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Population Effects on Biodiversity and Climate Change: Evidence from Recent Scientific Literature, 2010-2022

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Abstract

A search of the recent scientific literature on the impact of human population growth and population density on biodiversity resulted in 131 substantial papers and books published during 2010-2022. A review of this literature found that, in general, population growth and high population density are important drivers of deforestation, defaunation, and biodiversity loss. Increasing human numbers undermine the creation and effectiveness of protected areas and lead to conversion of essential wildlife habitat for agricultural production and other human uses that displace other species. Conversely, local human population decline sometimes provides opportunities for ecological restoration and improves chances of successfully restoring extirpated species. These findings appear to hold at most scales, from local to global, and for most taxa studied. Since large human populations cause biodiversity loss while small populations foster biodiversity protection, future human numbers will play an important role in enabling or preventing a sixth mass extinction of species on the planet Earth.

Introduction

There is a consensus among scientists that biodiversity is rapidly declining. In the last 50 years, wild vertebrate populations decreased by 69 per cent globally (World Wildlife Fund, 2022). Anthropogenic extinction levels are an estimated 1,000 times higher than the historical background rate and predicted to continue climbing (Pimm et al, 2014). The Secretariat of the United Nations Convention on Biological Diversity (2010) has estimated that humanity could extinguish one out of every three species on Earth within the next one to two hundred years. Even using conservative estimates for current extinction rates, and holding these rates steady, projecting them forward a few hundred years predicts immense losses (Ceballos et al, 2015).

The cause of global biodiversity loss is clear. Other species are being displaced by a rapidly growing human economy, driven, in part, by growing human numbers (Diaz et al, 2019). The Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) has observed in its first global assessment: "today, humans extract more from the Earth and produce more waste than ever before" (IPBES, 2019). During 1970-2020, when wild vertebrate populations declined by 69 per cent, human numbers doubled, the size of the global economy quadrupled, and international trade increased tenfold. The wildlife decline has been caused by human expansion. People took habitat and resources away from other species, displacing them, because there were a lot more of us and because our economy became more successful at transforming the wild world into resources for human profit and use.

It is standard in the conservation biology literature to explain causes of biodiversity loss in terms of five main direct drivers, the most important of which are habitat loss and overexploitation of wildlife, followed by pollution, invasive species, and climate change. All these direct drivers do enormous harm to other species on the land and in the oceans. These direct drivers are "underpinned by a set of demographic and economic indirect drivers that have increased, and that furthermore interact in complex ways" (IPBES, 2019). The term "indirect driver" is misleading - fundamental causes would be more accurate - yet the message is clear enough: "anthropogenic drivers of biodiversity loss, including habitat loss as a result of land-use and sea-use change, unsustainable agriculture, aquaculture and forestry, unsustainable fishing, pollution, and invasive alien species are [all] increasing globally" (IPBES, 2019). They are increasing due to escalating human numbers, wealth, and overall economic activity.

The IPBES has called for more research into the fundamental drivers of biodiversity loss (and, more tentatively, for public policies that directly address them). In response, the authors have recently published a paper exploring the roles that population growth and high population density play in biodiversity loss (Cafaro et al, 2022). In researching that paper, we became aware of many good recently published scientific studies. In this paper, we review this material, and present main findings in an effort to spur more work and debate on these essential topics.

The paper is organised as follows. The next section describes the methods that we adopted to search the published literature on aspects of population effects on biodiversity and climate change. This search resulted in 154 research papers and books. The third section of the paper presents main findings of this literature that highlight population effects on biodiversity. These population effects on biodiversity have been further classified in terms of ecological restoration, deforestation, protected areas, agriculture and defaunation. We also present main findings of selected literature on population impacts on climate change and biodiversity ethics. The last section of the paper puts forward a set of recommendations for securing and sustaining biodiversity on the planet. The regional perspective of the population effects on biodiversity, as revealed through the published literature reviewed by us, is presented in the table appended to the paper.

Methods

We searched the published titles and abstracts in the Web of Science that included the words 'biodiversity' and 'population' during the thirteen years between 2010 and 2022 inclusive. We then read this literature and listed those studies that have dealt in a substantive way with the connections between human numbers and biodiversity loss or protection. To be included in the review, papers needed to go beyond just reporting human population trends or mentioning them as impacting biodiversity. All papers included in the review grapple with population impacts quantitatively or report them as an important part of their results. Our aim was comprehensive coverage of peer-reviewed scientific papers that deal substantively with the connection between human numbers and biodiversity. In addition, we have also included 21 select publications from the previous decade (2000-2009) which seemed particularly relevant or influential. Finally, we queried first authors of these studies regarding any papers that we might have missed and took the opportunity afforded by the revision to add several more studies published since our initial review.

We have also searched and reviewed selected published literature on the connection between human population and climate change and on the ethics of biodiversity. We found that the recent literature on both topics is large and the selected published studies reviewed in the paper only provide an introduction. Nevertheless, we have included them in this paper as they deal with important adjacent and relevant topics of interest.

Results

Population Effects on Biodiversity

We have identified 154 studies providing significant analyses of the impact of human numbers on biodiversity (Table 1). We have grouped them into eight thematic areas. We list each study only once, despite some overlap in topics they cover. These studies have also been classified by geographical areas in an appendix to the paper.

The six key findings that we have been able to make in our review of 154 studies are as follows:

1. Much recent work has been done on population and biodiversity, spanning all parts of the globe, and examining the impact of population from many perspectives. While a few conservation biologists have called for such efforts in the past (Noss et al, 2012; Rust and Kehoe, 2017), it appears that their colleagues are finally taking up this suggestion. Although there remains ideological resistance to writing about population matters (see for example Hughes et al, 2023), the obvious, ongoing failure of conservation efforts that ignore the fundamental drivers of biodiversity loss seems to have tipped the scales. Just as biologists are coming to recognise continued economic growth

is incompatible with biodiversity conservation (Pacheco et al, 2016; Dasgupta, 2021), they now are documenting the ways through which excessively large populations harm biodiversity (Kraussman et al, 2013; Rees, 2023).

2. Population growth and high population densities are important drivers of deforestation, defaunation, and general biodiversity loss. It is striking that studies exploring the importance of population growth as a driver of biodiversity loss, and the importance of high population density as an impediment to conservation success, nearly always find their effects compelling. Many studies find population impacts as dominant in determining conservation success (McKee et al, 2013; Whitmee et al, 2015), particularly when paired with per capita resource consumption (Driscoll et al, 2018; Marques et al, 2019) or the proportion of the landscape in protected areas (Brashares et al, 2002; Krishnadas et al, 2018). The rest reliably find an important effect of human population, whether focused on preserving birds (Deinet et al, 2013; Gagné et al, 2016), mammals (Ripple et al, 2015; Berger et al, 2020), fish (Vincent, 2008; Lavides et al, 2020), insects (Sánchez-Bayoa and Wyckhuysb, 2019; Raven and Wagner, 2021), or plants (Thompson and Jones, 1999).

3. Smaller human numbers and lower human population densities increase chances to establish protected areas (PAs) and increase the effectiveness of PAs in preserving biodiversity. There are many reasons for this. More people make it harder to establish protected areas (Corlett, 2016; Crist et al, 2021). They also increase poaching in and near PAs (Qiu et al, 2018); decrease support for existing PAs (Guerbois et al, 2013; Symes et al, 2016); undermine connectivity between PAs (Wade and Theobald, 2010; Radeloff et al, 2015); and increase harvesting of essential resources in PAs (Shahabuddin and Rao, 2010; Figueroa, 2015). Increasing the size, number and effectiveness of PAs is necessary for preserving the remaining biodiversity on the planet. The biodiversity benefits of smaller human populations are, therefore, clear.

4. Decreasing human populations foster success in ecological restoration as they open up new areas as candidates for restoration (Dinerstein et al, 2017; Cafaro and Götmark, 2019) and make such efforts more likely to succeed (Navarro and Pereira, 2015; Pereira and Navarro, 2015). The decreasing extractive economic opportunities associated with depopulation may increase willingness among local residents to try new approaches to living with wildlife (Schnitzler, 2014; Rewilding Europe, 2021).

5. Larger populations increase agriculture demand and hence lead to the conversion of forests, wetlands, and other biodiverse ecosystems for agricultural use. In this way, population growth fuels a leading cause of biodiversity loss through agricultural (and aquacultural) conversion (Laurance

et al, 2014; Crist et al, 2017; D'Odorico et al, 2018). Similarly, population growth increases urban development, which is another important cause of habitat loss and habitat degradation leading to significant biodiversity loss (Hughes, 2017; Kolankiewicz et al, 2022).

6. Since large human populations cause biodiversity loss while small populations foster biodiversity protection, future human numbers will play an important role in building our capacity to preserve biodiversity going forward (Wilson, 2016; Crist et al, 2022). This is true at all scales, from the local (Parks and Harcourt, 2002; Robson and Rakotozafy, 2015) to the global (Molotoks et al, 2018; Pyšek et al, 2020). Studies from many parts of the world suggest this for particular taxa and for preserving biodiversity in general (Appendix Table). The present review suggests that growing numbers of conservation biologists are making this connection explicit (Chapron et al, 2019; Albert et al, 2021) and are willing to advocate policies to curb or reduce human numbers (Lopez-Carr and Ervin, 2017; Yi and Borzée, 2021).

To summarise, the published literature on population effects on biodiversity and climate change, reviewed in this paper, suggests that continued human population growth and high population densities are major causes of biodiversity loss, and, therefore, smaller human populations are necessary to preserve the biodiversity that is left on the planet.

Table 1 presents detailed results of the published literature on population effects on biodiversity that we have reviewed. The 154 studies identified in our literature search and reviewed here are grouped into eight categories of population effects on biodiversity: 1) human population and ecological restoration; 2) human population and deforestation; 3) human population and protected areas; 4) warnings and policy recommendations regarding population effects on biodiversity; 5) human population, agriculture, and biodiversity; 6) human population and biodiversity in large, multi-author syntheses; 7) human population and defaunation; and 8) human population and general biodiversity loss. This classification has been done to make the literature review thematic and, therefore, more appealing, and useful to the reader. It may, however, be noted that many studies included in this review cover more than one of the eight thematic areas described above. To avoid repetition, we have classified each study in only one of the eight categories based on the substantive findings of the study. The table presents name of author(s), year of publication and the title of the study. The key population-relevant findings of each study are summarised in one sentence that describes the main thematic area and the context in which the study has been carried out. This one sentence approach of literature review has been purposely adopted to keep the review findings short and simple. The studies reviewed here have also been presented in the Appendix Table by geographical areas, once again listing each study only once, so as to provide the regional context of population effects on biodiversity.

