The Modern Extinction Crisis and its Connections to Agriculture

Lisa E. Mills

Abstract

Human-induced threats to the world's biodiversity are numerous, but agriculture may be the most prevalent, rapidly expanding, and detrimental to ecosystems and surrounding wildlife. Expansion for agriculture is the main driver of habitat loss, causing population extinctions of native wildlife and cascading effects on ecosystem function, and also contributes to climate change, water pollution, causes rampant exploitation of wildlife considered to be pests, and facilitates the spread of invasive species. Agricultural practices, particularly livestock pasture for meat and dairy production, are the leading cause of environmental degradation and therefore species extinctions. However, there are ways to mitigate these negative effects if responsible and sustainable and innovative agricultural techniques are used, meat consumption is drastically reduced, and plant-based agriculture shifts to be more environmentally friendly and efficient.

I. Introduction to Extinction Events

The Earth has entered its sixth mass extinction event, the effects of which are almost all human-mediated (Ceballos et al. 2017; Minin et al. 2016; Ceballos et al. 2015; Lee and Jetz 2010;). Using very conservative models, estimates of the rate of extinctions within the last century are 100 times higher than the background, or "normal" extinction rate (Ceballos et al. 2015), with higher estimates of 1,000 times the background rate (de Vos et al. 2014; Pimm et al. 2014). A rich fossil record has provided scientists with a historical reference of past extinction events, and by using these data, the highest estimate of past extinction rates has been 2 extinctions per 100 years per 10,000 species (Ceballos et al. 2015). Based on this normal extinction rate, the number of known species that have gone extinct in the last century alone would have taken between 800 and 10,000 years to disappear (Ceballos et al. 2015).

It is very likely that many more species have gone extinct than we realize because of the difficulty of declaring a species extinct, and our uncertainty of the actual number of species that occupy our planet (Ceballos et al. 2017; Pimm et al. 2014). The International Union for Conservation of Nature (IUCN) Red List provides a great overview on the conservation status of much of the world's organisms, and many studies use information from this list to gain an understanding of the severity of the current extinction crisis. Although, this list has a strong bias for vertebrates and other well-studied organisms (Regneir et al. 2015), and much information on cryptic species and plants is missing. From the IUCN Red List, taxa that are particularly at risk of extinction include mammalian carnivores (Minin et al. 2016), species with specialized life histories (Thomas 2016), large mammals (Cardillo et al. 2005), species with small geographic ranges (Lee and Jetz 2010; Sodhi et al. 2008), amphibians (Pounds et al. 2006; Sodhi et al. 2008), and long-lived species with slow reproductive rates (Cardillo et al. 2006). However, many more groups of organisms are threatened with extinction for a variety of reasons discussed below.

This review paper aims to discuss the extent to which the modern extinction crisis has progressed and how it is inevitably intertwined with agricultural practices, as well as potential ways humans can mitigate the negative environmental effects we have already set in motion. The literature is vast regarding the current biodiversity crisis and what humans have done to cause such a decimation of wildlife, but there is much less work focusing on ways to reduce this impact, raising questions as to if it is even possible to implement worldwide changes before environmental effects become irreversible, and the only collection of life we know in this universe has been annihilated. There may be hope, however, if the growing countries of the world can band together to make conservation a priority and to stop senseless exploitation of wildlife, and if food production shifts to more ecologically friendly agroforestry and there is drastic reduction of meat consumption and subsequent reduction in land used for inefficient livestock grazing.

II. Population declines are a precursor to extinction

Earth's current extinction is much more severe when looking at population declines as well as actual extinctions. Many species have suffered drastic population declines from a multitude of anthropogenic influences discussed below, and these declines nearly always precede extinction. Ceballos et al. (2017) paints a realistic picture of vertebrate populations that are in decline. Using a sample of 27,600 terrestrial vertebrates, they found that 32% of these species have decreasing populations. Roughly 30% of all decreasing species are common enough to be listed as “low-concern” by the IUCN Red List, which raises concerns for the seriousness of the current extinction crisis. The population declines were so prevalent, this paper termed this current decrease of wildlife a “biological annihilation”, and suggested we need to address the consequences of this issue immediately.

Although Ceballos et al. (2017) dealt solely with vertebrate species, there is further evidence that less-studied animal taxa as well as plants are suffering from comparable population declines. Thomas (2016) reflects on the severe losses of butterflies across the globe, and that most scarce, specialized butterflies have disappeared. Burkle et al. (2013) notes that the extirpation of pollinator bee species has profound effects on the network of plant-pollinator interactions built up over millions of years of co-evolution. Ter Steege et al. (2015) published an extensive study on the relatively unknown status of tree species of the Amazonian rainforest and found that 36-57% of all Amazonian tree species are likely threatened, with a similar trend predicted for the rest of the world’s tropical flora, skyrocketing the number of threatened species on this planet. Invertebrates account for more than 99% of global biodiversity, yet they are largely unstudied, and most conservation efforts are geared towards the charismatic species of birds and mammals (Horwitz et al. 1999). An influential paper by Regneir et al. (2015) attempted to quantify the amount of invertebrate species that are threatened or have become extinct. Extrapolating from a random sample of terrestrial snail species, they estimate that 7% (130,000 extinctions) of Earth’s total species have perished. Compared to the known amount of extinctions (<1000), it is clear that only assessing the well-studied vertebrate taxa drastically underestimates the severity of the extinction crisis.

The most species-rich areas of our planet (the tropics of the Amazon, the Congo, and southern Asia) also have the largest concentrations of decreasing vertebrates (Ceballos et al. 2017). Tropical rainforests harbor more than 60% of all known species, but only represent 7% of Earth’s land surface (Laurance 1999). It is fairly well-known that biodiversity “hotspots” in the tropics are particularly at risk (Pimm et al. 2014; Lee and Jetz 2010; Bradshaw et al. 2009; Koh and Wilcove 2008; Sodhi et al. 2004), and that tropical regions harbor some of the world’s poorest and rapidly expanding populations of people (Bradshaw et al. 2009). Funding for conservation in these areas is low (Adenle et al. 2015), and deforestation for agriculture, especially for palm oil in Southeast Asia, is increasing rapidly (Bradshaw et al. 2009; Koh and Wilcove 2008; Laurance 1999). Healthy, unfragmented forests are essential for maintaining thriving populations of some of the world's most majestic and elusive creatures, and the impact this extreme decimation of natural habitat has upon not only wildlife, but the people of the world, cannot be understated.

