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Commentary

Toward a more holistic ecology, and science: the contribution of H.T. Odum

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In my role as a reviewer of the foregoing paper (Mansson and McGlade 1993), the editors have offered me the opportunity of a reply. H.T. Odum, for the sum of his contributions, needs no defense or apologia, and therefore this will not be that. He is a special brand of scientist, though, whose exact role in science is difficult to fathom since so much of his work is beset with the kinds of characteristics Mansson and McGlade have so pointedly exposed. He labors on the fringe of a new kind of macroscopic, or synthetic, knowledge about systems that are bigger than we are with only the tools, like thermodynamics, handed down from the more microscopic, analytical sciences of the past. These tools are not exactly appropriate, but the new ones required by the new science of holism have not been fashioned. Odum is one of the leaders trying to do this. In the due course of time, not in his lifetime or mine, offending methodologies and other defects which may infect his theory now will be shed like the old skin of a molting reptile, or exoskeleton of a metamorphosing insect, to reveal the hard center of his achievement which will be, in some form or other, an empirically tractable, conceptually rich, systems science of holoecology.

H.T. Odum is a supremely intuitive scientist. He literally walks on the unknown, and the secret of his appeal is that this triggers the passion for mystique and myth which all humans possess as an evolutionarily given response to what is unknown. This makes him an exceptional teacher, mentor, and source of inspiration to others. What I would like to do here is show the primacy of his grand sweep of intuition over details; the latter can fall by the kind of clinical dissection Mansson and McGlade have given, and a core edifice will still remain to be improved upon and perfected in later generations. Let me begin by, if it is not already obvious, revealing my personal biases about H.T. Odum; I am in the "inspired by" group above. The following remarks are from a paper I recently wrote (Patten 1993) for a Festschrift his students are now preparing to do him honor:

Few individuals get to create an entire paradigm in their lifetime. Most of us in science work in the footsteps of others. Howard T. Odum is one of those who created his own worldview, and a brand of science to go with it – an entirely new and original system theory of ecology. As with anything new, it has not sprung forth in full perfect flower; it could not – new theories are for perfecting, and paradigms must unfold over time. I do not always agree with all of 'HT''s ideas, and I know this places me with an often large set of people, including at times some of his own students and closest colleagues, and occasionally even himself. Any disagreement is usually over details, however, almost never about principles or major directions. What do so many scholars find so compelling about his work?

Insight, for one thing. No living person in the world, in my opinion, understands the inner workings of large, complex systems so well as this man. I came to this conclusion a long time ago at a meeting in Alta, Utah where I spent a number of days in contact with his 'ramblings on ecosystems'. His insight is deeply intuitive, very personal, and these qualities themselves are often a barrier to communication with others. There must be handwaving, body language and a certain amount of mystique because a scientific vocabulary of deep systems understanding has not yet been invented and mythology is the mode by which humans have always dealt with complexity and the unknown. H.T. Odum created his own picture language, 'energy-circuit language', to try to communicate scientifically what had heretofore been restricted to philosophy.

There is artistry. An artist dabs a few brush strokes of paint on a canvas and touches the human spirit. HT puts a few lines and shapes on acetates or pages and achieves the same about scientific matters to which only objectivity, not passion, is supposed to apply. He can evoke anything from humor to pensive contemplation and shared insight, depending on his own mood and intent. And his audiences always respond, because he touches them with science where only "the arts" are supposed to penetrate – in feelings. This man has the power to infuse others with his own dynamic enthusiasm for his subject; he often leaves more upset than calm in they see as important, why don't they do it or at least suggest how? If Odum is not capitalizing on "the current expansion of physical theory" to more fruitfully develop ecological theory, why don't they do it instead of criticizing? If Odum's work is fragmented, have they ever tried developing a coherent theory from the beginning and holding it unpublished and without benefit of feedback or reinforcement until it is perfected?

Those who know Odum well know him as a creative "systems thinker", an astute observer of nature, a field and laboratory ecologist who knows how to gather real data. They know he is not a rigorous technician, mathematician, or system theorist. With his mix of attributes, he has tried to develop an empirical systems paradigm for ecology. To interpret his thermodynamics (or mathematics, or system theory) in a "literal, physical sense" is tantamount to shooting fish in a barrel, and denies his more important role and true value to science. This is as an exciting originator of ideas in a difficult field where new ideas are at a premium. If he were an artist he would never be a fine-brush realist, but a broad-brush impressionist (and sometimes surrealist), capturing the broad sweep of nature's complex systems. The requisite broad brushes, of course, have not yet been invented, hence the need to use the finer bristles of reductionism (like thermodynamics) to be "scientific". Constructive critics might recognize and acknowledge some of these things.

