Jason Clay, World Wildlife Fund

Kent Redford, Archipelago Consulting

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Arcs of Habitat Loss

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Arcs of Habitat Loss
The Ecological Frontiers of Agricultural Expansion
A Concept

Jason Clay, WWF-US
Kent H. Redford, Archipelago Consulting

More than three-quarters of the Earth's ice-free land surface has been transformed by humans (Ellis and Ramankutty 2008). The oceans have also been transformed through warming, acidification, siltation and agrochemical runoff, overfishing, and destructive fishing practices. Though these alterations have met much of humanity's search for resources and made possible current levels of development, they have also produced negative impacts on climate, air and water quality, biodiversity, topsoil, and many other factors important for human well-being and the well-being of other species and ecosystems on the planet.

Food production is responsible for the largest single use of land. Over 1.5 billion hectares of the earth's land surface are devoted to cropland with another 3.3 billion hectares in pastureland—together covering 38% of the earth's ice-free surface (Foley et al. 2011). As such, agriculture is the major driving force for greenhouse gas emissions, chemical use, water take and effluent quality, soil degradation and nutrient runoff. Most of these effects have been driven by conversion of natural ecosystems to agricultural ones, many of which took place hundreds (e.g., North America) or thousands (e.g., Europe, India) of years ago. One area where habitat conversion has drawn much attention over the last 40 years is the Amazon forest. Dubbed an "arc of deforestation" the fact that this area involves tropical forests and the complete removal of natural habitat through deforestation and land clearing has meant that alteration of natural ecosystems for agriculture has most often been equated with tropical forests, particularly in the Amazon, and with deforestation.

The expansion of food production has involved many more ecosystem impacts than deforestation, with effects in many more ecosystems than tropical moist forests. Food production has affected grasslands, dry forests, boreal forests, savannahs, mangroves, soils, freshwater systems, groundwater and aquafers, the ocean and even the air and air quality. In addition to deforestation, increasing food production has involved ecosystem degradation and fragmentation, the spread of invasive species and disease, changes in hydrological regimes, weather and climate, the ocean bottom, and evolutionary trajectories.

Predictions vary, but with a business-as-usual scenario of human population growth—greater per capita incomes and increased consumption—food production will need to increase substantially. Most of the literature focuses on terrestrial production, and on the impacts on tropical forests. But it is not just forests at stake now, nor are they the only ecosystems that have been affected by food production to date. And, if people are to make responsible and informed decisions in the debates about "intensification" and "extensification," (Balmford et al. 2005) then we must include the full range of the earth's systems that will be affected, the different scales at which these effects will take place, the potential impacts of climate change, and, of course, the types of changes that are ongoing. If the production of food is to become more sustainable going forward, then we will have to find ways to better understand the range of impacts and optimize performance across the key ones rather than just maximize performance across one or two of them (e.g., productivity).

The purpose of this paper is to expand our collective thinking about the impacts of producing food by exploring a wider range of impacts of food production on terrestrial and aquatic ecosystems beyond tropical deforestation. Our goal is to present a system of "arcs" – areas of current expanding impacts of food production on a range of different "habitats" that must be considered for both ameliorative and restorative action. We focus on "primary" arcs, those ecosystems most affected by food production. Each of these primary arcs is connected to secondary and tertiary arcs, depending on the scale of interest. We focus on arcs from global to ecoregional scale, recognizing that there are finer scales worthy of investigation such as watershed and local topographic scale.

Unlike those who focus on the deforestation of tropical moist forests, we focus on primary arcs that have not been the subject of extensive work. The primary arcs we focus on are soils, groundwater, freshwater systems, temperate and tropical grasslands, tropical dry forests, and the ocean bottom.

Soils

Soils are a "three-dimensional regulatory system" that supports life on earth as well as the delivery of ecosystems services (Adhikari and Hartemink 2016). Operating at the intersection of geology, water, biology, and climate they are amongst the most biological diverse habitats on earth with one gram of soil containing tens of thousands of forms of life (Bender et al. 2016). Soil holds a reservoir of organic carbon that greatly exceeds the carbon in the global atmosphere and biosphere (Amundson et al. 2015). Soils vary with geology, climate, and biota and there are a very large number of types of soils -- for example over 20,000 soil types have been mapped in the U.S. alone (Amundson et al. 2015).

