds, reptiles, insects, and worms, mammals play a key role in food webs, featuring as both top predators and abundant prey. They act as ecosystem engineers, creating suitable habitats for other species, dispersing seeds, and ensuring the smooth working of global matter and energy cycles (Lacher et al. 2019). These functions add to their well-recognized contributions to the food system, such as pest control and pollination, and their direct supply of protein from game.

Regions with greatest mammal biodiversity include mountainous regions and low-latitude areas in the Andes mountain range, Atlantic forests in South America, and regions in Sub-Saharan Africa and Southeast Asia—all areas severely threatened by dramatic habitat loss (Grenyer et al. 2006; Pouzols et al. 2014; figure 10-1). With most mammal species living in forests, increased rates of deforestation due to agricultural expansion, and to a lesser extent logging and wood harvesting, are among the main threats to mammals.

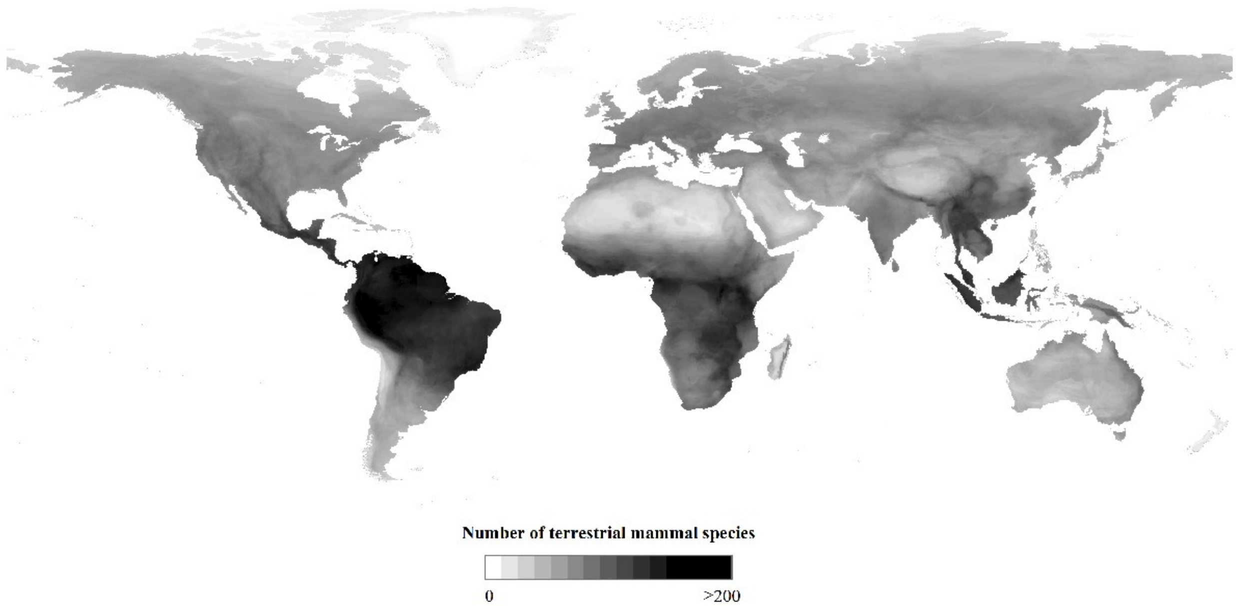


Figure 10-1: Species richness of global terrestrial mammals (~1km spatial resolution). Modified from IUCN and CIESIN (2015).

Beyond agriculture, overexploitation, including hunting of wildlife for food, poses an additional key threat to mammals and is contributing to their global extinction (Ripple et al. 2016).1 The so-called bushmeat crisis, a term used to describe the overharvesting of wildlife, has long been identified as an extraordinary threat to food security and to public health through emergent zoonotic diseases (Nasi et al. 2008). A recent global study showed that regions with high environmental degradation and human encroachment in previously biodiverse areas face major emerging zoonose risks (Allen et al. 2017), highlighting the link between ecosystem health, biodiversity conservation, and human health.

**Mammals at Risk**

To track the evolution of mammal species and help guide efforts to protect their diversity, the International Union for the Conservation of Nature (IUCN) has developed and maintains the Red List, the most widely used system for categorizing the extinction risk of species. According to the IUCN Red List, at least 21 percent of all mammal species are threatened with extinction, with estimates climbing up to 36 percent because of partial data deficiency (figure 10-2), that is, a lack of information sufficient to determine the extinction risk of some species (IUCN 2020a).

