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Ecotoxicology in an Era of Rapid Environmental Change

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At higher levels of biological organization (e.g., communities and ecosystems), attributes (e.g., energy transfer) are displayed that are not evident at lower levels (e.g., single species). Ecotoxicology involves testing that uses attributes at higher levels as endpoints. Ecotoxicologists have been accustomed to a relatively modest rate of environmental and ecosystem change. However, of particular importance at present is rapid global climate change caused, in large part, by anthropogenic greenhouse gas emissions. This rapid change has a major impact on all ecotoxicity testing from community level to microcosms and mesocosms. Many single species toxicity test methods have remained useful for over half a century and are useful in ecotoxicology as range finding tests. Microcosm and mesocosm toxicity tests, although in a period of rapid development, have remained useful, with minor modifications, for decades. Toxicity tests in field enclosures, also in early developmental stages, are expensive and often difficult to replicate and are at present, arguably, most affected by climate change because of invasive species and highly variable climate conditions. The acidification of the vast oceanic ecosystem together with overharvesting of a number of keystone fish species and damage to critical habitats, such as coral reefs, pose major difficulties with the design of ecotoxicological tests. Recovery to a stable condition better suited to both test design and selection of test species and communities may take centuries. Invasive species will probably be a problem in most, possibly all, ecosystems. Evidence must be collected about their response to potentially toxic substances. If they are more resistant to toxics than the indigenous species, they are more likely than the natives to aid in accumulating natural capital and providing ecosystem services. Invasive species may also have a wider distribution, at least initially, than many of the native species they are displacing, so determining their response to toxics is economically and ecologically justified. Ecological restoration will also be hampered by climate change, but ecotoxicologists should collaborate with restoration ecologists to increase opportunities for success. With nearly 100,000 chemicals in daily use and approximately 1,700 new chemicals being put into use annually, carrying out adequate toxicity tests on even a modest portion of the new chemicals will be a major challenge. Added to this problem is the inadequate number of ecotoxicologists and facilities available to do the research.

Significant changes in physical and biological systems are occurring on all continents and in most oceans. Anthropogenic climate change is having a significant impact on physical and biological systems globally (Rosenzweig et al. 2008) as well as the continental scale (Morris 2008). Moreover, species are becoming extinct at a rate not seen since the demise of dinosaurs — The Living Planet Index shows the devastating impact of humankind as biodiversity has plummeted by almost one-third in the 35 years to 2005 Dugan 2008). Scientists state that the current extinction rate is as much as 10,000 times faster than what has historically been recorded as normal. Loh (as quoted in Dugan 2008) notes: "It's very damning for the governments . . . that they are not able to meet the target they set for themselves [on biological diversity]. The talk doesn't get translated into action. We are failing and the consequences will be devastating."

This era of ecological disequilibrium could easily last for centuries since greenhouse gas emissions are still rising markedly and since carbon dioxide has a residence time of over 100 years in the atmosphere. If present trends continue, more than one-half the Amazon rainforest could disappear or be damaged by climate change and deforestation by 2030 (Eccleston 2008). In the battle with the brown plant hopper, which inflicts serious damage to rice plants, an important insecticide lost its punch when the hopper developed the ability to withstand up to 100 times the dose that previously killed it (Bradsher and Martin 2008). Climate instability will exacerbate pest control problems since natural predators of pests may be affected adversely and consequently reduce pressure on the pests.

Integrating Information

Professionals in areas between disciplines are, in the United States, sometimes referred to by stalwart, single disciplinarians as "tweenies." Ecotoxicologists must even go well beyond tweenies – such individuals are usually considered to be transdisciplinary. Integrating information (Cairns 2009, 2010) about ecosystem components so that it is useful to both those studying other components and decision makers requires significant amounts of time since each group's particular needs must be taken into account (Cairns 2007).

