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Ecotoxicology Risk Assessment for a Changing World

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Abstract

Exponential economic growth has resulted in grave damage to the biospheric life support system and the ecosystems that comprise it. The ubiquitous single-species toxicity tests provide crucial evidence on death, reproductive processes, and recruitment rates, but not on important ecosystem attributes such as community structure and function. The testing systems used (microcosms, mesocosms, and field enclosures) are not miniature ecosystems but can, if appropriately designed, furnish useful information on the risk of toxicants to important cause/effect pathways. Ecosystems provide important resources and services upon which humankind depends, so they deserve more protection than they are now getting. Ecotoxicology is based on the use of endpoints (e.g., nutrient cycling, energy transfer) characteristic of ecosystems.

Economic globalization has resulted in a marked increase in waste discharges in developing countries. Developed countries must help train ecotoxicologists in developing countries so that problems can be treated at the source where total societal costs are lowest. Developed countries must also avoid creating technologies that are inappropriate everywhere lest they be adopted by developing countries (e.g., "seeding" the oceans with iron). In addition, very rapid climate change provides many challenges to ecotoxicologists. Even small (2-3°C) increases in temperature may alter partitioning and uptake of many chemical substances. As the tropical zone moves both north and south, test species will change, as will the ecosystems they inhabit. Toxicity testing methods and procedures must be modified as rapidly as these ecological changes occur. Developing and obtaining approval for new ecotoxicity testing methods (e.g., American Society for Testing and Materials or European Union) will be a necessary but time consuming activity.

The information flow is inadequate between bottom-up (i.e., ecosystem component) information and top-down (i.e., system level) information. Yet a synthesis of the two types of information is essential for sound decision making. All components of the biosphere (e.g., air, water, land, biota) are important to systems (e.g., Gaia), but are all too often considered in isolation from each other. All too often, disciplines, even ecotoxicology, are too isolated from each other and the general public. The attacks on global climate change science and evolution in the United States are good examples of the consequences of this discontinuity. In addition, ecotoxicologists need to become more involved in the developing field of nanotechnology.

Keywords: Ecotoxicity testing, Ecosystem endpoints, Ecosystem level synthesis, Rapid global climate change, Risk to humankind.

"The thing that a lot of people cannot comprehend is that Mother Nature doesn't have a bullet with your name on it, she has millions of bullets inscribed with to who it may concern."

—Anonymous

"If the mortality rate seems high we must realize that Nature is a ruthless teacher. There are no second chances in Mother Nature's Survival Course."

— William S. Burroughs

"Nature favors those organisms which leave the environment in better shape for their progeny to survive."

—James Lovelock

"Ethics, too, are nothing but reverence for life. This is what gives me the fundamental principle of morality, namely, that good consists in maintaining, promoting and enhancing life, and that destroying, injuring, and limiting life are evil."

—Albert Schweitzer

Civilization and Ethics 1949

"Now there is one outstandingly important fact regarding Spaceship Earth, and that is no instruction book came with it."

—Buckminster Fuller

"Security is mostly a superstition. It does not exist in nature, nor do the children of men as a whole experience it. Avoiding danger is no safer in the long run than outright exposure. Life is either a daring adventure or nothing."

—Helen Keller

1. Will There be Enough Ecotoxicologists?

The daily news gives a "tip of the iceberg" perspective on ecotoxicological problems all over the planet. Many state that humankind cannot afford to address these problems; others maintain that humankind cannot afford not to address them. Many of the problems are urgent, with catastrophes likely if they are not addressed. The Intergovernmental Panel on Climate Change (IPCC) reports required efforts from thousands of scientists for well over a decade. Still, although this effort appears to have resulted in a paradigm shift in public opinion, it has not yet done so for political will. Environmental pollution is an equally complex problem and may require a professional effort comparable to that of the IPCC. Where will the credentialed professionals for such an effort come from?

Berlowitz (2007) states: "Currently the time to a doctorate degree for scientists and engineers ranges from 6.5 to 8 years, followed by prolonged post-doctoral training." A doctorate in the humanities generally requires 10 years to complete, and the average graduate debt levels for humanists are among the highest in the academic professions.

A relatively few people can carry out a synthesis of information if they have an outstanding support staff. Data gathering requires different levels of skill, depending upon the types of data gathered. More attention should be given to personnel needs in ecotoxicology.

