Asian J. Exp. Sci., Vol. 18, No. 1&2, 2004, 1-16

Ecological Tipping Points : A Major Challenge for Experimental Sciences

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Abstract : Tipping point situations occur when the forces that create stability are overcome by the forces that create instability, and the ship, vehicle, system, or global ecosystem tips into disequilibrium. The five great biotic extinctions provide persuasive evidence that global tipping points have been reached in the past. The sixth biotic extinction now underway is unique because of the dominant effects of anthropogenic activities. The quest for sustainable use of the planet requires that reaching tipping points be eliminated or, at the very least, minimized. The best way to determine the stress needed to induce a tipping point is to cross a major ecological threshold. The experimental sciences can help estimate the nature and location of thresholds, but ethical behavior and reducing unsustainable practices is the best way to achieve sustainability by taking precautionary measure to reduce the probability of reaching a tipping point.

Key Words : Tipping points Eco-ethics Sustainability Cumulative small decisions

The Tipping Point

Destabilization of Earth's biospheric life support system occurs when a major tipping point is reached or exceeded. The exact location of a tipping point is not known until a catastrophe occurs (*e.g.*, certain oceanic fisheries and coral reefs). Environmental conditions that are so favorable to *Homo sapiens* will almost certainly become less favorable, and the social injustices of humankind are less likely to be resolved. Avoiding these outcomes is the central goal of sustainable use of the planet. Experimental science can improve predictive tipping point models using microscale experiments.

The term *tipping point* refers to a situation in which the forces that create stability are overcome by the forces that create instability, and the ship, vehicle, or system *tips over* into disequilibrium (Ayres, 1998; Gladwell, 2000). Continued degradation of natural systems (*e.g.*, biotic impoverishment, depletion of natural capital, fragmentation of natural systems, pollution, and the increasing probability of major global climate change) indicates that Earth's ecological life support system (*i.e.*, natural capital and the ecosystem services it provides) may reach a tipping point in the first half of the 21^{st} century. Once an ecological system tips into disequilibrium, it will, over ecological time, probably reach a new, but quite different, dynamic equilibrium. During the transition period and even when a new but different dynamic stability has been reached, the quest for sustainable use of the planet will be seriously impaired. As the planet approaches or exceeds its carrying capacity for humans, one or more major tipping points seem inevitable. Determining the planet's precise carrying capacity for humans is one of the major challenges of the experimental sciences.

The Lifeboat Metaphor

Hardin's (1974) lifeboat metaphor is a useful way to focus the efforts of experimental science on saving the human species and its society from the consequences of a global collapse of the biospheric life support system. At the beginning of the 21^{st} century, persuasive evidence indicates that many lifeboats (*i.e.*, nations) are badly overcrowded and well beyond their carrying capacity. As Hardin (1976) points out, tragedy is the price of unrestrained freedom in the commons. The disjunction of individual "rights" and responsibilities cannot continue, even if the intentions are noble. However, as Hardin (1976) notes, science and robust information are essential in dealing with ethical issues. For example, the consequences of global warming could reduce the carrying capacity of many nations and result in millions, even billions, of environmental refugees who are seeking lifeboats that are not sinking. Regrettably, the carrying capacity of lifeboats is more visible to observers than the carrying capacity of nations. Philosopher Langer (1942) espoused the use of metaphors to approach complex, multidimensional problems. Consequently, for ecological tipping points related to the human condition, I have found Hardin's (1974) **"lifeboat ethics"** a particularly useful metaphor, especially when used concomitantly with Hardin's (1976) carrying capacity concept.

A multitude of ecological tipping points exist, from highly site specific to global, and are likely to be interactive. For example, a drought will affect both aquatic systems and terrestrial systems, including agriculture.

A few examples of reaching the tipping point that might well result in destabilization (possibly irreversible) follow :

1. Fires in Indonesia that send smog over tourist sites in Malaysia threaten the lucrative tourist industry (Sullivan, 2004).

2. The climate is likely to heat up faster than previous models have predicted (Environmental News Service, 2004a).

3. During the 21st century, support of 8 to 11 billion people will be exceeding difficult, at best. Consumption rates already exceed the many resources that are critical to human health (Palmer *et al*., 2004).

4. Even successfully restoring damaged ecosystems may merely create another tipping point. For example, Elizabeth Willott, University of Arizona, has discussed the issue of the return of mosquitoes when a wetland is restored. The ecological benefits of wetland restoration are well known (National Research Council, 1992), but the threat of diseases transmitted by mosquitoes will be increased by wetland restoration (World-Wire, 2004). Willott (World-Wire, 2004) believes that the best scenario depends on both ecological and social contexts. Illustrative questions about wetland restoration/mosquito return that could be addressed by experimental sciences follow.