Ecotoxicology is a complex, transdisciplinary endeavor, and effective decision making must be based on sound, integrated evidence. For those ecotoxicologists still adjusting to a transdisciplinary perspective, a brief review of the "Pellston Series" of books, which was a major part of the foundation of the field now called ecotoxicology, should be helpful. In a letter dated 29 November 1976, Dr. Alan W. Maki of the Environmental Safety Department, Proctor & Gamble, requested that a planning committee meet in Washington, DC, on 9 December 1976, to discuss the possibility of convening a workshop on the application of aquatic toxicity methodology. The planning committee in alphabetical order was John Cairns, Jr., C. E. Johnson, H. E. Johnson, Kenneth Macek, A. W. Maki, James Peterson, I. E. Wallen. Cairns, who was selected workshop chair, asked Maki and K. L. Dickson to be co-chairs and co-editors of the workshop proceedings. The workshops continued through the 1970s and 1980s because of the efforts of a large number of original and new contributors. After these two decades, the workshops and publications were carried on by the Society of Environmental Toxicology and Chemistry (Baird et al. 2006). One review of the workshop series notes:

> *The major contribution of the workshops to the profession was connecting toxicity with the environmental fate and transformation of chemicals, and, thus, bioavailablity. Astonishingly, before the first Pellston workshop, this now-obvious connection did not play a dominant role in the peer-reviewed professional literature or in government documents, although the indefatigable investigator could find some minor indications that some professionals were aware of the importance of these relationships. Major suggestions for new directions and challenges focus on: (1) an emphasis on ecosystem health and condition rather than on mere absence of deleterious effects; (2) entering the information age requires that the type of information discussed here be integrated with and related to the broader array of other types of information used in making decisions at the societal or system level – failure to do so will mean that hazard/risk information will have little or no impact; (3) restoration ecology must emerge as a field of considerable importance because inevitably some estimate of hazard/risk will be inaccurate and some damage will be done to ecosystems, which must then be repaired, (4) for all of this to function, environmental literacy must be markedly improved over its present level* (Hydrobiologia 1995, p. 87).

The need for a new field of environmental toxicology came to the forefront – renamed "ecotoxicology" – and was recognized by a substantial number of people who were searching for the unifying theme developed in the Pellston Series first book. As soon as the unifying theme was recognized, the development of the field of ecotoxicology was extremely rapid and continuous. The growth was so rapid that, in the beginning of the 21st century, less than 30 years after the first workshop in 1976, a 1,290-page book has been produced on the subject (Hoffman et al. 2003). This information is extremely important since, in an era of rapid climate change, ecotoxicology must continue its rapid growth to meet changing conditions.

Peak Oil

Peak oil will change the lives of humans in many ways. Ecotoxicologists will find that increased energy costs will affect the size and duration of testing (e.g., microcosms and mesocosms). The cost of transportation will increase, affecting field trips to validate predictions based on surrogate systems (i.e., laboratory) in natural, ecological settings. Trips to professional meetings are already affected by increased air fares. Equipment repairs requiring overnight delivery of parts will be more expensive. These examples are just the "tip of the iceberg."

New types of ecotoxicological challenges will also emerge, such as those involved in determining toxicity problems in processing tar sands, oil shale, and the like (Heinberg 2005). "The message here is that we are about to enter a new era in which, each year, less net energy will be available to humankind, regardless of our efforts or choices" (Heinberg 2005, p.6). New information can be obtained from the German Energy Group (EWG Paper 1/07 2008), which has some interesting predictions on peak coal – perhaps as few as 15 years away. Arguably, more important than peak oil or coal is that "new fields" are "tough oil and coal" – difficult and costly to obtain. The enormous energy available from fossil fuels will decline and have a major impact on society, including ecotoxicology. The challenge is interesting.

Factoring in Rapid Climate Change

As long as greenhouse gas emissions exceed the biosphere's ability to assimilate them, global climate change will continue. Lynas (2008) has produced a degree by degree guide to the plant's future, including many of the global heating impacts associated with a 1°C rise in temperature. The temperature scale (1-6°C) is based on the Intergovernmental Panel on Climate Change (IPCC) landmark 1.4°-5.8°C (2.6°-10.4°F) temperature range, published in its 2001 Third Assessment Report, which provides predictions of up to a 6° rise (reports free on line at http://www.ipcc.ch/). Just a 1°C global temperature increase can have enormous ecological and physical impact (e.g., glaciers melting), so ecotoxicologists should become aware of the probable environmental changes ahead.