III. Agriculture exacerbates human-caused threats to biodiversity

The main drivers of biodiversity loss are habitat loss and degradation, over-exploitation of wildlife, climate change, disease, pollution, and invasive species. Agricultural practices and expansion exacerbates each one of these threats, particularly habitat loss, and some illustrative examples are included below.

a. Habitat loss and degradation

It is well-known that habitat loss is another main driver of biodiversity loss, and it is a very complicated matter. The human population is growing rapidly, and the need for land for development and agriculture is not slowing down. Minin et al. (2016) states that habitat loss and degradation due to agricultural expansion threatens 69% of species, and developing countries, especially in Southeast Asia, Sub-Saharan Africa, and South America will experience the most amount of growth and subsequent habitat loss. Protected areas of undisturbed habitat remain the only areas where many species are able to thrive; however, the amount of protected areas, even if they are increased by as much as 17%, are not enough to support many organisms, especially mammalian carnivores (Durant et al. 2017; Minin et al 2016). The cheetah (*Acinonyx jubatus*) is confined to only 9% of its original range due to habitat loss, and threatened with population extinction in its many small, fragmented populations (Durant et al. 2017). The lion (*Panthera leo*) of West Africa, which has been found to be genetically distinct from other populations of lions, is critically endangered, with 1.1% of its original range remaining, all within protected areas (Henschel et al. 2014). Plants also suffer from habitat degradation; Laurance et al. (2006) found that forest fragmentation caused by deforestation in the Amazon rainforest drastically alters the composition of trees within the fragments, with population declines and extinctions of slow-growing and animal-dispersed trees, and increases of disturbance-adapted, fast-growing trees, and that these changes may accompany a myriad of negative ecological effects. There remains countless more examples of how habitat loss has drastically affects life on this planet, and with projected increases in food demand, deforestation and habitat loss will continue with haste, even with active conservation efforts.

Expansion for agriculture is the number one cause of habitat loss and degradation across the globe (Minin et al. 2016; Koh and Wilcove 2008; Batchelor et al. 2015). Goldewijk (2001) found that, in the past 300 years, global cropland increased by over five-fold, and the area of pastureland has increased over six-fold. The majority of agricultural development historically took place in grasslands and temperate forests of now developed countries, but in the last century, highly biodiverse tropical and developing regions have increasing amounts of land developed for agriculture. In Asia, more than 40% of rainforests have been lost (Wright 2005). The highest areas of deforestation occur in the Malay peninsula and surrounding islands of Borneo, Sumatra, and Java, with over 70% of lowland forests gone by 2010 (Wilcove et al. 2013), mostly due to oil palm plantations and the demand for pulp. In just a short 15-year period in Malaysia and Indonesia, 55-59% of oil palm expansion occurred at the expense of their extremely biodiverse tropical rainforests (Koh and Wilcove 2008). It is estimated that these areas could lose three-quarters of its original forest cover by 2100, which could lead to a loss of 13-42% of regional populations of all species, at least half of which would represent global species extinctions (Brook et al. 2003, 2006; Sodhi et al. 2004).

Although habitat loss for cropland represents a large amount of total habitat loss, more concerning still is the loss of land for livestock pasture and meat production. Approximately three-quarters of all agricultural land and one-third of all ice-free land is used for livestock production (Machinova et al. 2015), making it by far the biggest driver of habitat loss worldwide, and most likely the main driver of species declines and extinctions. In the Amazon rainforest, an area 21% of Brazil’s territory has been converted to agricultural lands for the production of beef, feedstock, and soy (Bianchi and Haig 2013), and nearly half of Costa Rica’s tropical forests have been converted to lands for livestock production (Morales-Hidalgo 2006). The demand for livestock lands is only increasing rapidly. Machinova et al. (2015) projects that, by 2050, the increasing demand for meat, particularly in developing countries, will require new areas for agriculture that are between 30-50% expansions of their total current agricultural areas. Wirsenius et al. (2010) projects that, by 2030, global agricultural land is likely to expand by 280 million hectares, with particular pressures on converting tropical ecosystems for livestock pasture. Cassidy et al (2013) cites that global crop demands, including crops used to feed livestock, will increase by 60-120% by 2050. Habitat loss is the most serious threat to biodiversity across the globe, and agricultural lands for crops and livestock constitutes most of the developed land on this planet, and is only projected to increase as the human population grows. In the future, not only are habitats and wildlife going to be decimated because of habitat loss, but there is going to be a serious issue regarding food security and scarcity if solutions aren't implemented immediately.

b. Over-exploitation of wildlife

Exploitation of wildlife from all over the globe is rampant, is a major driver of extinction in some notable species, and is often senseless. In many countries of Africa, trophy hunting of large mammals is rampant, as well as hunting animals for bushmeat. There is a back and forth in the scientific community whether trophy hunting actually decreases biodiversity, but the fact remains that some of Africa's iconic megafauna are threatened, including the African elephant (*Loxodonta africana*), the largest antelope in the world, the giant eland (*Tragelaphus derbianus*), and most of the big cats species of Africa (IUCN Red List). These species are still being poached and legally hunted for no reason other than a trophy or a decoration. Japan, Norway, and Iceland still allow commercial whaling operations operating under the guise of scientific research expeditions, and whales are still being slaughtered by the thousands. Right whales have historically been targeted by whalers, and the North Atlantic and North Pacific species of the right whale (*Eubalaena glacialis* and *Eubalaena japonica*) are listed as endangered on the IUCN Red List. Studies estimate between 5,500—11,000 *E. glacialis* individuals were killed between 1634-1951, and it was determined there were only 70 breeding females in 1998. (Reilly et al. 2012). An estimated 26,500-37,000 *E. japonica* individuals were killed between 1839-1909, and although it has been protected from hunting since 1946, illegal hunting continued until the 60s (Reilly et al. 2008). In both species, entanglements in fishing nets are a common occurrence (Reilly et al. 2012; Reilly et al. 2008). Today only species of low-concern are hunted, yet this is difficult to regulate. These countries have no need for the meat or blubber of these whales like the indigenous peoples did, but it is simply tradition and profit that drives the continuation of whaling. Another example of species decline after hunting on a massive scale is the passenger pigeon (*Ectopistes migratorius*). The last known passenger pigeon died in 1914, and Bucher (1992) states that it was a combination of massive sport hunting of millions of birds at a time, along with habitat and food loss that ultimately caused the extinction of an extremely populous species of bird. Humans may have a primal desire to hunt as a need to sustain themselves, but in the 21st century, we live in a globalized world and have no need to exploit the natural world at the rate we are now.

