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Phase Shifts or Flip-flops in Complex Systems

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Living things self-organize into systems that must be partly closed to maintain identity and integrity, but must also stay partly open in order to accumulate high quality resources in categories such as mass, energy and information and to void wastes also belonging to these categories. A living thing must also stay partly open in order to interact, often reciprocally, with other living systems and with features of its non-living environment. Non-living things may also self-organize systemically, but in less complex ways.

Living things in general have evolved capabilities to self-organize into a number of different complex phases, states or stages and to shift from one of these to another in response to changes in internal and external phenomena. Many living systems, especially organisms, have evolved capabilities to proceed autonomously through cycles of such stages. The life history of an insect, for example, exhibits a progression from fertilization to egg to larva to pupa to adult to dead body. Such a one-way or ontogenetic development with transformations between stages may be perceived as a special case of the kind of organizational changes that we focus on here; we do not include such specialized one-way cases in the present discussion. Instead, we focus on systemic reorganizations that occur between different relatively stable states of a living complex system and are reversible, more or less. (Of course, strict reversibility is not possible because living systems are subject to the second law of thermodynamics.) The kind of shifts on which we focus may occur abruptly and haphazardly in response to a particular kind of stimulus that is relatively unexpected and catastrophic in its context; or it may occur in a more orderly way for some stimulus that is always expected with significant probability in its context.

We emphasize that, for this essay, the concept of shift between phases has a similar meaning to flip between stable states, and a two-stage flip-flop between alternate states. We do not include a concept of ontogenetic, one way changes through a genetically pre-ordained series of stages; to do so would increase the scope of our essay beyond our present purposes.

We include as natural, some features of living things that some people would refer to as cultural. Some species such as humans may exhibit strong cultural features as well as the necessary natural features, while other species such as bacteria may exhibit few if any cultural features. We do not presume to understand fully any natural and natural/cultural features of reality that we address. Some people may perceive some features of humans and human societies to be both cultural and unnatural; our intent is not to include consideration of such unnatural features in the present essay.

The natural base of strongly cultural living systems must remain open to mass, energy, and information flows, as is the case with all living things. Cultural manifestations are also open culturally in that they thrive on such resources as beauty, ethical goodness, respect and caring and try to divest themselves of the opposite of these qualities; ugliness, evil, disrespect and hate.

ECO-STUDIES

Academically, numerous overlapping kinds of eco-studies may be perceived; we refer explicitly to five kinds here. The prefix eco- (from the Greek *oikos*, home as an edifice with its inhabitants) relates to a generic home-like phenomenon in which a living entity interacts with its living and non-living environment, which may include an artificial dwelling place. This approach parallels the combined consideration of text and context by some scholars with a focus on information.

A living entity may have living sub-entities within it. It follows from this basic perception that study of an eco-phenomenon transcends any conceptual dichotomy between analytical reductionism and observational or intuitive holism. Neither the reductionistic nor the holistic approach is wrong; instead each is just half-baked. Sometimes the eco-approach is termed *holonistic*, with the *hol* referring to whole, and the *on*, referring to part and this makes explicit the transcendence of the reductionism–holism debate.

The versions of eco-studies include:

1. *Eciatrics* (from *eco* and *iatros* as pertaining to physician or medicine) includes public health studies of humans and domestic animals with respect to effects of pathogens on organisms and populations, as in epidemiology, and risk assessment studies of effects of toxins and contaminants on the organismal and population health of humans and other species.
2. *Ecology* or *ecologics* (from *eco* and *logos* as pertaining to reasoned knowledge) here narrowly defined and including interactive aspects of meteorology, hydrology, geology as well as conventional biology, and relating to the contemporary real time processes of biological evolution.
3. *Economics* (from *eco* and *nomos* as pertaining to law or laws) in which the practices of benefit–cost accounting and monetary risk assessment may be of minor significance overall compared, say, to an understanding of the self-organizing features of local sharing of ecosystemic goods/bads and services/disservices in a

communitarian regime, and/or to global trade within a constrained free enterprise regime.

4. *Ekistics* (from *oikizo* meaning the establishment of a settlement) relating to the self-organizational development of human urban and rural settlements, physical infrastructures, industrial complexes, the information highway, etc.
5. *Ecumenics* (from *oikoumenos* meaning all beings in community) here with a focus on participatory governance within an extended community of interest groups or stakeholders, and including informal, extra-constitutional decision-making structures and processes that transcend boundaries between people of different nations and jurisdictions and thus complement the formal, constitutional laws, treaties and agreements of autonomous nations, as those were once perceived.