Table 1: Population effects on biodiversity. Review of published literature.

	Author(s) and title	Main findings
	Human population and ecological restoration	
1.	Cafaro and Götmark, 2019. The potential environmental impacts of EU immigration policy: future population numbers, greenhouse gas emissions and biodiversity preservation.	Population reductions have facilitated major ecological restoration projects in Europe and could help European nations meet their targets for increasing protected area acreage in the future.
2.	Dinerstein et al, 2017. An ecoregion-based approach to protecting half the terrestrial realm.	Current trends in rural population decrease facilitate the increased protected area acreages necessary to preserve global biodiversity.
3.	Navarro, 2014. *Rewilding Abandoned Landscapes in Europe: Biodiversity Impact and Contribution to Human Well-being.*	Nations with decreasing populations have opportunities to expand rewilding efforts and transform marginal agricultural lands into more valuable national parks and other protected areas.
4.	Navarro and Pereira, 2015. Rewilding abandoned landscapes in Europe.	Decreasing human populations reduce hunting pressures on European natural areas.
5.	Pereira and Navarro, 2015. *Rewilding European landscapes*.	Biodiversity restoration projects in Europe often depend on population decrease and land abandonment to succeed.
6.	Rewilding Europe, 2021. Our rewilding areas.	Major ecological restoration sites in Europe correspond closely to areas experiencing declining populations and reduced agricultural activity.
7.	Schnitzler, 2014. Towards a new European wilderness: embracing unmanaged forest growth and the decolonisation of nature.	Accepting depopulation and the spontaneous rewilding of former agricultural lands can help preserve Europe's biodiversity.
8.	Weisman, 2007. *The World Without Us*.	Areas depopulated by war, nuclear meltdown, and other anthropogenic debacles show how quickly wild nature returns when human beings leave.
9.	Wilson, 2016. *Half Earth: Our Planet's Fight for Life*.	Population growth has driven biodiversity loss in the Anthropocene epoch and ending population growth will be necessary to share Earth generously with other species.
10.	World Wildlife Fund, 2020. Bringing life to the lower Danube – a real success story for WWF in Ukraine.	Dike removal, species reintroductions, and other ecological restoration activities have been facilitated by population decline and agricultural abandonment.

Author(s) and title	Main findings
Human population and deforestation	
1. Brink and Eva, 2009. Monitoring 25 years of land cover change dynamics in Africa: a sample based remote sensing approach.	A high rate of population increase contributes to deforestation and loss of other natural areas in Africa.
2. Defries et al, 2010. Deforestation driven by urban population growth and agricultural trade in the twenty-first century.	Urban population growth is a significant driver of tropical forest loss in Africa, Asia, and Latin America.
3. Fentahun and Gashaw, 2014. Population growth and land resources degradation in Bantneka watershed, southern Ethiopia.	There is a strong correlation between human population growth and deforestation and reductions in wildlife populations.
4. Gorenflo et al, 2011. Exploring the association between people and deforestation in Madagascar.	Human population size is positively correlated with deforestation and species extirpation in Madagascar, although certain activities greatly increase human impacts.
5. Jha and Bawa, 2006. Population growth, human development, and deforestation in biodiversity hotspots.	Correlation between population growth and deforestation was positive in global biodiversity hotspots, although human development may ameliorate its effects.
6. Laurance et al, 2002. Predictors of deforestation in the Brazilian Amazon.	Highways and population growth played a critical role in Amazonian Forest destruction in the last four decades of the twentieth century.
7. López-Carr and Burgdorfer, 2013. Deforestation drivers: population, migration, and tropical land use.	Frontier colonization by small holder farmer migrants may be the main proximate cause of deforestation in Latin America, exceeding forest conversion caused by commercial logging and industrial agriculture.
8. Lu and Bilsborrow, 2011. A Cross-cultural analysis of human impacts on the rainforest environment in Ecuador.	In all cases and for all ethnicities, rapidly growing populations and sedentarization ensure that biodiversity loss and other environmental impacts continue to grow.
9. Morales-Hidalgo et al, 2015. Status and trends in global primary forest, protected areas, and areas designated for conservation of biodiversity from the Global Forest Resources Assessment.	A global assessment found a 1% increase in national population density and per capita GDP were associated with a 0.2% decrease in forest area.

Author(s) and title		Main findings
10.	Potapov et al, 2012. Quantifying forest cover loss in Democratic Republic of the Congo, 2000–2010, with Landsat ETM+ data.	Within Congo, forest loss is higher in areas with growing human populations, higher human population densities, and greater mining activity.
11.	Sisay and Gitima, 2020. Forest cover change in Ethiopia: extent, driving factors, environmental implication and management strategies, systematic review.	Forest loss in Ethiopia is closely linked to ongoing population growth.
12.	Whitmee et al, 2015. Safeguarding human health in the Anthropocene epoch: report of the Rockefeller Foundation–Lancet Commission on Planetary Health.	Population growth is an important driver of deforestation and biodiversity loss, particularly in tropical hotspots.
13.	Wright and Muller-Landau, 2006. The future of tropical forest species.	Remaining forest cover is closely correlated with human population density among countries in both the tropics and the temperate zone.
	Human population and protected areas	
1.	Brashares et al, 2002. Human demography and reserve size predict wildlife extinction in West Africa.	Human population and reserve size accounted for 98% of the observed variation in extinction rates between wildlife reserves in West Africa.
2.	Corlett, 2016. The role of rewilding in landscape design for conservation.	Rural population decreases have facilitated the creation of new protected areas.
3.	Crist et al, 2021. Protecting half the planet and transforming human systems are complementary goals.	To limit biodiversity losses, humanity must greatly expand protected areas, which will require much smaller human populations.
4.	DeSilvey and Bartolini, 2018. Where horses run free? Autonomy, temporality and rewilding in the Côa Valley, Portugal.	Creation of new protected areas has been facilitated by rural population decreases.
5.	Figueroa, 2015. Socioeconomic context of land use and land cover change in Mexican biosphere reserves.	Higher human and cattle populations increased habitat loss in Mexican biosphere reserves.
6.	Guan et al, 2021. Global patterns and potential drivers of human settlements within protected areas	Human access to protected areas is a better predictor of biodiversity loss than formal level of protection.

Author(s) and title		Main findings
7.	Guerbois et al, 2013. Insights for integrated conservation from attitudes of people toward protected areas near Hwange National Park, Zimbabwe.	Migration and rapid population growth into adjacent areas decreased local support for protecting biodiversity in an African national park.
8.	Krishnadas et al, 2018. Parks protect forest cover in a tropical biodiversity hotspot, but high human population densities can limit success.	In India's Western Ghats, the habitat value of protected areas declined precipitously as local human population densities increased.
9.	Leverington et al, 2010. Management effectiveness evaluation in protected areas –a global study.	Increased human population density reduces the effectiveness of protected areas in sustaining native biodiversity.
10.	Parks and Harcourt, 2002. Reserve size, local human density, and mammalian extinctions in US protected areas.	In the western United States, extirpation rates of large mammals within national parks increased with human population density outside park boundaries.
11.	Perino et al, 2019. Rewilding complex systems.	Evacuation of the entire local population from the Chernobyl Radiation and Ecological Biosphere Reserve has led to one of the most successful rewilding experiments in recent history.
12.	Qiu et al, 2018. Human pressures on natural reserves in Yunnan Province and management implications.	Reducing human population density and encouraging residents' outmigration can help preserve biodiversity in Yunnan, China.
13.	Radeloff et al, 2015. Housing growth in and near United States protected areas limits their conservation value.	Housing growth poses the main threat to protected areas in the United States, directly linking population growth to biodiversity loss.
14.	Robson and Rakotozafy, 2015. The freedom to choose: integrating community-based reproductive health services with locally led marine conservation initiatives in southwest Madagascar.	Through integrating community-based reproductive health services and marine conservation initiatives, more than 800 unintended pregnancies were averted, and a community-managed marine protected area was created.
15.	Shahabuddin and Rao, 2010. Do community-conserved areas effectively conserve biological diversity? Global insights and the Indian context.	Population growth may undermine biodiversity protection under customary management institutions, while declining populations help preserve stable forest cover.

Author(s) and title		Main findings
16.	Spear et al, 2013. Human population density explains alien species richness in protected areas.	Human population density surrounding parks was a significant and strong predictor of numbers of alien and invasive species across plants and animals.
17.	Symes et al, 2016. Why do we lose protected areas? Factors influencing protected area downgrading, downsizing and degazettement in the tropics and subtropics.	Increased human population densities within or near protected areas is an important cause of their being downgraded or downsized, leading to habitat loss and degradation.
18.	Veldhuis et al, 2019. Cross-boundary human impacts compromise the Serengeti-Mara ecosystem.	Regional population growth increases human impacts on biodiversity both within and outside important protected areas.
19.	Wade and Theobald, 2010. Residential development encroachment on U.S. protected areas.	Population growth-driven housing development is reducing biological connectivity around protected areas in the United States.
20.	Wittemyer et al, 2008. Accelerated human population growth at protected area edges.	Rates of deforestation are highest around protected areas where human population growth is greatest, linking population growth to habitat loss and fragmentation.
	Warnings and policy recommendations on population and biodiversity	
1.	Attenborough, 2011. Impact of population growth on the planet	More people lead to less wildlife.
2.	Albert et al, 2021. Scientists' warning to humanity on the freshwater biodiversity crisis.	The rapid rise of human populations and associated food production is increasing pressures on freshwater resources in many regions of the world, driving a rapid loss of freshwater biodiversity.
3.	Cafaro and Crist, 2012. *Life on the Brink: Environmentalists Confront Overpopulation*.	Population policies involve a choice about whether to share the Earth with other species or whether to continue to crowd them off the landscape.
4.	Cafaro et al, 2022. Overpopulation is a major cause of biodiversity loss and smaller human populations are necessary to preserve what is left.	Population growth is a fundamental driver of biodiversity loss, and population decrease facilitates ecological restoration efforts.
5.	Ceballos et al, 2015. Accelerated modern human-induced species losses: Entering the sixth mass extinction.	Avoiding a sixth mass extinction will require rapid, greatly intensified efforts to reduce habitat loss, overexploitation, and climate change—all of which are related to human population size and growth.