Agriculture and the protection of farmlands leads to massive amounts of exploitation of native wildlife. Bergstrom et al. (2013) focuses on culling of native wildlife of the United States government under the false pretenses of more efficient agriculture and greater game animal populations. Reportedly, every year since 2000, the government has been killing over 100,000 coyotes and prairie dogs, over 10,000 red foxes, racoons, skunks, a few thousand beavers, bobcats, and gray foxes, and a few hundred cougars and gray wolves, all of which have been petitioned to be culled to lessen the competition and predation on livestock. Killing of predators and small mammals around farmlands is rampant throughout the world, and often threatens the animal's local survival and may cause population extinctions (McManus et al. 2014). Shooting and trapping animals is also very costly to farmers and costs a farmer in the Serengeti around 19% of their annual income to continue depredation techniques (Holmern et al. 2007). These techniques are not only costly to farmers and threatening to animal populations, but killing on this massive scale does little to protect livestock from predation and competition. It has been shown that killing small mammals that supposedly compete for resources with livestock is senseless; burrows made by prairie dogs actually help cycle nutrients throughout the soil and increase plant productivity (Miller et al. 2007). Unless a predator is entirely extirpated from an area, which many of them unfortunately have been, there is little to no effect on killing predators to protect livestock (Mitchell et al. 2004). However, there are solutions available to farmers looking to protect livestock from predators, which include non-lethal techniques.

Non-lethal techniques to protect livestock that have been proven to be as successful and more cost-effective than traditional lethal methods of control (McManus et al. 2014). Strategies farmers can us to protect livestock include guard dogs and alpacas, livestock protection collars, startle tactics, and installing lighting fences and fladry. Responsible husbandry techniques should also be used to prevent predator attraction to the area, and these include simple measures such as corralling animals at night, limiting birthing to inside barns and clearing afterbirths quickly, clearing out carcasses of dead animals quickly, and maintaining a constant presence around the ranch to deter predators from entering. (Bergstrom et al. 2013). In McManus et al. 2014, ranchers in South Africa implemented methods of non-lethal control (guard animals and livestock collars) and compared them to traditional lethal methods. They found that after the first year, costs to maintain these methods were 69.3% less than lethal methods, and costs continued to decrease every subsequent year, with net losses from predation similar among the different treatments. While human-wildlife conflict can never completely be eliminated, healthy populations of wildlife are essential for maintaining the natural balance of the ecosystem, which is essential for the continuation of human civilization. The mindset that wild animals are pests should be changed, and we should instead focus on ways the humans and wildlife can live in harmony.

c. *Climate change and disease*

Climate change is linked to altering disease dynamics, and one such example is amphibians, specifically the genus of frog, *Atelopus*. In Pounds et al. (2006), analysis of changes in sea and air temperature along with the timing of frog declines concludes that climate change and warming temperatures in the tropics is a key factor in the decline of this genus. *Atelopus* is being ravaged by the chytrid fungus (*Batrachochytrium dendrobatidis)*, with an estimated 67% of the 110 known species of *Atelpous* likely extinct due to the fungus, including the Monteverde harlequin frog (*Atelopus* sp.) and the golden toad (*Bufo periglenes*). It is likely that climate change is shifting temperatures to the growth optimum of the fungus, increasing the severity of the outbreaks. Schloegel et al. (2006) reports on the recent extinction of the sharp-snouted day frog (*Taudactylus acutirostris*), and suggests that it may be the first reported case of extinction solely by disease. Sodhi et al. (2008) also names global warming and the chytrid fungus as a factor of amphibian declines, but large body size and small geographic ranges were found to be the main causes of amphibian declines, indicating that it is often a multitude of factors that contributes to extinction. Thomas et al. (2004) predicts that by 2050, between 15-37% of species sampled will be extinct or near extinction because of climate change alone, mostly species with small geographic range sizes who cannot migrate to a new area or adapt to changing environmental conditions and food availability. This is further indication that climate change is a serious threat to biodiversity, and ways to mitigate greenhouse gas emissions need to be addressed and implemented as soon as possible.

Ruminant animals, or animals with a digastric digestive system such as cows, sheep, and goats, ferment their food in their gut and produce large amounts of CO_2 and methane, both greenhouse gases. It has been estimated that methane produced by ruminant livestock accounts for between 14% (Machinova et al. 2013) to 22% (McMichael et al. 2007) of total greenhouse gas emissions, which is similar to industry and greater than that of transportation (McMichael et al. 2007). Nitrogenous fertilizers for livestock feed and manure also pollutes the air and water with N_2O, possibly the most detrimental effect of the livestock sector. The amount of N_2O released by livestock via manure is estimated to exceed the amount released by nitrogenous fertilizers worldwide (Bouwman et al. 2009). Although ruminants produce the greatest amounts of greenhouse gases, pigs and poultry also produce considerable amounts of these gases. Methane production from pigs is one-third less than that of cows and increases with lower-quality feed rich in fermentable carbohydrates, and methane and N_2O production from pig and poultry manure is still considerable, but much less than that of ruminants (Monteny et al 2006). It is clear that agriculture, particularly ruminant livestock production, increases greenhouse gas emissions and is a major threat to biodiversity.

d. Water Pollution

Water pollution threatens both salt and freshwater species around the world, and sends cascading effects throughout the ecosystem for those organisms that depend on the water for food and habitat, which is a majority of the biodiversity on earth. Nitrogenous wastes caused by anthropogenic influences finds its way into all types of water systems and are the most significant cause of water pollution globally (Moss et al. 2008). This nitrogenous runoff from agricultural, industry, and domestic lands enter watersheds and groundwater systems, finding its way to rivers and into the ocean. High nitrogen content in the water is linked to negative consequences to human health, as well as increasing eutrophication of the water, which increases the severity of algae blooms and causes decreasing oxygen availability which suffocates marine life (Bouwman et al. 2009). Nitrogen pollution has been found to directly threaten biodiversity from all over the world, including 78 species of federally listed endangered and threatened species in the United States, including corals, molluscs, beetles, amphibians, fish, and plants (Hernandez et al. 2016).