To study living systems, the psychologist and game theorist Rapoport (1986) has emphasized identity, organization and goal directedness. In a compatible way, the writer Koestler (1969) focused on self-organization, hierarchy and openness. Koestler excluded some connotations of hierarchy, e.g., the control hierarchy within a large military unit. Instead he referred to reciprocal nested interactions among *holons*, i.e., things that act as wholes but also as parts of larger wholes, within a form of organization that may be termed a *holonarchy*. A well-known example of a loose holonarchy is the interactive complex of nested formal and informal organizations within a multi-tiered form of liberal democratic governance, as may be described in ecumenics.

The conceptual domain that includes the five nested versions of eco-studies sketched above, plus some others, may be termed an *ecogeny*. The suffix refers to genesis, which refers here to emergent self-creation guided in part by *a priori* genetic hardware as well as by learned software, both augmented by new autonomous programming. Cooperative study by colleagues and ourselves in the North American Great Lakes Basin, for example, makes use of all those versions of eco-studies within an ecosystem approach that may be perceived as a special case of integrated ecogenic studies. Haas (1999) might refer to our self-organizing study group as a kind of epistemic community and we might refer to ourselves more specifically as an eco-epistemic community.

Here *epistemic* relates to a compendium of shared perspective and knowledge that is offered as having particular relevance to a major cultural challenge or opportunity. Some scholars may relate this epistemic concept to that of an expanded version of what Thomas Kuhn referred to as a scientific paradigm (see Fuller, 2000). Incidentally, we have chosen not to include an explicit notion of paradigm shift, but note that our version of that notion is implicit throughout. In other words, what we here define as *ecogeny* has flipped from being a suppressed theme within modernism to become a key theme within post-modernism.

Many non-living as well as ecogenic systems can exist in more than one phase, state or topological domain of attraction as the ecologist C S Holling has long emphasized. After being harangued by Holling for many years to provide him with Great Lakes data that would demonstrate ecological phase shifts, one of us, Regier, finally asked himself the question: “If phase shifts have occurred, where and how could we look for evidence of such events?” He decided to search for limits to the adaptive self-organization of a fish association (considered as a holon) to an array of intensifying stresses by humans in the larger environmental holon, and then examine whether another phase self-organized beyond a limit or threshold. Sure enough, the evidence was there, though it may not have been fully consistent with Holling’s expectations. (See section titled Benthic and Pelagic Attractors in Ecosystems for more information on this issue.)

Researchers on natural and cultural systems once used single phase, deterministic, cybernetic systems as models. Any phase shift was then perceived as a catastrophic failure of pre-programmed cybernetic adaptiveness. Researchers now perceive natural/cultural systems to be self-organizing and *morphogenetic*, and some phase shifts are just part of the adaptive, emergent capability of the evolving system. (Here morphogenetic implies that the forms or structures as morphs as well as the related processes of living things emerge through self-organizational genesis.) The death of a living system is an ultimate kind of phase shift when all adaptive capabilities are over-ridden, because the stresses either are too intense or act too rapidly.

When ecogenic realities are changing rapidly, as is now the case in many parts of the biosphere, one might expect adaptive and emergent phase shifts to be common, and catastrophic shifts all the way to systemic death to occur as well.

Selected examples are sketched below to demonstrate that phase shift events now occur ubiquitously. We note again that phase shifts may be referred to as flip-flops between organizational states as in discussion of major back and forth changes in the earth’s climate that have seemingly occurred suddenly in the past. We start with non-living systems, then turn to living systems in which cultural features are not emphasized, and then to living systems in which cultural features are emphasized. But we do not address unnatural things like any divine acts of deities or things for which no empirical data are conceivable.

EXAMPLES OF PHASES AND PHASE SHIFTS IN BIOPHYSICAL SYSTEMS

Different Phases of Water

Everyone knows that water can occur in different phases, e.g., liquid, solid and gas. When some research physicists focused on phase shift phenomena with water, their model implied the existence of a fourth phase, under special circumstances. They called it the *gaquid* phase and found that it materialized under the expected artificial combination of temperature and pressure.

