CHAPTER 13: SAVING BIODIVERSITY

I. What is Biodiversity?

We have examined at length what happens when a growing world economy pushes against planetary boundaries. The world now has 7.2 billion people and an output of around $90 trillion dollars, with both the population and global output continuing to rise. The world economy is continuing to grow at 3% to 4% per year, meaning a doubling every 20 years or so. There are already huge pressures on the world's ecosystems, on the climate, and on the oceans. We have not yet found a way to reconcile that continuing growth with environmental sustainability.

This trespassing of planetary boundaries is occurring in many ways, including climate change and pollution, but one of the most dramatic ways is the loss of the planet's biodiversity, the subject of this chapter. Humanity is putting so much pressure on the Earth that it is causing a dramatic increase in the rate of species extinction, estimated to be more than a thousand times faster than before the Industrial Revolution. There are many other phenomena associated with this loss of species, such as the decline of genetic diversity within species and the abundance of particular species. **The combined effect is so large that it is causing what could be the sixth great extinction on the planet.**

There is one overriding truth to this sixth wave of extinctions and the threats to biodiversity; that the threats are coming from many different angles. As is true of everything in sustainable development, we are dealing with a complex system, where there is not a linear effect from a single cause to a single outcome and then onto another effect. There are multiple stressors, multiple drivers of environmental change, and multiple causes of species extinction and the decline in abundance and genetic diversity. We must understand the complexity of this system, because no single approach will be sufficient to head off this sixth great extinction that threatens millions of species, including Homo sapiens – human beings, ourselves!

To understand biodiversity we must start with an understanding of an *ecosystem* – the collection of plants, animals, and microbial life interacting with the abiotic (nonliving) part of the local system with the energy and nutrient fluxes. The key is that this is a set of living organisms and a nonliving environment, all interacting in a system. Ecologists study ecosystems by studying the fluxes and dynamics of the system – how does nutrient flow take place within a food web, and within the processes of metabolism, oxidation, respiration, photosynthesis and other basic processes of metabolism in the living organisms within the system? How does the diversity of the species, and the diversity of the individual organisms within a species, affect the behavior of that whole ecosystem?

Another core concept of an ecosystem is its biological diversity, or *biodiversity*. Biodiversity is the variability of life that occurs at all different levels of organization. Biodiversity includes the variability of life within a species – each of us is different from other people, with different genetic codes. Biodiversity also includes the diversity of species within an ecosystem and the various relationships of the species, such as predator and prey, mutualism and parasitism. The interactions of diverse species determine fundamental characteristics of an ecosystem, such as whether the ecosystem is *biologically productive* (e.g. in the output of photosynthesis and in the amount of living matter, or biomass, in the ecosystem) and whether it is *resilient to shocks* such as changes in climate, the introduction of new species into the system, or the over-harvesting of one part of the system by human action (such as excessive fishing, logging, or hunting).

Finally, biodiversity also involves the diversity of species across ecosystems. The long-distance interactions of ecosystems, such as desert ecosystems interacting with humid ecosystems, affect the functioning of each ecosystem as well as for the regulation of the Earth as a whole. If a critical biome (such as the equatorial rainforests or the Arctic region) suffers a major change, for example as the result of human-induced climate change, the effects on other ecosystems can be profound through various long-distance interactions of Earth processes, including precipitation, winds, ocean circulation, chemical changes, and others.

Thus, to understand biodiversity we must understand the variation of life at all different levels of organization and how that variability affects the performance of ecosystems in ways that matter. One of the most important studies on the functioning of ecosystems was a major global effort that reported in 2005, called the Millennium Ecosystem Assessment, or MEA. The MEA took a global view of the major ecosystems in the world and tried to give a conceptual framing of how they function, how they interact, and how they provide various functions, or *ecosystem services*, for humanity.

One of the important schematic ideas that came out of the Millennium Ecosystem Assessment is the chart in Figure 13.1. The idea of this chart is to define how ecosystems affect human wellbeing. The left shows four categories of ecosystem services. The first, *provisioning services*, include the ways that ecosystems directly provide for human needs: providing food, fresh water, wood and fiber for building structures and clothing, and biomass for fuels. The second, *regulating services*, include various functions of ecosystems in controlling the basic patterns of climate, disease transmission, and nutrient cycling of fundamental importance to humanity, such as the fluxes of water, nitrogen, and oxygen. Ecosystems have huge effects on climate regulation. If the ecosystems of the Artic and Antarctic regions were to be dramatically changed by human-induced climate change, there would be powerful feedbacks on the rest of the planet. For example, the melting of the great ice sheets of Antarctica and Greenland would dramatically raise ocean levels worldwide, change fundamental patterns of ocean circulation, and also fundamentally change the Earth's energy balances and overall climate. The melting of ice in the tundra could potentially release huge amounts of methane and carbon dioxide, creating massive positive feedbacks that amplify human-induced greenhouse gas emissions.

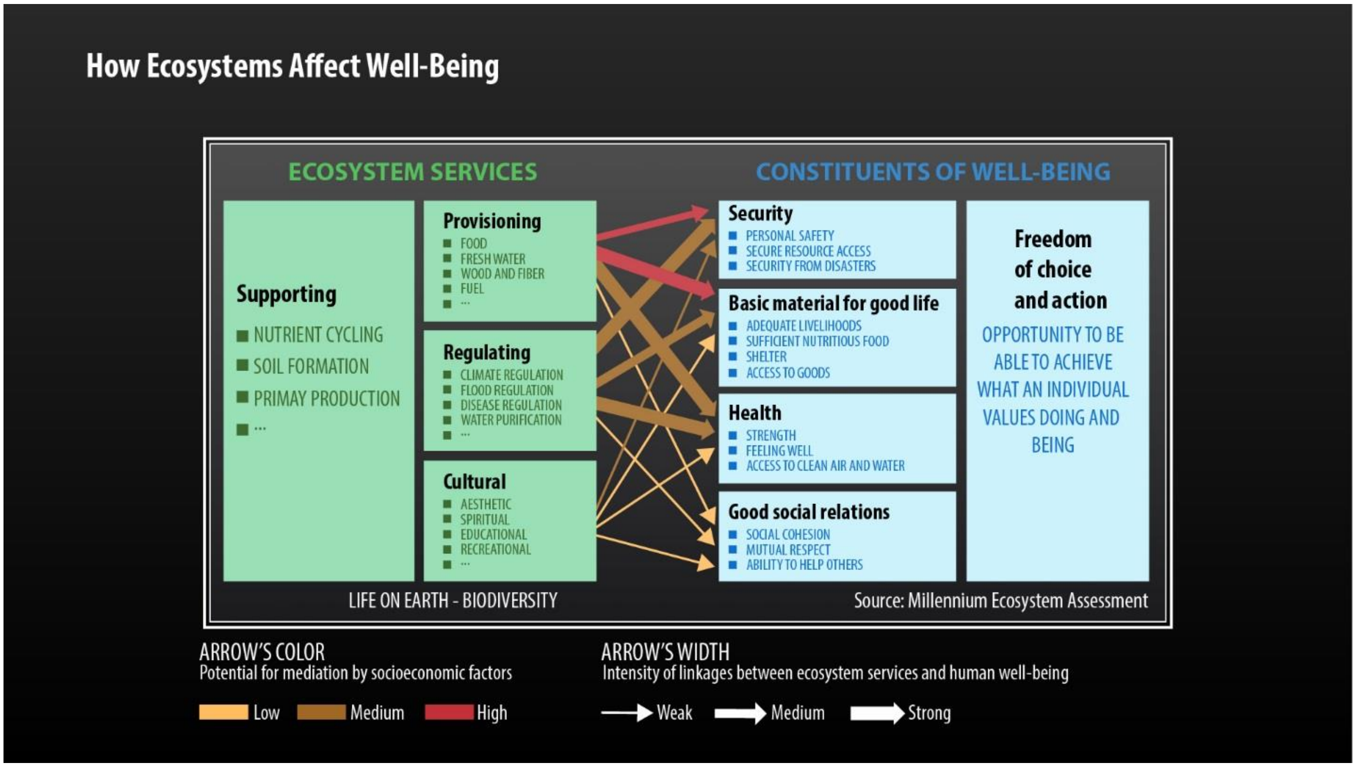


Figure 13.1. How Ecosystems Affect Wellbeing

Another example of regulatory services is flood control. Topographical features of ecosystems such as mangrove swamps often protect humans living near coastlines. If these coastal features are changed by human actions, there can be terrible consequences. Regions that were naturally protected by physical and biological features of the ecosystems can become highly vulnerable to floods. This happened, for example, in the Gulf of Mexico around New Orleans, where human actions affecting the flow of the Mississippi River ended up changing the flood dynamics around New Orleans and leaving the city and its environs exposed to the devastations of Hurricane Katrina in 2005.

Ecosystems also regulate pathogens (disease-causing agents) and pests, so when ecosystems are degraded, new pathogens, pests or invasive species can spread with devastating consequences to food production and human health. Changes in ecosystems (e.g. becoming wetter, drier, warmer, or open to new interactions of species) can lead to the emergence of new human diseases, such as *zoonotic diseases* that spread from animals to humans. HIV/AIDS is such a zoonotic disease, transmitted from chimpanzees to humans around 100 years ago somewhere in West Africa, perhaps as the result of human hunting and eating of chimpanzees as bush meat.

Invasive species are species that are introduced into a new ecosystem from the outside. Humans often bring plants and animals from one ecosystem to another, sometimes deliberately (e.g. for farming and tree cover) and sometimes by accident. The problem is that the newly introduced species may dramatically upset the regulatory function of the ecosystem, for example if the new species has no natural predators in the new ecosystem, and therefore multiplies in dramatic function, taking over the food chains in the ecosystem and driving out native species.

The third category of ecosystems services is called *supportive services.* These include processes like nutrient cycling and the formation of soils through the interaction of biotic and abiotic processes. Both nutrient cycling and soil formation are crucial underpinnings of agricultural productivity. Without healthy soils, nitrogen availability, and other supportive services (e.g. pollination by wild pollinators such as bumble bees), our food supplies would collapse.

The fourth and final category identified by the Millennium Ecosystem Assessment is *cultural services*, the ways that ecosystems enhance human values, aesthetics, religion, and culture in general. One of the greatest scientists of our age, the great biologist at Harvard University, Edward O. Wilson, has argued that humanity has a deeply ingrained love of biodiversity that we inherited during the long process of human evolution. He calls this trait *biophilia*, which he defines as "the urge to affiliate with other forms of life." Professor Wilson has given extensive, compelling evidence from the range of anthropological studies of how humanity feels at home in certain natural environments, and how the degradation of those natural environments can deeply upset our cultures, our mental wellbeing, our sense of aesthetics, and thus our overall quality of life.