This discussion is not a "how to" on ecotoxicology. Hoffman *et al*. (2003) used 1,290 pages to cover this subject. The discussion here concerns the almost alien world that humankind is likely to experience. The news about the rapid rate of change of global heating and other types of climate change has been unsettling. Currently, a probability exists of a huge temperature spike (Roach, 2007). Roach (2007) mentions the findings of Appy Sluijs, a paleoecologist at Utrecht University in the Netherlands, whose theory is that global heating could force a meltdown of the methane hydrates, ice-like deposits on the seafloor, which would release methane into the ocean/ atmosphere system. Sluiys notes that what started out as a moderate global warm up about 55 million years ago triggered a massive injection of greenhouse gases into the atmosphere that sent temperatures skyrocketing. This increase could create social, political, and ecological instability, which would be a difficult time for ecotoxicologists as both professionals and as individuals.

Judging from the slow pace of the politicians at the December UN global climate change conference in Bali, one would think the world had decades to take effective remedial action. This extended timing is simply not true. Most scientific evidence indicates that events are moving much faster than expected.

2. The Era of Ecological Disequilibrium

Increased variability is one of the signs that complex systems, such as ecosystems, are approaching or are in disequilibrium. How is deviation from the norm detected? Biological networks are nonlinear; moreover, connectivity within a network has an effect upon stability. Ecosystem stability is influenced by size (May, 1972, 1973), and fragmentation of ecosystems by such artifacts as roads, housing developments, and shopping malls (Pimm, 1984; Holt, 2006) also reduce stability. Biodiversity also influences stability since succession of species improves the chances of the most appropriate species being present. MacArthur and Wilson (1963) note that the further an area is from a source of colonizing species, the more impoverished the biota becomes.

Ecological disequilibrium is a complex subject, but *Homo sapiens* is clearly not benefiting the integrity of Earth's biospheric life support system. Such a path seems arrogant, selfish, and self-centered for organisms who have only been on Earth for about 0.04% of the 4.5 billion years it has existed.

3. Nanotechnology

William Ruckelshaus, twice head of the US Environmental Protection Agency (USEPA), and Clarence Davies (2007) remark upon the need to collect nanotechnology risk information. They note that currently only about 1-4% of the federal $1.4 billion spent on nanotechnology is devoted to its effects. Not surprisingly, the US government is relying on voluntary measures, which is the approach used on greenhouse gases (Cairns, 2007). Ruckelshaus and Davies (2007) make four important points.

(1) The USEPA has proposed a

voluntary program to collect nanotechnology risk information from industry, researchers, and others. This proposal was put forth two years ago. The USEPA should implement its own recommendations and put the information collection program in place immediately.

(2) At the same time it starts its voluntary program, the USEPA should revise the regulations under the Toxic Substances Control Act to cover nanomaterials explicitly. The USEPA should also ask the US Congress to amend the act to allow the USEPA to obtain the health and safety information it needs to evaluate new materials.

(3) Research on the effects of nanotechnology on human health and the environment should be greatly increased.

(4) Because nanotechnology needs a new type of oversight, USEPA should support a dialogue about developing an oversight system that is both more efficient and more effective than the current one – a dialogue involving consumers, environmental groups, and Congress.

All this development will require new equipment, new types of personnel, new standard methods for toxicity testing, new analytical methods, new laws and regulations, and, above all, increased ecotoxicological literacy in both the general public and its representatives.

4. Fossil Sunlight

By 2050, the global temperature will probably be warmer than it has been for 200,000 years, and, by 2075, it may be the hottest in 4 million years (Boyle, 2007). Boyle (2007) quotes Wallace Broecker, a geochemist at Columbia University's Lamont-Doherty Earth Observatory, as noting: "Earth's climate does not respond in a smooth and gradual way, rather it responds in sharp jumps." Temperature has effects on many aspects of ecotoxicology and Earth's biota, so these abrupt climate shifts will be a major challenge since carbon dioxide's residence time in the atmosphere is well over 100 years. Consequently, generations of ecotoxicologists can expect weird weather for an extended period of time after greenhouse gas emissions have been stabilized. One can only speculate about how much the field of ecotoxicology will change during this time

5. Politicians/Scientists/Tipping Points

Schulte (2007) notes that "partisan rhetoric is clouding debates on global warming, birth control, stem cell research, and evolution." He further notes that "only 24 of 535 members of Congress are scientists – that's including two veterinarians and an optometrist." In summer 2007, the American Association for the Advancement of Science (AAAS) hosted a workshop on campaign politics. Michael Brown, AAAS workshop coordinator and executive director of Scientists and Engineers for America states: "There is almost a culture built up to criticize scientists and the scientific process" (as quoted by Schulte, 2007).