When a liquid water system cools through 0 °C it freezes to become a solid water system. The detailed features of the freezing process are anything but deterministic in a simple way, when viewed at a molecular scale. In nature, it is generally not possible to predict either precisely how and when liquid water will freeze during a cooling regime or the crystalline form of ice that results.

The freezing phenomenon itself is of major importance to those aquatic living things which have to find some way to adapt anatomically and/or physiologically and/or behaviorally to freezing. Such adaptations in turn may be perceived to involve phase shifts in anatomy and/or physiology and/or behavior.

At a more macroscopic level, the kind of ice that forms in a stream is important ecologically. Anchor ice, frazzle ice and surface ice have quite different implications for brook trout, for example. From an ecological perspective, each of these involves a different kind of phase shift from liquid to solid.

Different Phases of Flow Dynamics

When water flows at low velocities across a smooth surface, it may move as a sheet with laminar flow; at higher velocities it may flow in complex turbulent swirls. Turbulent flow in turn may occur as a number of different sub-phases. Researchers in fluid dynamics have focused much scientific attention on: what determines which phase of flow regime will occur in a particular context; the macroscopic features of the threshold between the phases; and the more microscopic details of the phase shift process itself. Their understanding, condensed in the form of a Reynolds Number, allows them to predict quite accurately a phase shift between turbulent and laminar flow within a pure liquid. The more particles or lumps in the system, the less accurate any forecast based on such a pure system Reynolds Number will be.

The issue of phases and phase shifts in the flow regime is of key importance to aquatic organisms. While migrating, for example, salmon may use a standing wave in turbulent flow to catapult themselves over an obstruction in a river. To rest, a fish may select a site of laminar flow downstream from an obstruction and adjust its fins so that it rests lightly on the bottom.

One dramatic example of such phase shifts in fluids is the well-defined transition from conductive to convective heat transfer. If a fluid is contained between a hot and a cold boundary, heat transfer will occur through the fluid. Consider thin soup in a pot on a stove as an example. For small temperature differences between the surfaces, the heat transfer is by random molecular motion, *conduction*. However as the temperature increases, a critical point is reached at which a new phase emerges, convection. With convection the fluid molecules self-organize to move together in rolls or Bénard cells as coherent wholes. As the temperature difference between hot and cold boundaries increases, the original configuration of Bénard cells may self-organize into a more complex configuration. With each phase shift, more heat is transferred, per unit time, than in the previous phase.

At a human scale, avoiding the phase shift from conduction to convection is at the heart of the design of double pane and triple pane windows. These windows are designed so that convective heat transfer cannot emerge, thus limiting the heat loss through the window to that of conduction.

At a regional scale, on clear summer days with a particular kind of atmospheric stratification, the Sun's warming of the land surface leads to warming of the overlying air. Bubbles of such warm air of decreased density may then form spontaneously and episodically to rise and erupt into an overlying cooler layer; these bubbles of warm clear air may transform into cumulus clouds within the cooler layer. In particular locales, successive fluffy clouds that emerge may be evenly spaced in the drifting upper layer.

At the global scale, the emergence of large *convection* cells in the atmosphere, called Hadley cells (*see* **Hadley Circulation**, Volume 1), helps to transfer heat from the equator to the pole, thus reducing north-south temperature differences between the equator and the poles.

Many kinds of phase shifts may occur within the hydrosphere and the atmosphere, since these spheres consist of fluid components with different properties acting and interacting across boundary layers under the influence of solar radiation.

Flows in Water Courses and Flood Plains

Rivers carve water courses or channels out of the substrate to accommodate their flows during most days of a year, but not during high flow rates when flooding occurs. It is important to note that the course that a river cuts through a landscape is usually not large enough to include the flows of normal annual floods. The area known as the floodplain and its valley in turn have also been created, at least in part, by the continually shifting meandering river course, and especially by its floods. Hydrologists do not fully understand why a river self-organizes as a biphasal phenomenon, with one phase for small to moderate flows, and another phase for large flows. But hydrologists have inferred generalizations about the channels and flood plains of particular aquatic systems that have adapted over long periods of time to the underlying geology, under the influence of climatic regimes that have operated in quite predictable ways.

