Technocratic Optimism, H. T. Odum, and the Partial Transformation of Ecological Metaphor after World War II

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In 1933 Howard Scott, founder of the Technocracy movement, offered his audience the choice between "Science or Chaos":

> I have not inquired as to whether you do or do not like the idea [of Technocracy]. The events that are going to occur . . . within the very near future are not going to be respecters of human likes or dislikes. The problem of operating any existing complex of industrial equipment is not and cannot be solved by a democratic social organization. . . . [It] is a technical problem so far transcending any other technical problem man has yet solved that many individuals would probably never understand why most of the details must be one way and not another; yet the services of everyone . . . will be needed.[1]

The Technocracy movement commanded immense popularity for a brief period around the transition from the Hoover administration to that of Franklin Roosevelt.[2] It overshadowed all other proposals for dealing with the crisis of the Great Depression. The Technocrats proposed to replace what they called the "price system," which they saw as complex, unstable, and arbitrary, with equal allocations of nonaccumulable energy certificates. All materials and work could be measured in energy units; engineers, capable of making measurements free from the distorting interests of economics and politics, would organize society better than politicians. In fact, it was hoped that the transition to a Technocracy would occur without politics because, once it was understood that technocratic proposals would benefit society, the force

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[1] Howard Scott, *Science versus Chaos*! (New York: Technocracy, 1933).

[2] W. E. Akin, *Technocracy and the American Dream* (Berkeley: University of California Press, 1977).

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of logic would ensure their implementation. A Technocracy, like previous proposals for industrially based utopias, would require individual discipline and participation; in return, order would be restored to a world perceived as rapidly changing and disordered.[3] The popularity of their movement was transient, but the Technocrats' vision of reducing society to a single energy dial, to be adjusted objectively by social engineers, would recur in the field of ecology.

In October 1946 the Yale ecologist G. Evelyn Hutchinson (b. 1903) delivered a paper entitled "Circular Causal Systems in Ecology" to an interdisciplinary conference at the New York Academy of Sciences.[4] Hutchinson emphasized themes that would come to dominate ecology in the United States. In brief, he was exploring, as his title indicated, the concept of ecological relations as systems. This concept drew upon, but also made significant extensions to, the then-prevailing organicist accounts of ecological complexity.

Hutchinson's paper provides me with a convenient starting point from which to trace conceptual connections and to characterize changes after World War II in the way ecologists in the United States studied ecological complexity. I subsequently move my focus to H. T. Odum (b. 1924), a student of Hutchinson's, who extensively developed his program during the 1950s and pioneered the field that has come to be known as systems ecology.

Organicism, undergoing a transformation into a systems view, was at the same time a source of social metaphor; ecological and social concepts are strongly connected in Hutchinson's and Odum's thinking. Their work allows me to highlight aspects of their social context, in particular the "technocratic optimism" of the postwar years. The idea of technocratic management of society had a long history, but World War II, particularly as it was experienced by scientists, transformed the character of that political fantasy. Government funding and the organization of science under military imperatives produced significant results, giving currency to the belief that intervention on a large scale could be practically realized. Moreover, scientific control of complex systems seemed necessary to prevent further social upheavals or holocaust. Optimism about the benefits of such control over-

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[3] Howard Segal, *Technological Utopianism in American Culture* (Chicago: University of Chicago Press, 1985).

[4] G. E. Hutchinson, "Circular Causal Systems in Ecology," *Ann. N.Y. Acad. Sci.*, *50* (1948), 221–246.

shadowed possible doubts about its implications for democratic political life.

The term "technocrat" has come to denote someone advocating technical approaches to social issues. The technocrat believes that he can handle social complexity in a value-free manner, maintaining a distance from specific interests and political details, and that through such nondependency and disengagement he can best serve all. But it is typical of social philosophies framed in terms of universal interests that their proponents hold a special place in the proposed social organization. In my account I show that technocratic optimism facilitated H. T. Odum's early work in powerful ways; more than being the context of his work, technocratic optimism is constitutive of his concepts, methods, and organization of research. This interpretation of Odum's transformation of metaphor for ecological complexity represents a partial reconciliation of strong externalist and realist interpretations of science. The realism, however, is not centered on the scientist's representation of nature, but instead on the scientist's interventions within nature — interventions which society facilitates in actuality, as possibilities, or as powerful fantasies.