One important factor for ecotoxicologists is the shockingly short time remaining to implement remedial action. Ecotoxicology must evolve very rapidly to incorporate climate change effectively into its methods and procedures. The challenge of rapid climate change is described effectively below.

> *How serious is the threat to the environment? Here is one measure of the problem: all we have to do to destroy the planet's climate and biota and leave a ruined world to our children and grandchildren is to keep doing exactly what we are doing today, with no growth in human population or the world economy. Just continue to release greenhouse gases at current rates, just continue to impoverish ecosystems and release toxic chemicals at current rates, and the world in the latter part of this century won't be fit to live in* (Speth 2008, p. x).

Another approach that could help ecotoxicologists better understand the climate metrics that should be in their test systems is evidenced by a Danish team research effort (Friedman 2008). The objective of the team was to do something never done before — project a complete picture of the Greenland climate, from the Ice Age that lasted from 200,000 to 130,000 years ago, through the warming period known as the Eemian, that lasted from 130,000 to 115,000 years ago, through the last Ice Age from 115,000 to 11,730 years ago, right up to the present warming period. (Remember: Earth is usually an ice ball; the warm interglacial periods are the exceptions.)

However, Friedman (2008) does not have enough detail to redesign ecotoxicological testing for rapid climate change. Turney (2008) has written a small, well-referenced book that should be helpful in this regard: "In what appears to be a blink of an eye, the temperature of this planet went through the roof. This is the mother of all doomsday scenarios. This was the Palaeocene-Eocene Thermal Maximum (often shortened to PETM)." At present, somewhere on the order of 32 billion tons of carbon dioxide is emitted into the atmosphere each year and greenhouse gas emissions are still increasing.

Increased attention is being given to coal as a power source for electricity, but carbon capture is technologically feasible but expensive (Special Report 2008). The disposal of carbon dioxide is still problematic, and no cost-effective technology is presently available. The news media give much publicity to "clean coal," and many new electric power plants are being constructed before clean coal technology is available. As a consequence, greenhouse gas emissions are increasing, rather than decreasing, and this situation will probably increase the rate of climate change.

Developing Universal Test Methods

With the planet in ecological disequilibrium, determining which species to select for single species reference in ecotoxicology testing is difficult. However, desirable attributes are fairly obvious.

(1) The species can easily be raised in laboratories all over the world. Possibly a particular strain could be kept in one laboratory to reduce the variability of response;

(2) The toxicity testing procedure must be stated in detail so that trained technicians worldwide can be assured they are using comparable methods and procedures. Standard methods comparable in detail to those of the American Society for Testing and Materials (ASTM) should be produced by a committee of scientists from ecotoxicology laboratories from different regions of the world. Procedures for modifying the standard method based on new evidence should be in place as part of the final approval process;

(3) Once the standard test method has been approved, a process for certifying both laboratories and individuals as capable of producing sound results with the standard method should be established. Usually, this procedure consists of sending test samples known to the certifying organization to the candidate laboratories and/or individuals. Certification should be approved by a "world class" panel of ecotoxicologists since the consequences of certifying unqualified individuals and/or laboratories might well be appalling.

For chemicals that appear particularly hazardous, testing should be extended to standardized microcosm and mesocosm toxicity tests. As was the case for single species tests, these systems are used as references, so dependability and low variability are important.

Selecting Test Species, Microcosms, and Mesocosms for Local and Regional Toxicity Tests

Single species toxicity tests will likely continue to be used for setting ecotoxicological testing priorities. Using standard toxicity testing is obviously the least expensive approach, but is not very congruent with regional ecosystems. Clearly, water quality and other factors, such as temperature, will affect the response to most chemical substances. Since many, arguably most, ecosystems are in some degree of disequilibrium from anthropogenic and other stresses, deciding upon ecosystem attributes for testing requires exemplary judgment.

Three illustrative case histories of selecting ecotoxicological test specifications appropriate for different types of change follow.

(1) Rosenthal (2008) describes a case of increased dominance of jellyfish in ecoregions where they had been rarely seen and their becoming more numerous in areas where they had been established for some time. Some standard ecotoxicological tests will probably be suitable, especially for screening and range finding. After those preliminary tests, some environmental realism is essential, so creativity and professional judgment become extremely important. Some standard setting organizations have publications on standard practices that are useful guides, but are not substitutes for creativity and professional judgment.