Author(s) and title		Main findings
6.	Crist, 2019. *Abundant Earth: Toward an Ecological Civilization*.	Justice and prudence both counsel reducing human numbers to 1 or 2 billion and sharing Earth generously with other species.
7.	Crist et al, 2022. Scientists' warning on population.	Reducing the human population is necessary to address the collapse of global biodiversity and ensure long-term human wellbeing.
8.	Engelman and Johnson, 2019. Removing barriers to family planning, empowering sustainable environmental conservation: a background paper and call for action.	Conservation organizations can and should build family planning into their efforts to preserve biodiversity.
9.	Engelman et al, 2016. *Family Planning and Environmental Sustainability: Assessing the Science*.	Contraceptive availability benefits environmental sustainability, including biodiversity and forest protection.
10.	Foreman and Carroll, 2014. *Man Swarm: How Overpopulation is Killing the Wild World*.	Human overpopulation is the main driver of biodiversity loss and species extinction in the United States and globally.
11.	Ganivet, 2020. Growth in human population and consumption both need to be addressed to reach an ecologically sustainable future.	Limiting population growth and decreasing per capita consumption are both necessary to preserve global biodiversity.
12.	Hughes et al, 2023. Smaller human populations are neither a necessary nor sufficient condition for biodiversity conservation.	Human numbers have little impact on biodiversity losses and population control has no positive role to play in conservation.
13.	International Union for the Conservation of Nature (IUCN), 2020. Importance for the conservation of nature of removing barriers to rights-based voluntary family planning.	Nations should include rights-based voluntary family planning in their national biological strategic action plans to limit the negative impacts of human population growth on biodiversity.
14.	Kolankiewicz, 2012. Overpopulation versus biodiversity: how a plethora of people produces a paucity of wildlife.	In both tropical and temperate regions, human population increase leads to decreases in native biodiversity.
15.	Lidicker, 2020. A scientist's warning to humanity on human population growth.	Human-caused extinctions have reached an unprecedented rate, thanks in part to unprecedented human population growth.
16.	Lopez-Carr and Ervin, 2017. Population-health-environment (PHE) synergies? Evidence from USAID-sponsored programs in African and Asian core conservation areas.	Review of population-health-environment programs in eight developing countries found they achieved substantial improvements in maternal and child health and biodiversity conservation.

Author(s) and title	Main findings
17. Mora, 2014. Revisiting the environmental and socioeconomic effects of population growth: a fundamental but fading issue in modern scientific, public, and political circles.	Although tackling overpopulation will be difficult, continued neglect of this issue will decrease chances for humanity to reverse rapid biodiversity loss.
18. Mora and Sale, 2011. Ongoing global biodiversity loss and the need to move beyond protected areas: a review of the technical and practical shortcomings of protected areas on land and sea.	The only scenarios that end ongoing biodiversity loss require concerted efforts to reduce human population growth and consumption.
19 Noss et al, 2012. Bolder thinking for conservation.	Accepting continued population growth and economic growth ensures conservationists will make limited headway in stemming extinction.
20. Pacheco et al, 2016. Conservation as the new paradigm for development.	Development planning should include judgements on how many people ecosystems can sustain without degrading ecosystem services and losing species.
21. Pyšek et al, 2020. Scientists' warning on invasive alien species.	Rising human population size is driving biological invasions around the world, reducing overall global biodiversity.
22. Rewilding Charter Working Group, 2020. *Global Charter for Rewilding the Earth*.	Nations should enact laws and policies to lower human numbers in order to stem plummeting wildlife populations.
23. Ripple et al, 2017. World scientists' warning to humanity: A second notice.	Rapid population growth is a primary driver of biodiversity loss and other ecological threats.
24. Rust and Kehoe, 2017. A call for conservation scientists to empirically study the effects of human population policies on biodiversity loss.	High human population density and large size are linked with biodiversity loss, so conservation biologists should study the connections between them.
25. Shi et al, 2005. Integrating habitat status, human population pressure, and protection status into biodiversity conservation priority setting.	Areas with growing human populations should be prioritized for protection efforts since more people increase demand for land and resources and threaten natural habitats.
26. Shragg, 2022. On the wrong track: why the Endangered Species Act isn't enough.	Population growth undermines legal efforts to protect endangered species.

Author(s) and title		Main findings
27.	Yi and Borzée, 2021. Human population and efficient conservation: are humans playing ostriches and rabbits?	Current societies need to reject outmoded taboos against discussing overpopulation, which is the main cause of biodiversity loss and other global environmental problems.
	Human population, agriculture, and biodiversity	
1.	Crist et al, 2017. The interaction of human population, food production, and biodiversity protection.	Research suggests that the scale of human population and the current pace of its growth contribute substantially to the loss of biological diversity.
2.	Dinerstein et al, 2019. A global deal for nature: guiding principles, milestones, and targets.	The success of plans to boost food production while protecting biodiversity will depend on limiting human population growth.
3.	D'Odorico et al, 2018. The global food-energy-water nexus.	Human pressure on global water resources is increasing at alarming rates in response to population growth and changes in diet, leading to biodiversity losses in many parts of the world.
4.	Estes et al, 2012. Land-cover change and human population trends in the greater Serengeti ecosystem from 1984-2003.	Agricultural conversion of natural habitats to agriculture was greatest in areas with the highest rates of human population growth.
5.	Keenleyside and Tucker, 2010. Farmland abandonment in the EU: an assessment of trends and prospects.	Europe's rural population decline, and its extensive abandonment of less productive farmland have helped restore many formerly rare biological species.
6.	Kehoe et al, 2017. Biodiversity at risk under future cropland expansion and intensification.	Both agricultural expansion and agricultural intensification, driven by human population growth, are set to decrease biodiversity.
7.	Laurance et al, 2014. Agricultural expansion and its impacts on tropical nature.	Population growth in the tropics threatens to detonate an "agricultural bomb" that extinguishes numerous species.
8.	Maja and Ayano, 2021. The impact of population growth on natural resources and farmers' capacity to adapt to climate change in low-income countries.	Addressing rapid population growth is a crucial step in curbing biodiversity loss, particularly in Sub-Saharan Africa.
9.	Matanle, 2017. Towards an Asia-Pacific depopulation dividend in the 21st century: regional growth and shrinkage in Japan and New Zealand.	Rural population decrease in the Asia-Pacific region is creating opportunities to preserve biodiversity and revive traditional cultural activities.

Author(s) and title	Main findings
10. McKee and Chambers, 2011. Behavioral mediators of the human population effect on global biodiversity losses.	Human population density, agricultural land use, and species richness are the best combined predictors of threats to mammal and bird species.
11. Molotoks et al, 2018. Global projections of future cropland expansion to 2050 and direct impacts on biodiversity and carbon storage.	Global population increase threatens biodiversity, by driving habitat loss as a result of increasing cropland.
12. Ngwira and Watanabe, 2019. An analysis of the causes of deforestation in Malawi: a case of mwazisi.	The expansion of subsistence agriculture to meet the food needs of a burgeoning population has been one of the main causes of deforestation in Malawi.
13. Raven and Wagner, 2021. Agricultural intensification and climate change are rapidly decreasing insect biodiversity.	To limit the mass extinction of invertebrates, a lower human population and sustainable consumption levels will be necessary.
14. Scharlemann, 2005. The level of threat to restricted-range bird species can be predicted from mapped data on land use and human population.	Increasing rural populations lead to agricultural habitat conversion and loss of biodiversity.
Human population and biodiversity in large multi-author syntheses	
1. Barnosky et al, 2013. Scientific consensus on maintaining humanity's life support systems in the 21st century: information for policy makers.	Global population growth is driving species extinctions and human over-appropriation of the biosphere; limiting future population growth is key to reversing these trends.
2. Duraiappah and Naeem 2005. *Millennium Ecosystem Assessment: Ecosystems and Human Well-Being: Biodiversity Synthesis*.	The growth of agriculture is the primary driver of habitat loss in all human-dominated landscapes, and the primary threat to biodiversity worldwide.
3. Diaz et al, 2019. Pervasive human-driven decline of life on Earth points to the need for transformative change.	The human impact on life on Earth has increased sharply since the 1970s, driven by the demands of a growing population with rising average per capita incomes.
4. Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES), 2019. *Summary for Policymakers. Global Assessment Report on Biodiversity and Ecosystem Services*.	Biodiversity loss is underpinned by demographic and economic growth, which have increased in recent decades.
5. Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) and Intergovernmental Panel on Climate Change (IPCC), 2021.	Growth of human populations and their increasing wealth forecasts a sharp decline in global biodiversity in the future.

Author(s) and title	Main findings
6. Perrings and Halkos, 2015. Agriculture and the threat to biodiversity in sub-Saharan Africa.	There is a positive and generally significant correlation between numbers of threatened species and both population and per capita gross national income.
7. Secretariat of the Convention on Biological Diversity, 2020. *Global Biodiversity Outlook 5*.	Unsustainable population growth is helping drive rapid biodiversity loss.
Human population and defaunation	
1. Ahmed et al, 2014. Road networks predict human influence on Amazonian bird communities.	Road building leads to significant deleterious effects on birds, in part through encouraging regional population growth.
2. Ament et al, 2019. Compatibility between agendas for improving human development and wildlife conservation outside protected areas: Insights from 20 years of data.	Human population growth decreases bird and mammal abundance in lower income countries.
3. Beebee, 2022. *Impacts of Human Population on Wildlife: A British Perspective*.	The reasons usually given for wildlife loss in Britain are real but secondary to a single, primary cause: the attempt to accommodate more people.
4. Berger et al, 2020. Disassembled food webs and messy projections: modern ungulate communities in the face of unabating human population growth.	Human population growth has exterminated numerous ungulate and carnivore species and irrevocably changed ecological communities throughout the world.
5. Boitani and Linnell, 2015. Bringing large mammals back: large carnivores in Europe.	As rural populations have declined, carnivores have naturally recolonized many former agricultural areas in Europe.
6. Cardillo et al, 2004. Human population density and extinction risk in the world's carnivores.	Higher levels of exposure to human populations increase the extinction risk to carnivores.
7. Ceballos, 2017. Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines.	The ultimate drivers of rapid global biodiversity loss are human overpopulation and overconsumption.
8. Ceballos et al, 2020. Vertebrates on the brink as indicators of biological annihilation and the sixth mass extinction.	The acceleration of the extinction crisis is certain because of the still fast growth in human numbers and consumption rates.