There is a general and important link between biodiversity and ecosystem services. Biodiversity promotes the health, vitality, and productivity of ecosystems, and hence enables ecosystems to deliver their provisioning, regulatory, supportive, and cultural services. When biodiversity is threatened, however, the ecosystem functions are diminished, and the services they provide are undermined. Protecting biodiversity, in other words, is key to protecting ecosystem services more generally. Scientists have verified, for example, that a reduction of biodiversity of fish species (which is currently happening all over the world) leads to a reduction in the productivity of fisheries. This is also true for farms. Crop yields in the long term are higher and more resilient in farm systems that have a higher biodiversity. Yet many farm systems around the world are experiencing a dramatic loss of biodiversity, for example when farmers are encouraged to plant just one crop (i.e. a *monoculture*) and often with just one seed variety. Farmers may be advised, for example, that a particular seed offers them the highest yield of a staple crop. Rather than planting many varieties of rice or maize, as in their traditional practice, they therefore plant a single variety. The result in the short term might indeed be a higher yield, but the single variety within a single species leaves the farmer highly vulnerable to shocks, such as a change in weather patterns or the introduction of a new pest or pathogen. What starts out as higher farm productivity ends up as a disaster when the farm region succumbs to a devastating shock, such as drought, floods, heat waves, invasive species or new pathogens.

In summary, ecosystem services are vital for human survival and wellbeing. Biodiversity in turn is vital for healthy ecosystem functioning. Yet biodiversity is under unprecedented threat as the result of thoughtless, unknowing, human activity. We are undermining the very support structures for our biological survival and cultural vitality. Let us next turn to the ways that biodiversity and ecosystem functions are under threat. Then we will analyze what we can do to reverse these dangerous trends.

II. Biodiversity under threat

In ecosystem after ecosystem, biodiversity is under massive threat. It is already being reduced, degraded, and hugely threatened across the planet. For many reasons, this will be extraordinarily difficult to bring under control. A useful starting point to understand the human impact on biodiversity is the Human Footprint Map shown in Figure 13.2, developed at the Earth Institute. My colleagues at the Earth Institute took a number of indicators, including population density, land-use change, infrastructure coverage, railroads, roads, and other human changes; they aggregated and weighted these indicators; and used these to measure the extent of the human ecological footprint in each part of the world. The map demonstrates the vast sweep of humanity – human activity is pervasive. The human impact is significant in all parts of the world except in the most extreme environments, notably the desert regions, some parts of the equatorial rainforests (though these are also under threat) and the pole-ward (high-latitude) regions that are currently too cold for agriculture. All of the rest of the planet exhibits a heavy human footprint.

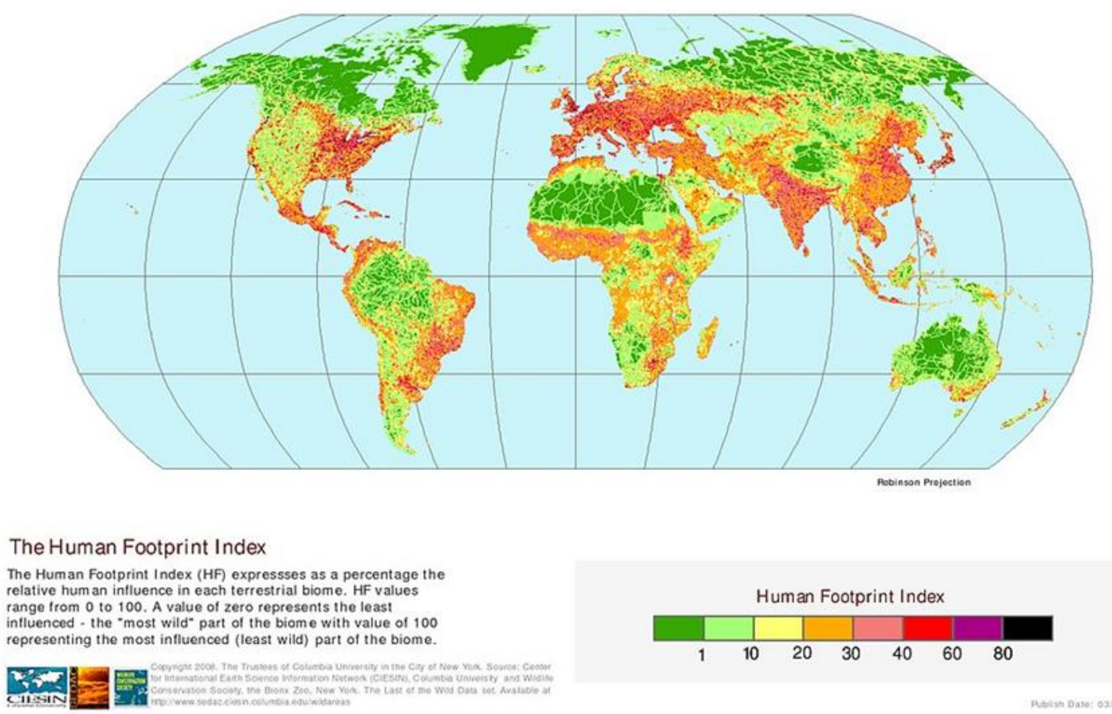


Figure 13.2. Human Footprint Index

The great ecologist Peter Vitousek made a similar, pioneering study more than 15 years ago, when he and his colleagues asked the question: How much of the global ecosystems is humanity appropriating? Their conceptual framework for that is shown in the flow chart in Figure 13.3. Professor Vitousek and colleagues mapped the various ways that humans impact the planet, and then tried to assess the human impact on ecosystems using several fascinating metrics. How much land has humanity transformed?

How much has humanity changed the carbon cycle? What has humanity done to water use and the water (hydrologic) cycle?

Fig. 1. A conceptual model illustrating humanity's direct and indirect effects on the Earth system [modified from (56)].

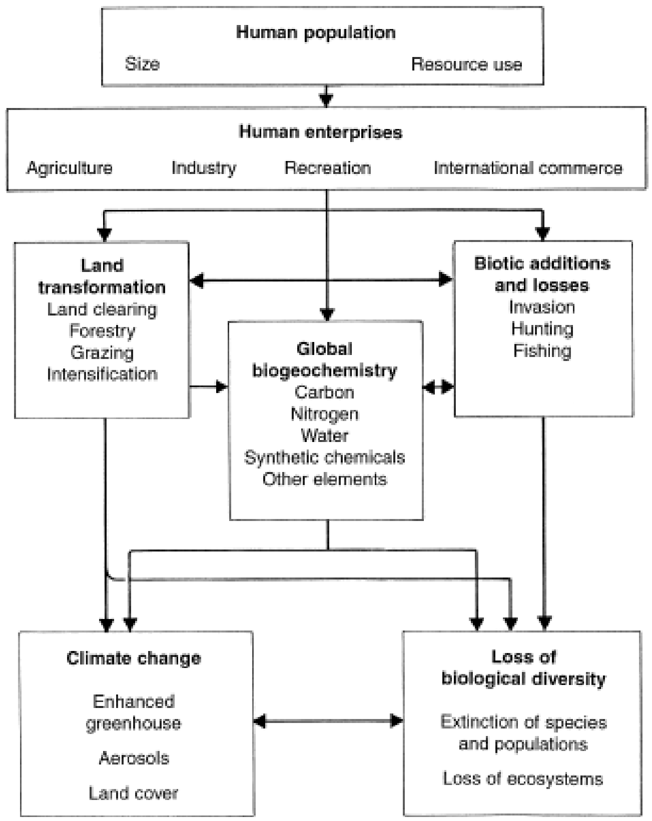


Figure 13.3. Model of Humanity's Direct and Indirect Effects on the Earth System

Their conclusion (which would be even stronger today), shown in Figure 13.4, revealed the extent of human impacts across all of these dimensions of the Earth's ecosystems. Humans have appropriated massive amounts of land for human use. Vitousek considered the total Net Primary Productivity (NPP) of the planet, meaning the total output of photosynthesis worldwide. He then asked how much of that NPP was taken by humans for our own species. He determined this share of NPP by adding up the human control of photosynthesis on all farms, pasturelands, and forest regions. He also added in the lost photosynthesis when humans cover the land with urban settlements and infrastructure such as roads.

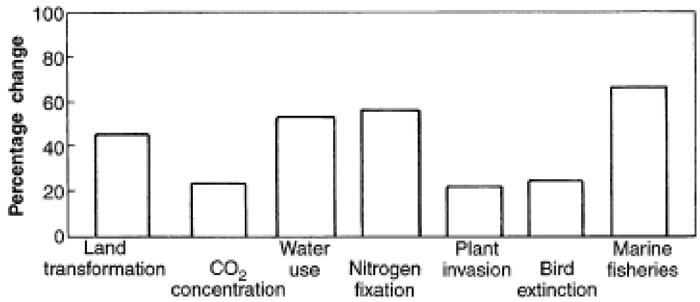


Fig. 2. Human dominance or alteration of several major components of the Earth system, expressed as (from left to right) percentage of the land surface transformed (*5*); percentage of the current atmospheric CO_2 concentration that results from human action (*17*); percentage of accessible surface fresh water used (*20*); percentage of terrestrial N fixation that is human-caused (*28*); percentage of plant species in Canada that humanity has introduced from elsewhere (*48*); percentage of bird species on Earth that have become extinct in the past two millennia, almost all of them as a consequence of human activity (*42*); and percentage of major marine fisheries that are fully exploited, overexploited, or depleted (*14*).

Figure 13.4. Human Dominance or Alteration of Several Major Components of the Earth System

The result is astounding. Humanity is now taking as much as 40-50% of all of the photosynthesis on the planet. We are commandeering the world's basic food supply – the output of photosynthesis – not for all species, but only for ourselves. It's like inviting 10 million guests (the roughly 10 million species on the planet) to a banquet, and then announcing that half of the food supply will go to just one of the guest, human beings. This is perhaps the most fundamental threat to biodiversity. Humanity is literally eating other species off of the planet!

Here is another way to see this problem. A species like ours – a mammal of average size of 50-75 kilograms per adult – might normally be expected to have some tens of millions of individual members of the human species on the planet (comparing with the numbers of other land mammals). Yet as the result of many technological and cultural revolutions, humanity no longer numbers in the millions but in the billions. As humanity has increased in numbers, roughly 10 times since around 1750, humanity has claimed more and more land for ourselves: to grow grains, raise livestock, and provision ourselves with forest products and fibers. The human footprint is everywhere. The appropriation of NPP is astounding. The result is devastating for biodiversity.