(2) The dead zone in the Gulf of Mexico (an area of hypoxia or low oxygen content that was first detected in the early 1970s) is correctable (Editorial 2008). This area is caused in large part by agricultural nitrogen and some urban effluent washed downstream via the Mississippi watershed. These additions cause a growth of algae that dies, decomposes, and lowers oxygen levels. The Gulf dead zone at the mouth of the Mississippi is not unique — dozens of smaller hypoxic zones occur along the US coastline where rivers discharge into the oceans (Editorial 2008). If nutrient input is markedly reduced, the algal blooms should be reduced or eliminated. The cause of dead zones has been known for about a decade, but no substantive remedial measures have been taken. Should ecotoxicological tests be based on ecosystem recovery or the status quo?

(3) The melting of glaciers due to global heating is exhibiting a variety of ecological impacts. Streams fed by glacier melt water that once rushed noisily downstream in July are now reduced to a quiet murmur (Knudson 2008). Nathan Stephenson, a research ecologist with the US Geological Survey in Three Rivers near Sequoia and Kings Canyon national parks states: “It’s almost a shock to find out how many things are changing and how rapidly they are changing” (Knudson 2008, p. 4). Due to the long residence time of carbon dioxide in the atmosphere (100+ years), lag time will be substantial before robust remedial measures are taken. At present, greenhouse gas emissions are still rising markedly globally, and no generally accepted target goals are in place for reducing atmospheric carbon dioxide or target dates for achieving the target goals. In this case, a test system based on estimated future ecological conditions may be appropriate. This approach is especially valid if one or more global tipping points have been passed and a return to past ecological conditions is unlikely.

In his letter to Japanese Prime Minister Yasuo Fukuda, which was sent before the G8 meeting in Japan, climatologist James Hansen describes the climate situation in vivid, disturbing terms.

> *Global climate is approaching critical tipping points that could lead to loss of all summer sea ice in the Arctic with detrimental effects on indigenous people and wildlife, initiation of ice sheet disintegration in West Antarctica and Greenland with progressive, unstoppable global sea level rise, shifting of climate zones with extermination of many animal and plant species, melting of most mountain glaciers with loss of freshwater supplies for hundreds of millions of people, and a more intense hydrologic cycle with stronger droughts and forest fires, but also heavier rains and floods, and stronger storms driven by latent heat, including thunderstorms, tornadoes, and tropical storms* (Hansen 2008).

Clearly, the planet is faced with climate instability, although quasi-steady states may exist in some regions. Universal tests will provide useful information on the range of concentrations that will probably provide the most useful information. However, various publications may help individuals new to ecotoxicology: D. J. Hoffman, B. A. Rattner, G. A. Burton, Jr. and J. Cairns, Jr. 2003. *Handbook of Ecotoxicology, Second Edition*; J. Cairns, Jr., ed. 1986. *Community Toxicity Testing*, Spec. Tech. Publ. 920; J. Cairns, Jr., K. L. Dickson and A. Maki, ed. 1977. *Estimating the Hazard of Chemical Substances to Aquatic Life*, Spec. Tech. Publ. 657.

Standard methods based on ASTM approval usually receive special recognition in US courts of law. Counterparts similar to ASTM exist in other developed countries. Standard methods are explained in great detail and can be used by any qualified professional since the development process is lengthy.

Developing Standard Methods for a Variety of Ecotoxicological Tests

Developing standard toxicity tests is very labor intensive. First, the types of tests needed must be determined and which, if any, of the already available testing methods are suitable candidates for standard methods. Second, the method must be carefully reworded so that qualified ecotoxicology professionals anywhere in the world can obtain comparable results by following the standard method precisely. Third, individuals and laboratories can be certified by correctly determining the median lethal response concentration or some other metric using an approved standard method.

Transportation will be increasingly expensive as the petroleum era ends, so increasing the amounts of ecotoxicological training and education will have to be carried out via the Internet. Numerous sites on the Internet offer training and services in ecotoxicology. As usual, “let the buyer beware” is a sound practice because the Internet is not famed for quality control and it may never be. Quality control is expensive and has not yet arrived for the Internet. However, individuals can check quality personally. Many professionals have personal websites that can be located by a search engine. The Science Citation Index (available on line and at academic libraries) has useful information on citation levels from 3,700 leading science and technical journals. Many scientific authors are willing to make reprints of some publications available via regular mail or by Internet. Quality control and personal education are very time consuming, but are a worthwhile, even essential, effort.