CIRCULAR CAUSAL SYSTEMS IN ECOLOGY

Hutchinson's "Circular Causal Systems" paper had two sections, disjunct in content and tone. The first section described the "biogeochemical approach," an intersection between biology and the study of the global distribution of chemicals. This approach to the study of ecology was mostly dry and quantitative; Hutchinson constructed budgets of carbon in the biosphere (Fig. 1) and of phosphorus in lakes, and he attempted to balance those budgets. Biological and physical processes were tightly linked; he discussed the activity of organisms in terms of their balancing effect on cycles of chemicals through organisms, the earth, oceans, and the atmosphere, and he related changes in biological productivity to changing concentrations of available nutrients.

The second section, on the "biodemographic approach," was speculative; Hutchinson developed it through mathematical equations proposed for population growth, with little reference to observations. The modeled populations met face-to-face, or variable-to-variable, and their mode of interaction and regulation was reduced to single mathematical parameters denoting reproduction, competition, or predation. The use of simple models led to the paper's culmination: a graph of scientific knowledge as a variable undergoing faster-than-exponential growth.

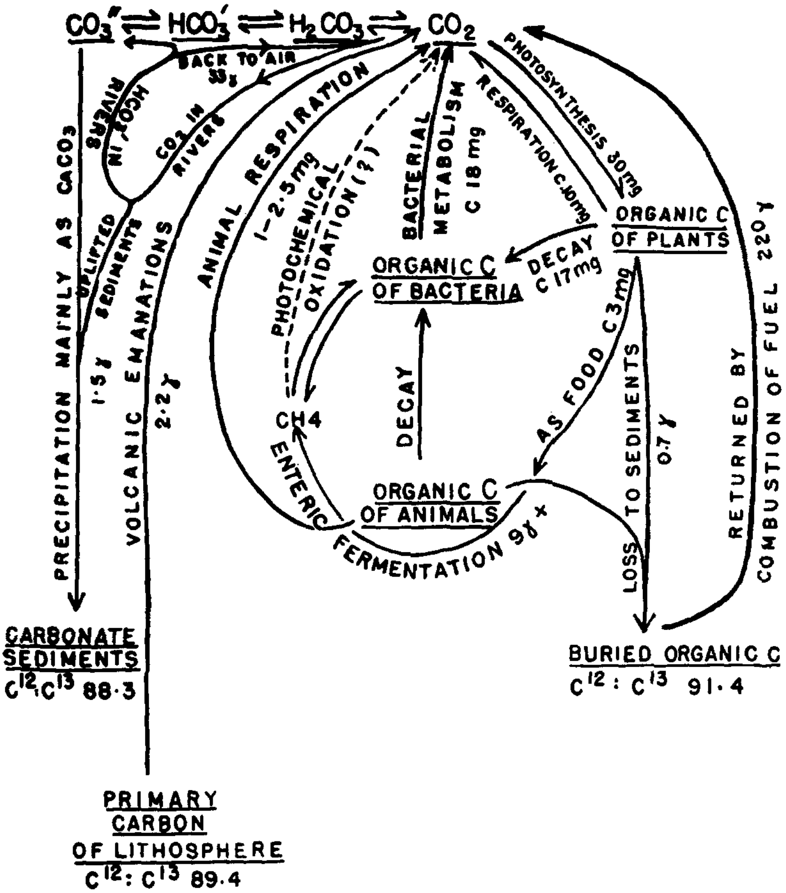

Fig. 1. The global biogeochemical cycle of carbon. (From G. E. Hutchinson, "Circular Causal Systems in Ecology," *Ann. N.Y. Acad. Sci.*, *50* [1948], 223.)

Although the two sections differed markedly, in the brief introduction to the paper Hutchinson provided a basis for unity, not only for those two sections of his paper but also for divergent currents within ecology. The "conditions under which *groups* of organisms exist," he remarked, should be seen as systems of circular causal paths, or feedback loops. These circular causal paths were "self-correcting within limits."[5] When the limits were exceeded, violent oscillations would drive some elements of the system to extinction; the original system would thus be replaced by a new one in which the lost element would play no part.

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[5] Hutchinson, "Circular Causal Systems," p. 221.