In the United States, the 2006 election was a response, in part, to the fact that the US Congress has been a slow and irresolute institution, especially when it comes to science issues (Editorial, 2008). The year after the Democrats took over the legislative branch, greenhouse gas emissions continued to escalate and atmospheric greenhouse gases may be reaching a major tipping point. The America's Climate Security Act is aimed at reducing greenhouse gas emissions to 60% of the current level by 2050. Even if passed by Congress and not vetoed by President Bush, it is too little and too late. Given this record, it is not surprising that funding for science is uncertain, despite the fact that ecosystem services are not like a water facet – they cannot be turned on when a need is perceived and get good results. The infrastructure should be there for both water supply and the supply of scientific information.

Why are the other developed democratic nations better able to cope with scientific issues, such as global climate change, without running into the problems that exist in the United States, especially in the Congress? The scientific process is not well understood by US politicians, and scientists shy away from running for elected office. Schulte (2007) states: "They've never been big in Congress, but as their work is challenged, they may change." Is it the fault of scientists that their elected representatives are not required to be as scientifically literate as they are in other countries? Former US President Abraham Lincoln approved the acts of incorporation of the US National Academy of Sciences (NAS), which was enacted by the Congress on March 3, 1863. The nation was expected to turn to NAS for independent, objective advice on issues that affect people's lives worldwide. The NAS has produced reports on global climate change that are congruent with publications of similar organizations (e.g., The Royal Society) worldwide. However, they have not persuaded US politicians to the degree that the aggregate evidence supports despite the fact that the United States has some of the leading global climate change scientists (e.g., James Hansen). The recently concluded (December 2007) UN conference on global climate change provided positive evidence of this assertion. It also provided substantive evidence that the US federal representatives at Bali did not represent the entire country since a second wave of US citizens representing US state and local governments affirmed that not all US leaders oppose mandatory cuts in global heating gases (Hanley, 2007). A much longer discussion is needed to explore the reasons for this disagreement, and ecotoxicologists should give attention to this difference and see what can be done about it.

6. Excessive Focus on Economic Growth

China's economic growth (e.g., over 10% per year) in the 21st century has produced millionaires and billionaires at an astonishing rate. Of course, most Chinese are far from achieving this status. However, China's growth has been both marred and threatened by two serious problems: (1) acute water shortages and water supplies contaminated by sewage, industrial wastes, agricultural runoff (including pesticides) and (2) use of illegal veterinary drugs (Barboza, 2007). In short, China has neglected protection of its ecological life support system to achieve spectacular economic growth. Barboza (2007) quotes An Taicheng of the Chinese Academy of Sciences: "China has to go to the sea because it's getting harder and harder to find clean water. Every year there are seafood safety problems. One day, no one will dare to eat fish from dirty water, and what will farmers do?" Clearly, ecotoxicologists all over the world should help their Chinese colleagues remedy this dangerous situation. Similarly, help should be given wherever the need is great because the biospheric life support system is global.

The irony is that both words, *ecology* and *economics*, are derived from the same Greek word *oikos*: "eco" = *oikos* = "house," or the environment humans live in. The Greek word *logos* (logy) means "to study." Consequently, "eco" + "logy" = *oikos* + *logos* = study of the environment humans live in. The Latin word *oeconomia* was derived from the Greek word *oikonomos*, which separates into *oikos*, meaning "house," and *nomos* meaning "managing." However, the fields of ecology and economics have arrived at a point where rapid economic growth is destroying the natural systems that supply resources for economic growth.

The basic problem is apparently that economists have forgotten that the human economy, a recent artifact, is a subcomponent of the biospheric life support system that provides conditions (e.g., temperature, atmospheric gas balance) favorable to human life. In addition, the biospheric life support system provides the resources upon which the human economy is based. This dichotomy is absurd and should cease immediately before hospitable planet Earth becomes inhospitable for humans.

