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# From national security to natural security

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From 10,000 meters up, the impact of humans on the Earth is clear. Cities spanning kilometers are connected by roadways stretching to the horizon. Crowding the spaces in between are fields that supply food and industrial feedstock to satisfy a variety of human hungers. These fields feed humanity. Through stewardship we maintain their productivity and thus sustain societies that extend around the globe; if these fields fall into ill health, or if we push them into sickness, we risk the fate of those same societies.

Humans have a long history of modifying the living systems they rely on. Forests in Europe and North America have been felled for timber and have regrown, while other large tracts of land around the world have been completely cleared for use in agriculture. The animals and plants we humans eat on a regular basis have been selected and bred over millennia to suit the human palate and digestive tract. All these crops and products are shipped and consumed globally to satisfy burgeoning demand.

Our technology and trade thereby support a previously unimaginable quality of life for a previously impossible number of people. Humanity has kept Malthus at bay through centuries of growth. Yet our increasing numbers impose a load that is now impacting nature's capacity to support human societies. This stress comes at a time when ever-larger numbers of humans demand more: more food, more clean water, more energy, more education, more entertainment, more *more*.

Increasing human demand raises the question of supply, and of the costs of meeting that supply. How we choose to spend or to conserve land, water, and air to meet our needs clearly impacts other organisms that also depend on these resources. Nature has intrinsic value for many people in the form of individual species, ecosystems, and wilderness; nature also constitutes critical infrastructure in the form of ecosystems that keep us alive. That infrastructure has quantifiable economic value. Consequently, nature, and the change we induce in it, is clearly interwoven with our economy. That is, the security and health of human societies depends explicitly upon the security and health of natural systems. Therefore, as economic security is now officially considered as part and parcel of national security strategy, it is time to expand our understanding of national security to include natural security.

Humanity already addresses economic security through the use of biotechnology. We plant vast acreages of crops whose genes have been directly altered to improve the economics of their use as food, fuel, and industrial feedstock. Smallholders in India planting genetically modified cotton have seen a 24 percent increase in yield through reduced pest damage and a consequent 50 percent increase in profit. U.S. farmers generate between 6 and 20 percent increase in profits by planting genetically modified crops, depending on the crop and the specific location.

More broadly, as I announced in a briefing to the U.S. Congress in November, genetic modification is used to produce crops, drugs, and industrial products that now contribute at least $350 billion to the US economy, the equivalent of about 2.5 percent of gross domestic product. Total global biotech revenues are roughly double those of the United States. Beyond physically moving DNA from one genome to another, it is becoming increasingly commonplace to 1) read DNA via sequencing, thereby creating an electronic description, 2) modify that electronic description to produce a new design— perhaps by combining genes and functionalities from several different species, 3) construct that newly designed genetic circuit via DNA synthesis, and finally 4) install the new genetic circuit in an organism. This effort, often called synthetic biology, is gradually, and with increasing success, bringing modern engineering principles to the design and construction of living systems. At present, the focus of any sort of genetic modification tends to be on species or products that have immediate value in easily identifiable markets such as food, fuel, or healthcare. Meanwhile, due to our increased demand for land, water, and food, species continue to go extinct at an alarming rate, and ecosystem degradation is beginning to impact our access to that same land, water, and food.

But what if humanity applied its growing biotechnological capabilities to support not just the human economy, but to support nature more broadly? What if we could use the tools of genetic manipulation to protect or even improve the health of species and ecosystems that we rely on, from bees to bats to coral reefs? In April, conservation biologists, synthetic biologists, and economists, among many others, met to consider these issues at the University of Cambridge in a meeting titled "How will synthetic biology and conservation shape the future of nature?" Predictably, as experts in the two fields met for the first time, there was curiosity, confusion, and more than a little consternation. At the end of the two days, attendees had established open lines for dialogue and, perhaps, avenues for collaboration. But much work remains to be done before the international community even begins to mesh synthetic biology with efforts to conserve the world's environment in the face of climate change.

**The daunting challenge.** The global population is expected to grow about 35 percent, to 9.5 billion by 2050. Between now and then, the world will increase its per capita demand for food, energy, and fresh water by as much as 70 percent. Even ignoring this increase, the impact of present demand is becoming ever clearer. The Fifth Assessment Report from the Intergovernmental Panel on Climate Change expresses these verdicts: Climatic warming is due to increased atmospheric carbon dioxide; it is "*extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century"; in the 21st century, "the rate of sea level rise will *very likely* exceed that observed during 1971–2010 due to increased ocean warming and increased loss of mass from glaciers and ice sheets"; and ocean acidity will rise due to increases in dissolved carbon dioxide. A recently leaked, forthcoming assessment due out next March warns that warming is likely to reduce agricultural output by as much as 2 percent per decade. Meanwhile, sea-level rise and ocean acidity are already beginning to pinch coastal economies.

