

New perspectives through brackish water ecology

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Abstract

According to conventional wisdom, the brackish water ecology of the Baltic, like all ecology, is a secondary science. That is, the phenomena it considers can be decomposed into series of more elementary events acting under a sequence of laws that culminates either in the netherworld of quantum physics or in the realm of the cosmological. Ecology, however, is not a derivative science; it is fundamental in its own right. The Baltic ecosystem, for example, is a complex system of many-components. Using combinatorics one may argue that most of the whole-system configurations which ecologists encounter comprise unique and original events that elude treatment via the conventional Baconian approach. Chaos does not reign, however, because there exist among the populations of the ecosystem self-reinforcing mutualistic loops that exert a form of selection upon their constituent members quite different from the 'natural selection' of evolutionary theory. This feedback gives rise to what Karl Popper described as 'propensities' that serve in contingent systems in lieu of conventional forces to maintain the coherence of the ecosystem. The ensuing autonomous 'ecodynamics' can be quantified using information theory, resulting in measures that can be used to compare the status of the Baltic ecosystem with those of similar bodies of water, such as Chesapeake Bay.

Introduction

The reports of the Plenary Session of the BSSC Congress 2001 that appear elsewhere in this volume represent some of the finest marine science being done on the Baltic Sea – and some of the best anywhere, for that matter. There are many adjectives one could use to describe such work – 'pioneering', 'insightful', 'extremely useful', and 'provocative' are a few that might come to mind. I wish to suggest yet another that some readers might find strange or misplaced, namely 'fundamental!'

'Brackish water science, fundamental?', one might ask in astonishment, 'How could such a thing possibly be?' After all, fundamental science is commonly reckoned to be what physicists do when they break apart atomic particles, or what cosmologists do when they estimate the age of the most distant matter. No one considers dragging a net through the water to sample cod to be a contribution to fundamental science. Why not? Because throughout the entire academic realm it is *implicitly* assumed that the events one directly experiences are always derivative. That is, the goal of science usually is to interpret the events one encounters directly in terms of smaller, more short-lived phenomena that may occur beyond one's immediate senses. Or, if such 'reductionism' is not one's cup of tea, one might imagine a universe where the unchanging and universal physical constants combine somehow to 'select' the material forms that are observed.

Such is the conventional wisdom on how one should view the natural world, and I choose to call these seldom-discussed assumptions, 'Genesis at the extremes'. In other words, one is to believe that original causes (if that term has any meaning) can arise only at the edges of existence – either among a completely random netherworld of atomic and molecular events or at the almost unimaginably distant reaches of time and space. Once they originate, however, it is assumed that their effects propagate to affect everyday experience according to concatenations of strict and inviolable laws. According to this view, the worlds of ecology, and of brackish water ecosystems, are like puppets that dance to tunes played by distant musicians. The ecologist's humble function in this scheme of science seems to be merely to elaborate the lawful mechanical threads that connect what is seen, like the number of cod in the Baltic, to phenomena one causal step removed, such as the rate of fishing or the amounts of phosphorus put into the watershed.

Indeed, it is difficult to imagine any other scenario that makes as much overall sense. Nevertheless, I would like to suggest at least one other possibility – an alternative that places ecology at the very center of what is happening; one that accepts that unique and spontaneous events can arise within ecosystems and affect other events up *and down* the scales of space and time (Ulanowicz, 1999). To elaborate this distinctly ecological paradigm, I will make reference to several ideas that for years now have been discussed among the sub-discipline called systems ecology, and I will try to give them more formal expression using propositions that have been expressed by two recent philosophers of science, Popper (1982, 1990) and Rosen (1985, 1991).

Truly unique events?

I begin by questioning the assumption of 'causal closure'. What this postulate means is that nothing truly spontaneous or original can happen at intermediate scales. Everything one sees in everyday life is the consequence of lawful mechanisms that involve material objects. True, as common wisdom teaches, some systems look quite random and disorganized, and the only mathematics available to describe them is probability theory. But the common belief is that things only seem random, and if one were able to gain sufficient and precise knowledge of what is happening among the system elements, it would become apparent that all are behaving in lawful, predictable ways. Whence, according to the assumption of causal closure, randomness is a pure illusion and not a real state of affairs.