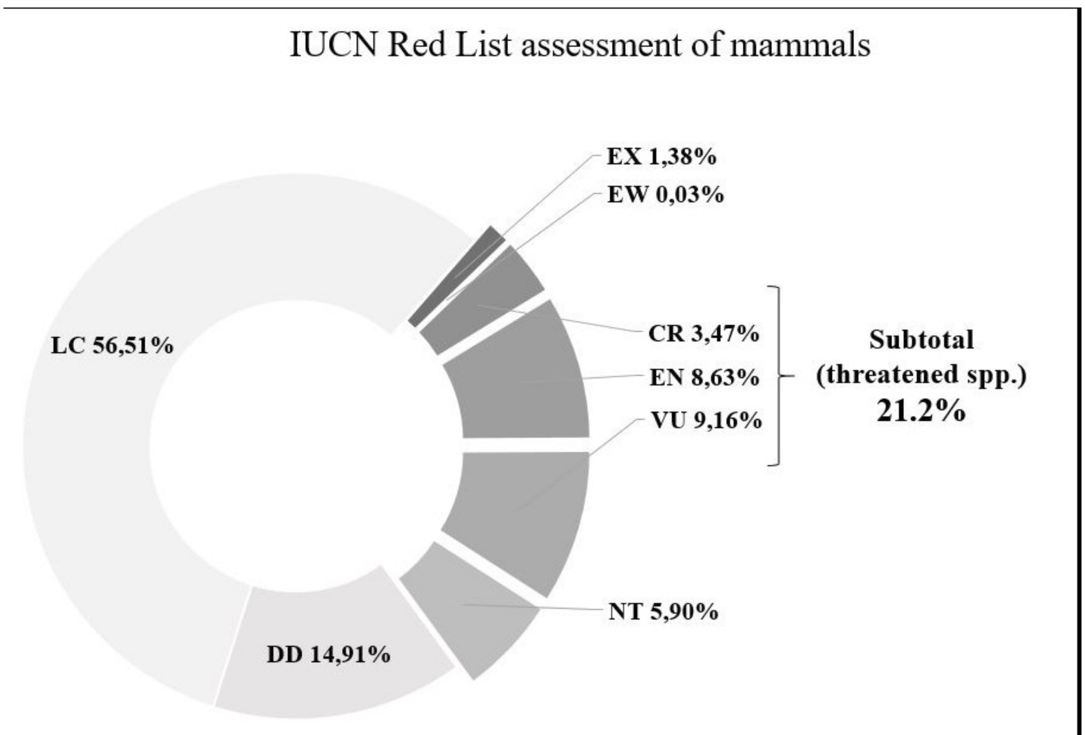


Figure 10-2: IUCN Red List assessment of marine and terrestrial mammals, including 5850 species assessed. Categories: EX - Extinct, EW - Extinct in the Wild, CR - Critically Endangered, EN - Endangered, VU - Vulnerable, NT - Near Threatened, DD - Data Deficient, LC - Least Concern. Source: IUCN 2020a.

About four fifths of the species for which data are deficient live in the tropics, regions home to some of the most diverse world habitats but also characterized by rapid land use transformation and habitat degradation. This implies that the largest knowledge gaps in terms of species extinction risks are concentrated in areas in high need of conservation. Similarly, most newly described species live in areas of high endemism but also rampant development (Reeder et al. 2007).

## Agriculture, the First Cause of Mammal Declines

The high level of globalization of our food supply implies that food is often consumed far from where is produced and where environmental damages take place; indeed, most agriculture expansion and intensification in intact tropical forests reflect production of commodities destined for export. Specifically, by far the leading cause of deforestation is cattle ranching, as intact forests are cleared for pasture. Other causes of deforestation, in order of importance, are crop agriculture of soy and palm trees for the production of palm oil, followed by mining and logging (see chapter 8). Eighty to 99 percent of the biodiversity impact of food crop consumption in industrialized countries occurs abroad (Green et al. 2019).

Expansion of palm oil, a strictly tropical crop, has put the major producing countries on an extinction highway. From 1990 to 2005, 57 percent of palm oil expansion occurred at the expense of primary forests in Malaysia and Indonesia, which are on track to lose 75 percent of their total forest area and up to 42 percent of all their regional species by 2100. At least half of these species are found nowhere else in the world (Brook et al. 2006; Koh and Wilcove 2008). Some of these forests' most majestic and iconic mammal species are already on the verge of extinction, such as the Sumatran rhino (*Dicerorhinus sumatrensis*), recently declared extinct in Malaysia, with only a tiny population surviving in Indonesia (Gokkon 2019), or the three remaining species of orangutan, all listed as critically endangered (Ancrenaz et al. 2016; Nowak et al. 2017; Singleton et al. 2017). Forest loss due to palm oil plantations is also disrupting the ecological and water balance that sustain other productive activities in nearby areas. Similarly, the fast encroachment on large plantations in Colombia, the first palm oil producer in Latin America to export more than 50 percent of its production, has locally displaced characteristic fauna of the Chocó biogeographic region, one of the most biodiverse regions of the country and the world (Myers et al. 2000). In addition, intensive pesticide use involved in growing palm trees has polluted water sources, making economically unviable many other crops in the region, including palm oil itself, the production of which suffered a steep decline a few years after being introduced (Lizcano 2018).

**Overexploitation**

Alongside agriculture-driven deforestation, the overexploitation of mammals for food is one of the most important threats to vertebrate species, including mammals. Nearly all countries and territories of the world (89 percent) have bird species that are threatened by overexploitation (BirdLife 2012), and for some species such as tortoises and turtles in Asia, hunting is a particularly serious threat. Yet hunters usually kill more mammals than birds, and more birds than reptiles. Thus, mammals appear to be more affected by overexploitation, with larger species, especially primates (126 species) and ungulates (65 species), particularly targeted. Notably, all the 301 mammals that are threatened by hunting are found in developing countries, and only 8 of these species are also found in developed countries (Ripple et al. 2016).

Defaunation, or the depletion of wildlife populations (Dirzo et al. 2014), is driven mainly by subsistence hunting and commercial hunting (Redford 1992), both legal and illegal. Subsistence hunting by low-density populations living in tropical forest and rural areas is a vital protein source, generally more important to indigenous people who have exercised this practice for centuries than to new settlers whose income allows them to access the domesticated animal market. Between 5 and 8 million people in South America, mostly indigenous and semirural communities, regularly rely on wild meat or bushmeat as an important component of household food security (Rushton et al. 2005), not necessarily in terms of quantity but as a key element in diet (Van Vliet et al. 2015). In the Amazonian trinational frontier, nutrients obtained through hunting activities and fishing play a key role in diversifying and enriching modern diets in semiurban areas. Bushmeat represents approximately 32 percent of the caloric intake, 72 percent of consumed protein, and 77 percent of iron in the diet of families who still consume it, and they obtain significantly higher amounts of vitamin C, iron, and zinc than families who do not eat bushmeat (Sarti et al. 2015). The number of households consuming bushmeat in the Amazon region could be considered low (14.3 percent) if compared with other tropical regions and reflects a change in food habits, because people living in transition zones between rural and urban areas experience an abrupt decrease in bushmeat consumption, replaced by an increasing intake of frozen chicken and beef (Nardoto et al. 2011).