Yet as we see in Vitousek's findings in Figure 13.4, the human impact does not stop with land use. It is across the board. Humanity has fundamentally changed the carbon cycle and already raised the level of carbon dioxide in the atmosphere to 400 parts per million compared with 280 ppm at the start of the industrial age. Humanity has appropriated huge amounts of water, especially to grow food, and now faces water crises in many parts of the world. Humanity has come to dominate the nitrogen cycle, turning atmospheric N_2 into reactive nitrogen (such as nitrates, nitrites, and ammonia) that can be used by plants. Humanity has introduced many invasive species into ecosystems, both intentionally and by accident, but in either case dramatically disrupting the ecosystems and food webs where those new invasive species have entered. Humanity has driven many other species to extinction (illustrated in Vitousek's study by the extinction of bird species). And last in Figure 13.4, humanity has deeply undermined the abundance of fish in all parts of the world, through systematic overfishing and by other human-caused changes in marine ecosystems (such as ocean pollution, chemistry, and physical destruction of ocean features such as sea beds and coral reefs).

Humanity is threatening so many species that we now need a systematic scorecard to understand what we are doing. The International Union for The Conservation of Nature (IUCN) is the global scorekeeper of endangered species. The diagram in Figure 13.5 explains the IUCN's classification system, ranging from species that are not threatened to those that have already been driven to extinction. We must note that the total number of species on the planet is unknown. Estimates range from around 10 million to 100 million species in total. The worldwide scientific community and the IUCN are still in the classification process for these species. Moreover, the status of most species has never been evaluated. There is no doubt that countless species are being driven to extinction before we even discover that those species exist. We are destroying the habitats of these species, and appropriating their water and food supplies, faster than we can even identify and name the species that are threatened by our actions.

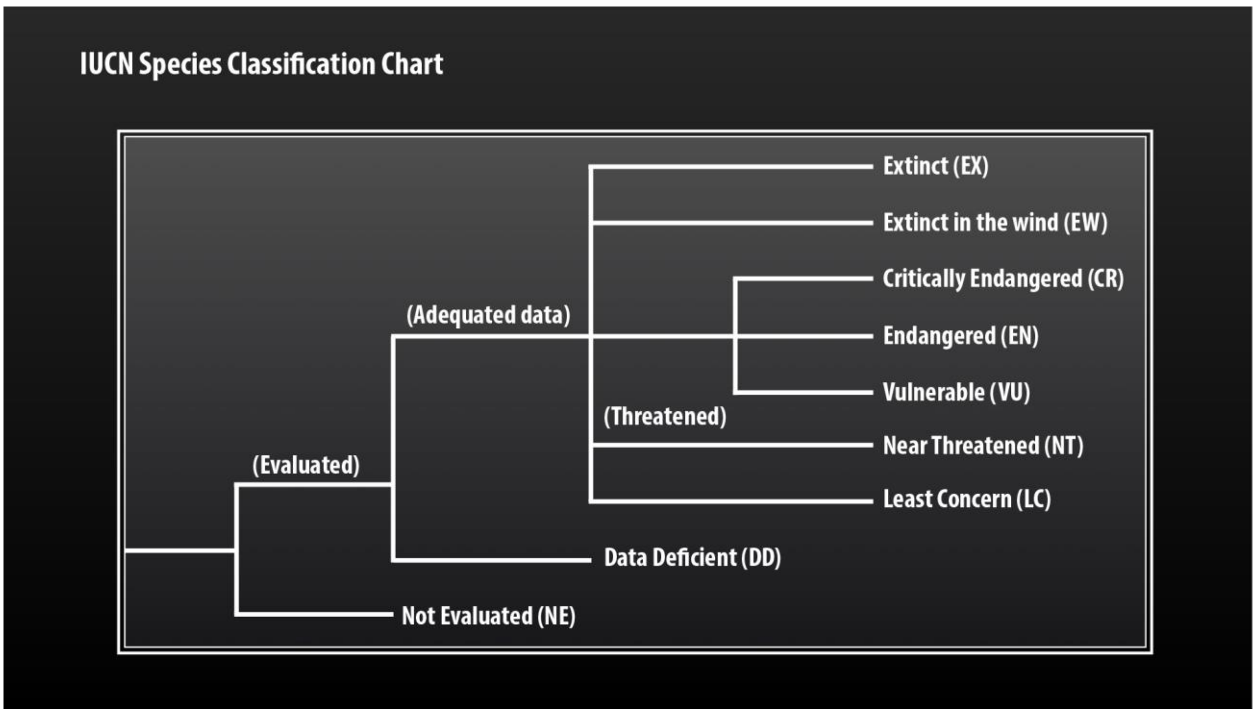


Figure 13.5. IUCN Species Classification Chart

The IUCN has a special classification called its "Red List," shown in Figure 13.6, of the most endangered species. The numbers are very frightening, because even in the very short period of time covered by the Red List, the numbers of critically endangered species have soared. This is partly because there are new, additional classification of species, but it is also very much because human activity is driving species to critical endangerment and to extinction all over the world. Huge numbers of species are collapsing, from plants, to amphibians, to pollinators such as bees, to the great apes.

Critically Endangered (CR)													
Group	1996/98	2000	2002	2003	2004	2006	2007	2008	2009	2010	2011	2012	2013
Mammals	169	180	181	184	162	162	163	188	188	188	194	196	196
Birds	168	182	182	182	179	181	189	190	192	190	189	197	197
Reptiles	41	56	55	57	64	73	79	86	93	106	137	144	151
Amphibians	18	25	30	30	413	442	441	475	484	486	498	509	519
Fishes	157	156	157	162	171	253	254	289	306	376	414	415	413
Insects	44	45	46	46	47	68	69	70	89	89	91	119	120
Molluscs	257	222	222	250	265	265	268	268	291	373	487	549	548
Plants	909	1,014	1,046	1,276	1,490	1,541	1,569	1,575	1,577	1,619	1,731	1,821	1,920

Endangered (EN)													
Group	1996/98	2000	2002	2003	2004	2006	2007	2008	2009	2010	2011	2012	2013
Mammals	315	340	339	337	352	348	349	448	449	450	447	446	446
Birds	235	321	326	331	345	351	356	361	362	372	382	389	389
Reptiles	59	74	79	78	79	101	139	134	150	200	284	296	313
Amphibians	31	38	37	37	729	738	737	755	754	758	764	767	773
Fishes	134	144	143	144	160	237	254	269	298	400	477	494	530
Insects	116	118	118	118	120	129	129	132	151	166	169	207	215
Molluscs	212	237	236	243	221	222	224	224	245	328	417	480	480
Plants	1,197	1,266	1,291	1,634	2,239	2,258	2,278	2,280	2,316	2,397	2,564	2,655	2,871

Vulnerable (VU)													
Group	1996/98	2000	2002	2003	2004	2006	2007	2008	2009	2010	2011	2012	2013
Mammals	612	610	617	609	587	583	582	505	505	493	497	497	498
Birds	704	680	684	681	688	674	672	671	669	678	682	727	727
Reptiles	153	161	159	158	161	167	204	203	226	288	351	367	383
Amphibians	75	83	90	90	628	631	630	675	657	654	655	657	656
Fishes	443	452	442	444	470	681	693	717	810	1,075	1,137	1,149	1,167
Insects	377	392	393	389	392	426	425	424	471	478	481	503	500
Molluscs	451	479	481	474	488	488	486	486	500	587	769	828	843
Plants	3,222	3,331	3,377	3,864	4,592	4,591	4,600	4,602	4,607	4,708	4,861	4,914	5,038

Figure 13.6. IUCN Red List

The human-induced pressures are coming in all directions: changes in land use, water supplies, nitrogen and other chemical fluxes, climate patterns, over-harvesting (by fishing, logging, hunting, and other extractive processes), urbanization, and more. The causes are so various, and so deeply intertwined in the world economy and in the soaring numbers of the human population, that reversing these adverse trends will be extremely difficult. We have yet to slow down the destruction of biodiversity, even more than 20 years after humanity agreed to the Convention on Biological Diversity (CBD) at the 1992 Rio Earth Summit. In other words, humanity is waking up to the problems, but not yet to the solutions.

III. Oceans and Fisheries

As humanity puts pressure on terrestrial ecosystems of all kinds (e.g. polar, alpine, tropical rainforests, dryland areas), we also put tremendous pressures on our marine ecosystems and the oceans. We are changing basic ocean chemistry. We are poisoning the ocean with pollution coming from huge oil spills and other disasters. And we are degrading the biodiversity in the oceans through other forms of human activities, especially through the overfishing and over-harvesting of marine life.

The oceans cover three-fourths of the earth's surface area, so this is no small part of humanity's relations to the physical earth. Our cities around the world hug the oceans, and depend on the oceans for trade, for economic activity, for our food supplies, for our proteins and invaluable nutrients such as omega-3 fatty acids from our fish intake. Keeping the oceans healthy is essential for human wellbeing.

Just as in other economic spheres, our technological know-how in harvesting ocean services, such as our ability to locate and capture fish, has improved enormously just in the last 60 years. We have "mastered" the oceans to the point of threatening marine life. Technological mastery, alas, does not meet intelligence, responsibility, or foresight.

The total fish catch around the world is illustrated in Figure 13.7 for the years 1950 to 2010. This fish catch is divided into two parts: the "wild" catch, mainly from oceans (but also from rivers and lakes), and aquaculture, or fish farming. The wild catch in 1950 was about 20 million tons. By 1990, that had become about 80 million metric tons, and then leveled off at that rate. Aquaculture rose from near zero in 1950 to around 20 million tons by 1990, and to around 75 million tons by 2010. The dramatic increase in the wild catch, up roughly four times, underestimates the true increase of fishing activity in the oceans because such estimates do not fully include the vast biomass (fish and other marine life) that fishermen throw back in the oceans as unwanted.