Although he was not the first to suggest it, Popper (1982) claimed that the universe is truly open. New and spontaneous events actually happen. Physicists who follow the Copenhagen School of quantum theory seem willing to accept this view, but only insofar as it pertains to events at very small scales. They note that when the randomness appearing at microscopic scales is viewed *en mass*, it usually averages out, and the aggregate follows a wholly predictable course. But Popper would not agree that randomness can occur *only* at the quantum level. No, he holds that truly unique and original events arise at macroscopic scales as well – for example at the scale of the reader's immediate senses.

How could this possibly happen? It is crucial here to point out that classical science always deals with simple systems – systems comprised of only one or a very few elementary material forms, where each form is represented by identical tokens that either act independently of each other or at most interact minimally. Under such conditions, there exists reasonable likelihood that the same configurations will occur again and again. Such repetition is essential to the empirical style of science proposed by Francis Bacon. With simple systems one consistently sees lawful reproducibility.

It is gradually becoming apparent, however, that not all systems are simple. Take the Baltic ecosystem, for example. Probably every Baltic ecologist, if supplied with a decent handbook, would have no difficulty going into the field or afloat on the Baltic and identifying, say, 100 distinct species of plants and animals. But it is not necessary to be even that complicated. About 40 of the most important types that inhabit the Baltic will more than suffice. Now, because this list will be comprised mostly of multicellular plants and animals, one could employ tools like biometrics or genetics to distinguish individual organisms within the groups. Again, to be quite conservative, it will be assumed that only 10 distinct individuals populate each category. In response to the question, 'How many configurations of these 400 individual organisms could be considered as separate events?', the branch of mathematics called combinatorics reveals that the answer is roughly 400! $(400 \times 399 \times 398 \times \ldots \times 3 \times 2 \times$ 1), or about 10^{870} (10 × 10 × 10 ... 870 times).

Now 100^{870} is an *immense* number of events. But the word 'immense' is used here not only according to its conventional meaning. The total is also immense in the sense defined by the late physicist/biologist Elsasser (1981) as transcending the bounds of the physical universe. Elsasser estimated according to the cosmology of his day that the known universe contained approximately 10^{85} elementary particles, and that 10^{25} nanoseconds of time (billionths of a second) have transpired since the Big Bang. He concluded that a maximum of approximately 100^{110} simple events could have elapsed over the lifetime of the known world. Any combination that would require significantly more than this number of events before it reappeared, quite simply is not going to do so. It must be considered a unique, one-time event. Now, one may quibble about the correct magnitude of Elsasser's threshold or about the actual number of combinations possible in a given system, but his conclusion remains inevitable. As soon as one begins to consider even moderately complex systems, one immediately encounters events that will never be repeated over the lifetime of our physical universe – whatever that may be. Furthermore, after one's eyes have been opened to the possibility of unique events, seeing them *everywhere* becomes unavoidable!

A world of propensities

What does this ubiquity of one-time events imply for the advancement of science? Does the existence of truly random events at larger scales mean that scientists should forget about trying to comprehend biological dynamics? Is it impossible to make any sense out of how the Baltic ecosystem is behaving? Of course not! – and Popper never intended any such pessimistic conclusions. Those familiar with Popper's dialogs with the early postmodernists are aware that he never envisioned a world of only chaos and absurdity. No, Popper clearly recognized that the world is organized, but not in a seamless way. He maintained that there always remain holes in its causal fabric.

In order to approach such a world in a rational manner and achieve what he called 'an evolutionary theory of knowledge', Popper (1990) recommended two actions: (1) It is necessary to reconsider how causality is viewed. Simple mechanism and material object may be insufficient to the task of science. (2) The simple unconditional probabilities, currently in use to quantify systems that are wholly disorganized, are inadequate to describe behaviors in an organized, yet contingent universe. It is therefore necessary to place greater emphasis upon so-called conditional probabilities that are appropriate to a world of occasional chance events, but which for the most part describe systems that appear to take on habits (Hoffmeyer, 1993), or exhibit what Popper called '*propensities*'.

The living world that Popper describes is not one governed entirely by rigid and unyielding laws, which he maintained are appropriate only in perfect isolation. Rather, organization arises out of the propensities

for forms and relations to persist over time, but not without occasional lapses, which he called interferences. Now, rigid laws yield unvarying results: If A, then B; if A, then B; if A, then B; ... etc., ad infinitum. If I were to suspend a ball in my hand and release it, it would certainly fall to the earth. By contrast, if I say that given A, there is a propensity for B to happen, it means: If A, then B; if A then B; ... if A, then B; if A, then C(!); if A then B; if A then D(!); etc. A cod feeds, it ingests a sprat; a cod feeds, it ingests a sprat; a cod feeds, it ingests a sprat; ...; a cod feeds, it ingests a squid(!) As just mentioned, such propensities are related to what are called conditional probabilities. Furthermore, Popper emphasized that propensities never occur in isolation, but always within a context (which may include other propensities). When the context changes, propensities can alter accordingly, just as the cod would likely change its dietary habits if a significantly new collection of prey were suddenly available to it.