Mansson and McGlade summarized Odum's work in terms of five conjectures. I will take each of these up in turn, below.

1. The energy numeraire

Energy as a universal currency, common denominator, or numeraire, is the main issue in the paper. Odum does believe, as his critics state, that "All significant aspects of ecosystems can be captured by the single concept, energy". However, the only truth he needs (to meet the measurement criterion) is that if an organism is put into a bomb calorimeter all its living complexities are reduced to a caloric equivalent. The energy contents are in fact models (many-to-one mappings, or homomorphs) of the real things, with all the shortcomings that all models have. Odum uses the energy equivalents as markers or tracers to discern the connective networks ("energy circuits") within his systems. Other ecologists use other substances or quantities in the same way; some have tried to use complex multicommodity storages and flows. Odum chose energy to gain the authority of physics, but any numeraire for ecological tracer purposes only needs to pass the "meal test" – if it can be eaten it generates connectivity and that is where ecosystems cohere. This is ecology, not physics, and maximum power (see later) needs to be nothing more profound, perhaps, than maximum meals. The numeraire or tracer or universal currency does not have to explain everything about ecosystems to be useful for what it does explain. In economics, not everything about societies is explained by money flows, but much of interest is and a quantitative science has certainly been made of it. It is the same for Odum's theory.

The real thrust of his theory, then, is not the *energy organization*, but just the *organization*, of complex systems. His insistence that all or most aspects of reality can be mapped into energy without loss of information is easily ignored, which I will do until someone discovers an inverse, one-to-many, map that recovers the information lost in aggregation to a single variable. Most of the interesting elements of Odum's theory do not derive from the energy numeraire. In fact, some of the overattention to energetics detracts from other developments that could be made. For me to interpret Odum constructively in my frame of reference, I can simply restate Conjecture 1 in something like the following form (which, I now realize, I've done unconsciously for many years): Empirically measurable energy in different forms, or other conservative quantities, can be used as a tracer (or numeraire, common denominator, etc.) to unravel certain design features of ecosystems – similarly to the way currency flow can give certain, though not all, information about societal organization.

Causation is such a complex phenomenon in the real world that it is doubtful if any universal numeraire can be found to reveal all the intricacies of natural organization. However, connectivity can be investigated through the use of conservative tracers that do apply (money, energy, etc.). This is what Odum does, and it is the part of his theory that remains after the energy trappings have been removed.

At one point Mansson and McGlade state that Odum's definition of energy itself is circular. However, replacing "heat" in the Odum quotation they provide by "heat energy" clarifies the fact that it is not. The definition merely describes energy degradation: energy, type 1 (e.g., solar radiation)→energy, type 2 (chemical)→energy, type 3 (heat); no circularity here.

"Useful energy" is given great attention in the paper. Mansson and McGlade are right – usefulness is contextual, and complex. For ecological purposes the "meal test" is simple, straightforward, accurate, and sufficient; it is the one that organisms live (or die) by. In their paper, the critics demonstrate well their acquaintance with the refinements of thermodynamics. They use the thermodynamic complexity of even simple systems to undercut Odum's applications of "street", or "field", thermodynamics to complex systems. Odum, however, knows full well that living things in nature don't (except incidentally) consume Gibbs free energy or exergy; the "meal" criterion is the one that really applies, and for ecological purposes the four laws of thermodynamics are only window dressing.

"Energy quality" is mentioned. Despite his single numeraire, Odum well recognizes the different forms of energy, and transformations between them. In fact, it is he only, among ecologists, who has expressed this in terms of energy quality, value or usefulness (embodied energy, or "emergy"), and its measure "transformity". There is nothing inherently wrong with these concepts, and contrary to Mansson and McGlade they are unrelated to maximum power, or maximum intrasystem univariate) resource from given source to terminal compartments in a system. This numeraire could be arbitrary, something readily measurable, and either a scalar or a vector. The maximization of flux would connect immediately to network flow theory, and the optimization problem would become, given a set of components (species, populations, resources, etc.) and conditions (physical constraints), to maximize the network flows between elements. This could be viewed as a problem of network self-design in evolution, with connectivity connotations (as, for example, in the max flow – min cut theorem; Ford and Fulkerson 1962), and with obvious linkages to Odum's ways of thinking about the driving forces behind ecosystem development.

In my opinion, then, Odum retards the full development of his own theory by his insistence that it be expressed in energy terms, unnecessarily narrowing its domain of applicability. It need not be, and this fact negates the central, thermodynamic criticisms of Mansson and McGlade. Odum's essential theory of ecosystem organization transcends the energy idiom in which he has chosen to express it.