The agricultural sector accounts for a majority of this type of pollution in the form of fertilizers and manure (Mekonnen and Hoekstra 2015; Bouwman et al. 2009). While manure can be used as compost for increasing crop yields, Bouwman et al. (2009) predicts that about 50% of animal manure from livestock gets reused as fertilizer for crops, but the remaining 50% gets lost to the environment at a much higher rate than natural ecosystems, causing pollution. The total leaching and runoff from the world's croplands is estimated to be 35 million tonnes of nitrogen per year, and 70% of this is directly from fertilizers and manure (Mekonnen and Hoekstra 2015). China by far has the most level of nitrogenous water pollution worldwide; the Yangtze River has experienced a 73% increase in pollution levels over the past 50 years, and about 96% of this pollution comes from the agricultural sector (Mekonnen and Hoekstra 2015). If the amount of fertilizers and livestock were reduced, and remaining manure from livestock was all going to be used sustainably as compost, we would see a great reduction in the amount of water pollution and an increase in the health of waters around the globe.

Plastic waste is another form of water pollution and is increasingly being found in oceans, causing massive declines in marine life. Plastic wastes are ingested by terrestrial and marine life, including endangered species such as California condors (*Gymnogyps californianus*), green sea turtles (*Chelonia mydas*), and sperm whales (*Physeter macrocephalus*)(IUCN Red List), but plastic ingestion threatens all types of life, including invertebrates. 95% of fulmars (*Fulmarus* spp.) washed up along the shore contained significant amounts of plastic in their guts (Foekema et al. 2013), and a recent study found that up to 90% of seabirds have plastic in their guts (Wilcox et al. 2015). Plastics are a particular threat because they don't decompose, can be misrecognized as food for animals, can break up into microscopic pieces, making it almost impossible to detect and clean, and are increasingly being used as disposable products in worldwide society. Concentrations of plastic in oceans are observed to be up to 580,00 plastic pieces per square kilometer (Wilcox et al. 2015), and will remain in the ecosystem for hundreds of years unless cleanup action is implemented, along with subsequent plastic waste reduction on a global scale.

e. Invasive species

Invasive species have drastically altered the landscape of habitats around the world, and consequently have changed community structures, food webs, and fundamental processes of some environments, causing cascading negatives changes in an ecosystem. Invasive species are largely introduced by humans either directly, such as ornamental plants, or indirectly by passive transportation, such as the brown tree snake on Guam (*Boiga irregularis*). This snake has devastated the native bird populations on Guam, who have not evolved with any natural predators, and have caused drastic population declines and extinctions of at least 5 species of birds on this island (Wiles et al. 2003). Aquatic environments are also very susceptible to proliferation of invasive species, as shipping and aquaculture transports many species outside of their native ranges (Molnar et al. 2008). Zebra mussels (*Dreissena polymorpha*) are one such aquatic invasive of the Great Lakes, and it has sent cascading effects throughout the environment, creating deadly algae blooms and decreasing oxygen and food for native fish (Strayer 2010). Invasive species are an indirect way humans negatively influence the environment around them, and many species of native wildlife have suffered and gone extinct because of our increasingly globalized world.

Agricultural can facilitate invasions of alien species, and livestock and other farm animals can be considered an invasive alien species, particularly in feral populations. Feral herbivores produce drastic changes on the land around them from overgrazing and trampling. On some environments, particularly on islands, introduced herbivores may have no natural predators and are able to proliferate at an alarming rate and change the composition of plants, affecting the food chain and causing negative consequences for native wildlife. In fact, feral pigs, goats, and rabbits, all species introduced for agriculture, are classified among the top 100 world's worst invasive species (Steinfeld et al. 2006). Habitat loss and fragmentation also increases the likelihood of invasive plant species, and invasive plants are most likely to be found in developed areas and around farmlands (Steinfeld et al. 2006). While agricultural practices and animals facilitate invasions of alien species, transportation remains one of the main reasons invasive species are able to colonize a new area (Molnar et al. 2008), and many invasive species are a threat to pastures, such as thistle and black mustard, which decreases the water content of pastures and causes billions of dollars of damage to pastureland annually (Steinfeld et al. 2006). Agriculture both proliferates and is threatened by invasive species, and careful planning and management needs to be implemented to prevent the drastic loss of biodiversity invasives cause.

IV. Solutions to the biodiversity crisis

a. Reduction of global animal product consumption

There remains a lingering question in the scientific community when looking at future food and environmental security; how will we be able to feed the growing human population while reducing our impact on the environment? It has been proposed by many intellectuals that the only way to do this without converting the remaining natural land cover to farmland, is to decrease the amount of meat and animal products consumed globally, and replace that need with highly nutritious and more ecologically friendly plant-based foods for the following reasons.

The consumption of meat, particularly beef, is much less efficient than eating plant-based foods. The feed conversion of beef is 25.0, meaning it takes roughly 25 pounds of feed to produce one pound of beef (Smil 2002). Pork is slightly more efficient with a feed conversion of 9.4 followed by chicken at 4.5, and carp at 2.3. (Smil 2002). According to Smith et al. (2013), it takes roughly 7.0 gigatons (Gt) of plant biomass to produce 0.26 Gt of meat, nearly 27 times less efficient, which is on par with the higher estimate cited by Smil. There are problems in relying on this method to estimate the relative efficiency of eating meat, as farming practices vary greatly, and the protein content of meat is higher compared to plant-based foods. However, there are many other ways to measure the efficiency of eating meat compared to plant-based foods. Mekonnen and Hoekstra (2012) found that the water footprint of meat products is much more than that of most plants. The water footprint of vegetables (measured in m^3/ton) was measured to be 322, 962 for fruits, 1,644 for cereals, and 9,063 for nuts, whereas the water footprint for chicken was 4,325, 5,553 for pigs, and 15,415 for beef. With the exception of nuts, which have a high fat and protein content relative to other plant products, all meat products were found to have much less water-use efficiency, with 29% of the total water footprint of the agricultural sector going towards the production of animal products.