Designing Ecotoxicity Testing Methods for a Highly Variable Climate

The planet is experiencing a highly variable climate, and emissions of greenhouse gases, which cause the problem, are still increasing. Ecosystems under stress usually exhibit an increased variability of some, perhaps all, of the attributes that characterize them. In aquatic ecosystems, dissolved oxygen concentration (DO), ph, and temperature, for example, may markedly exceed normal variability. The extremes, rather than the norms, will probably have the greatest effect upon the ecotoxicological norms. Such effects have been recognized for many years (Cairns and Scheier 1957), but are rarely incorporated into standardized toxicity tests. Interactions between and among various chemical substances (e.g., synergistic – i.e., more than additive) have also been recognized for years (Cairns and Scheier 1968), but, again, are difficult to incorporate into standardized testing methodology. Probably, in most cases, the most effective approach is the worst case scenario. In the worst case scenario, the investigator estimates the worst conditions likely to exist and develops an ecotoxicology test system that simulates them. If no observable deleterious effect is observed, the investigator can assume that the risk is negligible, unless the test design shows one or more serious deficiencies. Good judgment is essential in such situations, and outside review of the entire process (i.e, design, results, analysis) by well qualified, experienced practitioners is mandatory. Publication in a peer-reviewed, professional journal adds a major, additional safety factor.

Ecotoxicity testing in a rapidly changing environment is an unenviable task, with a high level of uncertainty. Ideally, ecotoxicity tests should be based on future conditions, which are problematic since climate tipping points are not evident until they have been exceeded. However, since books on tipping points have been designed for the general public (Lynas 2008), it may become more literate about the major climate changes likely with each 1°C rise in temperature. More detail, including maps and figures, is given in the IPCC reports; executive summaries are free on line. Alternatively, paper copies can be purchased. The reports are conservative, and the rate of change has generally been underestimated. The present rate of change will probably be markedly exceeded if positive feedback loops have a greater impact than they now do and/or if the number of coal fired electric power plants, lacking carbon sequestering capabilities, increase beyond the present level. At present, no effective, cost effective technology exists, and none is likely to appear in the next decade. Unless energy conservation receives a higher priority, greenhouse gas emissions will increase and climate change will accelerate.

Determining Numbers of Personnel Needed Globally to Carry Out Adequate Ecotoxicology Testing

In 1977, I had the honor of serving on the National Research Council (the operating arm of the National Academy of Science and the National Academy of Engineering) Committee, which published *Manpower for Environmental Pollution Control* (Gloyna et al. 1977). The basic approach to making the determination is still valid; both business and the military assess manpower requirements routinely. First, the tasks to be carried out are identified and prioritized. Second, both the number and types of professionals and the equipment and facilities needed to support them are identified. Third, the number of qualified personnel available to carry out the tasks is documented. Fourth, in the categories where insufficient qualified personnel are available to carry out the necessary tasks, an inventory of academic institutions with degree programs in the areas of the shortages should be polled to determine if and when an adequate supply of qualified personnel will be available. Fifth, in categories in which a shortage of qualified personnel is not and will not soon be available, there are two options: (a) see if professionals are available who might be given additional training to qualify them for these new responsibilities, (b) use financial (e.g., fellowships) and other enticements to attract more students into the pipeline.

A good way to identify the types of qualified personnel is to study the selection and flow of essential information. Cairns (2008) has described such a system for contaminated sediments, which are a major ecotoxicological problem. The integration of information is emphasized where the system level (i.e., top-down) information is integrated with component level (i.e., bottom-up) information to produce a synthesis. The personnel who are experienced in synthesis are scarce. Time, personnel, and resources are generally ignored and/or minimized in grants and project proposals. Since decision makers badly need a synthesis, this deficiency needs to be corrected now.