A world of selection

A world of propensities is certainly a rich and interesting place, but the question immediately arises, 'Why habits at all?' (Indeed, it is passing strange that hardly anyone ever asks the question, "Why laws?') Exactly what is it about ecosystems and other living systems that might foster the formation of habits? Why isn't all biological behavior completely opportunistic and random? The answer, as the reader may have already guessed, is 'selection'. Of course, that word is immediately associated with the natural selection of evolutionary theory, and to be sure, natural selection does play some role in ecosystem dynamics. But Darwin was careful to portray natural selection as something acting independently of the organism or system being studied - in pure form, something like the physical conditions of temperature, oxygen, or available space. Furthermore, it always acts in a negative way, i.e. it selects against unfit participants. Thus, natural selection remains external to the system to eliminate unfit specimens and, in tautological and directionless fashion, passively leaves those capable of surviving, simply to survive.

At the risk of appearing radical, I wish to suggest that a more immediate form of selection is at work as ecosystems develop - a form of selection quite unlike the conventional 'natural selection' in that it acts from *within* the ecosystem and establishes a



Figure 1. Schematic of a hypothetical 3-component autocatalytic cycle.

preferred *direction* for subsequent changes. Such selection is generated by generalized mutualism, or what in chemistry has been called 'autocatalysis' (Ulanowicz, 1997). An example of generalized mutualism could be the 3-element cycle of relationships shown in Fig. 1.

In this scheme one assumes that the processes associated with A have the *propensity* to augment those processes connected with B. I wish to emphasize the use of the word 'propensity' to mean that the response of B to A is neither obligatory nor exclusive. That is, A and B are not tightly and mechanically linked. Rather, whenever the processes associated with A increase in magnitude, most (but not all) of the time, those connected with B also will increase. The action of B tends to accelerate those of C in similar fashion, and C has the same effect upon A.

A particular instance of this configuration could be something like the cycle of material transfers in the Baltic ecosystem that occurs from (A) 'deposit feeders' to (B) 'carnivorous fish' and then to (C) 'sediment carbon' and back to (A) again. 'Deposit feeders' (A) include bottom-dwelling mussels, crabs and snails that feed on particles of detritus that fall to the bottom. Carnivorous fish (B), such as cod and herring, use these deposit feeders as food. The fish in their turn generate particulate waste (C) that falls to the bottom and provides food for the deposit feeders.

My favorite ecological example of autocatalysis exists outside the Baltic and is the freshwater community associated with the aquatic macrophyte, *Utricularia* (Ulanowicz, 1995). All members of the genus *Utricularia* are carnivorous plants. Scattered along its feather-like stems and leaves are small bladders, called utricles. Each utricle has a few hair-like triggers at its terminal end, which, when touched by a feeding zooplankter opens the end of the bladder and the animal is sucked into the utricle by a negative osmotic pressure that the plant had maintained inside the bladder. In the field *Utricularia* plants (A) always support a film of algal growth known as periphyton (B). This periphyton in turn serves as food for any number of species of small zooplankton (C). The three element catalytic cycle is completed when the *Utricularia* captures and absorbs many of the zooplankton.

Now, it follows almost by definition that autocatalysis is explicitly growth-enhancing. It increases the level of activity by all members of the loop. More important to my argument is that autocatalysis is capable of exerting selection pressure upon its ever-changing constituents. To see this, one assumes that some small change can occur spontaneously in B. If that change either makes B more sensitive to A or a more effective catalyst of C, then the change will receive increased stimulus (reward) from A. Conversely, if the change in B either makes it less sensitive to the effects of A or a weaker catalyst of C, then that alteration will likely diminish its own support from A. I note that such selection works on the processes or mechanisms as well as on the elements themselves. Hence, any effort to simulate development in terms of a fixed set of mechanisms is doomed ultimately to fail.