4. Hierarchical organization

Most scientists agree about the hierarchical organization of nature. Whether this is epistemic or ontic is moot for present purposes. However, whether hierarchical organization is necessary to maximize power, or "useful energy processing", or more general resource fluxes, is an ecologically interesting question. Odum's vision of taxonomic categories as a manifestation of energetics is interesting, though highly speculative, an example of the kinds of unique ideas he is capable of generating. Taxonomic categories are certainly epistemic, but in a phylogenetic context could have some energy or resource flux basis. That "taxonomic hierarchies are the energy spectrum of evolution", and that "species are smaller units with faster time constants that process energy to generate the next higher taxonomic category" are, to me, fanciful notions not (without more substance) to be taken seriously. My solution again – ignore it as the ramifications of a mind that spins off more good ideas than most, even if in a low proportion to total ideas. Never to recognize a possibility is never to open up the area for exploration, out of which something useful could come if not verification of the original idea. This, it seems, is in the error generation – error correction nature of science, and is the value of all pioneers, whose initial ideas rarely survive in original form.

5. Succession and maximum power

Ecological succession, according to Odum from Mansson and McGlade, proceeds to stable, symbiotic configurations directed by the maximum power principle. This appears to be an application, or restatement (since Odum is primarily concerned with ecosystems anyway), of Conjecture 3. The design (feedback) and associated dynamic (stability, predictability, controllability) features are compelling potential properties to evolve in ecosystems; that they may do so in response to some generalized optimality criterion (maximum power or other) remains to be seen.

In addressing this conjecture, Mansson and McGlade expose what I would regard as an unusual concept of steady state, i.e., $x^* =$ constant, where x^* is the steady state vector. Thus, they say "all oscillations should die out as the system approaches the steady state which maximizes power". Real systems, driven at different levels by sinusoids of different periods (diel, lunar, seasonal, annual, etc.) tend to have oscillatory steady states (in the short term; nothing stays steady in the long term). The Lotka-Volterra predator – prey model (homogeneous differential equations) is not driven by an environment; its oscillations are endogenous. It seems that Mansson and McGlade have mathematical models rather than real ecosystems in mind when they consider oscillations, steady states, Hopf bifurcations, and Hessian matrices.

Odum's systems are ecosystems; there are endogenous rhythms in their organisms and populations, to be sure, but the grand cycles of behavior are externally derived from the basic reality that the earth orbits the sun, spins on its axis, and has a satellite moon. Odum's vision of endogenous "pulsing" probably comes from simulations of systems (like the Lotka-Volterra) with quadratic terms in their equations, which he commonly uses; pulsing, or its opposite, damping, depends on the phasing of the oscillations of the paired state variables.

I am unable to evaluate Mansson and McGlade's treatment of oscillatory behavior in respect to the maximum power principle. They state that the principle requires that the oscillatory mode be always favorable in terms of power output, which can be tested using a Hessian matrix. But the maximum power principle gives no reason for this matrix to be either positive or negative definite, therefore is fundamentally flawed. Perhaps so, but I wonder if the connectivity (which determines minimum cut sets, hence maximum flows) and flux concomitants of power maximization would not in fact determine the condition by influencing the structure of the Hessian matrix.

Finally, Mansson and McGlade complain that there are too many admissible ecosystem configurations. However, just as evolution is a tautology, so is ecological succession. An infinitude of specific ecosystems is possible under a given set of conditions, in terms of the identity, number and distribution of species. But what cannot be violated is the underlying laws of assemblage formation, continuance, and change of the kind (e.g., maximum power) Odum is trying to discover.

Trivially, in every ecosystem there must be producer species, consumer species, and decomposer species (otherwise, in the last case, the world would fill up with the detritus of past production), all the outcome of past natural selection, and all functioning together with reasonable part→part compatibility and part→whole coherence to produce future selective pressures. But nontrivially, what are the laws of whole→part determination

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Mansson and McGlade vs. H.T. Odum: a further clarification

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At the conclusion of their critique of H.T. Odum's conjectures about thermodynamics and ecology, Mansson and McGlade (1993, p. 594) stated that "Although the prospects look dismal, we should in fairness note that the question of whether or not it will be possible to formulate an exergy concept that is applicable at the ecosystem scale remains to be resolved."

In my commentary on their paper (Patten 1993) I was critical of the harshness with which they advanced their views. I stated at one point that "The last sentence of their paper is brutal, and undeserved" (p. 598). This was not a reference to the sentence above, however, but to one that appeared just after it in the version of the manuscript I reviewed. I am pleased the authors chose to delete it, but I had no opportunity to change my statement before publication. This will serve to correct the record.

References

Mansson BA, McGlade, JM (1993) Ecology, thermodynamics and H.T. Odum's conjectures. Oecologia 93:582–596

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