Author(s) and title		Main findings
9.	Chapron et al, 2014. Recovery of large carnivores in Europe's modern human-dominated landscapes.	As rural populations have declined, carnivores have naturally recolonized many former agricultural areas in Europe.
10.	Cheetah Conservation Fund, 2018. The importance of human reproductive health and rights for cheetah conservation.	Limiting human population growth is key to cheetah conservation in Namibia, where more than 90% of cheetahs live outside protected areas.
11.	Colsaet et al, 2018. What drives land take and urban land expansion? A systematic review.	Population growth is positively correlated with wildlife habitat loss at both national and global levels.
12.	Deinet et al, 2013. Wildlife comeback in Europe: The recovery of selected mammal and bird species: final report to Rewilding Europe.	Between 1960 and 2010, a 28% decline in rural populations facilitated the recovery of many European mammal and bird species.
13.	Estrada et al, 2017. Impending extinction crisis of the world's primates: why primates matter.	Human population growth is a major contributor to primate declines around the world, driving increased hunting, deforestation, habitat fragmentation and other direct causes of primate loss.
14.	Gagné et al, 2016. The effect of human population size on the breeding bird diversity of urban regions.	Increasing human population size drives habitat loss, fragmentation, and disturbance, and decreases both breeding bird species richness and abundance.
15.	Harcourt and Parks, 2003. Threatened primates experience high human densities: adding an index of threat to the IUCN Red List criteria.	Higher human population densities increase the threat of extinction for primates.
16.	Marques et al, 2019. Increasing impacts of land use on biodiversity and carbon sequestration driven by population and economic growth.	Between 2000 and 2011, demographic and economic growth decreased global bird diversity, despite a reduction in land-use impacts per unit of GDP.
17.	McKee et al, 2013. Human population density and growth validated as extinction threats to mammal and bird species.	Increased human population density increases the risk of extinction for birds and mammals.
18.	Olden et al, 2006. Forecasting faunal and floral homogenization associated with human population geography in North America.	Increased human population size leads to more homogenized natural communities, across all taxonomic groups.

Author(s) and title		Main findings
19.	Prates and Perez, 2021. Late Pleistocene South American megafaunal extinctions associated with rise of fishtail points and human population.	Human population increase and associated hunting pressure drove late Pleistocene extinctions in South America.
20.	Ripple et al, 2015. Collapse of the world's largest herbivores.	Human population growth drives the habitat loss and overhunting decimating large herbivore populations throughout the world.
21.	Smil, 2011. Harvesting the biosphere: the human impact.	Wild vertebrate biomass is vanishingly small, having been largely replaced by human and domesticated animal biomass.
22.	Stanford, 2012. *Planet Without Apes*.	Rapid population growth has played an important role in driving Africa's commercial bushmeat trade and the extirpation of chimpanzees and gorillas from large areas.
23.	Sterling et al, 2006. *Vietnam: A Natural History*.	Overhunting, driven partly by rising populations, has led to "empty forest syndrome" throughout Vietnam.
24.	Tucker et al, 2018. Moving in the Anthropocene: global reductions in terrestrial mammalian movements.	Increased human population density interferes with feeding, mating, and migration of wild mammals.
25.	Visconti et al, 2011. Future hotspots of terrestrial mammal loss.	Expected growth in human populations and consumption in biodiversity hotspots threatens future mammal loss despite conservation efforts.
26.	World Wildlife Fund, 2022. *Living Planet Report 2022*.	Global vertebrate populations have declined 69% since 1970, driven by increased human numbers and economic activity, particularly the expansion of agriculture.
27.	Young et al, 2016. Patterns, causes, and consequences of anthropocene defaunation.	Stabilizing the human population and decreasing overconsumption are essential to halt current rapid decreases in animal populations.
	Human population and general biodiversity loss	
1.	Abegão, 2019. Where the wild things were is where humans are now: an overview.	The requirements of an expanding human population are strongly linked to wildlife depletion and the increasing difficulties facing biodiversity conservation efforts.

Author(s) and title	Main findings
2. Abell et al, 2011. Indicators for assessing threats to freshwater biodiversity from humans and human-shaped landscapes.	Areas with high human population numbers typically coincide with degraded aquatic ecosystems.
3. Bradshaw and Di Minin, 2019. Socio-economic predictors of environmental performance among African nations.	Increasing population density is strongly correlated with greater environmental degradation in Africa, suggesting that reducing population growth is necessary to preserve African biodiversity going forward.
4. Bradshaw et al, 2021. Underestimating the challenges of avoiding a ghastly future.	Excessive human numbers and overconsumption are driving a sixth mass extinction of Earth's biological species.
5. Burgess et al, 2007. Correlations among species distributions, human density and human infrastructure across the high biodiversity tropical mountains of Africa.	High rural population densities threaten biodiversity hotspots in Africa.
6. Cincotta and Gorenflo. 2011. *Human Population: Its Influences on Biological Diversity*.	Human population density has a powerful negative influence on the viability of populations for the vast majority of other species.
7. Cunningham and Beazley, 2018. Changes in human population density and protected areas in terrestrial global biodiversity hotspots, 1995–2015.	Average human population densities in global biodiversity hotspots increased by 36% between 1995 and 2015, double the global average, threatening conservation goals.
8. Dasgupta, 2021. *The Economics of Biodiversity: The Dasgupta Review*.	Lowering future human numbers can directly reduce demands on the natural world and reduce extinction rates.
9. Driscoll et al, 2018. A biodiversity-crisis hierarchy to evaluate and refine conservation indicators.	Human population size and resource consumption per capita are the fundamental drivers of biodiversity loss.
10. Dumont, 2012. Estimated impact of global population growth on future wilderness extent.	Wilderness areas around the world are threatened by the environmental impacts of the growing global human population.
11. Gorenflo, 2011. Human demography and conservation in the Apache Highlands ecoregion, US-Mexico borderlands.	Beyond a human population density of 10 persons per km^2, high biodiversity is unlikely in the apache highlands region.

Author(s) and title	Main findings
12. Haberl et al, 2014. Human appropriation of net primary production: patterns, trends, and planetary boundaries.	Economic growth and population growth result in increasing human appropriation of net primary production, driving biodiversity loss.
13. Hughes, 2017. Understanding the drivers of Southeast Asian biodiversity loss.	While urbanization often is claimed to take pressure off rural areas, it increases deforestation, pollution and the spread of invasive species, hastening biodiversity loss.
14. Kolankiewicz et al, 2022. *From Sea to Sprawling Sea: Quantifying the Loss of Open Space in America*.	Areas in the United States with rapidly growing populations had higher rates of habitat loss than areas with more slowly growing populations.
15. Kraussman et al, 2013. Global human appropriation of net primary production doubled in the 20th century.	Population growth helped drive increased appropriation of global net primary production in the 20th century and will continue to do so during the 21st.
16. Lavides et al, 2020. Patterns of coral-reef finfish species disappearances inferred from fishers' knowledge in global epicentre of marine shore fish diversity.	High Filipino population growth is depleting fish stocks and putting huge pressure on coral reefs.
17. McDonald et al, 2020. Research gaps in knowledge of the impact of urban growth on biodiversity.	Population growth is set to drive further urban growth, leading to direct and indirect biodiversity losses worldwide.
18. McKee, 2003. *Sparing Nature - The Conflict between Human Population Growth and Earth's Biodiversity*.	Every day, there is a net gain of more than 200,000 people on the planet, leading to the extinction of countless plant and animal species.
19. McKee, 2009. Contemporary mass extinction and the human population imperative.	The global pattern of biodiversity loss is clearly linked to the growth of humanity's population size and density, and losses of plant and animal species will continue if this growth continues.
20. McKee et al, 2004. Forecasting global biodiversity threats associated with human population growth.	Multiple regression analysis reveals that two predictor variables--human population density and species richness--account for 88% of the variability in threatened bird and mammal species across 114 continental nations.

Author(s) and title	Main findings
21. McKinney, 2001. Effects of human population, area, and time on non-native plant and fish diversity in the United States.	Higher human numbers increase the numbers of invasive plant and fish species, through both planned and inadvertent non-native species introductions.
22. Oueslati et al, 2015. Determinants of urban sprawl in European cities.	Increased population size leads to habitat loss in urban areas in Europe.
23. Paradis, 2018. Nonlinear relationship between biodiversity and human population density: evidence from Southeast Asia.	Human population pressure on biodiversity increased between 1990 and 2000 throughout Southeast Asia.
24. Pereira et al, 2020. Global trends in biodiversity and ecosystem services from 1900 to 2050.	A growing population and global economy have increased human demands for land and resources, causing habitat conversion and loss through a variety of proximate causes.
25. Pimm, 2014. The biodiversity of species and their rates of extinction, distribution, and protection.	Large human populations and their continued growth are driving global biodiversity loss.
26. Rees, 2023. The human eco-predicament: overshoot and the population conundrum.	Increasing human numbers on a finite planet necessarily competitively displaces wild species.
27. Sánchez-Bayoa and Wyckhuysb, 2019. Worldwide decline of the entomofauna: A review of its drivers.	One-third of the world's insect species are threatened with extinction due primarily to population-driven agricultural intensification.
28. Seto, 2011. A meta-analysis of global urban land expansion.	A direct correlation exists between increased population densities and loss of species and natural areas to development.
29. Seto, 2012. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools.	If current trends in population density continue, by 2030 urban land cover will nearly triple compared to 2000, resulting in considerable losses in key biodiversity hotspots.
30. Simkin et al, 2022. Biodiversity impacts and conservation implications of urban land expansion projected to 2050.	Population-driven urbanization is expected to be an increasingly prominent driver of biodiversity loss over the next 30 years.
31. Vincent, 2008. Reconciling fisheries with conservation on coral reefs: the world as an onion.	Unconstrained human demands, whether from overconsumption or overpopulation, threaten to overwhelm coral reef conservation and management efforts.