It should be noted in particular that any change in B is likely to involve a change in the amounts of material and energy that flow into the system to sustain B. Whence, a corollary of selection pressure is seen to be the tendency to reward and support changes that bring ever more resources into B. Because this reward process pertains as well to all the other members of the feedback loop, any autocatalytic cycle thereby becomes the center of a *centripetal* vortex, pulling as many resources as possible into itself. In such centripetal action the autocatalytic configuration is not simply reacting passively to its environment, but rather is an active agency that changes its surroundings.

It follows from centripetality that, whenever two or more autocatalyic loops draw from the same pool of resources, autocatalysis will *foster competition*. In particular, whenever two loops partially overlap, the outcome could be the exclusion of one of the loops. In Fig. 2b, for example, element D is assumed to appear spontaneously in conjunction with A and C. If D is more sensitive to A and/or a better catalyst of C, then there is the likelihood that the ensuing dynamics will so *favor* D over B, that B will fade into the background or disappear altogether (Fig. 2c). That is, autocatalysis selects in a *positive* way those ele-



Figure 2. (a) Original autocatalyic configuration. (b) Competition between component B and a new component D, which is either more sensitive to catalysis by A or a better catalyst of C. (c) B is replaced by D, and (d & e) the loop section A-B-C by that of F-D-E.

ments and mechanisms that favor an increase in its own action.

Of course, if B can be replaced by D, there remains no reason why C cannot be replaced by E (Fig. 2d) or A by F, so that the cycle A,B,C could eventually transform into D,E,F (Fig. 2e). One concludes that the characteristic lifetime of the autocatalytic form usually exceeds that of most of its constituents. This is not as strange as it may first seem. With the exception of neurons, virtually none of the cells that composed an individual's body seven years ago remain in place today. Very few of the atoms currently in that body were parts of it eighteen months ago. Yet if the mother of the subject were to see him/her for the first time in ten years, she would immediately recognize her child.

A depiction of the effects of autocatalysis upon relationships in the system might look something like the cartoon shown in Fig. 3. On the top is shown a hypothetical, immature 4-component network before autocatalysis has emerged. Below is depicted the same system after autocatalysis has matured. The magnitudes of the flows are represented by the thicknesses of the arrows.

Taken together, selection pressure, centripetality and a longer characteristic lifetime all point to the existence of a degree of *autonomy* of the larger structure from its constituents. Again, attempts at reducing the workings of the system to the properties of its composite elements will prove futile over the long run. Ecology is not simply a derivative of physics, chemistry or even of evolutionary theory.



Figure 3. Schematic representation of the major effects that autocatalysis exerts upon a system. (a) Original system configuration with numerous equiponderant interactions. (b) Same system after autocatalysis has pruned some interactions, strengthened others, and increased the overall level of system activity (indicated by the thickening of the arrows).

Causality reconsidered

By accepting the possibility of some degree of autonomous behavior in ecosystems, one is actually adopting a new perspective on causality, as Popper had advocated. It is significant that the selection generated by autocatalysis is exerted by a larger, longer-lived configuration upon its smaller, more transient constituents. Because autocatalysis is always the result of a formal configuration of processes, it becomes appropriate to follow the lead of Rosen (1985) and speak of this 'top-down' influence as an example of *formal cause* sensu Aristotle.

The possibility of top-down formal causality gives a very different color to ecology than one finds in evolutionary theory. The noted philosopher, Dennett (1995), for example, describes the progressive complexity of biological entities as analogous to 'cranes built upon cranes', whereby new features are hoisted on to the top of a tower of cranes where they then become the top crane that lifts the next stage into place. Dennett cautions, however, against considering any causality from above that does not have its foundations among smaller-scale mechanical agencies. Such prohibited agencies he calls a 'skyhook'.

I acknowledge Dennett's warning against skyhooks. I fear, however, that his mechanical crane metaphor leads one astray from the true face of nature, which in the case of living systems needs to be more organic in form. This point was driven home to me in one of the very few 'Eureka!' events that I have ever experienced (Ulanowicz, 2001). I was working distractedly in my garden, pondering why I thought Dennett's analogy was inappropriate, when my eye was drawn to a muscadine grapevine that has grown on the corner of my garden fence for the last twentyfive or so years. In the initial years after I had planted it, the lead vine had climbed the fence to become a central trunk that fed a lattice-work of grape-bearing vines (Fig. 4a). Eventually, the lateral vines had let down adventitious roots that met the ground somewhat less than a meter from the trunk (Fig. 4b). Then in the last few years, the main trunk had died and rotted away completely, so that the framework of vines was being sustained by the new roots, which themselves had grown to considerable thickness (Fig. 4c).