Soils supply seven principal services to humans: biomass production through agriculture and forestry; store, filter, and transform nutrients, pollutants, and water; create and maintain a pool of biodiversity; support human physical and cultural activities; serve as a source of raw material; act as a reservoir to hold carbon; and retain an archive of geological and archaeological heritage (Keesstra et al. 2016). The biodiversity in soil is little studied but includes untold numbers of vertebrate, invertebrate, and microorganisms linked together and to plants in complicated ecological networks. 'Green water'—the water in soil potentially available to plant roots and soil biota—is a critical part of soil resources. Agriculture depends on abundant green water and nearly 90% of the water consumed by crops worldwide is green water (Sposito 2013). Soil management is a key component of human health (Brevik et al. 2017).

Since humans began to cultivate food, they have been affecting soils, mostly negatively. The growing human population with its increasing and changing needs for food, fiber, and fuel and its increasing urbanization all put increasing demands on soil resources. In addition, technological innovations have also had increasing, and increasingly negative impacts on soils—metal and especially steel plows, animal traction to pull plows and then machines, and various forms of technology that make habitat conversion ever easier. Today, the area of land, and the soil that underlies it, is heavily influenced by crops, and grazing is roughly equivalent to the land area covered by ice or otherwise disturbed during the last glacial maximum (Amundson et al. 2015).

Growing food changes soil characteristics, soil biodiversity, soil water, and ecosystem flows. Removing natural vegetation, for agriculture or other purposes, changes the underlying soil in terms of texture, composition, carbon content, soil fauna, and more. Though contested, deforestation is said to have had the greatest impact on soil carbon causing on average of 25% of soil carbon to be lost (Smith et al. 2016). The largest decrease in soil carbon has been seen in temperate regions (52%) followed by tropical regions (41%) and boreal regions (31%) (Wei et al. 2014). Grasslands also contain large amounts of soil carbon which is negatively affected when converted to cropland—some estimate up to 50% more than is stored in forests worldwide (Conant 2010) - and have a more dynamic carbon balance due to grazing and burning (Conant 2010; Conant et al. 2017). Different land uses also have differential impacts on soil depending on the underlying soil type, use of fire, crop management, and soil management. Soils consistently used for agriculture change so much that they become "domesticated"—typified by their inability to maintain the qualities of the original soil and their reliance on human inputs for ongoing productivity (Amundson et al. 2015) including industrially produced mineral fertilizers and pesticides. To maintain soil productivity, strong human interventions in otherwise natural processes has become necessary (Bender et al. 2016).

Agricultural soils have not fared well as a result of human intervention. Most of the the world's soils are classified as being in only fair, poor, or very poor condition. (FAO and ITPS 2015). Between 1 billion and 6 billion hectares of the earth are considered degraded—many with soils no longer usable for conventional production (Gibbs and Salmon 2015). Soil erosion greatly exceeds soil production in many agricultural areas and nearly 33% of the world's arable land has been lost to erosion or pollution (Grantham Centre 2015). Erosion removes nutrients and dislodges sediment with knock-on impacts in drainages all the way into the ocean (Amundson et al. 2015).

Soil cultivation and land clearing for agriculture has made a major contribution to total anthropogenic greenhouse gas emissions and climate change. However, climate change is changing soils, cultivated and uncultivated, by speeding up the release of greenhouse gasses from soil organic matter (Amundson et al. 2015) and exacerbating anthropogenic changes in the Earth's climate (Hicks et al. 2017).

Groundwater

Groundwater is often described as the forgotten part of freshwater on which all life depends. Hidden below ground in soil and porous rock, groundwater is defined as water located beneath the earth's surface in an aquifer matrix as is distinguished from free surface water found in streams, reservoirs, or lakes. There is a dynamic exchange between the two as groundwater can become surface water through springs and wetlands and surface water can seep into the earth to become ground water (Siebert et al. 2010).