Author(s) and title		Main findings
32.	Waldron et al, 2017. Reductions in global biodiversity loss predicted from conservation spending.	Population growth and economic growth reliably predict biodiversity loss, while conservation investments can reduce these losses.
33.	Weber and Sciubba, 2018. The effect of population growth on the environment: evidence from European regions.	Higher population growth rates lead to increased habitat loss at the regional level in Europe.
34.	Williams, 2013. Humans and biodiversity: Population and demographic trends in the hotspots.	Global biodiversity hotspots have rapidly growing human populations, boding ill for their ability to preserve biodiversity long-term.
35.	Wilson, E.O. 2010. *The Diversity of Life*.	Population growth drives species extinctions in synergy with other factors in the "HIPPO" causal model of biodiversity loss.
36.	Wilting et al, 2017. Quantifying biodiversity losses due to human Consumption: a global-scale footprint analysis.	Population and per capita consumption largely determine national contributions to global biodiversity loss.
37.	Wood et al, 2000. The root causes of biodiversity loss.	Increased population density has been a major cause of biodiversity loss in numerous countries on all inhabited continents.

Population and Climate Change

It is well-established that human population growth is a leading cause of increased emissions of greenhouse gasses and hence global climate change (IPCC, 2022). Climate change, in turn, is one of five major direct drivers of global biodiversity loss. Many conservation biologists believe that the harmful impact of climate change on biodiversity loss will grow in coming decades. The literature on this topic is extensive. We list in table 2 a dozen recent studies that provide a good introduction.

Table 2: Population effect on climate change - evidence from select literature.

Author(s) and title		Main findings
1.	Bongaarts and O'Neill, 2018. Global warming policy: is population left out in the cold?	The potential carbon emissions reductions of reducing global population growth are large, with significant co-benefits for women's rights and economic development in poorer countries.

Author(s) and title		Main findings
2.	Das Gupta, 2013. Population, Poverty, and Climate Change.	Lowering fertility rates in the developing world could greatly aid their climate adaptation efforts, as well as contribute to climate change mitigation.
3.	Dodson et al, 2020. Population growth and climate change: addressing the overlooked threat multiplier.	Demographic trends will play a large role in determining the magnitude of climate disruption in the 21st century and how well societies adapt to it.
4.	Hickey, 2016. Population engineering and the fight against climate change.	The threats posed by climate change justify policies to reduce human populations, including incentivizing small families.
5.	Intergovernmental Panel on Climate Change (IPCC), 2022. *Climate Change 2022: Mitigation of Climate Change*.	Over the past three decades, population growth and economic growth have been the fundamental drivers of increased greenhouse gas emissions.
6.	Mitchell, 2012. Technology is not enough: climate change, population, affluence, and consumption.	To meet the challenge of climate change, humanity will have to address our excessive numbers and economic demands.
7.	O'Neill et al, 2015. Plausible reductions in future population growth and implications for the environment.	Limiting population growth can play a substantial role in mitigating global climate change.
8.	O'Sullivan, 2018. Synergy between population policy, climate adaptation and mitigation.	Voluntary family planning programs could significantly reduce global greenhouse gas emissions and increase the adaptability of poorer nations for the climate change that is coming.
9.	Ripple et al, 2020. World scientists' warning of a climate emergency.	Population growth is among the most important drivers of increases in carbon emissions and nations reduce their populations to fight climate change.
10.	Ripple et al, 2021. World scientists' warning of a climate emergency 2021.	Ending population growth and gradually reducing the human population by providing voluntary family planning, improving education, and supporting women's rights is necessary to limit global climate change.
11.	Spears, 2015. Smaller human population in 2100 could importantly reduce the risk of climate catastrophe.	Limiting population growth can play a substantial role in mitigating global climate change.

Author(s) and title		Main findings
12.	Wynes and Nicholas, 2017. The climate mitigation gap: education and government recommendations miss the most effective individual actions.	By more than an order of magnitude, having fewer children is the most effective action citizens in the developed world can perform to reduce their personal greenhouse gas emissions.

Biodiversity Ethics

Preserving biodiversity is not just a matter of scientific knowledge and technical and managerial problem-solving. It also rests on ethical commitments to the intrinsic value of other species and the moral discipline to limit human numbers and economic demands (IPBES, 2019). Once again, the literature on this topic is extensive. Table 3 presents key findings of a dozen recent studies that provide a good introduction.

Table 3: The ethics of biodiversity conservation - some recent work.

Author(s) and title		Main findings
1.	Borràs, 2016. New transitions from human rights to the environment to the rights of nature.	We must reject legal systems that treat the natural world solely as property to be exploited, rather than as an integral ecological partner with its own rights to exist and thrive.
2.	Bradshaw, 2018. Animal property rights.	Securing traditional property rights for wild animals could be an effective response to population growth-driven habitat loss.
3.	Cafaro, 2022. Reducing human numbers and the size of our economies is necessary to avoid a mass extinction and share Earth justly with other species.	The moral case for reducing excessive human numbers rests on duties to avoid exterminating other species or seriously harming future human generations.
4.	Cafaro, and O'Sullivan, 2019. How should ecological citizens think about immigration?	Sharing Earth justly with other species demands that overpopulated countries, such as the United Kingdom and the United States, reduce current fertility and immigration levels.
5.	Chapron et al, 2019. A rights revolution for nature: introduction of legal rights for nature could protect natural systems from destruction.	Securing legal rights to exist and flourish can level the playing field between people and other species, slowing biodiversity loss.

Author(s) and title		Main findings
6.	Donaldson and Kymlicka, 2011. *Zoopolis: A Political Theory of Animal Rights*.	Because wild animals have a right to the habitats they occupy, human beings should not increase their numbers to levels which make securing that habitat impossible.
7.	Hedberg, 2020. *The Environmental Impact of Overpopulation*.	If we extend moral consideration to other species, the incentives to reduce our numbers increase significantly.
8.	Pope Francis. 2015. *Laudato Si': On Care for Our Common Home*.	If we approach nature with awe and wonder, then we will preserve biodiversity and refuse to turn reality into an object simply to be used and controlled.
9.	Rolston, 2020. Wonderland Earth in the Anthropocene Epoch.	Humans should right-size our population in order to share Earth fairly with other species.
10.	Staples and Cafaro, 2012. For a species right to exist.	Nonhuman species have a right against untimely anthropogenic extinction, grounded in their intrinsic value and their beauty, complexity, and unique genealogies.
11.	Washington et al, 2018. Foregrounding ecojustice in conservation.	Justice demands a fair distribution of Earth's limited habitat among people and nonhuman species, which in turn demands people curb our numbers.
12.	Wienhues, 2020. *Ecological Justice and the Extinction Crisis: Giving Living Beings Their Due*.	All living beings are morally considerable, hence human numbers and economic demands must be limited as part of a compromise between human and nonhuman demands on the natural world.

Conclusions and Recommendations

We find it heartening to see all the good work done in recent years on population and biodiversity. Our first recommendation would be for redoubled work on this subject (Noss et al, 2012; Yi and Borzée, 2021). If these studies are right regarding the importance of human numbers in determining conservation success, this topic deserves even more attention. The work described here provides a solid foundation to build on.

Second, one especially deserving research area is population and ecological restoration (Navarro, 2014). Much of the evidence for the importance of population in opening up rewilding opportunities is anecdotal (Rewilding Europe, 2021) and more rigorous quantification is needed. The same holds for the impact of population on reducing human demands on restored areas and on protected areas generally (DeSilvey and Bartolini, 2018). Land managers and conservation biologists know this impact is

important. We need to know just how important, and how demographic trends open up or close down biodiversity conservation opportunities.

Third, with a critical mass of studies documenting the impact of population growth and population density on biodiversity loss, in many places for many taxa, there appears to be an opportunity to generalise this work and explain the fundamental causes of biodiversity loss in a more rigorous manner (Wilson, 2010). Just as atmospheric scientists have developed the Kaya identity to explain and predict changes in regional and global CO_2 emissions, conservation biologists should also develop and test models explaining and predicting biodiversity losses and gains (Cafaro et al, 2022). These models, like Kaya identity, will need to make a prominent place for changes in population and per capita consumption (McKee et al, 2004; Driscoll et al, 2018). However, which other fundamental technical, managerial, or biological factors need to be in the mix remains to be determined (Weber and Sciubba, 2018; Bradshaw and Di Minin, 2019). Developing rigorous quantitative models can make a real contribution to guiding and informing conservation policy going forward and help our societies face their environmental choices more honestly.

Fourth, we need to apply what we have learned about the impact of excessive human numbers and excessive per capita economic demands to conservation policy (Ripple et al, 2017; Ripple et al, 2020). Most conservation biologists believe that greatly increasing the amount of land and seas protected in PAs is necessary to preserve the remaining biodiversity on Earth (Dinerstein et al, 2019; Locke et al, 2019). However, the role of population reduction in achieving the goals of Half Earth or similar programmes remains largely unexplored (important exceptions are Crist et al, 2021; Crist et al, 2022). Similarly, the role of population growth in closing off conservation options, particularly at the national level where most substantial PA designations occur, is not yet fully understood (Liu et al, 1999; Symes et al, 2016; Qiu et al, 2018). How much of Germany or India, Mexico or New Zealand, would have to be set aside to preserve viable populations of their remaining native wildlife and how large a human population would be compatible with this goal need to be explored. Every conservation biologist should know how many people his or her country can support while also supporting viable populations of all its native species.

Fifth, conservationists need to ramp up our population advocacy (Attenborough, 2011; Washington et al, 2018). There is still much to learn, but the evidence is clear that reducing human numbers is one key to preserving the remaining biodiversity of Earth and dealing adequately with the whole suite of environmental problems that threaten humanity (Ceballos et al, 2015; Rewilding Charter Working Group, 2020). Reducing human numbers (and the size of our economies) is necessary to avoid a mass extinction and share Earth fairly with other species (Mora and Sale, 2011; Cafaro, 2022). We should advocate for universal access to contraception, greater educational opportunities for girls and young women, comprehensive sex education, government promotion of small family size, and other policies to reduce human fertility and promote smaller national populations (Crist, 2019; Engelman and Johnson, 2019).

Many biodiversity advocates focus on minimising the negative effects of people on biodiversity. These efforts are valuable and should continue, but the evidence presented here clearly shows that to succeed in preserving the remaining biodiversity on Earth, we must also reduce human numbers.

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Appendix Table: Population effects on biodiversity by geographical area.