There are no skyhooks here! The system always remains in contact with a foundation of bottom-up causalities that remain a necessary part of the narrative. It is the later structures, however, that *create* connections which eventually replace and *displace* (a)



Figure 4. (a) Young muscadine grapevine with central stem and branches. (b) Grapevine several years later, having developed adventitious roots to the sides of the main trunk. (c) Same grapevine two decades later. Original trunk has rotted away, but vines are sustained by adventitious root system.

their earlier counterparts. Top-down causality, totally alien to mechanistic-reductionistic evolutionary discourse, nevertheless fits the developmental situation perfectly. Development is like a muscadine grapevine. As strange as that analogy might seem at first, it describes development (and I would suggest also evolution) more fully than Dennett's mechanical construct.

Finally, to return to the directionality engendered by autocatalysis, it is an example of what physicists call *symmetry-breaking*. It is a strict departure from the symmetrical, non-directional world of physics. I be-



Figure 5. Diagram of the annually-averaged exchanges of carbon among the 14 major trophic aggregations of the ecosystem of the Baltic Sea. Units of biomass (inside boxes) are mg C m⁻²; units of flows, mg C m⁻² d⁻¹. Return flows to suspended Particulate Organic Carbon (14) are represented by open arrows; those to sediment POC (15), by filled arrows. Ground symbols represent dissipative respiration.

lieve Rosen would also suggest that such directionality resembles Aristotle's final cause, only it is far more elementary in nature. I caution that one should not confuse this very simplistic directionality with fullblown teleology. It is not necessary, for example, that there exist a pre-ordained endpoint towards which the system strives. The direction of the system at any one instant is defined by its state at that time, and the state changes as the system develops. For these reasons, I have chosen the term '*telos*' to denote this weaker form of directionality and to distinguish it from the rarer and more complex behavior known as teleology.

Ecodynamics

The stage has now been set to compare ecodynamics, as just described, with the conventional view of how systems operate and evolve. The common wisdom teaches that any truly original event can arise only in the microscopic realm of sub-atomic, or at most, molecular phenomena. Once an original change has occurred there, focus abruptly shifts in almost schizoid fashion, to the lawful world of organisms and other larger structures. But the common assumption is that nothing truly new can happen in this macroscopic world. It is the realm of regular and reproducible phenomena. A truly chance event at this level would upset the entire framework of precise, deterministic laws. According to these laws, those entities that are less able to act in coherence with the overall physical structure of their 'environment' are eliminated. As the adapted survivors reproduce, focus returns momentarily to the stochastic netherworld of molecules, where variety can emerge once more. It is by the accumulation of such microscopic variety that the living world is able to adapt to changes in the overall physical environment.



Figure 6. Diagram corresponding to Fig. 5 for Chesapeake Bay ecosystem.

The key difference in the ecodynamical scenario is that unique, original events may occur at *any* scale. They are appearing all the time, everywhere. Unlike in the accepted view of dynamics, most such genetic events do not threaten the established organization and remain of little or no consequence. Such neutral variety is allowed simply to accumulate. Occasionally, configurations arise that are deleterious to the autocatalytic feedbacks imbedded among the system structures, and these forms eventually fade from the scene, because they diminish their own feedback supports. On other rare occasions new configurations appear that resonate with the existing feedback dynamics, and these structures amplify to the extent that they displace some of the neutral variety.

This last point reveals a certain antagonism in the ecodynamic scenario between two opposing tendencies: The first is the propensity for autocatalysis to displace members of the system that do not contribute to its own activities. The second tendency is simply for neutral forms to accumulate. In the first instance, selection favors more highly constrained, efficient and organized networks of interactions, or ones with what I have called more 'ascendency'. In contrast, the collection of marginal, inefficient and disorganized processes gives rise to what I call the system's 'overhead'. In a purely mechanical world, the efficiencies associated with ascendency would eventually crowd out all the remaining overhead, resulting in a maximally efficient ecosystem configuration, or what Herbert Spencer called the 'survival of the fittest'.

The real world, however, doesn't seem to behave in such an extreme way. A maximally efficient system is also maximally constrained. It is 'brittle', in the words of Holling (1986) and unable to adapt to any change in its environment. Although inefficiencies and incoherencies tend to degrade the system performance (ascendency), they nevertheless also provide degrees of freedom that become absolutely essential to the survival of a system that has been subjected to a novel disturbance. When subjected to perturbation, the existing overhead offers the system potential repertoires that it can adopt to survive under the new circumstances. Without sufficient overhead, a system is unable to *create* effective responses to the challenges presented by its environment.