A river channel, flood plain and the larger valley are always dynamic; they may approach a steady state under conditions like those sketched above, but they are never in equilibrium with their surroundings. For example, a river never stops dissolving and eroding its substrates and walls. Living organisms, especially large plants and animals that eat the plants that live within and beside a river, strongly influence the self-organizing hydrological activities and usually have a taming influence on the waters, to the advantage of the organisms.

Cultural practices in a watershed strongly modify the temporal and spatial features of the natural flooding regime, e.g., by putting a river into an engineered channel, or by cutting down forests farther upstream. In effect a flooding phase shift occurs more frequently during a year if the watershed becomes ecologically degraded or is developed inappropriately, and the river has not had enough decades to adapt to those changes. Thus conventional unsustainable development has led to more frequent and more rapid phase shifts of the flow regime, and thus to more frequent and intense periods of turbulent stress for the living system of a river. Such a river may be perceived to be angry and may not approximate benign steady-state conditions at any time of year.

Phenology and Seasonal Phase Shifts

In temperate regions as in the Great Lakes Basin, the annual cycle involves a spring and summer phase that is dominated trophically by composers that use the sunlight's energy for photosynthesis, e.g., plants, and a fall and winter phase dominated by decomposers that use the energy of organic matter derived from photosynthesis and stored in summer, e.g., animals and fungi. Each of these phases and their transitions are intricately choreographed in what could be called a pristine, *old growth* state of the Basin ecosystem. The term is extended here beyond its familiar use as in old growth forest, to mean any ecosystem that has evolved its own complexity under benign conditions over extensive periods of time. Unsustainable development disrupts the natural self-organizing processes, so that the sequential features within phases and particularly during the phase shifts become less predictable, from the perspective of the extant species.

In warmer regions, the climate may include a wet season and a dry season. Cyclical changes, somewhat similar to those sketched above occur here, too.

Benthic and Pelagic Attractors in Ecosystems

Moderately deep natural aquatic ecosystems that are not much influenced by technologically careless humans usually have clear waters and a biotic association or benthos that is linked strongly to the bottom of the waters. In effect a benthic attractor or self-organizing system then emerges to serve its own ends, for example by preying on the open water association or *pelagos* to keep the water above it transparent and by hoarding phosphates and other nutrients that deprive pelagic organisms of these resources. Ecologically, the benthic association has similarities to the old growth state of primeval forests or grasslands. There are long-lived, large, sessile or sedentary plants, invertebrates and vertebrates with some of the latter migrating annually in stereotyped patterns. The dominant species of the benthos may be termed K-selected (see Box 1).

> **Box 1** The meanings of the r and K terms
>
> The r and K symbols originated in a particular formula for the physical growth of an organism, but have taken on a metaphorical life of their own in discussions of species successions as related to phase shifts. In an early successional stage, as in a cultivated field that is reverting to nature or with the herbaceous vegetation in a temperate forest in spring, r species that are small, short-lived, fast growing, early maturing and tolerant of fluctuating environmental conditions generally thrive and reproduce first. These are gradually replaced in late spring by activation of K species that are large, long-lived, slow growing, late maturing and intolerant of fluctuating environmental conditions. Within phase changes, the switch from dominance by one type to dominance by another is generally not complete (*see* **r–K Strategies**, Volume 2).

Unfortunately it happens that nearly all the cultural stresses imposed by humans act to impair and incapacitate such a benthic attractor. Near the surface in moderately deep waters, a pelagic attractor, mostly with r-selected species (see Box 1), may then self-organize because ample nutrients then occur in those waters. A burgeoning pelagic association may then act so as to further suppress the benthic attractor already harmed by unsustainable cultural practices. This is a case of positive feedback, which occurs commonly in an early stage of the self-organization of a phase of a living system. With further organization, negative feedbacks are generated within the evolving new phase to counter-balance the positive feedbacks, or even to exceed the positive feedbacks, as in some over-mature senile, or old growth manifestation of a phase in an ecosystem.

The terms *oligotrophic* (few food items) and *eutrophic* (many food items) are commonly used to denote aquatic systems in which benthic and pelagic attractors, respectively, are dominant. These may be taken to be code words, since much more than trophic status is involved in oligotrophic type and eutrophic type systems.

In Regier and Kay (1996) and Kay and Regier (1999), we have focused attention on the kind of phase shifts between states that are dominated by the benthic and the pelagic attractors in the three basins of Lake Erie. Other researchers are taking a comparable approach to shallow or *lentic* waters of coastal wetlands and deeper or *lotic* waters as in rift lakes.