Certifying both Individuals and Laboratories as Ecotoxicology Professionals and Laboratories

Certification is the process by which an authorized body, either a governmental or non-governmental organization, evaluates and recognizes either an individual or an organization as meeting pre-determined requirements or criteria. Ecotoxicology is a new, still rapidly developing field, so formal certification processes are not yet in place that are similar to those in medicine, law, pharmacology, engineering, aviation, and the like. However, even in fields where certification is well established, systematic examination of credentials is a good investment of time.

International Biodiversity Initiative

In the aggregate, all of the planet's species constitute the biospheric life support system, which has provided conditions favorable to the genus *Homo* for the past two million years. The biospheric life support system can also be regarded as the natural capital upon which all other forms of capital depend. Paul Ehrlich (personal communication) remarks: "The economy is a wholly-owned subsidiary of the environment." Given the importance of biodiversity and the biospheric life support system to humankind, one would think that protecting its integrity and health would be humankind's highest priority. Yet, the attitude of most politicians in the United States is that measures and laws to prevent climate change are acceptable only if they have no adverse effects upon the economy. However, "Time is fast running out to stop irreversible climate change, a group of global warming experts warns today. We may have only 100 months to avoid disaster" (Simms 2008). Actually, the planet could reach a global climate change tipping point much sooner if the stored carbon in permafrost, frozen hydrated methane on the oceans' floors, wetlands, and tundra is released at substantially greater rates than at present.

At the beginning of the millennium, the United Nations set a clear, measurable objective for biodiversity conservation. Only two years remain for the report on the target date agreed upon in 2002 by the Parties to the Convention on Biological Diversity (CBD). The goal is to achieve, by 2010, a significant reduction of the current rate of biodiversity loss at global, regional, and national levels as a contribution to poverty alleviation and to the benefit of all life on Earth (Loh 2008). The countries of the European Union also agreed in 2002 to a more ambitious target — to halt biodiversity loss by 2010. Both these targets are commendable and praiseworthy goals, but "Regrettably, in 2008, it does not look as if sufficient effort has been made to stem the loss of biodiversity, and it appears unlikely that the global 2010 target will be achieved" (Loh 2008, p. 1)

Humankind should be protecting the biospheric life support system as fiercely as a mother bear protects her cubs. However, the lack of response by humankind is not surprising when the workings of the human mind are taken into consideration.

> *No matter what we humans think about, we tend to pay more attention to stuff that fits in with our beliefs than stuff that might challenge them. Psychologists call this "confirmation bias." When we have embraced a theory, large or small, we tend to be better at noticing evidence that supports it rather than evidence that might run counter to it* (Marcus 2008, p. 53).

For all of humanity's lifetime, the biospheric life support system has kept Earth's climate suitable for humans. Why should it cease doing so now? Humankind drove automobiles and burned fossil fuels for the entire 20th century, and most humans in developed countries have not suffered badly from climate change. However, charismatic animals such as the polar bear or tiger are not usually observed in the wild by humans, so their extinctions might cause regret but would probably not be linked to the integrity and health of the biospheric life support system. "Lesser" organisms, such as pollinators and soil biota, serve useful but essentially invisible functions and will only be missed when the agricultural productivity that depends on them declines markedly. Even when large systems fail, humans are reluctant to associate their failure with personal behavior. After all, how much damage can one person do?

Complex, multivariate systems, both social and ecological, have multiple tipping points. When a tipping point (e.g., global climate) has been passed, the system never returns to the pre-tipping equilibrium condition, although it usually, after a long time period, reaches a new equilibrium state. However, the new state may not be favorable to humans or other life forms that flourished in the previous state. These interactions explain why biodiversity and the health of the biospheric life support system are so closely linked. The previous, five, great extinctions have resulted in the loss, up to 95 per cent, of Earth's species. The surviving species evolve into a diverse array of new species that collectively form a new biospheric life support system.

What the general public often fails to realize is that what it does to polar bears and other species it does to itself (Hertsgaard 2008). Proposals exist to "turn back time" by establishing pre-industrial levels of atmospheric carbon dioxide to prevent the worst impacts of global heating (Adam 2008). No proposal, as yet, has any validated, scientific evidence that it will work at the global level. After all, the present time is the first "global experiment" of this type. Even though robust evidence shows that small-scale restoration of damaged ecosystems is possible, such restorations are not possible on a global scale. At present, no international agreement exists that could return atmospheric carbon dioxide to pre-industrial levels, nor is widespread acceptance of this goal evident. Of course, new laws to implement these goals are needed, especially for the polar regions, but no legal framework is in place (Staff Writers 2008).