One concludes that natural ecosystems must always consist of some combination of disorganized freedom to adapt (overhead) as distinct from its organized functioning (ascendency). The actual ratio of flexibility to constraint will be influenced by the nature of the physical environment surrounding the system. In benign, almost predictable environments, such as that of the tropical rain forest, one expects to find proportionately more ascendency; whereas in rigorous environments, such as the boreal steppe, one anticipates a greater proportion of overhead.

Parsing constraint from flexibility

Thus far, I have engaged only in 'armchair theorizing', but science must be quantitative and operational. It is beyond the scope of this paper to explain in detail how ascendency and overhead can be measured (Ulanowicz & Norden, 1990). It is possible, however, to discover a hint of how it is done by referring again to Fig. 3, which illustrates the effects of autocatalysis on a system. The reader will recall that the top figure depicts an immature system with many ambiguities and flexibilities, i.e. one rich in overhead. By contrast, the bottom one shows a system that is very tightly constrained; one that is strictly organized (high ascendency) and inflexible.

That is to say, the structures of networks that depict how populations in the ecosystem are related to one another provide clues as to the relative amounts of organization vs. flexibility in the system. In the early 1940s the American ecologist Lindeman (1942) began a long tradition in ecosystems science by creating diagrams that were constructed in response to the questions, 'Who eats whom?' and 'By how much?' Fig. 5, for example, depicts the sources and average magnitudes of carbon that are ingested by each major group of consumers in the Baltic Sea ecosystem, as estimated by Dr Fredrik Wulff and his associates in the Department of Systems Ecology at Stockholm University (Ulanowicz & Wulff, 1991).

Applying a branch of mathematics called 'information theory', it becomes possible to quantify the variety of the processes that appear in this diagram. Variety = Organization + Flexibility.

In the case of the Baltic diagram just shown, 56% of the variety of processes appears as organization, while 44% remains as flexibility.

Baltic ecologists, of course, would be most interested in comparing the organizational status of their ecosystem with those of similar habitats elsewhere. In Fig. 6 is depicted another network that colleagues of mine estimated in similar manner for the Chesapeake estuary in the USA (ibid). When the organizational status of the Chesapeake is evaluated, it exhibits less organization (50%) and more disorganization (flexibility) than the Baltic. This evidence (along with others) led Prof. Wulff and myself to the unexpected conclusion that the Baltic is less disturbed than the saltier Chesapeake. This judgement contradicts the common wisdom that fresher water ecosystems are more vulnerable to nutrient additions than saltier ones. It would appear, then, that the 'health' of the Chesapeake ecosystem, as indicated by these measurements, has been more degraded in recent years than has been the case with the Baltic.

The ability to assess the overall health and integrity of an ecosystem is, of course, of great practical and political importance. But to Baltic ecologists I would like to suggest that ascendency theory conveys a message of even greater psychological importance. Over the entire history of ecology, it has been tacitly assumed that ecologists are second-class members of the scientific community. Whatever they may uncover, as exciting as it might be, they remain faced with the discouraging belief that their discovery must be analyzed further in terms of more fundamental events that lie the domains of colleagues in the fundamental sciences, like physics, chemistry, or evolutionary theory.

But with the new ecodynamics that I have just outlined, and with the help of tools such as ascendency theory, scientists are slowly coming to realize that they can observe directly some primary causes as they occur among the ecosystems they study (and, incidentally, among economic and social systems as well). Some of the phenomena depicted in these networks did not arise out of quantum or molecular physics. In fact, to reverse the tables somewhat, much of what persists in the forms of specific biomolecules (e.g. DNA sequences) or mechanisms have been selected by relational configurations that exist at the level of the whole ecosystem. That is, genes and mechanisms come and go as transients in a larger and more persistent *ecological* dynamic.

In closing, I wish to encourage brackish water ecologists to take heart! For they are not laboring in the shadows of some higher echelon of scientists who have a monopoly on basic research. When next they drag their net through the waters, when again they drop their corer into the muddy bottom, as they continue to labor at the microscope, counting the densities of copepods or algae, I would like to remind them that they are dealing with matters that arise, at least in part, out of causes that appear only over the length and the breadth and the depth of the Baltic Sea – not in some lifeless microscopic realm or in some cold distant reach of space. Baltic ecologists are engaging in *fundamental* research!

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