

ENVIRONMENT

Approaching the Limits

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One of the foundational principles of biology is that a population cannot grow forever in a finite ecosystem—a progressive system feedback of starvation, predation, and disease limits uncontrolled growth. The global human population has now nearly tripled since 1950, and economic activity increased tenfold, leading many to suggest that humanity is heading toward a population and consumption overshoot (resource depletion and correction, as economists would say). In *Harvesting the Biosphere*, Vaclav Smil traces the historical development of human consumption of biological resources and evaluates whether we could be approaching important global limits. Smil (an economist at the University of Manitoba) has written several books on global energy and other resource issues; here, he focuses on human consumption of the plant and animal life and whether current trends are sustainable.

To begin, Smil addresses whether the total plant and animal biomass on Earth can be measured adequately. Of greater value is the annual plant production of new biomass [net primary production (NPP)], which serves as the foundation of all food chains. The introduction of Earth-observing satellites in the 1980s provided the first defensible measure of plant growth at global scales, and Smil illustrates the latest capability with a NASA image of global annual NPP (which should have been reproduced in color). Smil traces the history of global estimates of NPP through to the now commonly accepted range of 53 to 59 Pg carbon per year for land and 50 Pg carbon for oceans, estimates rather well constrained by mass balancing

the global carbon cycle with the atmosphere and human emissions.

Smil next addresses the key question of what fraction of this global NPP humans currently consume. He critiques the methodology of estimates of the human appropriation of NPP (HANPP), beginning with Peter Vitousek *et al.*'s original (1986) calculation of 32 to 40% (1). Most authors define



Intensively farmed. Agricultural lands in Minas Gerais, Brazil (10 February 2011).

HANPP rather expansively as all biospheric production used for human benefit, a conceptually satisfying but methodologically challenging interpretation that includes crops, forest plantations, grazing land, and the negative impacts of habitat destruction and environmental degradation. Choosing to estimate HANPP using only agricultural and forestry harvest statistics, Smil arrives at a lower estimate of 17 to 20%, a level that might appear to be sustainable.

However, one cannot assume that all of global NPP is potentially available for human use. Some regions of the Amazon or Siberia, for example, are too remote for harvest. More important, do we really want to plow and clear the whole world? Most of us want to preserve some natural systems for biodiversity, ecosystem services (such as water and air purification), recreation, or aesthetic beauty. Human settlements and infra-

structure, termed impervious surfaces, presently cover only 0.44% of Earth's continental surface, whereas agriculture and grazing lands cover about 40%. Although global NPP currently appears stable, Smil suggests the great potential for pollution, exhaustion of soil nutrients, and irrigation depletion to substantially reduce the future NPP available for humanity. In addition, bioenergy is emerging as a massive new demand on NPP. Should fossil fuels become scarce, expensive, or unwanted, biofuels could, if allowed by policy and economic strategies, consume all remaining available NPP (2).

The future limits of HANPP become an urgent policy issue when one considers the 40% increase in global population expected over the next three or four decades and the expansion in living standards aspired to by the underdeveloped world. Smil expects that current policies will lead to a two- to threefold increase in HANPP demand in the next half century, and he rightfully asks if this increase is possible.

Scholars around the world have been asking roughly this same question since 1972, when the landmark *Limits to Growth* book appeared (3). More recent analyses—such as the global human footprint, planetary boundaries, and Gaia—address the question from various angles. Each has indicated that another half-century of the current trajectory of human development, consumption, and economic aspirations does not appear possible (4–7).

Smil's final recommendations echo others: global population must be stabilized at or below 9 billion; agriculture has to become sustainable, no longer relying on fossil-fuel-based fertilizers and mining groundwater for irrigation; meat consumption must be moderated; and food storage and processing must be improved and wastage minimized. Crucially, the rich nations have to share global resources more equitably with emerging countries, as simply growing more does not appear possible.

Full of recent references and statistics, *Harvesting the Biosphere* adds to the growing chorus of warnings about the current trajectory of human activity on a finite planet, of which climate change is only one dimen-

Harvesting the Biosphere
What We Have Taken from Nature

by Vaclav Smil

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sion. One can quibble with some assumptions or tweak Smil's calculations, but the bottom line will not change, only the time it may take humanity to reach a crisis point. Systems ecology teaches that the human population and consumption trajectories need a stronger feedback control than currently exists. Either we are smart enough to craft that feedback mechanism ourselves, or the Earth system will ultimately provide it. Unfortunately, the tragedy of the commons suggests that collective international actions to voluntarily reduce consumption are contrary to human nature.