	Author(s) and title	Key findings
	North and South America	
1.	Ahmed et al, 2014. Road networks predict human influence on Amazonian bird communities	Road building leads to significant deleterious effects on birds, in part through encouraging regional population growth.
2.	Cafaro and Crist, 2012. *Life on the Brink: Environmentalists Confront Overpopulation*.	Population policies involve a choice about whether to share the earth with other species or whether to continue to crowd them off the landscape.
3.	Foreman and Carroll, 2014. *Man Swarm: How Overpopulation is Killing the Wild World*.	Human overpopulation is the main driver of biodiversity loss and species extinction in the United States and globally.
4.	Gorenflo, 2011. Human demography and conservation in the Apache Highlands ecoregion, US-Mexico borderlands.	Beyond a human population density of 10 persons per km^2, high biodiversity is unlikely in the Apache highlands region.
5.	Kolankiewicz, 2012. Overpopulation versus biodiversity: how a plethora of people produces a paucity of wildlife.	In both tropical and temperate regions, human population increase leads to decreases in native biodiversity.
6.	Kolankiewicz et al, 2022. *From Sea to Sprawling Sea: Quantifying the Loss of Open Space in America*.	Areas in the United States with rapidly growing populations had higher rates of habitat loss than areas with more slowly growing populations.
7.	Laurance et al, 2002. Predictors of deforestation in the Brazilian Amazon.	Highways and population growth played a critical role in Amazonian Forest destruction in the last four decades of the twentieth century.
8.	López-Carr and Burgdorfer, 2013. Deforestation drivers: population, migration, and tropical land use. Environment.	Frontier colonization by small holder farmer migrants may be the main proximate cause of deforestation in Latin America, exceeding forest conversion caused by commercial logging and industrial agriculture.
9.	Lu and Bilsborrow, 2011. A cross-cultural analysis of human impacts on the rainforest environment in Ecuador.	In all cases, for all ethnicities, rapidly growing populations and sedentarization ensure that biodiversity loss and other environmental impacts continue to grow.
10.	McKinney, 2001. Effects of human population, area, and time on non-native plant and fish diversity in the United States.	Higher human numbers increase the numbers of invasive plant and fish species, through both planned and inadvertent non-native species introductions.

Author(s) and title		Key findings
11.	Olden et al, 2006. Forecasting faunal and floral homogenization associated with human population geography in North America.	Increased human population size leads to more homogenized natural communities, across all taxonomic groups.
12.	Parks and Harcourt, 2002. Reserve size, local human density, and mammalian extinctions in US protected areas.	In the western United States, extirpation rates of large mammals within national parks increased with human population density outside park boundaries.
13.	Prates and Ivan Perez, 2021. Late Pleistocene South American megafaunal extinctions associated with rise of fishtail points and human population.	Human population increase and associated hunting pressure drove late Pleistocene extinctions in South America.
14.	Radeloff et al, 2015. Housing growth in and near United States protected areas limits their conservation value.	Housing growth poses the main threat to protected areas in the United States, directly linking population growth to biodiversity loss.
15.	Wade and Theobald, 2010. Residential development encroachment on U.S. protected areas.	Population growth-driven housing development is reducing biological connectivity around protected areas in the United States.
		Europe
1.	Beebee, 2022. *Impacts of Human Population on Wildlife: A British Perspective*.	The reasons usually given for wildlife loss in Britain are real but secondary to a single, primary cause: the attempt to accommodate more people.
2.	Boitani and Linnell, 2015. Bringing large mammals back: large carnivores in Europe.	As rural populations have declined, carnivores have naturally recolonized many former agricultural areas in Europe.
3.	Cafaro and Götmark, 2019. The potential environmental impacts of EU immigration policy: future population numbers, greenhouse gas emissions and biodiversity.	Population reductions have facilitated major ecological restoration projects in Europe and could help European nations meet their targets for increasing protected area acreage in the future.
4.	Chapron et al, 2014. Recovery of large carnivores in Europe's modern human-dominated landscapes.	As rural populations have declined, carnivores have naturally recolonized many former agricultural areas in Europe.
5.	Deinet et al, 2013. Wildlife comeback in Europe: the recovery of selected mammal and bird species: final report to Rewilding Europe.	Between 1960 and 2010, a 28% decline in rural populations facilitated the recovery of many European mammal and bird species.

Author(s) and title		Key findings
6.	DeSilvey and Bartolini, 2018. Where horses run free? Autonomy, temporality and rewilding in the Côa Valley, Portugal.	Creation of new protected areas has been facilitated by rural population decreases.
7.	Keenleyside and Tucker, 2010. Farmland abandonment in the EU: an assessment of trends and prospects.	Europe's rural population decline, and its extensive abandonment of less productive farmland have helped restore many formerly rare biological species.
8.	Navarro, 2014. *Rewilding Abandoned Landscapes in Europe: Biodiversity Impact and Contribution to Human Well-being*.	Nations with decreasing populations have opportunities to expand rewilding efforts and transform marginal agricultural lands into more valuable national parks and protected areas.
9.	Navarro and Pereira, 2015. Rewilding abandoned landscapes in Europe.	Decreasing human populations reduce hunting pressures on European natural areas.
10.	Oueslati et al, 2015. Determinants of urban sprawl in European cities.	Increased population size leads to habitat loss in urban areas in Europe.
11.	Pereira and Navarro, 2015. *Rewilding European Landscapes*.	Biodiversity restoration projects in Europe often depend on population decrease and land abandonment to succeed.
12.	Perino et al, 2019. Rewilding complex systems.	Evacuation of the entire local population from the Chernobyl Radiation and Ecological Biosphere Reserve has led to one of the most successful rewilding experiments in recent history.
13.	Rewilding Europe, 2021. Our rewilding areas.	Major ecological restoration cites in Europe correspond closely to areas experiencing declining populations and reduced agricultural activity.
14.	Schnitzler, 2014. Towards a new European wilderness: embracing unmanaged forest growth and the decolonisation of nature.	Accepting depopulation and the spontaneous rewilding of former agricultural lands can help preserve Europe's biodiversity
15.	Weber and Sciubba, 2018. The effect of population growth on the environment: evidence from European regions.	Higher population growth rates lead to increased habitat loss at the regional level in Europe.
16.	World Wildlife Fund, 2020. Bringing life to the lower Danube – a real success story for WWF in Ukraine.	Dike removal, species reintroductions and other ecological restoration activities have been facilitated by population decline and agricultural abandonment.

	Author(s) and title	Key findings
		Africa
1.	Bradshaw and Di Minin, 2019. Socio-economic predictors of environmental performance among African nations.	Increasing population density is strongly correlated with greater environmental degradation in Africa, suggesting that reducing population growth is necessary to preserve African biodiversity going forward.
2.	Brashares et al, 2002. Human demography and reserve size predict wildlife extinction in West Africa.	Human population and reserve size accounted for 98 per cent of the observed variation in extinction rates between wildlife reserves in West Africa.
3.	Brink and Eva, 2009. Monitoring 25 years of land cover change dynamics in Africa: a sample based remote sensing approach.	A high rate of population increase contributes to deforestation and loss of other natural areas in Africa
4.	Burgess et al, 2007. Correlations among species distributions, human density and human infrastructure across the high biodiversity tropical mountains of Africa.	High rural population densities threaten biodiversity hotspots in Africa.
5.	Cheetah Conservation Fund, 2018. The importance of human reproductive health and rights for cheetah conservation.	Limiting human population growth is key to cheetah conservation in Namibia, where more than 90% of cheetahs live outside protected areas.
6.	Estes et al, 2012. Land-cover change and human population trends in the greater Serengeti ecosystem from 1984–2003.	Agricultural conversion of natural habitats to agriculture was greatest in areas with the highest rates of human population growth.
7.	Fentahun and Gashaw, 2014. Population growth and land resources degradation in Bantneka watershed, southern Ethiopia.	There is a strong correlation between human population growth and deforestation and reductions in wildlife populations.
8.	Gorenflo et al, 2011. Exploring the association between people and deforestation in Madagascar.	Human population size is positively correlated with deforestation and species extirpation in Madagascar, although certain activities greatly increase human impacts.
9.	Guerbois et al, 2013. Insights for integrated conservation from attitudes of people toward protected areas near Hwange National Park, Zimbabwe.	Migration and rapid population growth into adjacent areas decreased local support for protecting biodiversity in an African national park.

Author(s) and title		Key findings
10.	Maja and Ayano, 2021. The Impact of population growth on natural resources and farmers' capacity to adapt to climate change in low-income countries.	Addressing rapid population growth is a crucial step in curbing biodiversity loss, particularly in Sub-Saharan Africa.
11.	Ngwira and Watanabe, 2019. An analysis of the causes of deforestation in Malawi: a case of mwazisi.	The expansion of subsistence agriculture to meet the food needs of a burgeoning population has been one of the main causes of deforestation in Malawi.
12.	Perrings and Halkos, 2015. Agriculture and the threat to biodiversity in sub-saharan Africa.	There is a positive and generally significant correlation between numbers of threatened species and both population and per capita gross national income.
13.	Potapov et al, 2012. Quantifying forest cover loss in Democratic Republic of the Congo, 2000–2010, with Landsat ETM+ data.	Within Congo, forest loss is higher in areas with growing human populations, higher human population densities, and greater mining activity.
14.	Robson and Rakotozafy, 2015. The freedom to choose: integrating community-based reproductive health services with locally led marine conservation initiatives in southwest Madagascar.	Through integrating community-based reproductive health services and marine conservation initiatives, more than 800 unintended pregnancies were averted, and a community-managed marine protected area was created.
15.	Sisay and Gitima, 2020. Forest cover change in Ethiopia: extent, driving factors, environmental implication and management strategies, systematic review.	Forest loss in Ethiopia is closely linked to ongoing population growth.
16.	Spear et al, 2013. Human population density explains alien species richness in protected areas.	Human population density surrounding parks was a significant and strong predictor of numbers of alien and invasive species across plants and animals.
17.	Stanford, 2012. *Planet Without Apes*.	Rapid population growth has played an important role in driving Africa's commercial bushmeat trade and the extirpation of chimpanzees and gorillas from large areas.
18.	Veldhuis et al, 2019. Cross-boundary human impacts compromise the Serengeti-Mara ecosystem.	Regional population growth increases human impacts on biodiversity both within and outside important protected areas.