Groundwater, a critical contributor to human life, is almost exclusively drawn from wells deeper than 30 m. (Ho et al. 2016). Groundwater sources provide 40-50 percent of all water used for irrigation (IAH 2015; Famiglietti 2014) and almost half of all drinking water worldwide (NGWA 2016a) with over two billion people relying on groundwater as their primary water sources (Famiglietti 2014). Agricultural uses account for 70% of groundwater use (Aldava 2017). The percentage of irrigation done with ground water varies from 94% for Pakistan to 3% for Russia with the US at 71% and Mexico 72% (NGWA 2016). Groundwater can also be essential for other forms of food production such as aquaculture, hydroponics, etc. (NGWA 2016b).

Groundwater has been a critical factor in the 250% increase in food production achieved between 1970 and 2000. This major increase was accomplished on only 15% more land but with a 300% increase in irrigation water well extraction (IAH 2016). Availability of groundwater has often been a key factor in beginning higher-value irrigated agriculture since, in the tropics, it can make possible year-round production, higher quality production due to fewer pollutants and, as a result, increase compliance with health and safety standards (IAH 2016).

Groundwater has also played a key role in trade in “virtual groundwater” or embedded water in the export of crops grown with water in one country sold to another country. This production and trade have been based on increased groundwater use. A vast majority of the world’s population lives in countries sourcing nearly all their staple crop imports from partners who deplete groundwater to produce crops. This trade has increased by 22% in ten years, mostly owing to rises in production in India (23%), China (102%) and the USA (31%) (Dalin et al. 2017)

As a result of their extensive use for local production and consumption and international trade, groundwater aquifers are experiencing rapid rates of depletion. For example, in the US Ogallala Aquifer, fossil groundwater is extracted for irrigation at nearly ten times the rate of recharge (Russo and Lall 2017). Depletion is found in many of the largest aquifers such as those in northern China, southern Australia, the Sahara, southern South America and the northern Midwest and California’s Central Valley in the US (Famiglietti 2014). Twenty-one of 37 major global aquifers are being depleted more rapidly than they are being recharged (IAH 2016). The status of the other 16 is unclear.

In addition to posing risks to agricultural production and food security, overuse of groundwater affects natural systems. It can lead to depletion of streams, rivers and lakes with knock-on biodiversity impacts as well as irreversible salinization of aquifers in coastal areas and even land subsidence that permanently impairs the ability of aquifers to store water (OECD 2016). Removal of freshwater permits intrusion of seawater into freshwater aquifers (Allouche et al. 2017). Depleted aquifers can become a sink for salts leached from arid land (IAH 2016). Paradoxically, groundwater that is pumped from aquifers but not taken up by target irrigated plants can significantly contribute to changes in important flows and river ecologically in some basins (Grogan et al. 2017). The scale of South Asian irrigation is so vast that it has been shown to alter the monsoon (Guimberteau et al. 2012).

Some have forecast a 30% increase in water consumption by 2030 (Pittock et al. 2016). Projections of future growth in agriculture significantly overlap with aquifers from which groundwater is being unsustainably harvested (Gleeson et al. 2012). Increased use of ground water will impact both people - an estimated 1.7 billion people live in areas where groundwater resources are threatened—as well as freshwater systems and the species that depend on them (Gleeson et al. 2012).

Climate change impacts on groundwater will have impacts on both humans and the environment. Greater variability in both rainfall and drought complicates predicting the relationship between surface and ground water and their impact on both human and natural systems, both of which will be affected by the type of agriculture or other land cover (Pittock et al. 2016; Kløve et al. 2014).

Freshwater Ecosystems

Freshwater ecosystems including lakes, ponds, rivers, streams, springs, and wetlands occupy less than 1 percent of Earth’s surface yet support more species per unit area than terrestrial of oceanic ecosystems (Matthews 2016; Vörösmarty et al. 2015). They provide a wide range of benefits to society including climate regulation, nutrient cycling, water purification, water supply, food, energy, transportation, flood control and biodiversity conservation (British Ecological Society 2013; Castello and Macedo 2015). Of the freshwater types, rivers are particularly important, supplying around 80% of renewable freshwater used by humans (Vörösmarty et al. 2015). Often underappreciated is the role freshwater ecosystems play in providing food to at least 2 billion people—in many parts of the world this is the primary source of protein and micronutrients (Brooks et al. 2016).