Accounts of these costs are beginning to appear in the American popular press. Jobs and revenues are being lost in Washington State due to reduced oyster viability that is directly attributable to aquatic acidity increases. Flooding and property damage in Miami are rising due to a combination of subsidence, sea level rise, and saltwater intrusion. Even with drastic reductions in carbon dioxide emissions, which do not appear to be in the offing, anthropogenic global climate change will continue for decades, if not centuries.

Yet our footprints are often easy to overlook. Ecosystem change is so broadly writ on the planet—spanning continents, oceans, and centuries—that it can be difficult to comprehend. Similarly, it is difficult to imagine crafting solutions to large problems that may require new technology, changes in human behavior, and unprecedented international cooperation. Ángel Gurría, the secretary general of the Organisation for Economic Co-operation and Development, recently called for "the complete elimination of emissions to the atmosphere from the combustion of fossil fuels" by 2100. This goal, while critical and perhaps even eventually achievable, can itself seem as distant as 2100, given our current political resolve and technical capacity. The world can simplify the conversation by reducing the field of view to natural systems whose degradation or disappearance—whether or not that damage is directly caused by humans—will have quantifiable economic costs that may be preventable via application of synthetic biology. The obvious place to start is threats to the food supply.

**Of bees, and bats, and coral reefs.** If you eat, you rely on honeybees. Regrettably, due to a variety of causes, many bee populations have declined to the point where food crops are in jeopardy. Winter die-off rates have hit 30 percent annually over the last seven years, up from a historical 10 percent, and the price for renting beehives in California has tripled over the last decade. Entomologist Dennis van Engelstorp warns, "We're getting closer and closer to the point where we don't have enough bees to meet pollination demands. If we want to grow fruits and nuts and berries, this is important. One in every three bites [of food consumed in the U.S.] is directly or indirectly pollinated by bees." The cause of this decline is dubbed colony collapse disorder and is attributed to a constellation of interlocking causes.

At the very least, we should stop making the problem worse; Europe has banned a class of pesticide that is exceptionally hard on honeybees, though arguments persist about whether this action will make any difference. Most experts agree we need to do more. Efforts are already underway to breed bees that are resistant to pesticides and to mites that both prey on bees and transmit pathogenic viruses between bees. New technologies might facilitate these efforts. To be sure, the complexity of the problem is enough to give anyone pause, particularly those who might employ genetic modification. Should synthetic biologists focus on boosting apian immune systems? Should they focus on the mite? Apian viruses? How would any of this work in practice? The answers to those questions are not clear. But with such a large fraction of our food supply dependent upon healthy bees, it is clear that we should be working on all fronts to sort out potential solutions. And bees are not the only agricultural assistants in decline.

Bats are unsung partners of humans; by eating insects and pollinating various plants, bats contribute an estimated $23 billion annually to US farmers, equivalent to roughly 5 percent of America's total food crop revenue. Hundreds of predominantly rural counties in the United States *each* receives benefits worth between $20 million and $75 million annually from insectivorous bats. Tragically, bats in North America are being decimated by white nose syndrome, with nearly six million deaths as of mid-2012 and a mortality rate reaching 100 percent. The syndrome, caused by a fungus evidently imported from Europe, will eventually not only increase food costs but will increase downstream costs due to pesticide application and exposure. Moreover, the cost to replace the bats, assuming we could do it, is likely to be more than $23 billion, because whatever we invent is unlikely to be as efficient as the bats.

What might we do to assist bats, hold pesticide use in check, and thereby keep food prices from rising due to an ecological threat? Microbiologists are already exploring biological controls in the form of microbes that inhibit the fungus, which may be useful as a form of pest management but would also increase the evolutionary selection pressure on the fungus to improve its survival skills. Consequently, it is important to explore long-term solutions. European bats are resistant to the fungus, and one option is to introduce the appropriate European genes into North American bats via standard breeding.

But bats breed slowly, usually only having one pup a year and only five or so pups in a lifetime. Given the mortality rate due to white nose syndrome, breeding is probably too slow to be useful in near-term conservation efforts. The fungus itself is robust and persistent in bat caves, suggesting it may be hard to suppress or eradicate in the wild. It is possible, however, that synthetic biology could be used to intervene in some way, either by directly attacking the non-native fungus or by interfering with its attack on bats, thereby benefiting both biodiversity and food production.

Yet another threatened organism that contributes to human welfare is coral. Coral cover on many Caribbean reefs has declined as much as 80 percent over the past 30 years. Across the Indo-Pacific region, coral reefs are declining by 1 to 2 percent per year, threatening the more than $500 billion these ecosystems generate in annual services to human economies. This economic value includes food in the form of marine life and coastal protection from wave action.