In rural households of Central Africa, bushmeat represents up to 88 percent of the overall protein intake and nearly 100 percent of animal proteins (Koppert et al. 1996), suggesting that the meat supply from hunting is higher than the nonwild meat supply locally generated or imported (Fa et al. 2003). In a remote area of the eastern rainforest in Madagascar, wildlife consumption was associated with significantly higher concentrations of hemoglobin, an oxygen-carrying protein in red blood cells whose deficiency can lead to anemia. The removal of bushmeat would translate into a 29 percent increase in the number of children suffering from anemia, and three times the number of cases for children in the poorest households. The relation between micronutrient deficiencies such as iron anemia and the likelihood of developing other diseases, with negative health consequences for brain metabolism, neurotransmitter function, motor development, and emotional regulation, demonstrates the significant and far-reaching effects of losing wildlife species in the absence of other meat alternatives (Golden et al. 2011).

Although bushmeat contributes substantially to the diets of indigenous and semiurban communities (Koppert et al. 1996; Fanzo et al. 2013; Cawthorn and Hoffman 2015), human dependence on bushmeat results in unsustainable demand. This phenomenon is further aggravated by resource extraction from primary forests and higher failure rates in rain-fed crop production due to climate instability (Fa et al. 2005). Overexploitation as a byproduct of forest encroachment is exemplified in Maiko. Maiko is an emblematic national park embedded in the West African rainforest of the Democratic Republic of Congo, hosting unique biodiversity and wilderness preserved in more than 10,000 square kilometers of intact primary habitats. The park is home to endemic species such as Grauer’s gorilla and the okapi, as well as forest elephants, leopards, chimpanzees, and giant pangolins. This natural richness has also attracted a big bushmeat trade that is exacerbated by illegal mining of a mineral called coltan, an essential component of phones, computers, and solar panels (Ridder et al. 2013). Since the early 2000s, demand for bushmeat from Maiko has increased dramatically as thousands of people have settled near the mines, and animals in a radius of 5 to 10 square kilometers around mining camps have become a target. The bushmeat trade enabled by these mines is considered the single biggest threat to wildlife in the park (Redmond 2001; Hayes and Burge 2003; Fritts 2019). For instance, the

Grauer's gorilla population has dropped by 77 percent over a twenty-year period, and it is now listed as critically endangered on the IUCN Red List (Plumptre 2016).

Extraction industries propel forest encroachment and exacerbate fauna overexploitation. In Central Africa, for example, industrial logging has become the most extensive land use, with more than 600,000 square kilometers under concession, occupying 30 percent of a forest considered among the most pristine on Earth (Laporte et al. 2007). The illusion of a job opportunity in the logging industries attracts locals along with a large migration of hunters, traders, and their families, facilitating the establishment of villages with a fragile emerging subeconomy in remote areas (Cawthorn and Hoffman 2015). The human influx and increased forest access rapidly generate a huge demand for bushmeat as a response to the difficulty of accessing other meat options. The initial informal demand for bushmeat transforms into an in situ market with potential links to more developed external economies (Poulsen et al. 2009). Bushmeat consequently becomes a valuable commodity, transforming a subsistence activity into a commercial one, where profit is the main objective (Cawthorn and Hoffman 2015). Overexploitation of wildlife amid extraction activities in Central Africa exemplifies a worldwide trend that has put 285 mammal species on the threatened list of extinction due exclusively to human consumption (Ripple et al. 2016).

Consumption rates of bushmeat vary substantially worldwide depending on land productivity for other uses, abundance of wildlife, price and accessibility of meat alternatives, and wealth and preferences of consumers (Coad et al. 2019). A consistent relationship between wealth and wildlife consumption emerged across African countries, indicating that bushmeat is consumed in greater proportions (relative to other meats) depending on location by households with different income levels, namely wealthier households in urban areas and poorer households in rural areas (Brashares et al. 2011). In the Congo Basin, for example, urban consumption is widespread and correlated with income (Mbete et al. 2011), and although individual urban intake appears lower than that for rural people, aggregate consumption is higher in urban areas as a result of a larger population (Nasi et al. 2011). In Asian urban markets, the massive demand for wildlife products reflects status as such products are seen as a luxury good rather than a necessary protein source. In poorer countries, such as Laos, by contrast, game may constitute a significant supplement to urban diets, although diets have turned progressively to protein from farmed animals after the depletion of wildlife (Bennett and Rao 2002). In South America, urban bushmeat consumption was previously considered negligible (Rushton et al. 2005), but recent evidence shows that wildlife trade is increasing in response to external demand. In Peru, for example, current levels of the trade in primate species have been compared to numbers before the 1973 ban on international trade (Shanee et al. 2017). Increasing urban demand worldwide suggests that the consumption of bushmeat is no longer driven by subsistence needs but rather is increasingly spurred by a global and dynamic market thriving on the often illegal trade in “food delicacies” (Barnett 2000).