7. The Globalization of a Tribal Species

The genus *Homo* is estimated to be between 1.5 and 2.5 million years old. All species in the genus except *Homo sapiens* are extinct, although *Homo neanderthalensis* died out only 24,000 years ago and another species, *Homo floreiensis*, may have lived as recently as 12,000 years ago. For most of its 160,000 years on Earth, *Homo sapiens* (modern humans) have lived in small, tribal groups scattered thinly over the planet. The recent, rapid economic globalization has essentially eliminated traditional tribal groups, although they still exist in some remote areas. Humankind has not adjusted to this new situation.

Globalization has given access to the planet's resources to anyone or any organization that has the money. The components of the biospheric life support system have become commodities. The global commons is being plundered for profit (e.g., Leading Article, 2007), and the money goes to a few ultra-wealthy persons. The disparity that now exists between the ultra-rich (low numbers) and the ultra-poor (billions) would never exist in a tribe. This disparity, and environmental destruction, is the result of exponential economic growth. Corporations are not individuals – they are just legal documents to identify an entity whose primary purpose is profit. The enormous income gap between the very wealthy and the very poor will probably lead to social unrest as food and energy prices rise. This situation is not sustainable.

8. Solar Power

Zweibel *et al*. (2008) document how a massive switch from coal, oil, natural gas, and nuclear power plants to solar power plants could supply 69% of the electricity in the United States and 35% of its total energy by 2050. However, US$420 billion in subsides from 2011 to 2050 would be required to fund the infrastructure and make solar power costs competitive. This total is a fraction of the expense for the United States of the Iraq war. The energy in sunlight striking Earth for 40 minutes is equivalent to global energy consumption for one year. Zweibel *et al*. (2008) notes that the United States needs a bold plan to free itself from fossil energy, which is very dirty (coal) or very, very dirty (tar sands). The advantages of solar power are many: no annual fuel or pollution control costs like those for coal, oil, or nuclear power and only a slight cost for natural gas in compressed-air systems. When fuel savings are factored in, the cost of solar power would be a bargain in coming decades. All these changes would make life easy for ecotoxicologists, but, at present in the United States, the outlook is that coal and tar sands will triumph.

9. Assimilative Capacity

The concept of assimilative capacity has existed for centuries, although not formally stated. Agrarians observed that animal wastes were reincorporated into the terrestrial ecosystems on which they were deposited. In fact, one could make the case that, before humankind developed an industrial society, all wastes were actually resources for some species. The Industrial Revolution produced wastes that had no counterpart in nature or were discharged in vast quantities so that natural systems simply could not assimilate them (e.g., Cairns, 1977, 1981). In fact, both laboratory toxicity tests and field stream surveys had the goal of determining the no-observable-deleterious-effects threshold (assimilative capacity) for a wide variety of aquatic ecosystems. At present, one could reasonably assert that no wastes occur in natural systems because the output of some biological processes is the input for other biological processes. In my first professional position in 1948 at the Academy of Natural Sciences, Philadelphia, PA, USA, the group I worked with under the direction of Dr. Ruth Patrick, studied the changes in aquatic community structure when the assimilative capacity had been exceeded. My MS thesis (Cairns, 1948) was based on these changes, although the study was only part (from micro-organisms through fish) of the aquatic community response.

The most critical ecological problem of this era, global heating, is the result of exceeding the global assimilative capacity for carbon dioxide. As a consequence, the atmospheric concentration of carbon dioxide has been increasing with a variety of ecological effects that have been widely publicized. The basic challenge for ecotoxicologists is to develop industrial wastes that are beneficial to natural systems because they serve as resources. The industrial society must cease producing wastes that do not meet this criterion.

10. Sorry We Didn't See the Tipping Point

Multiple thresholds and breakpoints always exist in ecotoxicology. Even before human society became aware of climate change and related events, determining the threshold below which no-observable-deleterious effects occurred was a major problem (e.g., Cairns, 1992). Previously, ecotoxicological effect indices were evolving rapidly (Cairns and Pratt, 1987). Cairns (2000) provides a preliminary analysis of the role of ecotoxicology in industrial ecology and natural capita upon which sustainable use of the planet depends. However, the situation became much more challenging when McKibben (2007) reported on a paper by James Hansen that indicated that 350 part per million of carbon dioxide is the new threshold for climate change. Of course, atmospheric carbon dioxide is already at 383 part per million, so the "party" has already begun.

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