Freshwater ecosystems rely for their functioning on volume, timing quality and variability of water flows (Castello and Macedo 2015) and thus are very susceptible to human alteration. And humans have been altering both coastal and inland freshwater ecosystems for millennia. Managing freshwater ecosystems for human benefits has historically focused on direct benefits through drinking water, agriculture, food, power generation, industrial uses, or transport (Acreman et al. 2014). Increasing development and industrial uses has often meant increasing uses of water and increasing impacts on freshwater ecosystems (Davis et al. 2015).

Freshwater ecosystem loss is caused by conversion to agriculture, changes in water use and availability, increasing urbanization, disease control, invasive species, and on the coast, sea defenses, port development and agriculture (Davidson 2014). Globally, wetland conversion and loss are more than 50% and as much as 87% since the beginning of the 18th century with the pace of loss accelerating, particularly in Asia and especially for coastal wetlands (Davidson 2014).

Agriculture is the largest human use of fresh water in the world and much of it is either used before it reaches freshwater ecosystems of is extracted from such ecosystems. Agricultural uses, account for approximately 70% of total water withdrawals (Mancosu et al. 2015) and represents 92% of humanity's water footprint (Hoekstra and Mekonnen 2011). Rain-fed agriculture is the world's largest user of water (Foley et al. 2011). It is projected to double by 2050 (Pfister et al. 2011). However, most of this is green, or soil water, which accounts for 4-5 times more agricultural water use than blue, or free-flowing, water (Hoff et al. 2010). Nonetheless, in many regions increasing agriculture is based on increased use of blue water (Hoff et al. 2010).

Major degradation to freshwater systems through diversion of water, draining or drawing down water bodies, changes in flow regimes, breaking connectivity, pollution, and invasive species (Matthews 2016). At least half of the world's people suffer from polluted water (OECD 2017). In many parts of the world there is extensive loss of services from freshwater ecosystems. In China 43% of surface water is polluted and roughly 28,000 rivers have disappeared in the last few decades, due, in part, to water extraction for industry and agriculture (Matthews 2016). In addition, freshwater biodiversity has been degraded more than that of any other ecosystem (OECD 2017).

The Amazon basin is an example of such extensive alteration where hydrological connectivity regulating the structure and function of freshwater ecosystems and the services they provide has been disrupted by dams, mining, land-cover change and climate change (Castelo and Macedo 2015).

Much of the focus on water management has been on generating resources of direct use to humans but increasingly there is an emphasis on the indirect services freshwater ecosystems provide to both humans and nature. Recognition that biodiversity and ecosystem services rely on freshwater attributes has given rise to the concept of "environmental flows" that describes the quantities, qualities and patterns of water flows required to sustain freshwater ecosystems and their services (Acreman et al. 2014). Given that approximately 30% of present human water consumption is supplied from non-sustainable water resources and that this is expected to rise in coming decades (Wada and Bierkens 2014), the concept of environmental flows is a key component of future sustainability for both humans and freshwater ecosystems.

Freshwater systems are particularly vulnerable to recent human-induced global change because of their physical fragmentation within the terrestrial landscape which creates susceptibility to water diversion, damming, land-use change, land-based pollution, and climate effects. Consequently, declining water availability and quality will, by 205o, result in 2.3 billion people living in water basins experiencing severe water stress (Davis et al. 2015).

Nearly 80% of the global population experiences a high level of threat to their water security (Vôrösmarty et al. 2010). This threat is unevenly distributed with industrialized nations ameliorating the threat through infrastructure and developing nations with fewer means of mitigation experiencing the most serious threats (Green et al. 2015).

Climate change will have major effects on freshwater systems from whole basins such as the Amazon where both droughts and floods are predicted to increase partially because of large-scale loss of natural habitat in the basin (Castello and Macedo 2015). Climate change models suggest that in the future there will be both less renewable surface water and less groundwater, particularly in dry and Mediterranean climates, which will increase competition between water users and between humans and nature. In contrast, renewable water resources are predicted to increase at high latitudes. There will be decreasing storage of freshwater in glacier ice and snow, negatively affecting surface flows (Döll et al. 2015). Extreme weather events such as major floods or prolonged droughts are forecast to be more common as the climate changes. Such events have been shown to have significant impacts on freshwater ecosystems and the services they provide (British Ecological Society 2013).