References

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PHILOSOPHY OF SCIENCE

A Flawed Challenge Worth Pondering

Kristina Musholt

What are the limits of the scientific method? This is the question that lies at the heart of *Mind and Cosmos*. With science laying ever-increasing claims on questions once regarded as unanswerable by empirical means, philosopher Thomas Nagel argues that science is—in principle—unable to explain the mind. And because “mind is not just an afterthought or an accident or an add-on, but a basic aspect of nature,” science’s inability to account for mentality strikes at the core of its endeavor to make sense of the world.

Nagel (New York University) has long been concerned with the problem of consciousness and the question of whether consciousness can be reduced to its biological basis. In his famous paper “What is it like to be a bat?” (*J*), he argued that however much we may come to know about the physiology

of bats, we will never be able to know what it feels like to be one. Accordingly, the scientific method, in this case physiology, fails to provide us with a certain kind of knowledge—the understanding of what the phenomenal experience of a bat would be. Similarly, although neuroscience and psychology are currently making great strides toward a better understanding of the neural and functional correlates of consciousness, one can always ask why a particular brain state or function should be associated with a particular (or indeed any) conscious experience. Consciousness simply does not seem to be reducible to the functional role played by states or processes in the brain.

In *Mind and Cosmos*, Nagel picks up this argument and takes it a step further. He contends that the irreducibility of the mental to the physical also has implications for evolutionary theory. In his view, an evolutionary explanation for the appearance of consciousness would have to show “why the appearance of conscious organisms, and not merely of behaviorally complex organisms, was likely.” To do so, presumably, evolutionary theory would have to give an account of the adaptive role played by consciousness. However, if consciousness cannot be reduced to the functional role played by processes in the brain, natural selection has nothing to work on. For every adaptive function we can identify, one can always ask why it should have a particular (or any) phenomenal character. The alternative, that consciousness could be seen as a mere by-product (or spandrel) of evolution, appears equally unsatisfying to Nagel because he takes consciousness to be one of the “systematic features of the natural world.”

Thus, we are left with “a double mystery”: We can explain neither the relation between the mental and the physical nor how or why consciousness evolved. According to Nagel, this should encourage us to look for a radical alternative to the “materialist neo-Darwinian conception of nature.” Indeed, Nagel believes that to make progress with regard to these questions, we need a major conceptual revolution akin to the scientific revolution itself. More precisely, he holds, we should consider the possibility that life and consciousness might not just be a result of the laws of physics and chemistry in combination with natural selection. What else might there be? Nagel does not give us much detail about the alternative he envisages; his aim is “to present the problem rather than to

propose a solution.” He does, however, point to the Aristotelian notion of “natural teleology” for a possible alternative—that is, the idea that there is a purpose or direction in the evolution of life.

Although Nagel presents us with good reasons to reject reductionism (the view that everything that exists, including consciousness, can ultimately be explained in terms

of physics), his claims for the necessity of a major scientific revolution are much less compelling. Indeed, whereas he takes reductionism to be the mainstream position in philosophy and science, Nagel is in fact far from being alone in making the case for antireductionism. Yet the fact that not every phenomenon is fully explicable in terms of physics does not imply that materialism (the view that everything

that exists is ultimately physical) is false or that science is in need of radical overhaul. The problem of consciousness could be a conceptual problem, whose solution (or dissolution, as some philosophers would have it) simply falls outside the remit of empirical science.

Moreover, it remains unclear why Nagel insists that evolutionary theory must demonstrate that the appearance of consciousness was something to be expected in order to render it intelligible. We have perfectly reasonable explanations for many events that were unlikely to occur but did. It remains even more unclear how the alternative that Nagel gestures toward is any more illuminating than the theories he rejects. Why should it be any less mysterious to think that consciousness is the result of teleological principles in addition to natural selection than that it is the unlikely (though not impossible) result of natural selection alone? That said, Nagel's arguments against reductionism should give those who are in search of a reductionist physical “theory of everything” pause for thought.

Overall, many aspects of *Mind and Cosmos* are problematic. Nonetheless, the book serves as a challenging invitation to ponder the limits of science and as a reminder of the astonishing puzzle of consciousness. Whether or not you believe that this puzzle can ultimately be solved by science, it is certainly one worth thinking about.

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Mind and Cosmos
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