Commercial hunting includes the consumption of body parts as medicine (affecting sixty-seven species of mammals globally), the capture of live animals for the pet trade (forty-six species), and ornamental uses such as trophies (thirty-six species) (Ripple et al. 2016). Live trade and ornamental use affect wild mammals living primarily in Southeast Asia and secondarily in Africa and Latin America (Baillie et al. 2004), with an exorbitant demand for various wildlife products originating in China, Southeast Asian countries, the United States, and the European Union. More than 260 tons of wild meat per year were estimated to be smuggled in personal baggage into just one European airport (Paris Roissy-Charles de Gaulle) in 2008 (Chaber et al. 2010). Pangolins, the most traded wild mammal, and jaguar body parts are quoted in the Asian market at prices as high as cocaine (Navia 2018). According to a local newspaper, in one day about 4 tons of smuggled frozen pangolins were seized in Zhuhai, China, one of the largest cases of smuggling a protected animal (Liu and Weng 2014). Pangolins are imported mostly from Africa but also from Malaysia (EIA 2020), and jaguars are taken from throughout their geographic range in America. Both species are prized because of nonscientific claims of medicinal use, consumed as "wildlife delicacies," and, in the case of jaguar fangs, seen as a symbol of status, strength, and power. Demand for wild meat by growing numbers of urban and foreign consumers as a symbol of wealth rather than an alternative to rural poverty has fueled a globalized market with unsustainable levels of hunting, originating mostly in tropical regions and targeting population centers all over the world. The illegal wildlife trade market has been estimated at between $7 and $23 billion a year (Wilkie and Carpenter, 1999; Nellemann et al. 2016).

The bushmeat crisis caused by commercial and subsistence hunting is catastrophic not only for wildlife but also for the livelihoods of people who rely on it as a major source of protein. Exploitation rates for countries in the Congo Basin indicate that if current extraction levels continue, there will be a severe protein deficit by 2050 and insufficient non-bushmeat protein produced to replace the amounts supplied by wild meat (Fa et al. 2002). Most countries in the region, where 60 percent of all mammal species hunted are exploited unsustainably, will have to find different sources of protein from the agricultural sector (Fa et al. 2003). Conversely, if harvesting is reduced to sustainable levels, proteins from sources other than bushmeat will not be able to meet the dietary needs because of the low agricultural production, a limited livestock sector, and a rapidly increasing population (Barnett 2000). A severe loss of bushmeat protein will exacerbate malnutrition and poverty, putting the livelihoods of millions of people at risk unless alternatives are promptly developed (De Merode et al. 2004; Cawthorn and Hoffman 2015).

Beyond the devastating impacts on human food security and biological diversity, the economic and consequences of wild animal trade cannot be overstated. For example, pangolins are a prime suspect among possible animal sources of the COVID-19 pandemic that originated in Wuhan, China, because dozens of people infected early in the outbreak worked in a live-animal market where pangolins were traded, although tests of coronavirus samples found at the market have yet to determine the precise animal source of the pathogen. The SARS epidemic in 2002 also originated in China and is believed to have jumped to humans from civets also in a market illegally trading wildlife (Cyranoski 2020).

**Invasive Alien Species**

Invasive species are a product of human activities that deliberately or accidentally transport and introduce large numbers of species to areas beyond their natural distribution. They have a range of well documented impacts in their new environments, including direct competition for resources or the introduction of pathogens that sicken or kill native species, and they are often cited as one of the most common causes of recent and ongoing extinctions (Doherty et al. 2016). Alien species were listed as the single cause of extinction for 47 percent of all extinct mammal species in the IUCN Red List (Bellard et al. 2016). Introduced species, including mammals, at times responding to specific agricultural aims, have extinguished native species in many parts of the world. For example, Pacific rats reached New Zealand with the first human immigrants. Now evidence of predation on invertebrates and vertebrates shows that Pacific rats are responsible for local and global extinctions of species including beetles, grasshoppers, land snails, frogs, lizards, small seabirds, and land birds (Atkinson 1996).

Not only biodiversity is threatened by alien species. Feral pigs, native to Eurasia and North Africa and introduced in the United States and Australia, are estimated to cause about $0.8 billion in damages to the agricultural sector in the United States and at least $80 million per year in Australia. Soil erosion, damage to agricultural crops including vegetables, fruits, orchards, and vineyards, and the spread of diseases to livestock including tuberculosis, brucellosis, and rabies are among the negative consequences. Introduced rodents are also among the species causing serious damage to farms, industries, and homes all over the world, demonstrating our limited ability to control exotic species once introduced. On farms, rats and mice are particularly abundant and destructive, causing $19 billion in damages per year in the United States and about $25 billion per year in India (Pimentel et al. 2001).

**Climate Change**

Climate change is expected to alter species distribution, abundance, phenology (the timing of events such as migration or breeding), morphology (size and shape), and genetic composition (Baillie et al. 2004). Although few mammal species have been recorded to be affected by climate change, a recent analysis of observed impacts has shown that the proportion of mammals already experiencing negative effects may be ten times higher than previously thought (Pacifici et al. 2017). Under a business-as-usual scenario with increasing greenhouse gas emissions, 16 percent of species are predicted to become extinct as their geographic ranges become unsuitable due to climate-related effects (Urban 2015; Costa et al. 2018).

Some species are already experiencing the effects of climate change on their survival (Jones and Rebelo 2013). For instance, in 2018 in Portugal some bat colonies completely avoided winter hibernation, a synchronized natural strategy to avoid the lack of food resources in winter that should normally happen between December and February, and for the first time recorded, some individuals gave birth earlier. The effects of a changing climate are potentially catastrophic for bats, especially in temperate areas, because the absence of hibernation can start pregnancies sooner, putting the offspring at risk of malnutrition and mortality (Briggs 2018).