	Author(s) and title	Key findings
	Asia, Australia, and Oceania	
1.	Hughes, 2017. Understanding the drivers of Southeast Asian biodiversity loss.	While urbanization often is claimed to take pressure off rural areas, it increases deforestation, pollution and the spread of invasive species, hastening biodiversity loss.
2.	Krishnadas et al, 2018. Parks protect forest cover in a tropical biodiversity hotspot, but high human population densities can limit success.	In India's Western Ghats, the habitat value of protected areas declined precipitously as local human population densities increased.
3.	Matanle, 2017. Towards an Asia-Pacific depopulation dividend in the 21st century: regional growth and shrinkage in Japan and New Zealand.	Rural population decrease in the Asia-Pacific region is creating opportunities to preserve biodiversity and revive traditional cultural activities.
4.	Paradis, 2018. Nonlinear relationship between biodiversity and human population density: evidence from Southeast Asia.	Human population pressure on biodiversity increased between 1990 and 2000 throughout Southeast Asia.
5.	Qiu et al, 2018. Human pressures on natural reserves in Yunnan Province and management implications.	Reducing human population density and encouraging residents' outmigration can help preserve biodiversity in Yunnan, China.
6.	Shahabuddin and Rao, 2010. Do community-conserved areas effectively conserve biological diversity? Global insights and the Indian context.	Population growth may undermine biodiversity protection under customary management institutions, while declining populations help preserve stable forest cover.
7.	Sterling et al, 2006. *Vietnam: A Natural History*.	Overhunting, driven partly by rising populations, has led to "empty forest syndrome" throughout Vietnam.
8.	Vincent, 2008. Reconciling fisheries with conservation on coral reefs: the world as an onion.	Unconstrained human demands, whether from overconsumption or overpopulation, threaten to overwhelm coral reef conservation and management efforts.
9.	Yi and Borzée, 2021. Human population and efficient conservation: are humans playing ostriches and rabbits?	Current societies need to reject outmoded taboos against discussing overpopulation, which is the main cause of biodiversity loss and other global environmental problems.

	Author(s) and title	Key findings
	Global and inter-regional	
1.	Abegão, 2019. Where the wild things were is where humans are now: an overview.	The requirements of an expanding human population are strongly linked to wildlife depletion and the increasing difficulties facing biodiversity conservation efforts.
2.	Abell et al, 2011. Indicators for assessing threats to freshwater biodiversity from humans and human-shaped landscapes.	Areas with high human population numbers typically coincide with degraded aquatic ecosystems.
3.	Albert et al, 2021. Scientists' warning to humanity on the freshwater biodiversity crisis.	The rapid rise of human populations and associated food production is increasing pressures on freshwater resources in many regions of the world, driving a rapid loss of freshwater biodiversity.
4.	Ament et al, 2019. Compatibility between agendas for improving human development and wildlife conservation outside protected areas: Insights from 20 years of data.	Human population growth decreases bird and mammal abundance in lower income countries.
5.	Berger et al, 2020. Disassembled food webs and messy projections: modern ungulate communities in the face of unabating human population growth.	Human population growth has exterminated numerous ungulate and carnivore species and irrevocably changed ecological communities throughout the world.
6.	Cardillo et al, 2004. Human population density and extinction risk in the world's carnivores.	Higher levels of exposure to human populations increase the extinction risk to carnivores.
7.	Ceballos et al, 2020. Vertebrates on the brink as indicators of biological annihilation and the sixth mass extinction.	The acceleration of the extinction crisis is certain because of the still fast growth in human numbers and consumption rates.
8.	Cincotta and Gorenflo. 2011. *Human Population: Its Influences on Biological Diversity*.	Human population density has a powerful negative influence on the viability of populations for the vast majority of other species.
9.	Colsaet et al, 2018. What drives land take and urban land expansion? A systematic review.	Population growth is positively correlated with wildlife habitat loss at both national and global levels.
10.	Corlett, 2016. The role of rewilding in landscape design for conservation.	Rural population decreases have facilitated the creation of new protected areas.

Author(s) and title		Key findings
11.	Crist et al, 2017. The interaction of human population, food production, and biodiversity protection.	Research suggests that the scale of human population and the current pace of its growth contribute substantially to the loss of biological diversity.
12.	Cunningham and Beazley, 2018. Changes in human population density and protected areas in terrestrial global biodiversity hotspots, 1995–2015.	Average human population densities in global biodiversity hotspots increased by 36% between 1995 and 2015, double the global average, threatening conservation goals.
13.	Defries et al, 2010. Deforestation driven by urban population growth and agricultural trade in the twenty-first century.	Urban population growth is a significant driven of tropical forest loss in Africa, Asia, and Latin America.
14.	Diaz et al, 2019. Pervasive human-driven decline of life on Earth points to the need for transformative change.	The human impact on life on Earth has increased sharply since the 1970s, driven by the demands of a growing population with rising average per capita incomes.
15.	Dinerstein et al, 2017. An ecoregion-based approach to protecting half the terrestrial realm.	Current trends in rural population decrease facilitate the increased protected area acreages necessary to preserve global biodiversity.
16.	D'Odorico et al, 2018. The global food-energy-water nexus.	Human pressure on global water resources is increasing at alarming rates in response to population growth and changes in diet, leading to biodiversity losses in many parts of the world.
17.	Driscoll et al, 2018. A biodiversity-crisis hierarchy to evaluate and refine conservation indicators.	Human population size and resource consumption per capita are the fundamental drivers of biodiversity loss.
18.	Dumont, 2012. Estimated impact of global population growth on future wilderness extent.	Wilderness areas around the world are threatened by the environmental impacts of the growing global human population.
19.	Duraiappah and Naeem, 2005. *Millennium Ecosystem Assessment: Ecosystems and Human Well- Being: Biodiversity Synthesis*.	The growth of agriculture is the primary driver of habitat loss in all human-dominated landscapes, and the primary threat to biodiversity worldwide.
20.	Engelman et al, 2016. *Family Planning and Environmental Sustainability: Assessing the Science*.	Contraceptive availability benefits environmental sustainability, including biodiversity and forest protection.

Author(s) and title		Key findings
21.	Estrada et al, 2017. Impending extinction crisis of the world's primates: why primates matter.	Human population growth is a major contributor to primate declines around the world, driving increased hunting, deforestation, habitat fragmentation and other direct causes of primate loss.
22.	Guan et al, 2021. Global patterns and potential drivers of human settlements within protected areas	Human access to protected areas is a better predictor of biodiversity loss than formal level of protection.
23.	Haberl et al, 2014. Human appropriation of net primary production: patterns, trends, and planetary boundaries.	Economic growth and population growth result in increasing human appropriation of net primary production, driving biodiversity loss.
24.	Harcourt and Parks, 2003. Threatened primates experience high human densities: adding an index of threat to the IUCN Red List criteria.	Higher human population densities increase the threat of extinction for primates.
25.	Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES), 2019. *Summary for Policymakers. Global Assessment Report on Biodiversity and Ecosystem Services.*	Biodiversity loss is underpinned by demographic and economic growth, which have increased in recent decades.
26.	Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) and Intergovernmental Panel on Climate Change (IPCC), 2021. *Co-sponsored Workshop on Biodiversity and Climate Change: Scientific Outcome*.	Growth of human populations and their increasing wealth forecasts a sharp decline in global biodiversity in the future.
27.	Jha and Bawa, 2006. Population growth, human development, and deforestation in biodiversity hotspots.	Correlation between population growth and deforestation was positive in global biodiversity hotspots, although human development may ameliorate its effects.
28.	Kehoe et al, 2017. Biodiversity at risk under future cropland expansion and intensification.	High human population density and large size are linked with biodiversity loss, so conservation biologists should study the connections between them.
29.	Laurance et al, 2014. Agricultural expansion and its impacts on tropical nature.	Population growth in the tropics threatens to detonate an "agricultural bomb" that extinguishes numerous species.
30.	Leverington et al, 2010. Management effectiveness evaluation in protected areas – a global study.	Increased human population density reduces the effectiveness of protected areas in sustaining native biodiversity.

Author(s) and title		Key findings
31.	Lidicker, 2020. A scientist's warning to humanity on human population growth.	Human-caused extinctions have reached an unprecedented rate, thanks in part to unprecedented human population growth.
32.	Lopez-Carr and Ervin, 2017. Deforestation drivers: population, migration, and tropical land use.	Review of population-health-environment programs in eight developing countries found they achieved substantial improvements in maternal and child health and biodiversity conservation.
33.	Marques et al, 2019. Increasing impacts of land use on biodiversity and carbon sequestration driven by population and economic growth.	Between 2000 and 2011, demographic and economic growth decreased global bird diversity, despite a reduction in land-use impacts per unit of GDP.
34.	McDonald et al, 2020. Research gaps in knowledge of the impact of urban growth on biodiversity.	Population growth is set to drive further urban growth, leading to direct and indirect biodiversity losses worldwide.
35.	McKee, 2003. *Sparing Nature—The Conflict between Human Population Growth and Earth's Biodiversity*.	Every day, there is a net gain of more than 200,000 people on the planet, leading to the extinction of countless plant and animal species.
36.	McKee and Chambers, 2011. Behavioral mediators of the human population effect on global biodiversity losses.	Human population density, agricultural land use and species richness are the best combined predictors of threats to mammal and bird species.
37.	McKee et al, 2004. Forecasting global biodiversity threats associated with human population growth.	Multiple regression analysis reveals that two predictor variables, human population density and species richness, account for 88% of the variability in threatened bird and mammal species across 114 continental nations.
38.	McKee et al, 2013. Human population density and growth validated as extinction threats to mammal and bird species.	Increased human population density increases the risk of extinction for birds and mammals.
39.	Molotoks et al, 2018. Global projections of future cropland expansion to 2050 and direct impacts on biodiversity and carbon storage.	Global population increase threatens biodiversity, by driving habitat loss to increase cropland.