   (a) What mosquito species are present?

   (b) What threats do these species pose for humankind?

   (c) What management strategies will effectively manage mosquitoes with minimal risk? Doubtless, situations will occur in which ecosystem health seems incompatible with human health, but the experimental sciences should be able to provide a means of making these objectives congruent.

5. Milan (2004) has produced an excellent summary of the problem of environmental refugees. She quotes Essam El-Hinnaevi of the Natural Resources and Environment Institute

in Cairo, Egypt, as estimating refugees at about 30 million. This number will increase if environmental and economic conditions worsen in parts of the developing world. To remediate this situation, experimental sciences must be integrated with economic models to avoid tipping points in either one, since they are interactive.

6. Hawley (2004) summarizes a UN conference on desertification with the statement that the world is turning to dust. Lands the size of the small US state of Rhode Island are becoming desert wasteland every year. Inevitably, residents of these areas will attempt to flee to greener areas by the millions. The role of experimental sciences is clear: determine how to stop this deleterious process and restore damaged ecosystems to some semblance of their previous condition.

7. Kirby (2004) reports that rising temperatures are shrinking all but two of the main glaciers that supply quality water to Europeans. A global climate observing system could help reduce the risks associated with climate change if long time scale weather patterns are better understood (Dominquez, 2004).

8. Balmford *et al*. (2004) have identified a major research opportunity for experimental scientists. One way of increasing marine harvests is a global system of Marine Protected Areas (MPA). Models extrapolating available data from 83 MPAs worldwide suggest that a global a MPA network might cost between $5US billion and $19US billion annually and would probably create 1 million jobs. These gross network costs are less than current government expenditures on harmful subsidies to industrial fisheries. The MPAs will increase the likelihood of attaining sustainable fisheries, securing vital ecosystem services, and enhancing revenues from ecotourism. This situation is a win/win endeavor that lowers costs and improves marine fisheries. Certainly more such situations are available for the experimental sciences to explore.

9. Major obstacles exist to the involvement of the experimental sciences in these issues. Efforts are being made to alter the process in which scientists play an important role in hearing and assessing allegations of research misconduct (Environmental News Service, 2004b). The executive editor of the prestigious journal *Science* and the Chief Executive Officer (Alan Leshner) of the American Association for the Advancement of Science (AAAS) believe that scientists contribute a critical level of objectivity, balance, and technical expertise that prevents damage to the public's trust in the scientific process, which a single administrative law judge could not provide, says Mark Frankel, director of the program on Scientific Freedom, Responsibility, and Law at AAAS (Environmental News Service, 2004b). Marquis (2004) reports that UN officials and diplomats state that the administration of US President Bush is seeking to isolate the UN agency involved with population control from the groups that work with it in China and elsewhere. The US is not the only country where scientists must defend their research from denigration by political ideologues.

The Cumulative Impact of Small Decisions : Reaching Tipping Points Incrementally

Small decisions considered in isolation from the same decisions by others can have a vast impact on the tipping points of both human society and the planet's ecological life support system (Cairns, 2003). For example, taking a trip to a particular beach on a particular day and time can result in a monumental traffic jam if large numbers of people make the same decision. In the United States, the decision to purchase a **sport utility vehicle** (SUV) or other vehicle that consumes substantial amounts of petroleum products (instead of a more fuel efficient vehicle) results in increased dependence on foreign oil and increased production of greenhouse gases. These small decisions in the aggregate can result in resource wars (*e.g.*, for oil) and global warming. Decisions such as these can exert a tyranny over the lives of humans that they should, but often do not, anticipate. A seemingly harmless personal decision can have a cumulative impact that results in casualties in a resource war and/or climate change.

In contrast, a seemingly insignificant (on a global scale) personal decision to purchase a fuel efficient vehicle or use public transportation can, given a large number of similar decisions, have a positive effect on humanity by reducing the impetus for resource wars and by reducing the global impact of greenhouse gases. At higher levels of social and political organization (*e.g.*, countries, states, provinces), the decision to preserve and protect natural systems (*e.g.*, wetlands and old growth forests) will, if carried out by large numbers of political entities, have major beneficial ecological effects (*e.g.*, each small political unit could decide, as a matter of policy, to ensure that the rate of ecological restoration exceed the rate of ecological damage). This decision would be a major step toward sustainable use of the planet.