Temperature variations are also influencing the progression and severity of emerging pathogens (Verant et al. 2012). White-nose syndrome is a recently discovered fungal pathogen in bats that seems to be exacerbated by increased energetic stress and is causing the most precipitous decline in bat populations ever reported. By 2012, the pathogen had killed more than 5 million individuals belonging to seven different species in the United States (Wibbelt et al. 2010; Reeder et al. 2012), including the little brown bat (*Myotis lucifugus*), once a common species whose population declined by 1 million individuals, almost causing its regional extinction (Frick et al. 2010). Extrapolations based on the 4–8 grams of insects that each little brown bat can eat per night averaged about 1,000 metric tons of insects that are no longer being consumed each year (Sherwin et al. 2013). The extraordinary capacity of bats to eat huge numbers of insects, including agricultural pests, exemplifies their contribution to the regulation of population cycles and potential outbreaks (Whitaker 1995). Emerging diseases in mammal species providing key ecosystem functions such as pest control could prove economically disastrous for the agricultural sector (Boyles et al. 2011).

## Conservation Goals and Targets

Recognizing the importance of biodiversity (of genes, species, and ecosystems) underpinning Earth systems on which human economic and social systems rely, and acknowledging that biodiversity is under threat due to human activities, international treaties and conventions have been set to guide countries on conservation priorities with a broad range of objectives. The Convention on International Trade in Endangered Species of Wild Fauna and Flora, for example, is an international agreement between governments that entered into force in 1975 and aims to ensure that international trade in wild animals and plants does not threaten their survival.

The UN Environment Programme also recognized the need for an international convention on the protection of biodiversity. A process that started in 1988 took the form of a global commitment to sustainable development, recognized as the Convention on Biological Diversity and entered into force with 168 countries in December 1993. Since then, several decisions, conferences, reports, strategic plans, protocols, and assessments have been developed to create a framework where countries can follow the state and trends of diversity but are also informed of further relevant steps to implement actions at the national, cross-sectoral, and policy level that would lead to the overall goal of protecting global biodiversity. As part of the Convention on Biological Diversity actions, the Aichi Targets have been established as a strategic plan to be implemented between 2010 and 2020. Aichi Target 12 in particular requires that by 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained (see also chapters 8, 9, and 11 in this book). However, biodiversity continues to decline steeply, and recent projections suggest that it is unlikely that most of the Aichi targets will be achieved.

More recently developed, the Sustainable Development Goals have been promoted by the United Nations as another attempt to call for political action to stop worldwide biodiversity decline. In particular, Goal 15 establishes that "urgent and significant action [should be taken] to reduce the degradation of natural habitats, halt the loss of biodiversity and, protect and prevent the extinction of threatened species" by 2030. In an attempt to describe which actions would be necessary to achieve these goals, Visconti et al. (2016) estimated how a set of different economic scenarios could affect conservation objectives. Under a business-as-usual scenario, where patterns of consumption and production remain the same as in the recent past and human population follows current trends, land use and climate change are predicted to outpace the ability of many mammal species to adapt, causing a steady decline in species richness and abundance. In contrast, under a "consumption change" alternative scenario, driven by measures to reduce deforestation and logging and set aside areas for biodiversity protection, the percentage of large mammals at risk of extinction is reduced from the current 34 percent to 18 percent.

Reducing meat consumption is a key element of proposed scenarios in which both biodiversity and zero hunger targets are achieved. A major misuse of natural resources derives from livestock production, with only 10 to 30 percent of animal feed ultimately converted into edible products. Additionally, based on dietary recommendations, a major reduction in meat intake could take place in every region of the world except for Africa and some areas in Asia. Food waste reduction is an important complement because one third of global food production is lost, with most of it occurring at the retail and consumption stage in North America, Oceania, and Europe. Improved access and distribution of food and a substantial reduction in consumption of meat and dairy products are projected to significantly lower the amount of agricultural land needed to maintain a stable and sufficient food supply in the long term, and they will increase the likelihood of meeting biodiversity objectives (Van Vuuren et al. 2012).

Interestingly, a report issued in January 2020 that was intended to describe the consequences of environmental degradation in terms of gross domestic product (GDP) highlights converging points between biodiversity conservation scenarios and better economic performance. For instance, up to 2050, a business-as-usual scenario would result in GDP losses of about 0.7

percent per year due to the loss of ecosystem services, whereas a “global conservation” scenario, with targeted environmental changes, would be the only one yielding global GDP gains (Johnson et al. 2020).

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has documented that by maintaining the current unsustainable patterns of food production and consumption, most countries will miss the agreed biodiversity goals for 2030 and 2050, with negative impacts on the contributions of nature to human well-being. However, it also demonstrates that scenarios that take substantive and immediate action to halt environmental degradation and avoid species extinction are still a possible pathway to achieve the goals (Díaz et al. 2019). If Sustainable Development Goals and future biodiversity and environmental targets are to be achieved, each country must take responsibility and define how to act to stop and reverse the declining biodiversity trend (Mace et al. 2018). Institutional capacity and funding availability highly influence the achievement of suggested targets; therefore, governments play a central role defining and enforcing national and regional actions to achieve the global targets. Broader recognition of the role of business and finance sectors has also shed light on a dramatic change in efforts to be led by them, because their global reach through international trade and globalized value chains gives them the capacity to drive biodiversity protection (Díaz et al. 2019).

## Economic and Environmental Benefits of Conserving Mammals

Our global food supply depends on well-functioning ecosystems, and biodiversity is the backbone of those systems (Díaz et al. 2019). Natural areas, from the boreal forests to the tropics, need healthy fauna to support human populations (Redford 1992). Some examples of how mammals participate in ecosystem functions and provide benefits to people are shown in table 10-1. One way mammals contribute is by increasing biomass production and carbon capture in soil, which is important to both crop production and climate change mitigation (Sobral et al. 2017). When carcasses, food scraps, and animal feces decompose, microbes break them down into a nutrient-rich soil that stores carbon or releases it for plants to grow and store it. Organic carbon is the basis of soil fertility, an essential element of crop productivity (Herrick and Wander 2018). Additionally, soil's ability to sequester carbon is increasingly recognized as essential to limiting climate change.