Perhaps the most concerning part of raising animals for food production is the large amount of land that is needed relative to growing crops. The livestock sector uses about 70% of the global agricultural land (van Zanten 2016), while supplying only 21% of the weight of food in the global diet (Machinova et al. 2015). There is also a great disparity among the amount of animal products consumed per country; developed countries have animal product consumption rates of 40% or more of diets per mass, where sub-Saharan countries and Southeast Asia have low consumption rates of less than 10%. (Machinova et al. 2015). As countries develop, it is likely that they will increase the amount of animal products per capita, as is the case with China, who increased animal product consumption for 5% to 20% since the 1960s (Machinova et al. 2015). Because of this, the projected amount of habitat loss used only for livestock and animals will constitute a much greater threat to biodiversity than expansion for plant products.

Crop farming is clearly more efficient than animal farming in regards to the amount of people a certain amount of land can support. If the amount of land used for livestock farming were to be converted to more efficient and less environmentally degrading plant products, we would have enough food to support the growing population without an increase in habitat loss, with a subsequent reduction in the amount of water pollution, gas emissions, and exploitation that livestock farming perpetuates. Currently 36% of the calories produced by the world's crops are being used as animal feed (Cassidy et al. 2013). If food was grown for direct human consumption and meat production was reduced, calories available for directly for humans would increase as much as 70%, which could feed an additional 4 billion people (Cassidy et al. 2013). Similarly, Waggoner (1996) projects that if all people were to be fed a vegetarian diet, our current croplands would be enough to support 10 billion people and eliminate world hunger.

Soy and other legumes are also excellent sources of protein and can provide humans with all the essential amino acids; soybeans average twice the amount of protein of beef, pork, or chicken by weight, while the land area needed to produce these cuts of meat requires 3x more land for chicken, 9x more land for pork, and 32x more land for beef (Machinova et al. 2015). Plant products are not only more energy efficient, less environmentally harmful, and just as nutritious as meat, but are much healthier for humans, which should provide incentives for people to start transitioning to more plant-based diets. Eating large amounts of animal products is strongly associated with heart disease, obesity, cancer, and diabetes, among other ailments (Machinova et al. 2015; McMichael et al. 2007; Campbell et al. 1998). Although vegan diets are found to be deficient in B vitamins, this can easily be avoided by eating small amounts of leans meats such as fish or taking supplements. Although vegetarian and vegan diets are gaining popularity, it is unnecessary and impractical to cut all meat and meat products out of the global diet. The aim should be to reduce the amount of these products to sustainable levels, ideally to 10% of the global food consumption by weight. Due to the myriad of negative environmental effects consuming large amounts of animal products has on this planet, reducing the amount of these products consumed is a viable solution to the biodiversity crisis.

Additionally, if some areas of degraded livestock pasture were to be restored converted into protected areas, it would become a safe haven for the threatened species who need large amounts of protected areas in order to thrive. It has been demonstrated that when former pastureland is left to its own devices after the removal of cattle, the ecosystem repaired the immense damage done to the land in just 23 years, with a 90% decrease in the amount of bare soil, and a 388% increase in rushes and willows (Batchelor et al. 2015). If meat consumption was reduced to only 10% globally like Machinova et al. (2015) suggests, there would be no need to convert natural habitat into agricultural lands, and we could instead focus on preserving the remaining land and making it suitable for the amazing diversity of life found in the few pockets of undisturbed land there is left on this planet.

b. Increasing productivity and sustainability of existing agricultural lands

There is a great debate in the scientific community on whether land-sparing (increasing productivity of agricultural lands, while making the habitat unsuitable for wildlife), or land-sharing (increasing the desirability of agricultural lands to wildlife, while decreasing yields) is the most effective solution to the biodiversity crisis. The impact of eco-friendly farming on wildlife is described below.

There is a growing amount of evidence that some species are able to thrive better in disturbed habitat and on eco-friendly farms. Tscharntke et al. (2014) gave an overview of the different environmentally-friendly farming techniques, and if they are effective way to combat habitat loss for agriculture in the tropics. Agroforestry is a technique that conserves trees and bushes in farmlands and produces environmentally-friendly “shade crops”. These the farmlands unfortunately do have lower yields than traditional, clear-cut practices, but famers are able to compensate for this by applying for a sustainability certification on their farm, and can reasonably charge more money for their products. While the goal of these certifications is to be wildlife friendly, currently there is little evidence that biodiversity increases with these practices. Some studies aim to quantify this; Kleijn et al. (2006) compared the biodiversity benefits of environmentally-friendly farming techniques to traditional methods to see if more species actually benefited from these techniques. They found that in all agri-environment schemes, biodiversity was marginally to moderately positive with species of plants, birds, bees, grasshoppers, crickets, and spiders. However, uncommon species were not found in most agri-environment farming, indicating these schemes are not useful to the conservation of rare and uncommon species, which need more elaborate conservation measures and large areas of unmodified habitat. Torralba et al. (2016) also compared benefits of agroforestry to traditional farming. They found that erosion control, biodiversity, soil fertility and ecosystem services such as nutrient cycling all increased with agroforestry farming. Birds benefitted the most for these techniques, followed by plants, fungi, and insects. These results can be interpreted to say that ecosystem function does increase with agroforestry farming, but again, most rare species still need undisturbed habitat in order to thrive, and incentives for farmers to apply these practices is low.