With respect to the whole gamut of aquatic ecosystems, there may be more kinds of attractors, and related phase shifts. One such state, that of a *saprobien system*, is particularly objectionable to humans in warmer parts of the world. European researchers who studied the effects of sewage outfalls on rivers starting a century ago first described a saprobien system. Just downstream from an outfall, sewage decomposes aerobically and this process may quickly exhaust the oxygen in the water. With farther movement downstream, the aerobic organisms die and anaerobic organisms become dominant. Ecological production by anaerobes may generate foul smelling gases based on reduced forms of sulfur, carbon and nitrogen, as also is the case with poorly managed cesspools. Farther downstream, the demand for oxygen by the biota can be met by the slow diffusion of oxygen from the atmosphere into the water, and this marks the downstream boundary of the saprobien system.

The saprobien system bears some resemblance to the decomposer association that forms on the bottom of strongly eutrophic lake waters of moderate depth.

Excessive enrichment of waters with plant nutrients may cause more severe eutrophication as hypertrophy. In relatively quiescent waters there may then emerge a surface association with floating and decomposing mats of algae, fungus, slimes and bacteria together with blooms of toxic algae where the matting is not continuous.

Caddy (1993) has observed ecological phenomena in enclosed and semi-enclosed seas subjected to unsustainable development that are similar to the phase shifts that we and others have inferred for freshwaters.

FROM GREY–BROWN TO GREEN–BLUE TECHNOLOGY

In the past, hydrological engineers were expected to correct the destructive behavior of streams that were excessively turbulent because of abuse upon abuse to which these streams and their watersheds had been subjected. Though the ecological causes of the destructiveness of an abused stream were understood in the mid-19th century by George Perkins Marsh (*see* **Marsh, George Perkins**, Volume 3) and others, there was not then an adequate planning or regulatory capability (see following section) to correct enough of these abuses at their sources to permit the stream to recover its gentler features. So the engineers resorted to dealing with local effects where some crisis had erupted, often by creating an ugly new water course with concrete and steel and enclosing it with tall fencing because people who fell into raging waters in such a channel were likely to drown. This concrete and steel *grey–brown technology* exacerbated the turbulent adverse effects downstream, which then called for more concrete and steel with more muddy water, etc. This is an example of positive feedback within anti-ecological technology.

A phase shift in planning and management of such human-altered streams occurred when the governance processes switched so that a watershed ecosystem approach came to use nature's way; *green–blue technology*. This phase shift involves compatible phase changes in the disciplines of engineering, of planning and in the expectations of affected residents. Such a comprehensive phase shift might be resisted by a government administration committed to encouraging the production and sale of concrete and steel, say, and to providing remunerative contracts for conventional engineering and construction firms. Government patronage, with the help of grey–brown bureaucrats, has long funded ecosystemically abusive engineering works related to harbors and streams. The institutional connections between a government agency, an industry and the relevant profession or interactive set of professions that led to such autocatalysis or positive feedback has been referred to as an *iron triangle* in the US.

With streams of the Great Lakes Basin, we appear to be in the throes of a phase shift toward an ecosystem/watershed/landscape approach, i.e., to green–blue technology.

A CRUCIAL CULTURAL PHASE SHIFT AT A GLOBAL LEVEL

As has become increasingly obvious in many United Nations (UN) conferences since 1970, a crucial policy initiative on food, environment, population and development anywhere in the world has been to facilitate the self-empowerment of women (*see* **Ecofeminism**, Volume 5). Eco-feminists can explain much better than we can the necessity for a cultural phase shift toward a status for women that they prefer and must have. This involves a systemic change in the status of men, or at least of some men. According to women leaders of this movement, such a phase shift should not be a zero-sum game, in that few women want to compete directly with men to the disadvantage of men. Instead the shift should move from a culturally impoverished state of male dominance to a richer and better state of cross gender partnership.

At the UN Conference on Population and Development in Cairo in 1994, for example, strong resistance to such a phase shift came from male clergy who propounded narrow, fundamentalistic versions of the Judeo–Christian–Muslim family of religions. Though they may raise important ethical issues, such clerics and their male followers may not be disinterested personally since they may lose status and power with such a shift. Many men who are not constrained by these fundamentalisms are making common cause with self-empowering women.