Table 10-1. Examples of Mammal Species' Role and Their Contribution in the Ecosystem

| **Role or Contribution** | **Mammal Species** | **Common Name** | **Effects in the Ecosystem** |
|---|---|---|---|
| Top predators | *Canis lupus*<br>*Gulo gulo*<br>*Puma concolor*<br>*Panthera onca*<br>*Ursus americanos*<br>*Ursus arctos*<br>*Ursus maritimus* | Gray wolf<br>Wolverine<br>Puma, cougar<br>Jaguar<br>Black bear<br>Grizzly bear<br>Polar bear | Absence of apex or top predators, generally large carnivores, reduces control over mesopredators, which can reduce populations of birds, including pollinators and pest regulators (Crooks and Soulé 1999; Prugh et al. 2009). |
| Pollinators | For a comprehensive list of flying pollinator mammal species, see Regan et al. (2015). | | Bats are the principal pollinators among mammals, pollinating a large number of economically and ecologically important plants known to provide valuable products to humans, including numerous fruits and important commodities for the industry (Regan et |

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|---|---|---|---|
| | | | al. 2015; Bumrungsri et al. 2009). |
| Terrestrial seed dispersers | *Sciurus granatensis*<br>*Macaca nemestrina*<br>*Muntiacus muntjak*<br>*Loxodonta africana*<br>*Sus scrofa*<br>*Tapirus indicus*<br>*Helarctos malayanus*<br>*Antechinus stuartii*<br>*Petaurus breviceps*<br>*Ateles paniscus* | Red-tailed squirrel<br>Pig-tailed macaque<br>Red muntjac<br>African forest elephant<br>Eurasian wild pig<br>Malayan tapir<br>Sun bears<br>Brown antechinus<br>Sugar glider<br>Red-faced spider monkey | Play a key role in the maintenance and natural regeneration of forest areas, especially in the tropics (McConkey 2000). Their presence ensures forest functionality and more productive agroforestry systems (Paolucci et al. 2019). As forest cover influences interactions between land surface and the lower atmosphere, forests have the capacity to affect regional climate (Lawrence and Vandecar 2015; McAlpine et al. 2018). For instance, in Borneo, historical climate analyses showed that deforestation is associated with increased daily temperatures and reduced precipitation, which in turn affects the agricultural production of important crops such as palm oil (Oettli et al. 2018). |
| Pest control | *Eptesicus fuscus*<br>*Myotis lucifugus* | Big brown bat<br>Little brown bat | Mammal species control herbivorous arthropods, including pest insects. Bats have been demonstrated to indirectly suppress the presence of pest-associated fungus and its toxic compounds. In the United States the value of insectivorous bats connected to the agricultural sector is about US$22.9 billion a year. Only for corn, it is estimated that the suppression of herbivory by insectivorous bats is worth more than US$1 billion globally (Boyles et al. 2011; Maine and Boyles 2015). |
| Maintenance of water-pro- | *Tapirus pinchaque*<br>*Tremarctos ornatus* | Mountain tapir<br>Spectacled | Play vital ecological role as seed dispersers in the cloud forests and Páramos of the northern |

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|---|---|---|---|
| viding ecosystems | | bear | Andean ecosystems, which serve as vital watersheds for all the ecosystems lying below them, including those on which humans' water supply and crops depend (Downer 2001; Caveljer et al. 2011; Lawrence and Vandecar 2015). |
| Maintenance of genetic varieties of domesticated animals | *Bubalus bubalis* | Wild Asian buffalo | Buffalo breeds that defend themselves against predators are a good livestock alternative that improves meat production while preventing human–wildlife conflicts (Payán et al. 2015). |
| Ecosystem engineers | *Puma concolor*<br>*Bubalus arnee*<br>*Castor fiber* | Puma<br>Wild water buffalo<br>Beaver | By increasing habitat heterogeneity, ecosystem engineers increase the number of species of plants in forests and riparian zones and create new microhabitats, which are home to many insects, amphibians, birds, and fish species, with the correlated benefits of rich ecosystems such as reduction of pest outbreak risk (Wright et al. 2002; Deinet et al. 2013; Elbroch et al. 2017; Barry et al. 2019). |

*Note.* List of species given is not comprehensive.

Increasing studies report the potential mammals have as an effective, economical, and simple way to capture carbon from the atmosphere. For instance, whales have a great capacity to sequester carbon to the deep sea. When they die, they sink to the bottom of the ocean, taking an average of 33 tons of $CO_2$ out of the atmosphere. Whales also act as multipliers of phytoplankton, some of the smallest creatures on Earth and the base of aquatic food webs in the ocean (Lavery et al. 2014; Roman et al. 2016). In balanced ecosystems the importance of phytoplankton also lies in their role as a key mediator of the biological carbon pump, responsible for the net transfer of $CO_2$ from the atmosphere to the oceans and then to the sediments, subsequently maintaining atmospheric $CO_2$ at significantly lower levels than would otherwise be the case (Riebesell et al. 2007; Basu and Mackey 2018). More whales equal more phytoplankton, more fish in the ocean, and less $CO_2$ in the atmosphere. On top of their intrinsic value as living creatures, carbon sequestration, fishery enhancement, and tourism make whales' contribution to healthy ecosystems worth billions of dollars, adding to the increasing reasons to protect them (Roman et al. 2014; Chami et al. 2019).