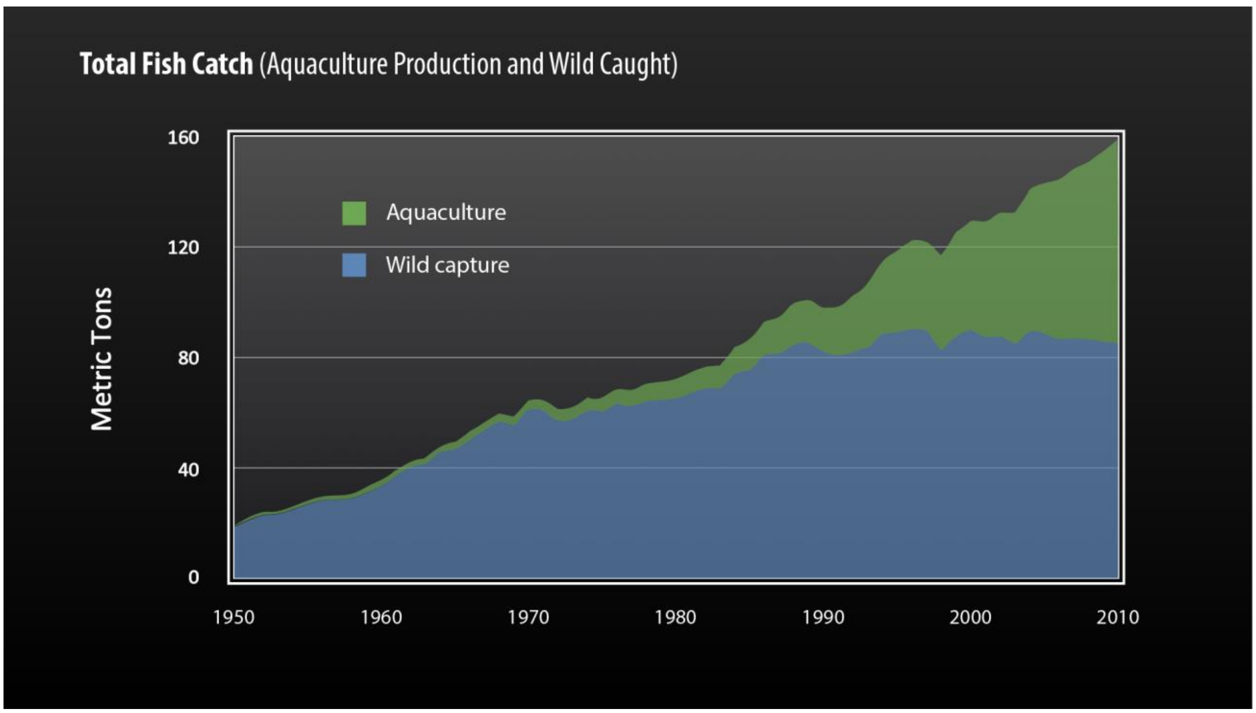


Figure 13.7. Total Fish Catch (Aquaculture Production and Wild Caught)

The data in Figure 13.7 suggest a basic lesson. The ocean catch reached a maximum extent around 1990 and further increases in fish take have come through managed aquaculture. We can say that this is bad news and good news and bad news again. The first piece of bad news is that humanity hit the limits of ocean fishing, and in fact, exceeded those limits. Over-fishing has led many fisheries around the world into decline or complete collapse. The threats of overfishing in the oceans remain perilous till today in most fishing regions of the world. The good news is that aquaculture has been able to grow to meet humanity's growing demand for fish in the diet. This is good news indeed, since fish are a key, nutritious part of the human diet, especially rich in needed oils and proteins. The second piece of bad news, however, is that aquaculture itself threatens the environment in many ways. The cultivation of fish in the managed fish farms can lead to spread of disease, excessive nutrient flows of many kinds, and threats to wild fish populations when farm fish escape into the wild. In short, aquaculture can be highly desirable if it is operated in a responsible manner, but that is a complex challenge given all the things that can go wrong.

How did the massive increase of the wild fish catch occur? It resulted from a huge increase of fishing activity, shown in Figure 13.8, which compares the intensity of fish fleets in different fisheries around the world in 1950 and in 2006. Fisheries back in 1950 operated along a few key coastal and river regions. By 2006, fisheries were operating throughout the oceans, including the high seas, wherever they could hunt and capture fish in large numbers. As in so many sectors of the world economy, ocean fisheries experienced many huge technical advances. These included the use of long line nets that allowed for a much greater capture of fish; the use of various kinds of remote sensing to identify where the fish are located; and the use of ocean trawling to capture bottom-dwelling fish and other marine life on the ocean floor, in a manner that often completely devastates the highly complex, bio-diverse marine ecologies on the ocean bottom.

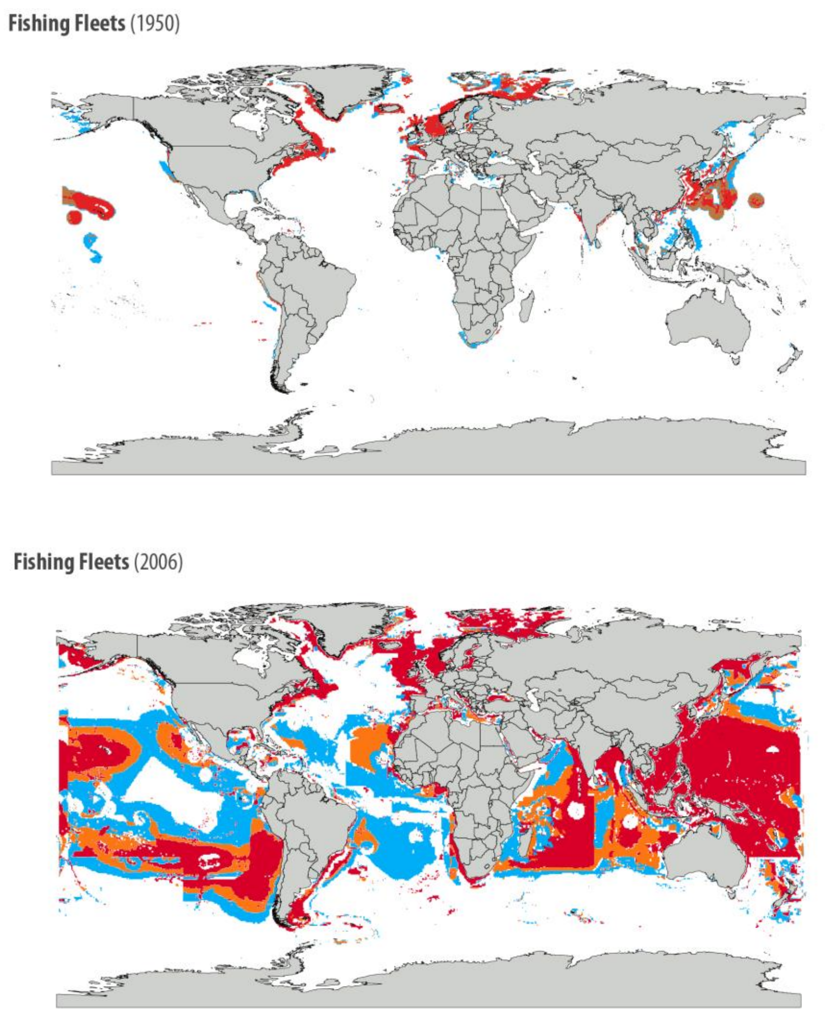
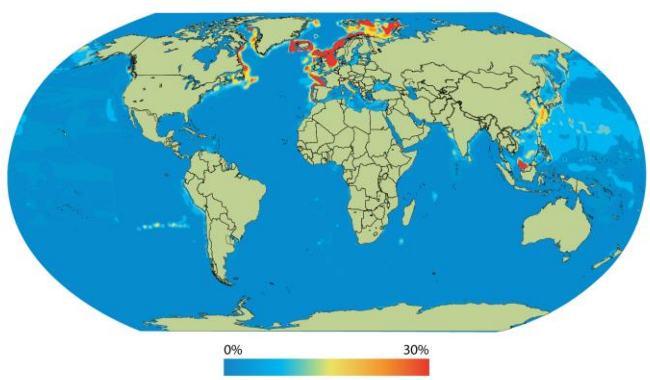


Figure 13.8. Fishing Fleets (1950, 2006)

The consequence is that the technological advance of ocean fisheries, as is so often the case, has not been the friend of marine biodiversity and marine ecosystem sustainability. Technological advance in fishing has led to a huge increase in the wild catch. Yet is has also led to the depletion of ocean fisheries, a huge loss of biodiversity, and a huge threat to the productivity of marine ecosystems.

To get an indicator of the overall human impact, one can look at the amount of primary production required (PPR) to feed the wild fish catch in a given region of the ocean, measured as a fraction of the total photosynthesis in that part of the ocean. For example, if the ocean feedstock of the wild catch equals one-third of all the photosynthesis in that part of the ocean, we say that the human appropriation of ocean primary production is therefore one-third. This concept, devised by marine scientist Wilf Swartz and others (PLoS, 2010), is akin to Vitousek's concept of the human appropriation of NPP (net primary production), which Vitousek had applied to terrestrial photosynthesis. The results in Figure 13.9 show fisheries where the amount of net primary production associated with that amount of fish capture is already in a danger zone, of 30% of primary production in many fisheries around the world. Comparing 1950 and 2005, we see the massive increase in the human appropriation of marine primary production.

The Spatial Expansion and Ecological Footprint of Fisheries (1950)



The Spatial Expansion and Ecological Footprint of Fisheries (2005)

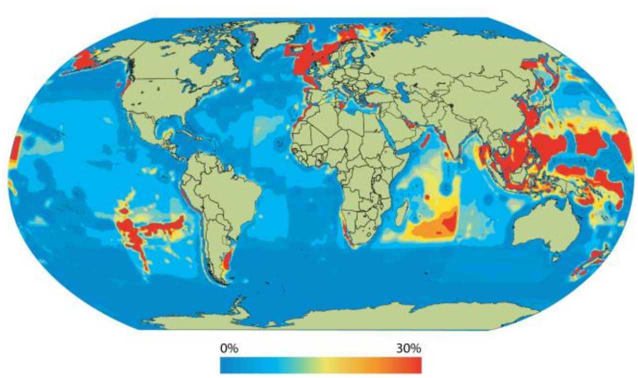


Figure 13.9. Spatial Expansion and Ecological Footprint of Fisheries (1950, 2005)

One implication of this finding is that not only is humanity driving down levels of fish abundance to the point of threatening their very survival, but we are also changing the *structure and functioning* of the marine ecosystems as well. One example of this is called “fishing down the trophic chain.” Humanity first eats, and depletes, the large fish at the top of the food chain – the fish that eat other fish. Then, after exhausting the supplies of fish at the top of the food chain, humanity eats fish lower down the food chain, eventually exhausting their supply as well (that is, driving them to extinction or to very small populations). Step by step, we rely on smaller and smaller fish, and on fish closer to the base of the food chain (that is, fish that eat directly the photosynthetic output of the ocean, rather than other fish). The fish ecologists (ichthyologists) measured the average trophic level of the fish that are caught; the evidence shows that over time, more of the catch is lower down the trophic chain. Humanity is very good at eating those prized fish at the top of the food chain, the predators of the predators of the predators; therefore they are being depleted rapidly, forcing humanity to go lower down on the food chain.