Author(s) and title		Key findings
40.	Mora and Sale, 2011. Ongoing global biodiversity loss and the need to move beyond protected areas: a review of the technical and practical shortcomings of protected areas on land and sea.	The only scenarios that end ongoing biodiversity loss require concerted efforts to reduce human population growth and consumption.
41.	Morales-Hidalgo et al, 2015. Status and trends in global primary forest, protected areas, and areas designated for conservation of biodiversity from the Global Forest Resources Assessment.	A global assessment found a 1% increase in national population density and per capita GDP were associated with a 0.2% decrease in forest area.
42.	Pereira et al, 2020. Global trends in biodiversity and ecosystem services from 1900 to 2050.	A growing population and global economy have increased human demands for land and resources, causing habitat conversion and loss through a variety of proximate causes.
43.	Pimm, 2014. Global trends in biodiversity and ecosystem services from 1900 to 2050.	Large human populations and their continued growth are driving global biodiversity loss.
44.	Pyšek et al, 2020. Scientists' warning on invasive alien species.	Rising human population size is driving biological invasions around the world, reducing overall global biodiversity.
45.	Raven and Wagner, 2021. Agricultural intensification and climate change are rapidly decreasing insect biodiversity.	To limit the mass extinction of invertebrates, a lower human population and sustainable consumption levels will be necessary.
46.	Ripple et al, 2015. Collapse of the world's largest herbivores.	Human population growth drives the habitat loss and overhunting decimating large herbivore populations throughout the world.
47.	Ripple et al, 2017. World scientists' warning to humanity: A second notice.	Rapid population growth is a primary driver of biodiversity loss and other ecological threats.
48.	Sánchez-Bayoa and Wyckhuysb, 2019. Worldwide decline of the entomofauna: a review of its drivers.	One-third of the world's insect species are threatened with extinction due primarily to population-driven agricultural intensification.
49.	Scharlemann, 2005. The level of threat to restricted-range bird species can be predicted from mapped data on land use and human population.	Increasing rural populations lead to agricultural habitat conversion and loss of biodiversity.
50.	Secretariat of the Convention on Biological Diversity, 2020. *Global Biodiversity Outlook 5*.	Unsustainable population growth is helping drive rapid biodiversity loss.

Author(s) and title		Key findings
51.	Seto, 2011. A meta-analysis of global urban land expansion.	A direct correlation exists between increased population densities and loss of species and natural areas to development.
52.	Seto, 2012. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools.	If current trends in population density continue, by 2030 urban land cover will nearly triple compared to 2000, resulting in considerable losses in key biodiversity hotspots.
53.	Simkin et al, 2022. Biodiversity impacts and conservation implications of urban land expansion projected to 2050.	Population-driven urbanization is expected to be an increasingly prominent driver of biodiversity loss over the next 30 years.
54.	Smil, 2011. Harvesting the biosphere: the human impact.	Wild vertebrate biomass is vanishingly small, having been largely replaced by human and domesticated animal biomass.
55.	Symes et al, 2016. Why do we lose protected areas? Factors influencing protected area downgrading, downsizing and degazettement in the tropics and subtropics.	Increased human population densities within or near protected areas is an important cause of their being downgraded or downsized, leading to habitat loss and degradation.
56.	Tucker et al, 2018. Moving in the Anthropocene: global reductions in terrestrial mammalian movements.	Increased human population density interferes with feeding, mating, and migration of wild mammals.
57.	Visconti et al, 2011. Future hotspots of terrestrial mammal loss.	Expected growth in human populations and consumption in biodiversity hotspots threatens future mammal loss despite conservation efforts.
58.	Waldron et al, 2017. Reductions in global biodiversity loss predicted from conservation spending.	Population growth and economic growth reliably predict biodiversity loss, while conservation investments can reduce these losses.
59.	Weisman, 2007. *The World Without Us*.	Areas depopulated by war, nuclear meltdown and other anthropogenic debacles show how quickly wild nature returns when human beings leave.
60.	Whitmee et al, 2015. Safeguarding human health in the Anthropocene epoch: report of the Rockefeller Foundation–Lancet Commission on Planetary Health.	Population growth is an important driver of deforestation and biodiversity loss, particularly in tropical hotspots.

	Author(s) and title	Key findings
61.	Williams, 2013. Humans and biodiversity: population and demographic trends in the hotspots.	Global biodiversity hotspots have rapidly growing human populations, boding ill for their ability to preserve biodiversity long-term.
62.	Wilson, 2016. *Half Earth: Our Planet's Fight for Life*.	Population growth has driven biodiversity loss in the Anthropocene epoch and ending population growth will be necessary to share Earth generously with other species.
63.	Wilting et al, 2017. Quantifying biodiversity losses due to human Consumption: a global-scale footprint analysis.	Population and per capita consumption largely determine national contributions to global biodiversity loss.
64.	Wittemyer et al, 2008. Accelerated human population growth at protected area edges.	Rates of deforestation are highest around protected areas where human population growth is greatest, linking population growth to habitat loss and fragmentation.
65.	Wood et al, 2000. The root causes of biodiversity loss.	Increased population density has been a major cause of biodiversity loss in numerous countries on all inhabited continents.
66.	World Wildlife Fund, 2022. *Living Planet Report 2022*.	Global vertebrate populations have declined 69% since 1970, driven by increased human numbers and economic activity, particularly the expansion of agriculture.
67.	Wright and Muller-Landau, 2006. The future of tropical forest species.	Remaining forest cover is closely correlated with human population density among countries in both the tropics and the temperate zone.
68.	Young et al, 2016. Patterns, causes, and consequences of anthropocene defaunation.	Stabilizing the human population and decreasing overconsumption are essential to halt current rapid decreases in animal populations.
		No specific geographical focus
1.	Attenborough, 2011. Impact of population growth on the planet.	More people lead to less wildlife.
2.	Barnosky et al, 2013. Scientific consensus on maintaining humanity's life support systems in the 21st century: information for policy makers.	Global population growth is driving species extinctions and human over-appropriation of the biosphere; limiting future population growth is key to reversing these trends.

Author(s) and title		Key findings
3.	Bradshaw et al, 2021. Underestimating the challenges of avoiding a ghastly future.	Excessive human numbers and overconsumption are driving a sixth mass extinction of Earth's biological species.
4.	Cafaro et al, 2022. Overpopulation is a major cause of biodiversity loss and smaller human populations are necessary to preserve what is left.	Population growth is a fundamental driver of biodiversity loss and population decrease facilitates ecological restoration efforts.
5.	Ceballos et al, 2015. Accelerated modern human-induced species losses: entering the sixth mass extinction.	Avoiding a sixth mass extinction will require rapid, greatly intensified efforts to reduce habitat loss, overexploitation, and climate change—all of which are related to human population size and growth.
6.	Ceballos et al, 2017, Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines.	The ultimate drivers of rapid global biodiversity loss are human overpopulation and overconsumption.
7.	Crist, 2019. *Abundant Earth: Toward an Ecological Civilization*.	Justice and prudence both counsel reducing human numbers to 1 or 2 billion and sharing earth generously with other species.
8.	Crist et al, 2021. Protecting half the planet and transforming human systems are complementary goals.	To limit biodiversity losses, humanity must greatly expand protected areas, which will necessitate much smaller human populations.
9.	Crist et al, 2022. Scientists' warning on population.	Reducing the human population is necessary to address the collapse of global biodiversity and ensure long-term human wellbeing.
10.	Dasgupta, 2021. *The Economics of Biodiversity: The Dasgupta Review*.	Lowering future human numbers can directly reduce demands on the natural world and reduce extinction rates.
11.	Dinerstein et al, 2019. A global deal for nature: guiding principles, milestones, and targets.	The success of plans to boost food production while protecting biodiversity will depend on limiting human population growth.
12.	Engelman and Johnson, 2019. Removing barriers to family planning, empowering sustainable environmental conservation: a background paper and call for action.	Conservation organisations can and should build family planning into their efforts to preserve biodiversity.

Author(s) and title		Key findings
13.	Gagné et al, 2016. The effect of human population size on the breeding bird diversity of urban regions.	Increasing human population size drives habitat loss, fragmentation, and disturbance, and decreases both breeding bird species richness and abundance.
14.	Ganivet, 2020. Growth in human population and consumption both need to be addressed to reach an ecologically sustainable future.	Limiting population growth and decreasing per capita consumption are both necessary to preserve global biodiversity.
15.	Hughes et al, 2023. Smaller human populations are neither a necessary nor sufficient condition for biodiversity conservation.	Human numbers have little impact on biodiversity losses and population control has no positive role to play in conservation.
16.	International Union for the Conservation of Nature (IUCN), 2020. Importance for the conservation of nature of removing barriers to rights-based voluntary family planning. Motion at IUCN World Conservation Congress.	Nations should include rights-based voluntary family planning in their national biological strategic action plans to limit the negative the impacts of human population growth on biodiversity.
17.	Kraussman et al, 2013. Global human appropriation of net primary production doubled in the 20th century.	Population growth helped drive increased appropriation of global net primary production in the 20th century and will continue to do so during the 21st.
18.	McKee, 2009. Contemporary mass extinction and the human population imperative.	The global pattern of biodiversity loss is clearly linked to the growth of humanity's population's size and density, and losses of plant and animal species will continue if this growth continues.
19.	Mora, 2014. Revisiting the environmental and socioeconomic effects of population growth: a fundamental but fading issue in modern scientific, public, and political circles.	Although tackling overpopulation will be difficult, continued neglect of this issue will decrease chances for humanity to reverse rapid biodiversity loss.
20.	Noss et al, 2012. Bolder thinking for conservation.	Accepting continued population growth and economic growth ensures conservationists will make limited headway in stemming extinction.

Author(s) and title		Key findings
21.	Pacheco et al, 2016. Conservation as the new paradigm for development.	Development planning should include judgements on how many people ecosystems can sustain without degrading ecosystem services and losing species.
22.	Rees, 2023. The human eco-predicament: overshoot and the population conundrum.	Increasing human numbers on a finite planet necessarily competitively displaces wild species.
23.	Rewilding Charter Working Group, 2020. *Global Charter for Rewilding the Earth*.	Nations should enact laws and policies to lower human numbers in order to stem plummeting wildlife populations.
24.	Rust and Kehoe, 2017. A call for conservation scientists to empirically study the effects of human population policies on biodiversity loss.	High human population density and large size are linked with biodiversity loss, so conservation biologists should study the connections between them.
25.	Shi et al, 2005. Integrating habitat status, human population pressure, and protection status into biodiversity conservation priority setting.	Areas with growing human populations should be prioritized for protection efforts since more people increase demand for land and resources and threaten natural habitats.
26.	Shragg, 2022. On the wrong track: why the Endangered Species Act isn't enough.	Population growth undermines legal efforts to protect endangered species.
27.	Wilson, E.O. 2010. *The Diversity of Life*.	Population growth drives species extinctions in synergy with other factors in the "HIPPO" causal model of biodiversity loss.