What are some of the implications of a gender-related phase shift for Great Lakes Basin ecosystems, say? The phase shift from the grey–brown to green–blue technology sketched above may well be due in part to the increased participation in recent decades by women in all aspects of research, planning and management related to those streams.

Twenty years ago one of us, Regier, supervised the thesis research on the fish of the Credit River (near Toronto) by Deborah Martin, now Deborah Martin-Downs (Martin, 1984). She had learned to identify all fish in all life stages so that it would seldom be necessary to kill and preserve specimens. So she had data but few specimens, and sometimes could not respond in the usual way to a query whether she really had seen a specimen of a particular species at a particular locale. Though there were raised eyebrows and some testy queries during her oral examination, nobody considered the absence of dead specimens as a serious weakness of her method, and all respected her ethics. Such ethics may require that high expertise in recognizing fish species in the field be demonstrated for skeptical colleagues.

In the Great Lakes Basin since the 1950s, some, and perhaps most of the key environmental victories have been won with leadership by women. Many of the women were unpaid volunteers or underpaid activists. Mostly it has been well paid men who then led with the implementation.

Men should participate in correcting the degradation now so obvious in ecosystems everywhere. Of course, there were always individual men who were not part of the degrading culture. Similarly there were women who were willingly part of it, and may occasionally have been leaders of the degrading progressive modernism (*see also* **Ecofeminism**, Volume 5).

INDIGENOUS PEOPLES AND CORRECTION OF AN EARLIER PHASE SHIFT

In the UN conferences of the 1970s (on food in 1970, on the environment in 1972 and on population in 1974), some attention was focused on the injustices directed toward indigenous peoples as a consequence of invasions of their lands and waters by modern progressives. This theme became much more pronounced in the 1990s UN conferences on the environment and development, population and women. Agenda 21, issued by the 1992 UN Conference on Environment and Development in Rio de Janeiro, has a strong section on indigenous peoples.

With respect to Great Lakes Basin waters, aboriginals' non-ceded rights are coming to be recognized again, very belatedly. Since many aboriginals, both women and men, are re-committing themselves and their people to nature stewardship, this process of re-empowerment should be welcomed.

As with empowerment of women, re-empowerment of indigenous peoples should enrich our impoverished culture. Tolerance of diverse cultures may be as desirable as biodiversity. The phase shift toward fair status for indigenous or native peoples is not yet assured in the Great Lakes Basin generally, or elsewhere in the world. Non-native guardians of these waters are committed to partnerships with the native guardians (*see also* **Indigenous Knowledge, Peoples and Sustainable Practice**, Volume 5; **Religion and Environment Among North American First Nations**, Volume 5).

FROM MODERNISM THROUGH POST-MODERNISM TO WHAT?

Some thirty years ago the Western World apparently passed beyond the centuries-long era of modern progress, in a massive cultural phase shift that is still underway. The management guru, Drucker (1989) has sketched this shift in ways that many would consider brash, but after publishing widely acknowledged seminal works for over 50 years; some continuing brashness from Drucker may be tolerable. Drucker's ecological perspective on all of this emerged out of the new discipline of business administration, and is similar to what we refer to here as *ecogenic*.

One of us, Regier (1995), has listed some 15 transitional phenomena that occurred in or about 1968, at about the time inferred by Drucker to be the height of land between the conceptual basin of the modern era and the conceptual basin of the new era. The latter era is still apparently nameless; though some people refer to it as *post-industrial* or *post-modern*.

Stronger commitments to *deontological* ethics (ethics based on a deep shared sense of what is right and what is wrong with respect to duty) may increasingly be trumping modernist commitments to utilitarian ethics; ethics based on the greatest good for the greatest number. Integrity may be a code word for such a deontological commitment. In the 1960s social integration, toward a new and desirable cultural integrity, was directed toward correcting racial and gender inequities in Western countries. Since then, integration of many indigenous peoples into emerging political systems has been leading toward a mosaic landscape integrity that is apparent politically, culturally and ecologically, from an ecogenic perspective.

Agenda 21, that outcome of the 1992 UN Conference on Environment and Development in Rio, includes deontological as well as utilitarian commitments to global programs of several kinds, e.g., to preserve biodiversity. Thus a deontological commitment to biodiversity concerning Great Lakes Basin waters links to a compatible global commitment. Such connections should be recognized and be supported by strong institutional links, as has been attempted at the federal Canadian level. Local stream stewards, say, could draw encouragement from the sense that they are necessary parts of a global ethical commitment to ecological integrity.