Economic versus Ecological Decisions

Arguably, the primary reason why economic decisions routinely displace ecological decisions is because economists provide a clear, positive vision of the benefits and neglect the unfavorable effects. Buying a vehicle is both an economic and an ecological decision, but the latter is poorly understood. For example, advertisements for automobiles show a shiny, new vehicle, which, in the advertisements, never suffers from engine trouble or other mechanical defects and is driven by attractive people through spectacular scenery. In addition, the vehicles are never, ever shown in traffic jams.

To be effective, the environmental movement needs an equally persuasive vision that is inspiring, optimistic, and understandable. The quest for sustainable use of the planet is such a vision, but it, like the advertisements, needs to be repeated continually achieve global acceptance. At the very least, terms such as *sustainable use of the planet*, *sustainability*, and *sustainable development* should be used often enough to deserve inclusion in *The New Dictionary of Cultural Literacy* (Hirsch *et al.*, 2002). The advocates of economic growth as the measure of progress have been so visible that environmental concerns are only given passing attention. This lack of acknowledgment is simply not acceptable! In the long run, both tipping points and carrying capacity are major survival factors.

To complement the environmental aspirations for sustainable use of the planet, humankind must aspire to live in mutualistic harmony with the 30+ million life forms with which it shares the planet. The aspiration must include a strong vision of a habitable Earth for future generations of humankind and other species. The health of the planet's ecological life support system must take precedence over economic health, which is dependent upon it. Sustainable use of the planet is a vision that is magnificently beautiful, and its accomplishment will free humankind of the guilt it should feel for impoverishing posterity and driving other species to extinction. People must learn to think for themselves and practice freedom of thought in an unfree world that is dominated by commercial advertising, which vastly enriches a comparative few people while billions live on US$ 3.00/day/capita or less.

An Illustrative Case History of An Environmental Decision Still In Progress : Two Sewers And A Wildlife Habitat

I chose this case history about the sewer system of the small university town of Blacksburg, Virginia, USA, not only because I live here, but also because one would expect the citizens of a major university town to have a more cosmopolitan view than residents of towns lacking a university. Certainly, a sizable number of similar environmental case histories exist that collectively represent the types of decisions that might push the global environment and human society toward tipping points. Each decision must be made on both local and global criteria (*e.g.,* what if large numbers of individuals or political units made the same decision?).

A quality sewerage system that rarely overflowed has been in use up to the present (2004) for the small town of Blacksburg. Tom's Creek, a relatively unpolluted stream, flows through a quality wildlife habitat in the town's newly acquired Heritage Park and Natural Area and through a mix of woods, wetlands, pastureland, hayfields, old field vegetation, and various types of rural-residential development. Recently, additional development and heavy rains have combined to cause sewer overflows and raise short-and long-term sewer capacity concerns. Consequently, Blacksburg was favoring a centralized sewer line through Tom's Creek Basin (TCB). This central sewer line would cross Tom's Creek and its tributaries an estimated 30 times, creating a 12.5-mile, 40-foot-wide swath (20 feet permanently cleared) of disrupted woodlands, wetlands, and other floodplain vegetation, and likely harming ecosystem species along the creek and its tributaries. Scheim (2003) asserts that the TCB sewer line advocates have various options that would simultaneously address the sewer capacity concerns and reduce environmental impacts, such as (1) employing new decentralized wastewater treatment facilities, (2) using force mains to keep the sewer line away from the riparian corridor, and/or (3) pumping the sewage back to a new sewer line along a major highway corridor that does not contain a series of sensitive riparian ecosystems. A decision favoring the TCB sewer would have a detrimental impact on the riparian corridors within the Heritage Park and Natural Area, as well as miles of other riparian ecosystems. It could also spur land development in a manner that would further degrade the TCB (L. Skabelund, 29 August 2003, personal communication).

The final decision is still in doubt. In September 2003, the town Planning Commission decided not to support an amendment to the town's comprehensive plan that would allow for a sewer system in the Tom's Creek area – the final decision rests with the Town Council. Since the first draft of this manuscript was written, an election dramatically altered the composition of Town Council. Apparently, the voters did not favor the expensive, environmentally harmful sewer plan. Two main points are important in this case history. First, wildlife habitat is continuously threatened by the constant expansion of community infrastructure and land development into sensitive ecosystems, while wildlife seldom threatens developers. As a consequence, developers can concede a few small decisions and still prevail, at least until humankind becomes more devoted to the protection of other life forms and the ecosystems they inhabit. Second, similar situations exist worldwide and, if enough small decisions harm wildlife, a global ecological tipping point will be reached.