Grasslands

Grasslands are stable ecosystems that can have long-lived plants, many endemic species, and complex food-webs with very high biomass of species (Bond and Parr 2010) and vast amounts of organic matter and soil carbon. Grasslands are one of the world’s most extensive biomes, occurring on all continents except Antarctica, covering approximately 26% of the world land area and 70% of the world agricultural area (Conant 2010). They are found in a wide range of environmental conditions from the tropics to the Arctic, from sea level to mountain tops and from good to poor soils (Veldman et al. 2015). Definitions of grasslands vary and though grasses and other grass-like plants are the dominant vegetation form, grasslands also include many other types of plants, including trees. The issue of grasslands is further complicated by natural grasslands, overplanted natural grasslands, and established pastures and grasslands that are planted.

Climate, fire, and grazing are the three key factors responsible for the origin, maintenance, and structure of most grasslands (Blair et al. 2014). Grasslands are carbon-rich, containing what some estimate to be nearly 50% more than stored in forests worldwide (Conant 2010), but unlike forests, most of the carbon is found below-ground. And there is more carbon sequestered in grasslands than forests. Decomposition is slow, especially in temperate areas, and therefore the soils are often fertile (Blair et al. 2014). Unlike forested systems the above-ground carbon is cycled much more rapidly through burning, grazing, and habitat conversion (Lehmann and Parr 2016). Grassland soils have the potential to store a large amount of carbon depending on their management, underlying geology, and vegetation cover (McSherry and Ritchie 2013). Grasslands contribute 30% of global terrestrial net primary productivity and store 15% of the world's carbon.

Grasslands have received much less attention than forested ecosystems, yet their conservation status is, in many ways, worse than that of forests and temperate grasslands are classified as the world's most endangered biome (Hoekstra et al. 2005). The fertile soils of unplowed grasslands and the absence of trees have made grasslands a key target for agriculture after the invention of the steel plow by John Deere in 1837, much of the world's grasslands on fertile soils have been converted to agriculture (Dixon et al. 2014). For example, over 80% of North America's central grasslands have been converted to agriculture (Egoh et al. 2016) and in 2014 the northern Great Plains lost more acres to conversion than the Brazilian Amazon (WWF 2016). Grasslands have been shown to be the biome most impacted by land-use pressures (Newbold et al. 2016).

As well as being completely converted, grasslands are also undergoing widespread degradation caused most frequently by climate change and human activities. At a global scale almost half of grassland ecosystems are classified as degraded with the largest area of degradation occurring in Asian grasslands (Gang et al. 2014). Fire is a normal part of grasslands but when too frequent or in the wrong season can degrade the ecosystem and rasslands account for approximately 85% of the global land area burnt annually (Parr et al. 2014).

Estimates are that globally 800 million people rely directly on grasslands for their livelihoods (Blair et al. 2014). In the tropics, grassy biomes are home to somewhere between 500 million (Bond 2016) and a billion people (Lehmann and Parr 2016). Direct use of grasslands by local human populations is greatest in Africa and Asia and less important in Latin America and Australia. Most commonly harvested are firewood, medicinal plants, food, non-timber forest products, and construction material (Lehmann and Parr 2016). Water provisioning is also a key ecosystem service provided by grasslands (Egoh et al. 2016). Finally, much of the world eats domesticated grasses such as corn, rice, wheat, oats, barley, and sorghum (Blair et al. 2014) and grasslands harbor genetic richness of these and related species.

Grasslands are used not only for agriculture, but also for animal husbandry with grazing by sheep, goats, cattle, horses, yaks, and other domesticated livestock. Measures of agricultural production often underestimate the contribution such livestock production makes to local human populations, especially poorer pastoralists (Boval et al. 2017). Grassland use is also a part of commercial livestock production wherever they occur.

Grasslands are threatened by a variety of factors including climate change, elevated CO2 concentrations, increasing nitrogen deposition, invasive species, habitat fragmentation, degradation due to overgrazing, changes in natural disturbance regimes like fire, and woody plant expansion (Blair et al. 2014). Agricultural expansion is currently targeting many grassland areas in South America, southern Africa, North America, and Asia (Dixon et al. 2014). Rising human population, growing markets, and growing market connectivity (e.g., China's "Belt and Road" He et al. 2016) indicate that grasslands will be further degraded (Blair et al. 2014). Foreshadowing the importance of China's belt and road strategy, the production of soy in the Russian Far East (at the expense of both grasslands and boreal forests) for export to China has tripled in the last decade. And, in central Canada, farmers report that in 2000 they could produce four crops whereas today they can grow 22, exporting some five million tons of pulses to India alone. In North Dakota, farmers report that the growing season is three times longer than it is today.