CONCLUSIONS

Nine kinds of systemic phase shifts have been sketched above, all in a conceptual context of dynamic self-organizing ecogenic systems. We hope that this evidence suffices to make the point that such phase shifts are now ubiquitous in all the five versions of eco-studies to which we have referred here. If so, our educational, research, practice and governance initiatives should more clearly reflect that awareness.

Practically, a precautionary principle invoked in the context of a commitment to sustainable and responsible use implies that informed judgement be exercised to avert phase shifts to undesirable states. Once a phase shift has occurred, efforts to reverse the shift may be very costly and take much time because of the effects of systemic inertia or hysteresis.

There is, as yet, no strong empirical evidence to support optimism about the 21st Century. The new era, following the cultural phase shift sketched above, may play out worse than the progressive modern era that is now behind us. For example, it may turn out that our environmental and cultural reforms will have been too little and too late; and we humans may trigger flips into a succession of less desirable states of kinds that we have not yet encountered. Ecogenically there may then be no way back to something resembling an earlier manifestation of our biospheric home.

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REFERENCES

Caddy, J F (1993) Towards a Comparative Evaluation of Human Impacts on Fishery Ecosystems of Enclosed and Semi-enclosed Seas, *Rev. Fish. Sci.*, **1**(1), 57–95.

Drucker, P F (1989) *The New Realities*, Harper and Row, New York.

Fuller, S (2000) *Thomas Kuhn: a Philosophical History for Our Times*, University of Chicago Press, Chicago, IL.

Haas, P M (1999) Social Constructivism and the Evolution of Multilateral Environmental Governance, in *Globalization and Governance*, eds A Prakash and J A Hart, Routledge, London.

Kay, J J and Regier, H A (1999) An Ecosystemic Two-phase Attractor Approach to Lake Erie's Ecology, in *State of Lake Erie (SOLE) – Past, Present and Future*, eds M Munawar, T Edsall, and I F Munawar, Ecovision World Monograph Series, Backhuys Publications, Leiden.

Koestler, A and Smithies, J R (1969) *Beyond Reductionism*, Hutchinson, London.

Martin, D K (1984) The Fishes of the Credit River: Cultural Effects in Recent Decades, M.Sc. Thesis, Department of Zoology, University of Toronto.

Rapoport, A (1986) *General System Theory: Essential Concepts and Applications*, Abacus Books, Cambridge, MA.

Regier, H A (1995) Ecosystem Integrity in a Context of Ecostudies as Related to the Great Lakes Region, in *Perspectives on Ecological Integrity*, eds L Westra and J Lemons, Kluwer Academic Publications, Dordrecht.

Regier, H A and Kay, J J (1996) An Heuristic Model of Transformations of the Aquatic Ecosystems of the Great Lake – St. Lawrence River Basin, *J. Aquat. Ecosyst. Health*, **5**, 3–21.

FURTHER READING

Caley, M T and Sawada, D (1994) *Mindscapes: the Epistemology of Magoroh Maruyama*, Gordon and Breach, London.

Kay, J J (1984) *Self-Organization in Living Systems*, Ph.D. Thesis, Systems Design Engineering, University of Waterloo, Waterloo.

Rapport, D J and Regier, H A (1995) Disturbance and Stress Effects on Ecological Systems, in *Complex Ecology: The Part-Whole Relations in Ecosystems*, eds B C Patten and S E Jorgensen, Prentice Hall, Englewood Cliffs, NJ.

Regier, H A, Jones, M L, Addis, J, and Donahue, M (1999) Great Lakes – St. Lawrence River Basin Assessments, in *Bioregional Assessments: Science at the Crossroads of Management and Policy*, eds K N Johnson, F Swanson, M Herring, and S Greene, Island Press, Washington, DC.

Regier, H A, Welcomme, R L, Steedman, R J, and Henderson, H F (1989) Rehabilitation of Degraded River Ecosystems, *Can. Special Publication Fish Aquat. Sci.*, **106**, 86–97.

Steedman, R J and Regier, H A (1987) Ecosystem Science for the Great Lakes: Perspectives on Degradative Transformations, *Can. J. Fish Aquat. Sci.*, **44**(Supplement 2), 95–130.