Ecologists speak of the “trophic level” of organisms. Plants that produce their own food are called *autotrophs*, and are assigned a trophic level 1.0. All animal species must get their food by eating autotrophs or by eating other species of animals. All such species are called *heterotrophes*. Herbivores that directly eat autotrophs are assigned a trophic level 2.0. Carnivores that eat herbivores are assigned a trophic level 3.0. Carnivores that eat other carnivores are assigned a trophic level 4.0. And so on up the food chain.

When humanity fishes down the food chain, it means that the diet starts with wild fish with high trophic numbers, and then over time, shifts to diets of wild catch with lower trophic numbers. This phenomenon is shown in Figure 13.10, which measure the average trophic level of the catch brought in from the fisheries, both wild and aquaculture. The top blue line is for the marine fisheries, and the red line is for freshwater fisheries. We see that in both cases, humanity is fishing down the trophic levels, giving further evidence that humanity is exhausting the supplies of the high-trophic species.

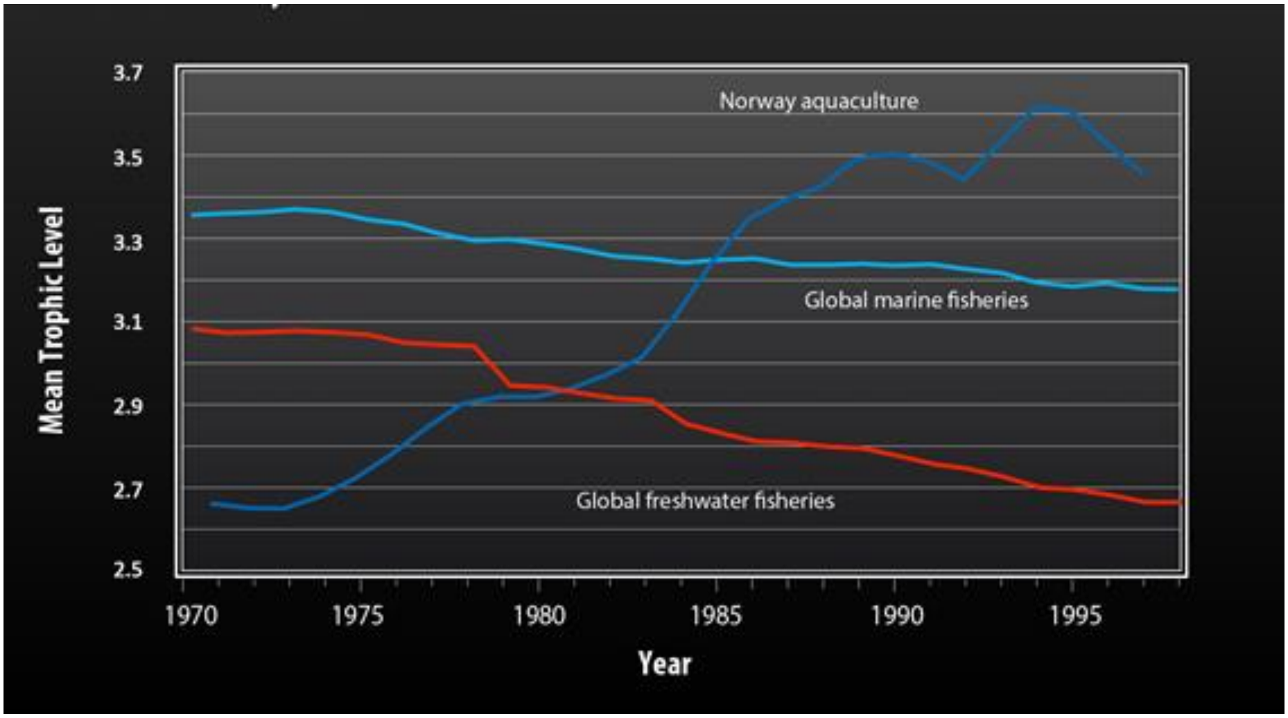


Figure 13.10. Average Trophic Level in World Fisheries

We also see that Norway's managed aquaculture is producing fish higher on the trophic level, such as Atlantic salmon (trophic level above 4) and Arctic char. These are highly satisfying for the human diet but complicated ecologically. High-trophic fish grown in captivity need massive quantities of fishmeal, and this in turn is provided by wild capture of lower trophic fish in the oceans. Thus, even though fish are grown in aquaculture, it does not mean that they are not impacting the oceans. More aquaculture of high trophic fish leads to increased demand for fishmeal, in turn putting pressure on ocean ecosystems.

Marine ecologists try to estimate the *Maximum Sustainable Yield* (MSY) of a fish type in order to determine a safe level of wild catch. The question that they ask is how much of a specific type of fish can be taken safely from a fishery (in an ocean, river, or lake) without depleting the fish stock? The typical answer is given by the upside-down U shown in Figure 13.11. Consider a fishery in one part of the ocean. Suppose that if left alone, without any fishing at all, there would be 1,000 fish (or perhaps 1,000 tons) in the fishery. Since the population at 1,000 is stable (and maximized) at 1,000, any fishing at all is bound to lead to a lower fish population.

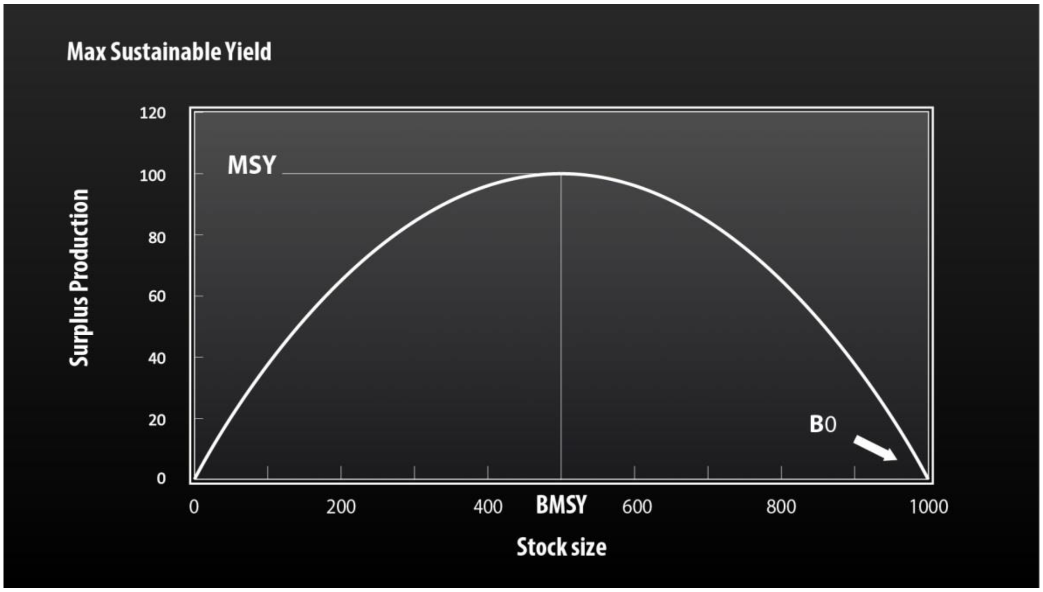


Figure 13.11. Maximum Sustainable Yield Calculation

Now suppose that the fish population is at 800. If left alone, the fish population would tend to increase gradually back to 1,000. Perhaps the 800 fish would give rise to 860 fish in the following year, a net increase of 60 fish. If the fishery catches those 60 fish, then the 800 fish this year would lead to 800 fish again next year. Thus, for a fishery with a potential population of 1,000, but at 800 fish currently, the fishery could sustain annual fishing of 60 fish without raising or lowering the fish population. In Figure 13.11, a fishery at 800 fish (shown on the horizontal access) has a "surplus production" of 60 (shown on the vertical access).

Next suppose that the fish population is at 500. When the fish population is 500, the population tends to increase by 100 fish per year. If those 100 fish are caught each year, the fish population stays at exactly 500 fish, enabling an annual catch of 100. We see in the inverted-U in Figure 13.11 that a fish population of 500 has a "surplus production" of 100 fish.

At what level is the surplus production maximized? We see clearly that the Maximum Sustainable Yield occurs when the fish population is exactly 500 fish, half of the potential population. At that level, the fishery can support an annual catch of 100 fish and still remain with a stable population. Yet what happens if the fishery catches 200 fish in that year? Obviously the fish population would tend to fall, becoming just 400 fish the following year. And if the over-fishing continues, for example another 200 fish caught in the following year, the fish population would be less than 300 the third year. Eventually, the fishery would be driven to exhaustion, with no fish and no prospect of future catches!

The MSY therefore is a policy tool, telling fishermen how many fish it is safe to catch each year. Yet will the fishermen listen to the advice? Each individual fisherman might still try to maximize his own catch, while hoping that other fishermen will abide by the limits of the fishery. The result would be a "tragedy of the commons," where every fisherman over-fishes and the combined effect is to drive the fishery to exhaustion. For this reason, the government might have to enforce a maximum level of total fishing, for example, by giving out permits that tell each fishing vessel how much fish they are allowed to catch, with the sum of the permits equaling the maximum sustainable yield of 100 fish per year in a fishery with 500 fish. In recent years, many fisheries around the world have successfully deployed tradable permit systems, in which the total permits are equal to the estimated MSY, and in which individual fisherman are allowed to buy and sell permits from other fisherman. In this way, the most productive fishermen buy the rights to fish from the least productive fishermen, but still do not violate the overall limit of the MSY.

The concept of the Maximum Sustainable Yield has become even more complicated in recent years, as ecologists have come to understand that it is not good enough to regulate the catch one species at a time, but rather they must regulate the entire ecosystem as a whole. If just one species is regulated, the change in its abundance might negatively impact the abundance of other species that depend on the first species in the food chain. For this reason, marine ecologists now talk about ecosystem-wide sustainable yields, which treats the ecosystem in a more holistic manner.