Biodiversity benefits of eco-friendly farms and disturbance vary with region and species, making this problem hard to quantify. Some species are negatively impacted by disturbance; Hamer et al (2003) found that composition of butterfly species in Borneo changes in response to forest gap disturbance, and species with narrower distributions and light tolerant species increasing with increased disturbance, while other species declined after logging. Peh et al. (2005) found that only 73-75% of the 159 bird species in Malaysia persisted after selective logging 30 years ago, and only 28-32% of these birds used mixed-rural habitats and farmlands to breed. Based on this evidence, it is suggested that eco-friendly farming should still be implemented in areas close to large protected areas to provide buffer zones for rare species to flourish, but the most effective technique for biodiversity conservation may to be increase production on existing farmlands to feed to growing population, without sacrificing the limited amount of lands we have for only marginal benefits. However, food production per acre of land has already increased dramatically, and there may be a limit to how much we are able to produce. In order to supply the world with food without compromising environmental security, innovative solutions need to be implemented

Creative solutions to increase food production are on the rise. The most promising new technologies for food production include urban and vertical farming. Urban farming is the practice of growing crops in cities, either indoors, on rooftops, or on small sections of lands in and around population centers. Rather than destroy native habitats to provide space for outdoor crops, food production can be shifted to cities. By farming indoors, vertical space can be used to provide local food to millions of people with an extremely small amount of space. Orsisini et al. (2014) projects that, if all available rooftops were used to plant vegetables in Bologna, Italy, it could provide its inhabitants with 77% of its vegetable requirements, as well as network of green corridors of over 94 km, improving air quality, urban biodiversity, and emissions from food transportation. Rooftop farming, in conjunction with vertical, indoor farming holds the promise to provide local food to the world's major population centers, while improving city health and aesthetic. There are limitations to these methods, as only wealthy countries have the money to spare to start an urban farming movement, and indoor plants require a significant amount of energy to grow in a world where energy production is unsustainable. Urban farming would likely not solve the problems of habitat loss in Southeast Asia for palm oil and pulp, or in places far from population centers. However, if cities were to be more sustainable and produce their own food, there would be less demand for food from farms near biodiverse habitats, reducing the need for agricultural lands and preventing habitat loss, while improving the urban dweller's health as well.

Increasing productivity of livestock farms poses many problems. Increasing productivity per animal is associated with greater industrialization of livestock farming, which generally means factory farms, which often decreases nutrition content and is cruel and inhumane. Meanwhile, grass-fed beef and free-range poultry are labelled as being more humane and healthier, but require large amounts of land, and meat from these animals is often leaner and produces less calories. It is clear there is no catch-all solution for increasing productivity of animal farms while doing good to the environment and remaining ethically sound. There are small things farmers can do to offset negative environmental effects of animal farming. Monteny et al. (2005) proposes several options to mitigate greenhouse gas emissions from livestock. They propose that increasing production per animal and modifying their diet to more complex starches which reduce fermentation are reasonable measures to decrease the amount of emissions per animal. To decrease exploitation of wildlife caused by livestock farming McManus et al. (2014) suggests using guard animals and livestock collars to protect livestock from predators and decrease the amount of wildlife being killed, and shows that it is more cost effective to do so. In these small ways, it is possible to reduce our effect on the environment and native fauna around livestock farmlands. Although, with the projected increase of agricultural lands and livestock production, the most effective solution would be to reduce the demand for meat and dairy products and thus the number of animals.

V. Conclusions

It is no mystery as to why we live in a world of environmental problems and massive declines of wildlife around the globe. The biodiversity crisis is linked to human population growth and the increasing demand for land needed for development and agriculture, which decreases habitat for native wildlife and cause a myriad of negative environmental effects. The documented effects of human's negative effects on this Earth are numerous and well-studied, yet the literature is scarce as far as real-world solutions we can implement to help mitigate our effects on the environment. Many studies focus on "what-if" scenarios, and lack data on any real solutions that are currently being implemented. The very complicated nature of the biodiversity crisis makes it very difficult to implement change, and the only real way any significant amount of change can occur is if environmental protection policies are implemented on a global scale, and the mindset of the entire human population changes to become more sustainable and mindful of the resources on our planet. This change is slowly taking place, however, as we can see with the rise of vegetarianism and veganism, the demand for organic and pasture-raised foods, and an overall shift to try to become more sustainable. In order to perpetuate these values, education needs to shift to focus more on living sustainably and reducing waste, nutrition and how to prepare fresh foods, and sex education needs to focus on proper methods of birth control instead of abstinence. The government also needs to provide incentives to farmers to use responsible animal husbandry techniques and eco-friendly agriculture instead of providing massive subsidies to multi-billion dollar meat and dairy companies, and preventative birth control methods should be provided free of charge to help curb population growth. It is in these small ways that the global mindset can change to become more mindful of the ways we impact this planet, and resources can go into saving the only cumulation of life we know of in this universe, while improving human health and well-being at the same time.

Acknowledgements

I would like to thank Dr. Forrest for the feedback regarding the topics of this research paper, as well as my peer reviewers and classmates for providing me with ideas and critiques.

References

Adenle AA, Stevens C, Bridgewater P. 2014. Global conservation and management of biodiversity in developing countries: An opportunity for a new approach. Environmental Science and Policy. 45: 104-108.

Batchelor JL, Ripple WJ, Wilson TM, Painter LE. 2015. Restoration of riparian areas following the removal of cattle in the northwestern Great Basin. Environmental Management. 55:930-942.

Bergstrom BJ, Arais LC, Davidson AD, Ferguson AW, Randa LA, Sheffield SR. 2013. License to kill: Reforming federal wildlife control to restore biodiversity and ecosystem function. Conservation Letters. 2(2):131-142.

Bianchi CA, Haig SM, 2013. Deforestation trends of tropical dry forests in central Brazil. Biotropica. 45:395–400.

Bouwman AF, Beusen AHW, Billen G. 2009. Human alteration of the global nitrogen and phosphorus soil balances for the period 1970–2050. Global Biogeochemical Cycles. 23(4).

Bradshaw CJA, Sodhi NS, Brook BW. 2009. Tropical turmoil: a biodiversity tragedy in progress. Frontiers in Ecology and the Environment. 7(2):79-87.

Brook BW, Sodhi NS, Ng PKL. 2003. Catastrophic extinctions follow deforestation in Singapore. Nature 424:420–423.

Brook BW, Bradshaw CJA, Koh LP, Sodhi NS. 2006. Momentum drives the crash: Mass extinction in the tropics. Biotropica. 38:302–305.

Bucher EA. 1992. The causes of extinction of the Passenger Pigeon. Current Ornithology. 9:1-36.

Burkle LA, Marlin JC, Knight TM. 2013. Plant-pollinator interactions over 120 years: Loss of species, co-occurrence, and function. Science. 339(6127):1611-1615

Campbell TC, Parpia B, Chen J. 1998. Diet, lifestyle, and the etiology of coronary artery disease: The Cornell China Study. The American Journal of Cardiology. 82(10):18-21.