Ecotoxicology in a changing environment must develop in this fluid and uncertain framework. Ecotoxicologists have been adaptive and creative during the last four decades and are capable of meeting these new challenges with distinction.

An Illustrative Future Ecotoxicology Research Area

One of the major issues in ecotoxicology for the 21st century has been identified — fewer boys are being born than girls (Mittelstaedt 2008). The phenomenon does not appear to be occurring uniformly throughout the world. The Aamjiwnaang First Nation in Canada has experienced dramatic differences in proportion of male (fewer) babies and female (appears normal) babies. Other important matters that deserve rigorous ecotoxicological study follow.

> *(1) . . . women in prenatal groups started remarking on how everyone in their groups was having girls. . . . Jim Brophy, who runs the occupational-health centre of nearby Sarnia, Ont., was holding discussions five years ago with residents worried over the discovery of elevated levels of mercury and lead in soil on the reserve. Out of the blue, someone asked if anyone else had noticed anything odd going on – like more girls being born than boys. . . .The University of Pittsburgh's Debra Davis, in a study issued last year, found that the U.S. and Japan combined had a staggering tally of 262,000 "missing boys" from 1970 to about 2000 because of a decline in the sex ration at birth. Although it could be a statistical anomaly, she says the figure is "very worrisome."*
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> *(2) Dr. Davis, director of the Centre for Environmental Oncology at the University of Pittsburgh Cancer Institute, points out another disturbing trend – the rise in what scientists have dubbed testicular dysgenesis syndrome, a catch-all phrase for a raft of male reproductive-system ailments.*
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> *Among them is hypospadias, a disfiguring penis abnormality in babies where the urinary opening is on the underside rather than its normal position on the tip. The condition is not new, but boys today are far likely than their fathers to be born with it. The incidence, adjusted for population size, is up about 60 per cent since the mid-1970s in Canada. Other countries have also experienced increases.*
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> *(3) the incidence rate of testicular cancer in young Canadian men aged 20 to 44, for reasons unknown, has risen 54 per cent from 1983 to 2005 according to figures complied by Cancer Care Ontario.*
>
> *(4) . . . levels of testosterone – the hormone that choreographs male development from libido to muscle mass – have inexplicably declined in U.S. mean over the past two decades by nearly 20 per cent.*
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> *(5) A recent study found that women in the San Francisco area during the 1960s who had higher levels of PCBs gave birth to a third fewer boys than women with low amounts of the chemical, suggesting in utero exposures to the now-banned toxin were able to cull males.*
>
> *(6) Oddities among males are also occurring in the animal kingdom. Studies in the laboratory and in the wild show that man-made contaminants often attack males of different species with greater ferocity.*
>
> *(7) For Dr. Davis, there are just too many peculiar things happening to be mere coincidence. "These things theoretically have a common etiology," she says. "Something is tweaking what we can think of as boy-making cells."*

> *(8) A theory rapidly gaining currency is that man-made substances are upsetting the intricate working of hormones – the chemical messengers that even in mere parts per trillion are able to control key aspects of sexual and mental development.*
> *(9) University of Florida zoologist Theo Colborn . . . co-wrote Our Stolen Future, which first raised the possibility that synthetic chemicals may interfere with normal hormone functioning. More recently, she has begun giving lectures on "the Male Predicament."*
> *(10) Dr. [Frederick] vom Saal, a professor at the University of Missouri, ears that male babies are facing "a perfect storm" from a variety of synthetic chemicals that simultaneously boost their estrogen exposure while cutting levels of testosterone and thyroid hormones* (Mittelstaedt 2008, pp. 1-7).

Obviously, evidence is needed on a wide range of issues. Some illustrative questions follow.

(1) What is the fate and distribution of these chemicals in the environment?
(2) Are effects on other vertebrates similar to those in humans?
(3) How many chemicals are causing such effects?
(4) How can exposure to them be reduced?

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