Concerns Related to The Over-Consumption of Hydrocarbons

Another probable tipping point is objectively assessed in The Association for the Study of Peak Oil and Gas (ASPO) Newsletter (No. 31, July 2003). A depletion picture is given at the beginning of the report (http://www.energiekrise.de) and the report notes "The U.S.A.'s hydrocarbon resources made it the world's hegemonic power but it is in a position it can no longer sustain." (In short, if a situation is unsustainable, a tipping point has been reached.) The report also notes that the United States is an extravagant consumer of oil; it produces less than 10% of the world's oil but consumes 26% and imports nearly 60% of its consumption at a cost of around US$330 million/day – the biggest component of its trade deficit. In addition, world oil *discovery* peaked 40 years ago and has been in decline ever since.

Kolankiewicz (2003) gives a superb analysis of the problems of developing a sustainable energy policy for the United States, which is important because America is the world's largest consumer of energy. In addition, most of Kolankiewicz's insights apply to other countries as well, especially the population growth component. Growth in national energy consumption in the United States can be explained by population growth, which is driven primarily by immigration levels and is projected to continue growing rapidly through the 21st century. The methodology used for estimating the proportion of increasing energy use that can be attributed to population growth was developed by Holdren (1991) and originally published in the Festschrift issue of *Population and Environment* (I am indebted to V. D. Abernethy, then editor of the journal, for calling it to my attention). Kolankiewicz (2003) also discusses this article.

Global Warming

Sea level rise, along with other consequences of global warming, is likely to be a major tipping point. Skeptics of greenhouse gas effects always point to modest increases in atmospheric warming, but ignore the very significant heat absorption of the world's oceans. Levitus (2000) notes that large portions of the world's oceans have exhibited changes of oceanic heat content over the last 50 years, which is justification for great concern. When oceanic heat absorption has diminished or stopped, non-linear atmospheric change is highly probable. In short, the tipping point might well be close. Probably, if Levitus is correct, a major biotic signal should come from global corals (P. Leigh, 24 July 2003, personal communication). In my opinion, humankind is already taking the test (as the quote from Vernon Law notes). The lesson that follows may last centuries or longer.

Each individual contributes to the greenhouse gases that produce global warming, but the range of these contributions is notable. A citizen in India uses about 5 gigajoules per year of fossil energy while each citizen in the United States uses 287 gigagoules per year (Wackernagel and Rees, 1996). Clearly, some individuals have a better opportunity to reduce fossil fuel consumption than others. However, at present, the US government does not appear likely to eliminate subsidies for automobiles that are not fuel efficient or legislate in favor of fuel-efficient automobiles or alternative forms of transportation. A widespread sense of ethical responsibility could achieve the same goal without the government. At present, there seems no way to resolve this impasse. If unsustainable practices continue or worsen, catastrophes will occur as global tipping points are reached or exceeded. Although people on the planet are in vastly different circumstances, accepting an ethical responsibility for posterity should be a unifying goal. If the cumulative impact of small decisions results in catastrophes, all humankind will suffer.

During the 20th century, the “available” per capita ecological space on Earth has decreased from between 5 and 6 hectares to only 1.5 hectares (Wackernagel and Rees, 1996). Obviously, the “window of opportunity” to avoid catastrophes is decreasing with alarming rapidity.

Ignoring Scientific Evidence and Analysis

During a substantial period of the 20th century, science in the United States was esteemed and scientists were highly regarded. This scenario exists no longer – to those on the political left, science is just another value judgment, no better or worse than a diverse array of other value judgments. To the political right, science is all too often an obstacle to economic growth, and the views of highly regarded, internationally known scientists are blatantly ignored. For example, an *op-ed* piece by Schlesinger (2003) emphasized the scientific uncertainties (which are inevitable components of all science) and ignored the conclusions of mainstream scientists who have been telling society that accelerating emissions of greenhouse gases have an extremely high probability of injuring both the natural systems and economies of the planet. Of course, political and business leaders *trust* scientists and their evidence when they support the agendas of politicians or business leaders, but ignore or dismiss both scientists and evidence when they do not.

Two world-class scientists, both with seminal publications on climate change, responded to Schlesinger's editorial (2003). One of them, Schlindler (2003), called attention to the remarkable similarity to the situations in the early 1970s when 99% of the scientists in the field indicated that controlling phosphorus would control eutrophication of the North American Great Lakes and prominent political and business leaders assured Americans that thousands of peer-reviewed papers in professional journals were invalid because a small group of skeptical individuals said so. These skeptical individuals would probably have had little influence if not for a well-orchestrated campaign supported by television advertisements, political lobbyists, and glossy pamphlets supporting the skeptics and denigrating the views of mainstream scientists. Schlindler's qualifications to make authoritative, scientific statements were appended to his response; Schlesinger's qualifications are political, not scientific, yet his editorial criticized the research of credentialed scientists!