Lower livestock productivity rates, stagnant crops, and the projected scarcity of limiting resources such as water exemplify the increasing threat that climate change poses to agricultural production. Between 2003 and 2013, the agricultural sector in developing countries in Africa, Asia, and Latin America absorbed one quarter of the total economic losses caused by climate-related extremes. Frequent, intense, unpredictable climatic disasters such as droughts, floods, and storms caused an estimated $70 billion lost in production for the livestock and crops subsector (FAO 2015). In Europe, the heat catastrophe of 2003 produced livestock and crop losses of approximately $12.3 billion, and countries such as Portugal faced the worst forest fire season in decades, with wildfire deaths and 400,000 acres of timber loss (Epstein and Mills 2005). Other significant threats to livestock include the higher risk of contagion of new diseases, nutritional deficiencies, and heat stress, resulting in an overall reduction in production. Lower supplies of milk and meat and the disruption of reproductive processes have been demonstrated to cause decline and instability in prices and loss in net values of animal stocks (Kuczynski et al. 2011; Escarcha et al. 2018).

Here again, natural ecosystems offer solutions, because biodiversity is increasingly relevant for the possibilities that genes and gene combination offer to adapt to extreme weather conditions, diseases, and parasites (Lande and Shannon 1996). Genetic manipulation to produce new breeds and crop varieties has increased in recent decades. Enhancement of animal adaptations to extreme environmental conditions and increased tree productivity in forestry systems are only a couple of the many success stories of the use of genetic diversity (Maxwell 1994; Diaz et al. 2019). The sustainability of animal production systems thus depends on the continuing availability of a wide diversity of animal genetic resources and raw materials, many of which are uniquely contained in the forests and natural habitats of the world (Kantanen et al. 2015).

**Mammal Conservation in Agricultural Landscapes**

Policies to preserve mammals are essential to ecosystem function and food production systems. Most of these policies can be put into practice on a regional or local basis and support integrated management of agricultural and biodiversity areas, as detailed below.

1. Restriction of agricultural expansion in areas of special importance for biodiversity to maintain critical habitat.

- Prioritize the conservation of areas holding special values for biodiversity (endemic species, high species richness, endangered species) to prevent the conversion of forest or natural habitats to agricultural production. Restrict the future expansion of agriculture, including industrial-scale logging, to preexisting cropland or degraded habitats.

- Avoid protected area downgrading, downsizing, and degazettement (Mascia et al. 2014).
- Develop landscape-scale planning programs that integrate the sustainable use of natural resources and make use of diverse conservation strategies (Garnett et al. 2018; IUCN WCPA 2019).

2. Promote long-term sustainable and productive use of current agricultural land.

- Payments for biodiversity to farms that provide evidence of good ecological performance, including allocating a minimum permanent percentage of agricultural land as biodiversity promotion areas. Increased benefits if allocated within a connectivity matrix that favors the migration of apex species 0(Jason et al. 2016).
- Payments for good practices to farms able to demonstrate the implementation of management measures, for example through the adoption of physical barriers that prevent human–wildlife conflicts (Payán et al. 2013; Valderrama et al. 2016).
- Compensation for production losses (livestock, fruits, vegetables) due to human–wildlife conflicts while implementing landscape-level, long-term institutional strategies to prevent further conflicts.
- Taxes to limit the excessive use of synthetic inputs. Restrictions based on scientific recommendations of what is biologically sustainable in the local context. This will also reduce greenhouse gas emissions, with positive effects on both biodiversity and climate change mitigation.

- Penalties for water contamination and tradable water right permits to limit water consumption above established thresholds according to farm size, crop type, and other local users.
- Eliminate subsidies that contribute to unsustainable use of resources and reduce biodiversity (e.g., overuse of synthetic inputs such as fertilizers and pesticides).
- Develop and implement policies to promote good agricultural practices that increase local conservation of biodiversity, for example, by retaining natural habitats in farmlands (Dicks et al. 2014).
- Promote well-conserved habitats for species connectivity within the agricultural matrix (Crick et al. 2020).
- Promote mixed farming practices and crop heterogeneity at the landscape level, which are particularly beneficial for farmland wildlife.
- Restrict the use of alien species unless absolutely necessary, and only then under tight introduction measures.

3. Ensure funding for research and implementation of conservation strategies that favor both biodiversity and agricultural production.

- Redirect funds collected from environmental taxes (e.g., carbon tax), fees, and penalties to biodiversity conservation and sustainable agricultural development, for example by providing farmers with incentives for innovation in good environmental practices.
- Allocate resources to benefit farmers who adhere to ecological certification programs. Provide payments for production costs, especially when farmers are transi-

tioning to better practices and probably facing higher costs (Blackman and Naranjo 2003).

- Fund joint strategies by environmental and agricultural agencies and external independent monitors, to promote good production standards at the individual farm level.
- Secure sufficient, stable, and long-term financial resources that attract producers to implement sustainable production strategies.
- Encourage conversion to ecological intensification strategies (Garibaldi et al. 2019) by offering clear economic benefits for demonstrating good practices.

4. Increase collaboration between public and private sectors at the local, regional, and international levels.

- Ensure that producers and suppliers have access to information and technology that enable them to benefit from organic production, certification programs, and fair or direct trade markets.
- Increase collaboration between various government agencies (environment, agriculture) to identify agricultural production areas where it is possible to conserve biodiversity through connecting corridors of natural habitat (Parmesan 2006; Aguiar et al. 2016).
- Develop joint strategies with farmers to achieve stable or high crop productivity and resilience in the long term by protecting ecosystem services such as natural pest control and pollination.
- Facilitate data exchange between research institutions, universities, and private and government entities that promote sound agricultural practices.