If the oceans were troubled only by the excessive wild catch of fish, we would have trouble enough, yet the sad fact is that humanity is assaulting marine ecosystems on many fronts. Figure 13.12 illustrates the risks facing corals around the world, with the dots' different colors showing the various ways that humanity is threatening the coral life. These threats include: acidification of the oceans, warming of the oceans, coral destruction by tourists, overfishing, direct harvesting of the corals themselves (e.g. for home ornaments), dynamite used for fishing, pollution, and sedimentation caused by human actions (e.g. construction, mining, deforestation, and flooding, which lead to the sedimentation of coral habitats). Human activities on multiple fronts are thereby driving corals to depletion and perhaps extinction for many species. Such multiple impacts – harvesting, pollution, climate change, etc., – illustrate the more general point that the human threats to biodiversity do not arise from a single factor, but from the sum of many factors.

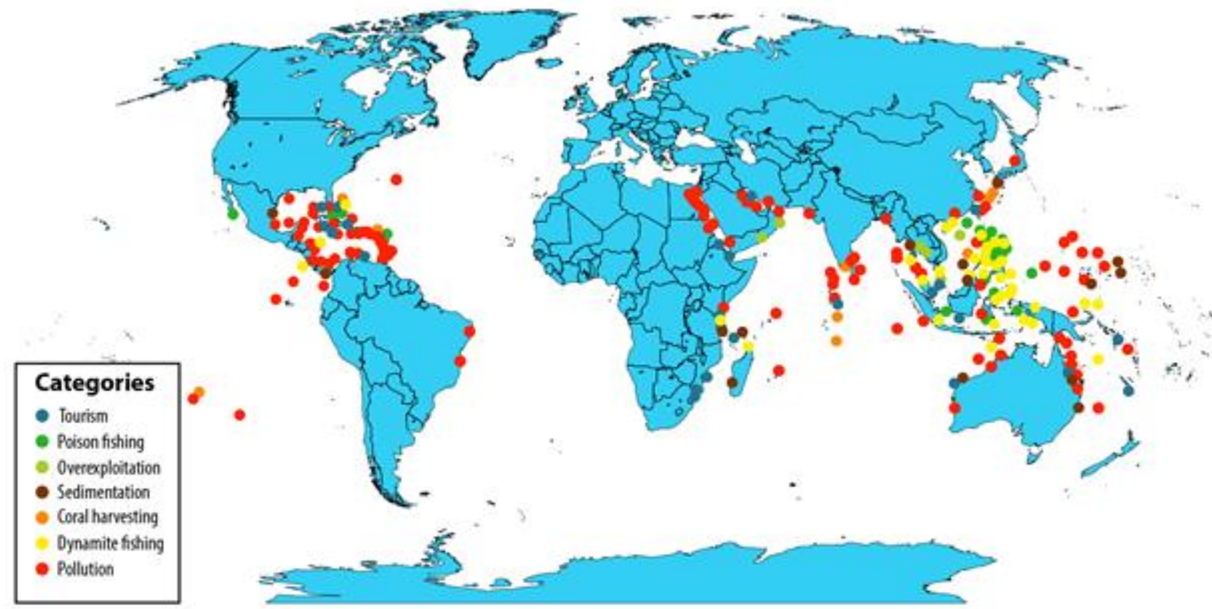


Figure 13.12. Major Observed Threats to the World's Coral Reefs

We have huge problems. We have some tools to address them, but the fair summary is that our oceans are at profound and still-growing risk because of the multiple pressures of human activity. We depend on the oceans in countless ways for our wellbeing and for our very survival. If we do not take care and face up to these multiple assaults, we will face growing crises in the not-so-distant future.

IV. Deforestation

Forests remain one of the major parts of terrestrial ecosystems on the planet, covering 31% of the total land area; yet the natural forest cover used to be a far higher proportion of the earth's land area before humanity got to it. Humanity has been in the business of clearing forests for thousands of years. This is an ancient story, but we continue to lose a lot of forest area today because of the increasing human pressures on forest systems, and the long-distance forces of international trade. When we lose forests, we degrade ecosystems and lose a tremendous amount of biodiversity. Our three great equatorial rainforest areas (the Amazon basin, the Congo Basin, and the Indonesian archipelago) are home to a remarkable extent of the planet's biodiversity, but this biodiversity is quickly being lost.

The map in Figure 13.13 gives an indication of the extent of past deforestation and some of the challenges of current deforestation. Every shaded area of the map originally had forest cover. The very light shaded areas, say in Western Europe or across China or across the Eurasian land mass, are areas that have already been deforested, with the deforestation occurring hundreds or even thousands of years ago. Only the dark shaded regions are still forested today. The main forests are in the high latitudes (e.g. northern Canada, Europe, and Russia), the east coast of the US (which was converted to farmland in the 19th century but which more recently has been re-converted to forest) and along the equator, with the three great rainforest regions.

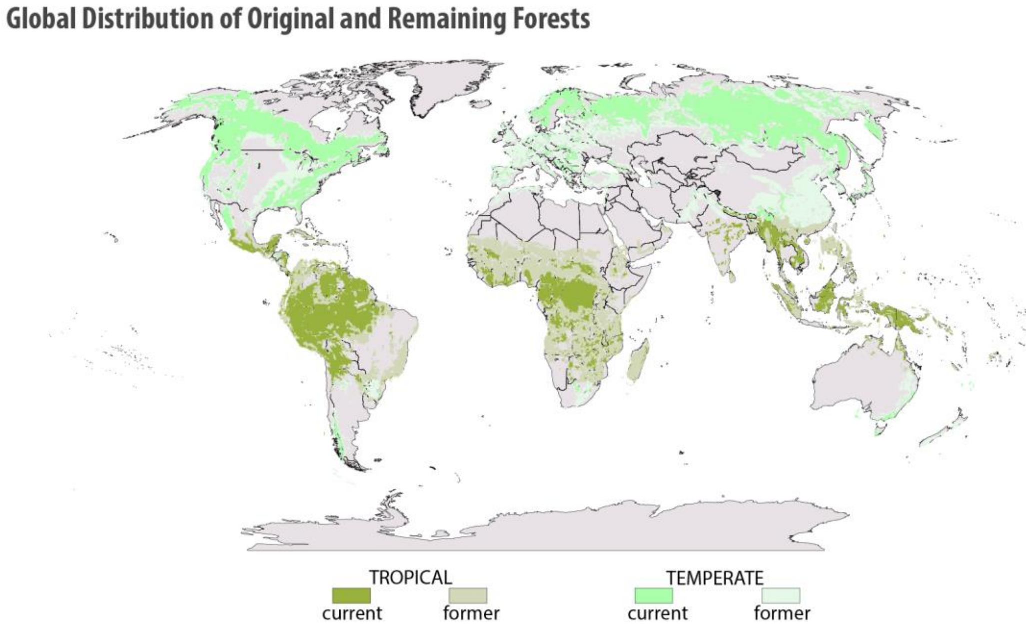


Figure 13.13. Global Distribution of Original and Remaining Forests

Today, most deforestation is taking place in the fast growing tropical and subtropical regions, and notably in the rainforests where population densities were traditionally low, but are now rising. These rainforests regions are increasingly encroached upon for human provisioning, such as for tropical logging, for farmland and pastureland, and for provisioning of peasant smallholders who go in to the forests for fuel wood or for other needs. The result is that while temperate zone areas were deforested a long time ago, it is now the tropical areas that today are being deforested most quickly. The rainforests, regions of astounding biodiversity, are now facing major disturbances and human impacts. The map in Figure 13.14 shows the current patterns of deforestation. The red regions are regions of rapid deforestation. We see the losses in the Amazon, the Congo Basin, and the Indonesian archipelago. The dark green regions – including the east coast of the US, Scandinavia, and parts of northern China – are undergoing reforestation, mostly involving the return of farmland to forestland.

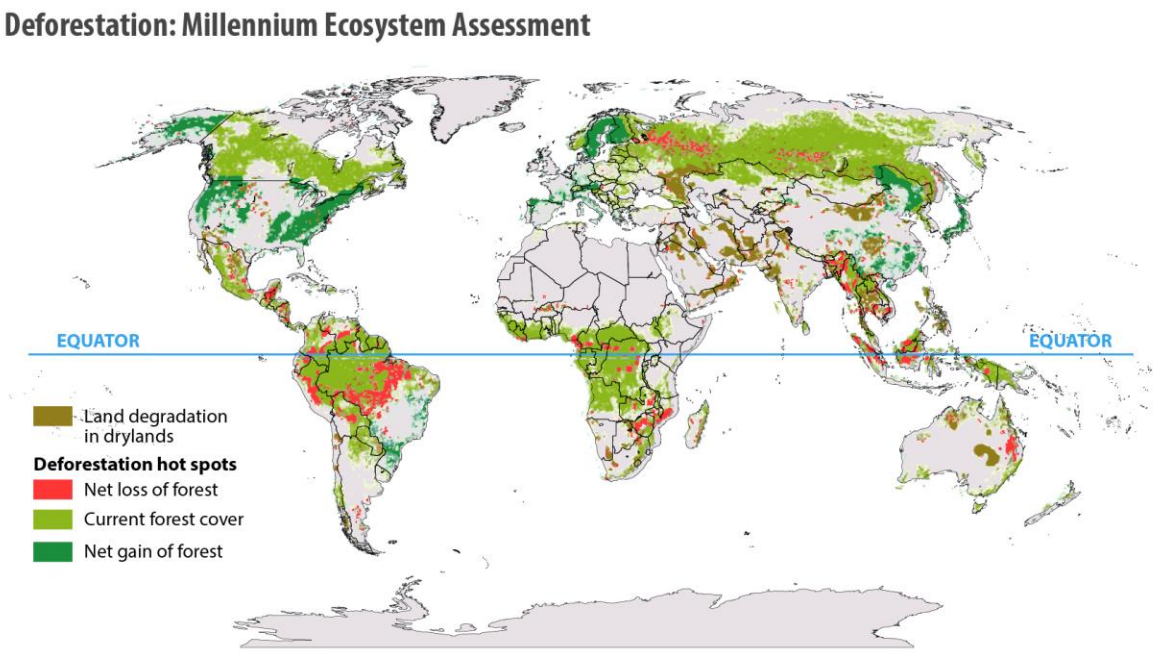


Figure 13.14. Deforestation: Millennium Ecosystem Assessment

James Lovelock, creator of the Gaia theory of the interconnectedness of the world's ecosystems and the regulatory processes of those ecosystems at planetary scale, emphasized that when we degrade one ecosystem we impede or undermine the functioning of ecosystems in other parts of the planet. Lovelock said about the deforestation of the tropical rainforests: "No longer do we have to justify the existence of humid, tropical forests on the feeble grounds that they might carry plants with drugs that cure human disease... Their replacement by cropland could precipitate a disaster that is global in scale." For example, rainforests serve to keep the planet cool by maintaining extensive cloud cover that reflects incoming ultraviolet radiation back into space rather than allowing the UV radiation to reach and warm the Earth. If the Amazon dries out (due to human-induced climate change), or disappears as the result of forest clearing to make way for farmland, the Amazon's cloud cover would shrink as well, thereby changing the Earth's reflectance (albedo) and causing a potentially large positive feedback to warm the planet further. Lovelock's point is that the impacts of massive deforestation can be far greater than we would recognize, beyond the direct impact of the loss of the local ecosystem services. Earth systems science teaches that the interaction of the ecosystems in their global regulation of climate, water cycle, and nutrient cycles is also of huge significance for planetary balances and for human wellbeing.