Emerging threats to grasslands include land management for carbon sequestration (e.g., planting trees for carbon sequestration in grassland areas) and increasing atmospheric levels of carbon dioxide which favors plants with C3 photosynthesis (e.g., trees) over those with C4 photosynthesis (i.e., grasses) (Parr et al. 2014). This pattern of increasing the abundance of woody plants in grassland has already been shown to be occurring in many tropical grasslands (Stevens et al. 2017). Finally, grasslands have been targeted for production of biofuel crops, and if the market increases for such crops, grassland conversion is predicted to increase significantly (Blair et al. 2014).

Tropical Dry Forest

Dryland biomes extend well outside the tropics and cover 41.5% of the earth's surface. The most recent estimate is that 1079 million hectares of the biome is forest. This makes the area of dry forest equivalent to that of tropical moist forest and substantially larger than previous estimates due to differences in satellite data mapping approaches and differing definitions (Bastin et al. 2017). Dry tropical forests once occupied up to 40% of all tropical forest prior to large-scale deforestation (Murphy and Lugo 1986).

Dry forests found in the tropics are defined by FAO as those experiencing a tropical climate with summer rains, a dry period of five to eight months and annual rainfall from 500 to 1500 mm (FAO 2001 in Blackie et al. 2014). Around half of these forests are in South America with the remaining divided between North and Central America, Africa, and Eurasia with a small percentage in Australasia and Southeast Asia (Miles et al. 2006)

Tropical forests are often found in areas of high human population density with long histories of human settlement (Murphy and Lugo 1986). It is therefore not surprising that tropical and subtropical dry broadleaf forest is the most endangered biome on Earth and one of the least conserved (Dinerstein et al. 2017). In the Americas less than 4% of their current extent is protected, less than a seventh of the conserved area of tropical rainforests (Calvo-Rodriguez et al. 2016). Threats to tropical dry forest vary with region: climate change is important in the Americas, habitat fragmentation and fire in Africa and agricultural conversion and human population density in Eurasia (Miles et al. 2006).

Tropical dry forests support some of the world's poorest people, particularly in Africa, supplying food, fuel, and fodder, particularly in times of scarcity. They provide a wide range of ecosystem services including supporting agricultural systems for subsistence farmers as well as non-timber forest products (Blackie et al. 2014). They also play key roles in carbon storage and the creation and protection of soil as well as the storage and release of water (Calvo-Rodriguez et al. 2016).

Favorable climates and fertile soils have led to higher human population densities in tropical dry forest than most other biomes. Yields of numerous food crops are higher in drier and more seasonal tropical regions (Murphy and Lugo 1986) and this is reflected in the fact that 32% of dry broadleaf forests have been converted to cropland—the highest of all tropical biomes (Phalan et al. 2013). Conversion of dry forest has been accelerated by intensive cultivation of crops, such as sugar cane, rice, and soy, or by conversion to pasture for cattle (DRYFLOR 2016).

Dry forest areas in South America, Eurasia and Africa are very suitable for cultivation, with over 60% of these areas considered suitable for agricultural expansion (Miles et al. 2006). Large scale investments in commercial agricultural production have had major impacts on dry forests of Latin America, particularly the cerrado and the chaco where both soy and beef expansion has converted major parts of both ecosystems (Calvo-Rodriguez et al. 2016). African dry forests are the target of both Chinese investments (German et al. 2011) and active expansion of soybean production facilitated by help from Brazil and Argentina (Gasparri et al. 2016) though at least in the latter cases this has largely stopped due to drastic slowdown in global demand and domestic economies that no longer generate excess funds for investing in Africa. Biofuel crops are also suitable for dry forest areas, adding uncertainty to how agriculture production will unfold in the future (Laurance et al. 2014).