Woodwell (2003) noted that the US administration moved rapidly in 1992 to join other nations in signing and ratifying the Framework Convention on Climate Change. The science was persuasive then and is even more so years later. Contrary evidence produced by credentialed scientists is miniscule. As Woodwell correctly remarks, a major destabilization of the global environment is underway. Beyond these existing effects, long-term effects may result in irreversible drastic changes in climate.

In contrast to Schlesinger's political credentials, both Schlindler and Woodwell are members of the US National Academy of Sciences, and each has received many honors from scientific organizations. Each has numerous publications in peer-reviewed scientific journals, which operates as a quality control system to ensure accuracy. As Kinne (2003) remarks, "*The growing influence of science on human societies and their multiple activities has recently caused forces to enter the scene that are not part of the scientific process in its original sense; forces that are primarily fueled not by scientific evidence or argument but by political or economic interests*."

The experimental sciences will be essential to identifying site-specific issues that have already resulted from global warming. Rosen (2004) describes one such situation where climate warming has already caused dangerous erosion and floods to villages in Alaska that are inhabited by Native Americans. Edith Vorderstrasse, Mayor of Barrow, Alaska, testified to a US Senate Appropriations Committee that Native American had to decide whether to try to fight the local changes or give up and move. This situation will doubtless be repeated all over the planet, and experimental scientists could play a major role in both developing data and communicating the results to local people.

The Population Problem

Hardin asks : "*What is the force that keeps individuals from abusing the right to determine their own abilities and needs in a small community, but not in a large*?" His answer is: the effective force of shame. The Tikopian population of around 1,200 (until recent years) was normally in equilibrium with the food supply but, from time to time, famine appears to have been operative the relation of population to natural resources was not expressed in purely individual terms, but in terms of family equilibrium (Firth, 1983). Celibacy, abortion, infanticide, war, and leaving the tiny island also kept the population in balance with its resources. One might conclude that the sanctity of human life was not an end in itself but the true endpoint being the preservation of society. Sustainable use of the planet has the goal of preserving humankind for an indefinite period of time and, one assumes, human society as well. It is not clear how this will be accomplished at the global level.

Individuals born before 1950 are members of the first generation in history to witness a population doubling during their lifetime (Brown, 2001).

In short, more humans have been added to the world's population since 1950 than during the 4 million preceding years (United Nations, 2001).

Regrettably, many people regard this rate of growth as normal rather than aberrant. There has been a decline in population growth – but still, between 2001 and 2002, births exceeded deaths by 74 million. The world's population reached 6.2 billion. Some estimates (United Nations Population Division, 2003) are that the present world human population, now 6.3 billion, will rise to 8.9 billion by 2050. The US Bureau of the Census (2002) projects that present United States population of 291 million may reach over 1 billion during the next 41 years, and over 90% of the increase will be caused by immigrants since 1970 and their descendents (McKenna, 2003). In contrast to the US "open door" policy, Italy has apparently done a few simple calculations on the effects of illegal immigrants, and the Italian navy and coastguard vessels are to fire with live rounds on boats carrying illegal immigrants (Italy Shoot-to-Kill-Order, 2003). Both responses appear to be a result of a perception that the immigration is excessive in terms of the nations assimilative capacity – in short, a perceived tipping point.

Conclusions

It is quite clear that both Earth and humankind are approaching a number of tipping points. When any component of the global life support system tips over into disequilibrium, it is likely to hasten the arrival of other components at their tipping points. It seems highly probable that at least one major tipping point will be reached in the 21st century, and exceeding one major tipping point will produce others. Replacing unsustainable practices with sustainable practices is a prudent measure that should be implemented immediately.

Ecosystems have a number of tipping points or thresholds, but these are typically determined after ecosystem resiliency has been exceeded. It is also highly probable that humankind is unaware of the existence of many ecological tipping points. Instead of seeing how close humankind can come to a tipping point without suffering, it would be prudent to establish a mutualistic relationship with natural systems that will preserve their health and integrity. Both eco-ethics and sustainability ethics favor this policy. A mutualistic relationship has the great advantage of favoring protection of ecosystem resilience, which adds a safety factor. Resolving these issues will be a major challenge for experimental sciences in the 21st century.

Acknowledgments

Karen Cairns transferred the handwritten draft to the typed format, and Darla Donald provided editorial assistance. Lee Skabelund provided useful comments on the first draft. Paula Kullberg called some very useful publications to my attention.

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