What is the cause of the mass deforestation? Some of the human impact of deforestation is internally driven, mainly by growing populations within countries. Yet a huge amount is also coming from international trade, from the demands halfway around the world for forest products. This is very difficult to control because it means the high levels of demand, often from rich countries or rapidly growing economies like China, overwhelm local protective services, often through illegal means. One of the major drivers is the soaring demand for palm oil, which is a very versatile product. In places like Malaysia and Indonesia there has been massive deforestation, replacing the highly bio-diverse existing rainforest area with a monoculture of palm oil. A similar driver is the rising demand for soybeans in world markets (e.g. by China), which in turn is leading to deforestation in the Amazon rainforest.

The resulting losses of biodiversity will be phenomenal in terms of the regulatory functions of these ecosystems and the threats to the survival of key endangered species such as the orangutan in Indonesia and Malaysia. The demand for tropical forest products is insatiable. If markets are not controlled, international trade will lead to continued massive deforestation. Unless we start managing tropical forests in a sustainable manner, these ecosystems will irreversibly collapse.

There are, of course, several efforts to do something about this. A notable effort is to link the conservation of the rainforests and forests in general with the climate change agenda. Perhaps 15% of the total carbon dioxide emissions each year come from land use change, especially from deforestation. In recent years, an effort has been launched as part of the climate mitigation effort to reduce our carbon footprint in terms of emissions coming from deforestation in addition to CO_2 emissions from the energy sphere. The main project to avoid deforestation is called UN-REDD+, Reduced Emissions from Deforestation and Forest Degradation. REDD+ targets both the thinning and clearing of forests. The idea, which is an excellent one, is to give financial incentives to local farmers and communities (including indigenous populations) to protect the forests.

The REDD+ programs replace part of the income that the communities would lose in the short term from their inability to over-exploit forest products with a sustainable flow of income of other kinds, including a top-up of income provided by donor countries. Norway, for example, has offered $1 billion to Brazil in a REDD+ initiative for forest communities in the Amazon to play the role of protecting the Amazon rather than facilitating its loss. The map in Figure 13.15 shows the countries participating in UN-REDD+. The countries in red are actively receiving United Nations support for developing REDD+ programs. Other partner countries are shown in blue. This is a very important effort, but it is still a relatively small counter-pressure to the overwhelming market forces coming from global trade for the products directly from the forests themselves, or for the products that are grown when the forests are cleared and replaced by other kinds of economic activity such as farming and livestock.

The UN-REDD Programme currently supports 47 partner countries across Africa, Asia-Pacific and Latin America and the Caribbean. To-date, the UN-REDD Programme's Policy Board has approved a total of US$67.8 million for National Programmes in 16 partner countries. These funds support the development and implementation of National REDD+ Strategies.

Countries with UN-REDD National Programmes: Plurinational State of Bolivia, Cambodia, Democratic Republic of the Congo (DRC), Ecuador, Indonesia, Nigeria, Panama, Papua New Guinea, Paraguay, the Philippines, the Congo, Solomon Islands, Sri Lanka, the United Republic of Tanzania, Viet Nam and Zambia.

Other partner countries: Argentina, Bangladesh, Benin, Bhutan, Cameroon, the Central African Republic, Chile, Colombia, Costa Rica, Côte d'Ivoire, Ethiopia, Gabon, Ghana, Guatemala, Guyana, Honduras, Kenya, the Lao Peoples' Democratic Republic, Malaysia, Mexico, Mongolia, Morocco, Myanmar, Nepal, Pakistan, Peru, South Sudan, the Sudan, Suriname, Tunisia and Uganda.

Figure 13.15. UN-REDD Programme

V. International Dynamics

The world's nations, realizing how much danger there is in the loss of global biodiversity, have taken at least some steps to try to pull back from the sixth great extinction. Some are indirect; for example, riding on the climate control effort through REDD+. There have been treaties limiting some kinds of trans-boundary pollutants that threaten the oceans, and some agreements on global fisheries. In addition to these, there have been at least a couple of very important head-on attempts to focus on biological diversity.

Two of the most important attempts have been through international treaties. The single most important of these is the 1992 Convention on Biological Diversity (CBD), the core purpose of which is to slow and reverse the loss of biodiversity. The second is the 1973 Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), which tries to restrict trade in endangered species.

Both have experienced successes and failures. The most important point to emphasize time and again is that the pressures of the global economy are so strong that even when treaties or regulations are put in place, vested interests often give a powerful counterforce to these measures, and control mechanisms are often at the mercy of illegal activities, of bribery, of corruption, of other limits of enforcement. The weight, force and momentum of the world economy are often so powerful that the world economy runs roughshod over attempts at regulation.

CBD is a valiant attempt to try to get under control the human threat to biological diversity. It is one of the three great multilateral environmental agreements reached at the Rio Earth Summit in 1992, along with the UN Framework Convention on Climate Change (UNFCCC) and the UN Convention to Combat Desertification (UNCCD). CBD has accomplished a bit, but it has not at all accomplished its core goal of heading off the massive loss of biodiversity. The convention articulates that goal as follows:

> "The objectives of this Convention, to be pursued in accordance with its relevant provisions, are the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources…"

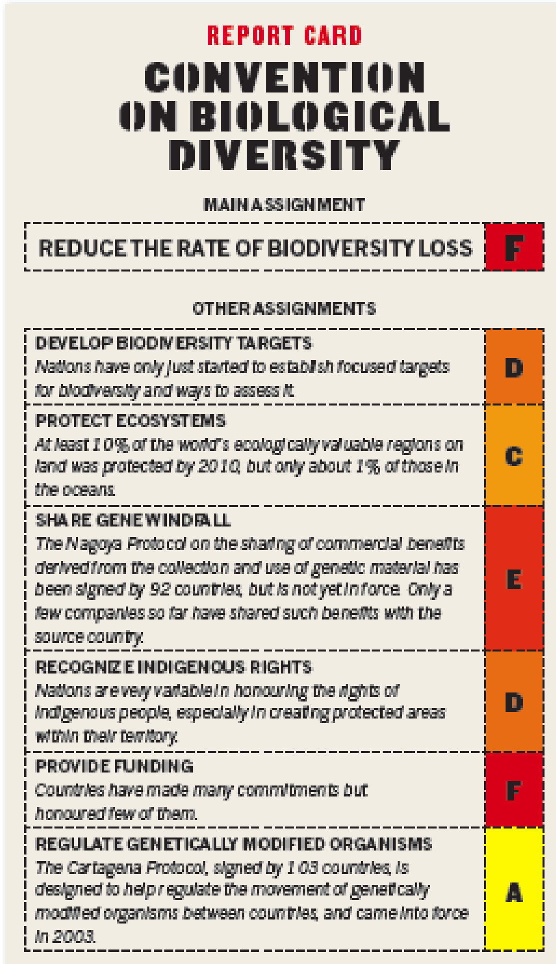
It is important to underscore that CBD puts great emphasis not only on conserving biological diversity, but also on the fair and equitable sharing of the benefits arising out of the utilization of genetic resources. At the time, it was thought that an incredible bonanza could be expected out of what was called bio-prospecting – that scientists would enter the world's forest regions and identify new blockbuster drugs of both profound medical and financial value. The question was how to make sure that the host countries would benefit from these discoveries. This is not an entirely fanciful idea – nature certainly has chemical compounds of profound benefit still to be discovered. One of the greatest discoveries that I see in my everyday work is an ancient Chinese herbal remedy for fever, the wormwood plant, which became the source of the modern molecule Artemisia, used to fight malaria. But a lot of the impetus in 1992 and a lot of the mishaps with the CBD since then came from the notion that we should be focusing our efforts on the wealth from bio-prospecting, rather than on limiting human activity in order to prevent a collapse of ecosystems and biodiversity for our much deeper, longer-term wellbeing.

The treaty has accomplished a certain bit, but it has fallen far short of what it should be doing. One of the main reasons for that is the disgraceful behavior of the government of the United States, my own country. Though US scientists and some politicians were leading proponents of the treaty negotiations, the right-wing politicians in the United States started to lobby against the treaty even during the negotiations. By the time the treaty was finalized for the 1992 Rio Earth Summit, President George H.W. Bush decided not to sign it under pressure from members of his own party. The next year, President Bill Clinton came to office, signed the treaty and submitted it for Senate ratification, which in the United States system requires a two-thirds vote of the Senate. The Senate committee reading this treaty gave its approval, but the Senate has never ratified the treaty.

It is quite remarkable what happened next. So-called free-market politicians in the US rejected the idea that the world should agree to an equitable and fair sharing of biological products. Let the US drug companies make a massive profit, they said. One suspects that powerful industrial lobbies made their voices heard. Then, private developers began loudly calling for the right to buy US federal land to mine, to drill for oil, or for fracking shale gas. They argued that the CBD would be a menace to their profit-maximizing property rights.

This type of “free market” sentiment is startlingly misguided, because markets should serve human purposes, not be ends in themselves, or vehicles for rapacious greed that imposes huge social costs on others. When markets do not take into account the profound externalities of individual behavior such as the loss of biological diversity or species extinction, free markets become the antagonist of human wellbeing. A radical ideology that says, “Leave me alone, I have the perfect right to destroy species,” can obviously create havoc. While the US remains an observer to the CBD, its absence as a signatory has gravely weakened the implementation of the treaty. When the Parties to the CBD pledged in 2002 in their strategic plan to slow and reverse the loss of biodiversity by the year 2010, there was little practical effect. By 2010, the extent of loss of biodiversity was greater than ever.