Climate change could cause dryland biomes, including forests, to expand by 11 to 23% by the end of the 21st century, replacing neighboring biome types (Huang et al. 2015). Such changes will take place through increases in frequency and intensity of droughts, and concomitant fire increase (Calvo-Rodriguez et al. 2016), affecting species, ecosystems, and human populations (Allen et al. 2017; Bastin et al. 2017). Climate change will also be affected by land cover changes and growing human populations with increased incomes and increasing per capita consumption that, particularly in developing countries, will increase the risk of land degradation, loss of ecosystem services and loss of biodiversity (Bastin et al. 2017).

Ocean Bottoms and Disturbance of Benthic Areas

The bottom of the ocean is perhaps not an obvious habitat to choose, yet it has been, and continues to be, significantly impacted by human activity. From the continental shelves to the benthos, as technology has developed there has been an ever-increasing use of bottom trawling technologies to catch seafood (Martin et al. 2015). Much of this has been directed at continental shelves, areas of the ocean under 200 meters in depth where the impacts of this technology have been extensively studied, but as stocks on the shelves have become over-exploited, bottom trawling has extended beyond the shelf break (Clark et al. 2016) where soft, muddy bottoms account for the largest portion of the global seabed and therefore constitute the largest biome on earth (Martin et al. 2015).

Bottom trawling is a fishing method consisting of pulling a heavy device connected to a net along the ocean floor that gouges deep and long tracks and destroys all bottom-dwelling organisms that cannot move out of the way—it has been called “plowing the deep-sea floor” (Puig et al. 2012). One quarter of marine fish production is caught with bottom trawls and dredges on continental shelves around the world (Collie et al. 2016). Trawl fisheries rapidly increased from the 1950s off all six continents and by the 1960s trawling for fish was found on all continental shelves of the world (Martin et al. 2015). Trawling is so common that an estimated 75% of the world’s continental shelf area has been affected by it (Oberle et al. 2016). In some places trawling is done often and extensively—for example in 1998 bottom-dragged gear affected every square meter of the Gulf of Maine at least once a year (Dorsey and Pederson 1998 in Martin et al. 2015). Whereas in European waters mean trawling intensity ranged between 0.5 and 8.5 times per year (Eigaard et al. 2017)

Bottom trawling, like plowing in terrestrial landscapes, can literally turn the benthic structure upside down. It has collateral and often severe impacts on marine ecosystems including scraping and ploughing of the seabed, resuspension of sediments that smother fauna, killing of non-target organisms, particularly those immobile organisms that extend above the ocean bottom (e.g., corals and sea stars) and dumping of processing waste. Affected are habitat quality, biodiversity, and the structural and functional integrity of ecological communities (Clark et al. 2016).

Direct effects on the benthos occur through dislodgement or damage of individuals and includes removal of organisms that structure the environment (e.g., corals) and homogenization of sediments creating changes that negatively affect the ability of other organisms to recruit into the area (Clark et al. 2016). Changes that occur in the benthos are different from changes in communities in shallower water because the rates of recovery are significantly slower due to lower temperatures, lower biological productivity, and the presence of organisms with longer generation times (Clark et al. 2016).

Organisms living on hard substrates are more severely affected than those on soft substrates (Halpern et al. 2007). Cold-water reef structures house communities of fish and provide nursery, spawning and protective habitat that are lost when trawlers destroy the reef-building organisms (Clark et al. 2016). On the more common soft bottoms, bottom-trawling rivals natural processes as a driver of sediment dynamics on continental margins and in places where it is done repeatedly, can create a degraded stable state (Martin et al. 2015).

Trawling can produce pronounced impacts on the ocean floor itself, including resuspension, erosion, increased near-bottom turbidity, and changes to the morphology of the seabed (Martin et al. 2015). The trawling-induced resuspension of sediment is so vast that it equals the sediment mass supplied to the continental shelves through all the world’s rivers (Oberle et al. 2016). On upper continental shelves bottom trawling has been so extensive that it has become an important driver of deep seascape evolution the effects of which have been compared to agricultural plowing on land (Puig et al. 2012).

Other Habitats to Be Considered
Mangroves
Coral Reefs
Estuaries
Air, CO2, and GHG emissions
The Ozone Layer
The Ocean Surface
Ocean Acidification
Terrestrial Sand Deposits

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