Cardillo M, Mace GM, Gittleman JL, Purvis A. 2006. Latent extinction risk and the future battlegrounds of mammal conservation. Proceedings of the National Academy of Sciences of the United States of America. 103(11):4157-4161.

Cardillo M, Mace GM, Jones KE, Bielby J, Bininda-Edmonds ORP, Sechrest W, Orme DL, Purvis A. 2005. Multiple causes of high extinction risk in large mammal species. Science. 309(1538):1239-1241.

Cassidy ES, West PC, Gerber JS, Foley JA. 2013. Redefining agricultural yields: From tonnes to people nourished per hectare. Environmental Research Letters. 8.

Ceballos G, Ehrlich PR, Dirzo R. 2017. Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines. Proceedings of the National Academy of Sciences of the United States of America. 114(30): 6089-6096.

Ceballos G, Ehrlich PR, Barnosky AD, Garcia A, Pringle RM, Palmer TD. 2015. Accelerated modern human–induced species losses: Entering the sixth mass extinction. Science Advances. 1(5).

De Vos JM, Joppa LN, Gittleman JL, Stephens PR, Pimm SL. 2014. Estimating the normal background rate of species extinction. Conservation Biology. 29(2).

Durant SM, Mitchell N, Groom R, Pettorelli N, Ipavec A, Jacobson AP, Woodroffe R, Bohm M, Hunter LTB, Becker MS et al. 2017. The global decline of cheetah *Acinonyx jubatus* and what it means for conservation. Proceedings of the National Academy of Sciences of the United States of America. 114(3):528-533.

Foekema EM, De Gruijter C, Mergia MT, van Franeker JA, Murk AJ, Koelmans AA. 2013. Plastic in north sea fish. Environmental Science & Technology. 47(15):8818-8824.

Goldewijk KK. 2001. Estimating global land use change over the past 300 years: the HYDE database. Global Biogeochemical Cycles. 15(2):417–433.

Hamer KC, Hill JK, Mustaffa N, Sherratt N, Maryati M, and Chey VK. 2003. Ecology of butterflies in natural and selectively logged forests of northern Borneo: The importance of habitat heterogeneity. Journal of Applied Ecology. 40(1):150-162.

Henschel P, Coad L, Burton C, Chataigner B, Dunn A, MacDonald D, Saidu Y, Hunter LTB. 2014. The lion in west Africa is critically endangered. PLOS ONE. 9(1).

Hernández DL, Vallano DM, Zavaleta ES, Tzankova Z, Pasari JR, Weiss S, Selmants PC, Morozumi C. 2016. Nitrogen pollution is linked to US listed species declines. BioScience. 66(3):213–222.

Holmern T, Nyahongo J, Roskaft, E. 2007. Livestock loss caused by predators outside the Serengeti National Park, Tanzania. Biological Conservation. 135:518–526.

Horwitz P, Recher H, Majer J. 1999. Putting invertebrates on the agenda: political and bureaucratic challenges. Transactions of the Royal Zoological Society of New South Wales, Mosman: 398-406.

Kleijn D, Baquero RA, Clough Y, Diaz M, De Esteban J, Fernandez F, Gabriel D, Herzgog F, Holzschuh A, Johl R. 2006. Mixed biodiversity benefits of agri-environment schemes in five European countries. Ecology Letters. 9:243-254.

Koh LP, Wilcove DS. 2008. Is oil palm agriculture really destroying tropical biodiversity? Conservation Letters. 1(2): 60-64.

Laurance WF. 1999. Reflections on the tropical deforestation crisis. Biological Conservation. 91:109-117.

Laurance WF, Nascimento HEM, Laurance SG, Andrade A, Ribeiro JELS, Giraldo JP, Lovejoy TE, Condit R, Chave J, Harms KE, D'Angelo S. 2006. Rapid decay of tree-community composition in Amazonian forest fragments. The Proceedings of the National Academy of Sciences of the United States of America. 103(50):19010-19014.

Lee TM, Jetz W. 2010. Unravelling the structure of species extinction risk for predictive conservation science. Proceedings of the Royal Society B. 278(1710).

Machovina B, Feeley KJ, Ripple WJ. 2015. Biodiversity conservation: The key is reducing meat consumption. Science of the Total Environment. 536(1): 419-431.

McManus JS, Dickman AJ, Gaynor D, Smuts BH, and MacDonald DW. 2014. Dead or alive? Comparing costs and benefits of lethal and non-lethal human–wildlife conflict mitigation on livestock farms. Oryx. 49(4):687-695.

McMichael AJ, Powles JW, Butler CD, Uauy R. 2007. Food, livestock production, energy, climate change, and health. The Lancet. 370(9594):1253-1263.

Mekonnen MM, Hoekstra. 2015. Global gray water footprint and water pollution levels related to anthropogenic nitrogen loads to fresh water. Environmental Science & Technology. 49(21):12860-12868.

Mekonnen MM, Hoekstra AY. 2012. A global assessment of the water footprint of farm animal products. Ecosystems. 15(3):401-415.

Miller BJ, Reading RP, Biggins DE, Detling JK, Forrest SC, Hoogland JL, Javersak J, Miller SD, Proctor J, Truett J et al. 2007. Prairie dogs: An ecological review and current biopolitics. The Journal of Wildlife Management. 71(8):2801-2810.

Minin ED, Slotow R, Hunter LT, Pouzols FM, Toivonen T, Verberg PH, Leader-Williams N, Petracca L, Moilanen A. 2016. Global priorities for national carnivore conservation under land use change. Scientific Reports. 6.

Mitchell BR, Jaeger MM, Barrett RH. 2004. Coyote depredation management: current methods and research needs. Wildlife Society Bulletin. 32(4):1209-1218.

Molnar JL, Gamboa RL, Revenga C, Spalding MD. 2008. Assessing the global threat of invasive species to marine biodiversity. Frontiers in Ecology and the Environment. 6(9):485-492.

Monteny G, Bannink A, Chadwick D. 2006. Greenhouse gas abatement strategies for animal husbandry. Agriculture, Ecosystems and Environment. 112:163-170.

Morales-Hidalgo, D. 2006. Tree cover assessment: with special focus on the relative position issue. Case Studies in Open Areas in Costa Rica. Cuvillier Verlag.