The three multilateral environmental agreements of the Rio Earth Summit were reviewed 20 years later at the Rio+20 Summit. At that time *Nature* magazine conducted an in-depth analysis of what had happened under the various treaties, and created a report card for each. Figure 13.16 shows the report card for the Convention on Biological Diversity. Its main assignment was to reduce the rate of biodiversity loss; it received a grade F, total failure. This treaty has not slowed the loss of biodiversity. For its other assignments: develop targets, a D; protect ecosystems, a C; recognizing indigenous rights, a D; financing to offset the loss of biodiversity, a solid F. The one high grade that was given was creating a regulatory framework around genetically modified organisms. Whether that framework eventually serves the human purpose or inadvertently chokes off the benefits that advanced genetics might give for seed breeding remains to be seen.



REPORT CARD

CONVENTION ON BIOLOGICAL DIVERSITY

MAIN ASSIGNMENT

REDUCE THE RATE OF BIODIVERSITY LOSS	F

OTHER ASSIGNMENTS

DEVELOP BIODIVERSITY TARGETS *Nations have only just started to establish focused targets for biodiversity and ways to assess it.*	D
PROTECT ECOSYSTEMS *At least 10% of the world's ecologically valuable regions on land was protected by 2010, but only about 1% of those in the oceans.*	C
SHARE GENE WINDFALL *The Nagoya Protocol on the sharing of commercial benefits derived from the collection and use of genetic material has been signed by 92 countries, but is not yet in force. Only a few companies so far have shared such benefits with the source country.*	E
RECOGNIZE INDIGENOUS RIGHTS *Nations are very variable in honouring the rights of indigenous people, especially in creating protected areas within their territory.*	D
PROVIDE FUNDING *Countries have made many commitments but honoured few of them.*	F
REGULATE GENETICALLY MODIFIED ORGANISMS *The Cartagena Protocol, signed by 103 countries, is designed to help regulate the movement of genetically modified organisms between countries, and came into force in 2003.*	A

Figure 13.16. *Nature* Report Card: Convention on Biological Diversity

The only other semi-decent grade is a C in protecting ecosystems. One of the provisions in the Convention on Biological Diversity was to set aside protected zones; the graph in Figure 13.17 shows the cumulative protected areas in the world. National parks, national reserves, protected wildlife refuges, marine protected zones and so forth have increased in the previous decades. This rise in protected areas, in particular of marine protected areas, is a contribution of the Convention on Biological Diversity. The treaty has had some effect, but the overall verdict of an "F" grade gives a fair summary of its lack of success.

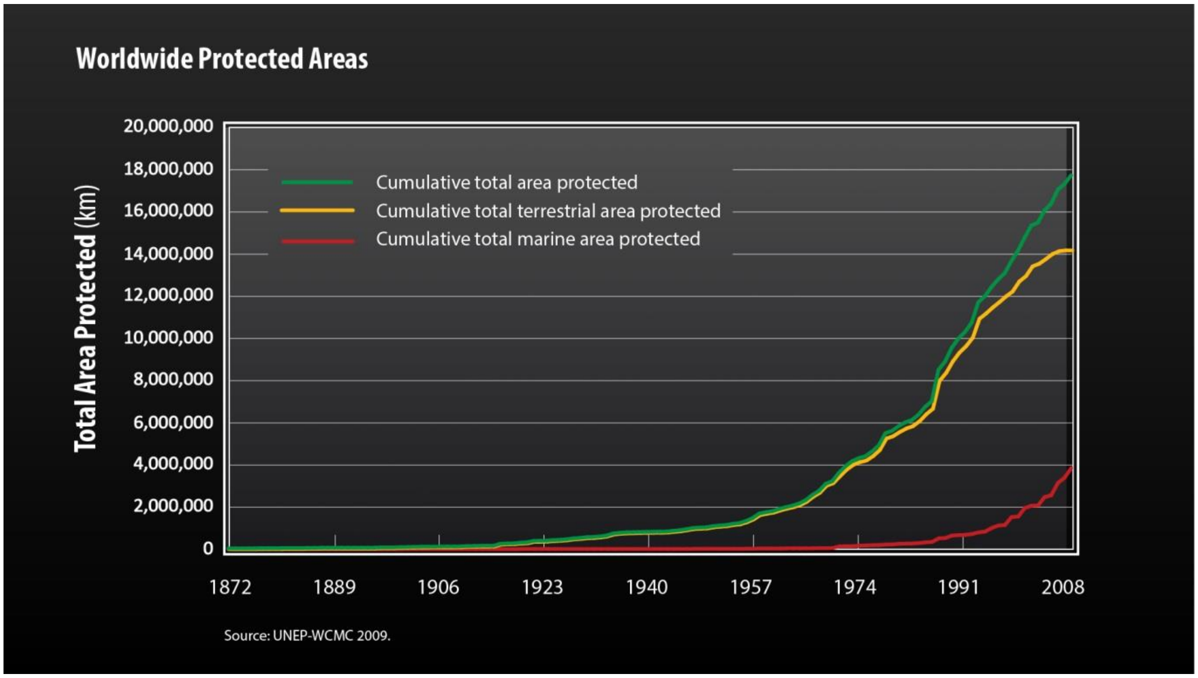


Figure 13.17. Worldwide Protected Areas

Another very important treaty preceded the Convention on Biological Diversity by a couple of decades; the Convention on International Trade in Endangered Species (CITES), which was signed in 1973 and went into effect soon thereafter. The idea of CITES is to reduce the pressures and dangers of species extinction by regulating trade specifically in endangered species. The treaty classifies endangered species; species that are not yet endangered but could become so unless trade is reduced; and species whose trade indirectly imperils species in endangerment of extinction. Within those three categories, CITES covers 35,600 plant and animal species right now.

CITES has had an important effect, but like all international law, the forces of the world economy can sweep aside what is on paper and often have absolutely devastating consequences. An example of this is the recent surge in illegal trade of rhinoceros horns, and the massive kill-off of rhinoceroses because of the soaring demand. Virtually all of this demand comes from China, where rhinoceros horn is a treasured part of the pharmacopoeia of traditional Chinese medicine. It is an extraordinarily valued commodity, but the black rhinoceros is also an extraordinarily endangered species and its numbers have fallen precipitously; in November 2013 the Western Black Rhino sub-species was officially declared extinct. It is not surprising when you consider that the market price for a rhinoceros horn has reportedly reached $65,000 per kilo, higher than gold. There are thus bound to be tremendous pressures and corruption along every part of the supply chain.

A very important recent study by Professor Manfred Lenzen of the University of Sydney and his colleagues found that trade in products like rhinoceros horns and elephant tusks are a pervasive problem, not specific to a couple of headline products but involving many thousands of endangered plant and animal species. The results show that about one-third of endangered species are part of important global trading chains. This means it is not good enough to stop local pressures; essentially the full weight of the $90 trillion world economy is providing the fuel for the massive loss of biodiversity. A useful graphic from the Lenzen study, shown in Figure 13.18, traces worldwide supply chains and shows both the supply and the demand sides. The main point of this graph is that the issue is in global supply chains, and many countries engaged in threats to biodiversity as both suppliers and consumers.

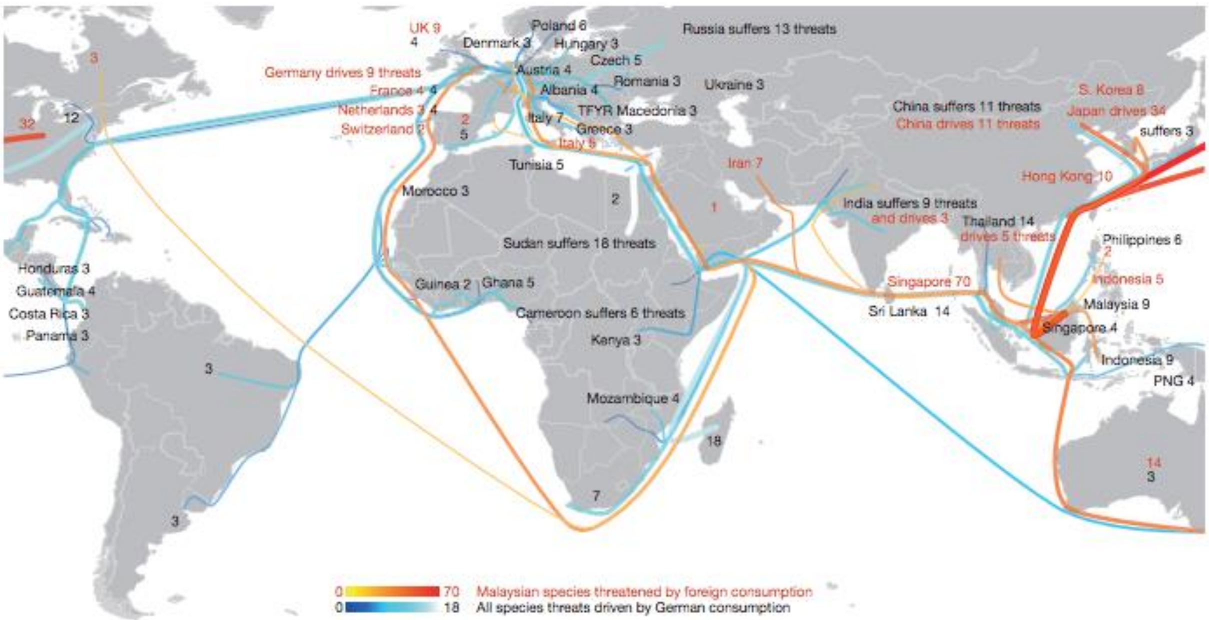


Figure 3 | Flow map of threats to species. Flow map of threats to species caused by exports from Malaysia (reds) and imports into Germany (blues). Note that the lines directly link the producing countries, where threats are recorded, and final consumer countries. Supply-chain links in intermediate countries are accounted for but not explicitly visualized. An interactive version is available at http://www.worldmrio.com/biodivmap/.

Figure 13.18. Worldwide Supply Chains

The conclusion is that the global efforts over many decades have not yet come to grips with the sixth great extinction wave. Humanity's power over ecosystem functions and its endangerment of biodiversity are so significant and coming from so many different directions that we still lack the public awareness, the political impulse, and the economic incentives to get this right. When the world met at Rio+20 in June 2012 and received the report card of an F on implementing the Convention on Biological Diversity, the UN Framework Convention on Climate Change, and the UN Convention to Combat Desertification, it was clear to governments that something different must be done. We need a breakthrough in global policy and action under a new set of Sustainable Development Goals that at least have the potential to help us move from the very threatening path of business as usual to a true path of sustainable development.