Regardless of the cause of the decline, improving the natural security of reefs would clearly improve human physical and economic security, and there are tools that could be brought to bear. Some corals are resistant to increases in both temperature and acidity, and efforts are already afoot to identify the genes responsible and to try to propagate them through breeding. Many attendees at the meeting in Cambridge wondered whether other means, including synthetic biology, might be useful or necessary to create resistant corals. What if we could isolate the relevant genetic circuits and, if required, transplant them into other coral species? This is undoubtedly a hard problem, with implications that should be carefully considered. But the fate of many ecosystems and human communities may rest on preserving coral reefs around the globe.

**The back-up plan.** The flashiest proposal on the table at Cambridge was the idea of restoring extinct species. Through our often heavy hand, humans have eliminated whole species from the planet, occasionally through simple greed. Both the wooly mammoth and the passenger pigeon fell victim to human hunger, leaving what Stewart Brand calls "holes in nature." Brand, among others, suggests that we apply our rapidly improving genome engineering skills to restore missing species and to thereby fill in the holes. This idea, also variously referred to as revivification, de-extinction, or reanimation, has now been aired at TED conferences, in the pages of *Nature*, *Science*, *National Geographic*, and *The New York Times* and is the focus of a new foundation, Revive and Restore, dedicated to bringing back extinct species. De-extinction is increasingly said to be technically feasible, is certainly intriguing, and represents the grandest example of applying the capabilities emerging via synthetic biology to fields such as conservation biology. Starting the project with culturally important species may even pay for developing technologies that can subsequently be applied to less glamorous, but potentially more ecologically and economically important species.

However, like the mammoth itself, the *idea* of de-extinction may be an example of a “charismatic megafauna” in the menagerie of ideas being forwarded to fix the planet and repair damage we have wrought. It may also be a distraction from more concrete and perhaps more pressing interventions in changes to the climate and to ecosystems that are immediately important to human wellbeing.

The world cannot embark on a discussion of synthetic biology and environmental conservation without considering repercussions. Nature is changed—and sometimes damaged—by humanity’s constant selection and transplanting of species, as the interlopers find ways to insinuate themselves into local ecosystems and economies. Even a simple list of damaging introductions, accidental and intentional, could easily exceed the word limit of this essay. In the United States alone, introduced species—ranging from tamarisk, kudzu, and eucalyptus to green crabs, zebra mussels, and snakes—cause at least $150 billion annually in direct economic damage, including damage to crops, property, human and animal health, and water supplies. This accounting of easily quantifiable costs does not include the value of lost ecosystem services, such as water purification, let alone the cost of species extinction, yet already it amounts to about 20 percent of total U.S. agricultural revenues and approximately 1 percent of gross domestic product. Moreover, that one percent of GDP constitutes primarily lost value, rather than a cost of remediation or repair that might in turn create jobs. Historically, each one percent gain (or loss) in GDP is correlated with about a half a percent gain (or loss) in employment across the economy (this is known as Okun’s Law), which means that invasive species constitute a natural security threat that costs the livelihoods of approximately 750,000 Americans annually, demonstrating again that threats to natural security are clear and present threats to national security. While the above statistics concern the US economy, international trade and the transportation of non-native species have created threats to the natural security, and thus to the national security, of every nation on the planet.

If natural security can be improved through changes in human behavior then we should by all means work toward that end. The simpler solution is usually the better solution. For example, increased education and customs enforcement might reduce the transportation of exotic species. It also might be a good idea to stop using those pesticides and antibiotics that appear to create more problems than they solve when introduced into the environment. Moreover, at the level of complex systems such as the environment and the economy, technological fixes are probably best reserved until the international community tries, and exhausts, efforts to change human behavior. But what if the damage is too far along or cannot otherwise be addressed by changes in behavior? We should at least consider the possibility that a technological fix might be worth a go, if for no other reason than to begin to create a back-up plan.

Given the time scales involved in manipulating complex organisms and ecosystems, exploring the option of any back-up plan means getting started early. It also means thoughtfully considering which interventions would be most appropriate and urgent, including an initial evaluation of whether changes in human behavior are likely to have any effect. If major changes in human behavior cannot be brought about, a technical solution may be the world’s only chance. And at the rate the world is going, busily fiddling away while ecosystems burn, a back-up plan formulated now may well turn out to be the only plan. Given the observed degradation to ecosystems and food production capacity, the application of synthetic biology to conservation may become a national security imperative. We are facing such large problems that it would demonstrate extremely poor judgment not to evaluate all possible means to improve both human and natural security.

Humanity owes itself—and nature—a serious inquiry that asks what sorts of tools might be used to save the species and environments on which human beings and all other life on the planet rely. Human security requires natural security; perversely, the greatest threat to natural security stems from human action. If humans are to continue to thrive, we must determine how to become nature's greatest hope.

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