Moss B. 2008. Water pollution by agriculture. Philosophical Transactions of the Royal Society B: Biological Sciences. 363(1491):659-666.

Orsini F, Gasperi D, Marchetti, Poivene C, Draghetti S, Ramazzotti S, Bazzocchi G, Bazzocchi G, Gianquinto G. 2014. Exploring the production capacity of rooftop gardens (RTGs) in urban agriculture: The potential impact on food and nutrition security, biodiversity and other ecosystem services in the city of Bologna. Food Security. 6(6):781-792.

Peh KSH, de Jong J, Sodhi NS, Lim SLH and Yap CAM. 2005. Lowland rainforest avifauna and human disturbance: persistence of primary forest birds in selectively logged forests and mixed-rural habitats of southern Peninsular Malaysia. Biological Conservation. 123(4):489-505.

Pimm SL, Jenkins CN, Abell R, Brooks TM, Gittleman JL, Joppa LN, Raven PH, Roberts CM, Sexton JO. 2014. The biodiversity of species and their rates of extinction, distribution, and protection. Science. 344(6187).

Pounds AJ, Bustamante MR, Coloma LA, Consuegra JA, Fogden MPL, Foster PN, La Marca E, Masters KL, Merino-Viteri A, Puschendorf R et al. 2006. Widespread amphibian extinctions from epidemic disease driven by global warming. Nature. 439(12).

Regnier C, Achaz G, Lambert A, Cowie RH, Bouchet P, Fontaine B. 2015. Mass extinction in poorly known taxa. The Proceedings of the National Academy of Sciences of the United States of America. 112(25) 7761-7766.

Reilly SB, Bannister JL, Best PB, Brown M, Brownell Jr. RL, Butterworth DS, Clapham PJ, Cooke J, Donovan G, Urbán J, Zerbini AN. 2012. *Eubalaena glacialis*. The IUCN Red List of Threatened Species: e.T41712A17084065.

Reilly SB, Bannister JL, Best PB, Brown M, Brownell Jr. RL, Butterworth DS, Clapham PJ, Cooke J, Donovan G, Urbán J, Zerbini AN. 2008. *Eubalaena japonica*. The IUCN Red List of Threatened Species: e.T41711A10540463.

Schloegel LM, Hero JM, Berger L, Speare R, McDonald K, Daszak P. 2006. The Decline of the Sharp-Snouted Day Frog (*Taudactylus acutirostris*): The first documented case of extinction by infection in a free-ranging wildlife species? EcoHealth. 3(1):35-40.

Sodhi NS, Bickford D, Diesmos AC, Lee TM, Koh LP, Brook BW, Sekercioglu CH, Bradshaw CJA. 2008. Measuring the meltdown: Drivers of global amphibian extinction and decline. PLOS One. 3(2).

Sodhi NS, Koh LP, Brook BW, Ng PKL. 2004. Southeast Asian biodiversity: an impending disaster. Trends in Ecology and Evolution. 19(12).

Smil V. 2002. Eating meat: Evolution, patterns, and consequences. Population and Development Review. 28(4): 598-639.

Smith P, Haberl H, Popp A, Erb K, Lauk C, Harper R, Tubiello FN, de Siqueira Pinto A, Jafari M, Sohi S et al. 2013. How much land-based greenhouse gas mitigation can be achieved without compromising food security and environmental goals? Global Change Biology. 19(8):2285-2302.

Steinfeld H, Gerber P, Wassenaar TD, Castel V, Haan CD. 2006. Livestock's long shadow: environmental issues and options. Food and Agriculture Organization of the United Nations, Rome.

Strayer DL. 2010. Alien species in fresh waters: ecological effects, interactions with other stressors, and prospects for the future. Freshwater Biology. 55(1):152-174.

ter Steege H, Pitman NCA, Killeen TJ, Laurance WF, Peres CA, Guevara JE, Salomao RP, Castilho CV, Amaral IL, de almeida Matos FD. 2015. Estimating the global conservation status of more than 15,000 Amazonian tree species. Science Advances. 1(10).

Thomas CD, Cameron A, Green RE, Bakkenes M, Beaumont LJ, Collingham YC, Erasmus BF, De Siqueira MF, Grainger A, Hannah L, 2004. Extinction risk from climate change. Nature. 427(6970):145–148.

Thomas JA. 2016. Butterfly communities under threat. Science. 353(6296):216-218.

Torralba M, Fagerholm N, Burgess PJ, Moreno G, Plieninger T. 2016. Do European agroforestry systems enhance biodiversity and ecosystem services? A meta-analysis. Agriculture, Ecosystems, and Environment. 230:150-161.

Tscharntke T, Milder JC, Schroth G, Clough Y, DeClerck F, Waldron A, Rice R, Ghazoul J. 2014. Conserving biodiversity through certification of tropical agroforestry crops at local and landscape scales. Conservation Letters. 8(1): 14-23.

van Zanten, HH, Mollenhorst H, Klootwijk CW, van Middelaar CE, de Boer IJM. 2016. Global food supply: Land use efficiency of livestock systems. The International Journal of Life Cycle Assessment. 21(5):747-758.

Waggoner 1996. How much land can ten billion people spare for nature? Daedalus. 125(3):73-93.

Wilcox C, Van Sebille E, Hardesty BD. 2015. Threat of plastic pollution to seabirds is global, pervasive, and increasing. Proceedings of the National Academy of Sciences of the United States of America. 112(38):11899-11904.

Wilcove DS, Giam X, Edwards DP, Fisher B, Koh LP. 2013. Navjot's nightmare revisited: Logging, agriculture, and biodiversity in Southeast Asia. Trends in Ecology and Evolution. 9:531-540.

Wiles GJ, Bart J, Beck Jr RE, Aguon CF. 2003. Impacts of the brown tree snake: Patterns of decline and species persistence in Guam's avifauna. Conservation Biology. 17(5):1350-1360.

Wirsenius S, Azar C, Berndes G. 2010. How much land is needed for global food production under scenarios of dietary changes and livestock productivity increases in 2030? Agricultural Systems. 103:621-638.

Wright JS. 2005. Tropical forests in a changing environment. Trends in Ecology and Evolution. 20(10):553-560.