- Promote education and research that increase public and government awareness of consumption, production, and trade patterns and their effects on human well-being and biodiversity.

5. Cooperation between agricultural, environment, and interior ministries to develop policies that support sustainable agriculture and biodiversity.

- Ensure institutional capacity and transparency for the enforcement of international treaties and conventions.
- Enforce international commitments and national regulations across all actors in the supply chain, including producers, suppliers, and final consumers.

**Country Cases**

Beaver Comeback

Beavers once lived throughout Eurasia, but by 1920 the species had reached a historical low, with fewer than 1,200 individuals surviving in five fragmented populations. Agricultural expansion and overexploitation for beavers' fur and supposed medicinal benefits put this large rodent at the edge of extinction. Hunting restrictions and long-term conservation efforts to recover their natural habitats have allowed a remarkable recovery over the past forty years (Deinet et al. 2013). Completely extirpated from Latvia and Sweden in the nineteenth century, those two countries currently represent almost 50 percent of the total European population, an extraordinary recovery because there are more than 100,000 individuals in Latvia.

Beavers are recognized as ecosystem engineers; the river canals, dams, and ponds they build create microhabitats for other species, including insects, amphibians, fishes, and birds

(Deinet et al. 2013). In the United States, beaver constructions along rivers improve habitat quality and the quantity of steelhead trout and salmon, both important species for the fishing industry (Malison et al. 2015; Bouwes et al. 2018). Ponds also raise groundwater elevation, increasing river flows throughout the summer as water is slowly released. This increases habitat for fish during hot, dry summers. Raising the groundwater level also increases the number of birds and invertebrate biomass, which benefits agricultural production and biodiversity (Oomes et al. 1996).

Another important service provided by beavers is carbon storage. Differences in total organic carbon between abandoned and active beaver meadows suggest that carbon storage declines substantially as beavers disappear and meadows dry out (Wohl 2013). Maintaining beaver populations in the wild results in ponds standing as substantial sinks for watershed nitrogen, reducing eutrophication and habitat degradation and improving water quality (Lazar et al. 2015).

Beaver reintroduction programs provide nature-based solutions to water shortages in agricultural landscapes (Puttock et al. 2017), which are proven to be more cost-effective than human intervention. Although beavers were almost extinguished because of their great capacity to modify landscapes, sometimes causing flooding in lowland areas, the current consensus is that their benefits outweigh the disadvantages. Nonetheless, ecologically sound management is needed in areas where they share their habitat with people and agricultural landscapes.

## Poison-Free Pest Control

The remarkable usefulness of bats has long amazed farmers (Olson and Maher 2018). Today, bats are increasingly recognized for their effective pollination of fruits and their capacity to control pests (Riccucci and Lanza 2014; Aziz et al. 2017).

Bats eat up to 100 percent of their body mass in insects on a nightly basis, benefiting farmers in countries around the globe, including Brazil, Indonesia, Spain, and the United States. This natural pest control is an effective alternative to excessive pesticide use, which threatens human health and the environment. In Spain, for example, the soprano pipistrelle bat controls infestations of a moth species known as the rice borer; the economic value is at least €21 per hectare, equivalent to the avoided pesticide expenditure alone (Puig-Montserrat et al. 2015).

Biodiversity of bats in their natural ecosystems is essential to prevent pest outbreaks. In a tropical lowland forest in Panama, the diversity of bats and birds reduces insects on plants, thus reducing herbivory and the risk of pest outbreaks. Experiments show that bat-exclosed plants suffered 209 percent more herbivory than control areas where bats were present, demonstrating a dramatic ecological effect previously overlooked (Goldingay et al. 1991; Kalka et al. 2008). Understanding the mechanisms that link ecological systems to human well-being is fundamental in a changing world. Because of the complexity of natural processes, it is sometimes difficult to recognize nature's benefits to humans. Despite their ecological importance and contribution to human food security (Wanger et al. 2014), 192 out of 1,280 species (15 percent) are currently categorized as endangered (IUCN 2020b).

## Conclusions

The global pattern of mammal diversity is similar to that of birds and amphibians, with the greatest numbers of species residing in regions such as Sub-Saharan Africa, Southeast Asia, and the Andes mountain range and the Amazonas in South America. Because the majority of mammal species prefer forests as their main habitat, deforestation and forest degradation are among the main reasons for mammal population decline. The encroachment of the agricultural frontier into natural habitats, intensive pesticide use in large extensions of heavily industrialized crops, invasive species, and overexploitation of hundreds of species have put at the verge of extinction approximately 22 percent of all mammal species. As people have begun to recognize this decline in biodiversity and its threat to human well-being and food security, many have called for international treaties and conventions to reverse this trend. Unfortunately, we are far from achieving these targets, as biodiversity continues a steep decline.

The positive feedback between biodiversity and well-functioning ecosystems underpins human well-being and the entire global food system. Healthy populations of diverse mammal species have the potential to control crop pests, create microhabitats for other beneficial organisms, increase ecosystems' capacity to absorb carbon, and offer genetic opportunities for adaptation of domesticated animals. Mammals are outstanding allies in a changing world where events that jeopardize our ability to produce food, such as severe droughts, pest outbreaks, and climate instability, have become the new normal. Actionable policies are essential to protect mammals' diversity and their contributions to sustainable agricultural practices.

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**Endnotes**

1. Like mammals, birds and amphibians also suffer tremendously from habitat loss and overexploitation to different degrees, and their endangerment is strictly related to the threats to mammal population from agriculture and other human activities, leading, in turn, to pollution, climate change, and species invasion (Grenyer et al. 2006).