Hutchinson drew the implication that natural systems would, therefore, have mechanisms to damp oscillations and thereby ensure their persistence. This self-regulation might be purely physical — for example, excess atmospheric carbon dioxide dissolving in the ocean. Or it might be primarily biological — the inhibitory effect of organisms on each other in limited space, expressed in the terms of the logistic equation for population growth.

For Hutchinson, whether ecology was biogeochemical or biodemographic — or, in other words, whether ecology was descriptive and quantitative or abstract and mathematical — it was nevertheless united by a theoretical proposition: Groups of organisms are systems having feedback loops that ensure self-regulation and persistence.

HUTCHINSON: CONCEPTUAL CONNECTIONS

Hutchinson's paper presents an almost perfect study for a history of scientific ideas. His conceptual precursors can easily be traced: the first biogeochemists, V. Goldschmidt and V. Vernadsky,[6] and the "biodemographers" V. Volterra, A. Lotka, and F. Gause.[7] The contemporary connections are also clear, both within ecology and through a series of influential meetings sponsored by the Macy Foundation. And the paper also foreshadows the future, almost uncannily: Hutchinson's biogeochemical approach, developed by his student H. T. Odum, becomes systems ecology; the biodemographic approach becomes community ecology. Another of Hutchinson's students, Robert MacArthur, was responsible for the direction taken by community ecology after the late 1950s.[8] However, since the present paper is oriented toward the development of systems ecology after World War II, I will leave aside Hutchinson's precursors as well as MacArthur and community ecology to concentrate on the biogeochemical approach to the study of ecological systems.[9]

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[6] Hutchinson edited and condensed a translation of Vernadsky's "Problems of Biogeochemistry, II: The Fundamental Matter-Energy Difference between the Living and Inert Natural Bodies of the Biosphere," *Trans. Conn. Acad. Arts Sci.*, *35* (1944), 485–517.

[7] See Sharon Kingsland, *Modeling Nature: Episodes in the History of Population Ecology* (Chicago: University of Chicago Press, 1985).

[8] Ibid., chap. 8.

[9] Although not universally accepted by ecologists, the distinction I am using in this paper is that community ecology emphasizes population sizes and

Hutchinson stressed the importance of analysis in ecological studies, and his quantitative, chemical approach contributed to that analysis. He criticized ecological principles that maintained a dualism between living formations and their physical conditions (climate, soil, and so on), and he worked to integrate biological and physical processes in a practical program of ecology. Hutchinson placed his analytic approach in contrast to the increasingly elaborate schemes of his contemporaries, schemes for the classification of ecological communities, of their sequences of development or succession, and of the end points or climaxes of the successional sequences. Similarly, he wanted to go beyond discussion about whether communities were organisms at some higher level. Reviewing *Bio-Ecology*, a text book of general ecology published in 1940 and written by the influential ecologists Frederick Clements and Victor Shelford,[10] Hutchinson had commented that their "general principles are . . . mainly classificatory." He concluded, "if . . . the community is an organism, it should be possible to study its metabolism."[11]

Ecologists must analyze ecological metabolism, and in this spirit Hutchinson had enthusiastically sponsored Raymond Lindeman's short career in ecology and encouraged his analyses of energy flow through trophic levels of ecosystems (that is, through plants, herbivores, and carnivores).[12] In a commentary to Lindeman's classic but unfortunately posthumous paper, "The Trophic-Dynamic Aspect of Ecology" (1942), Hutchinson remarked that Lindeman "came to realize . . . that the most profitable method of analysis lay in the reduction of all the interrelated biological events to energetic terms."[13] Hutchinson's emphasis on analysis meant more, however, than measurement of energy and elemental flows; he had begun to search for a theoretical basis to that analysis. He commented that the formulation of Lindeman's energy analysis

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interspecies interactions while systems ecology emphasizes nutrient and energy flows between compartments. There are, of course, systems in community ecology, but they require a separate history. See E. F. Keller, "Demarcating Public from Private Values in Evolutionary Discourse," *J. Hist. Biol.*, this issue.

[10] Frederick Clements and Victor Shelford, *Bio-Ecology* (New York: John Wiley and Sons, 1939).

[11] G. E. Hutchinson, "Review: Bio-Ecology," *Ecology, 21* (1940), 267–268.

[12] R. E. Cook, "Raymond Lindeman and the Trophic-Dynamic Concept in Ecology," *Science, 198* (1977), 22–26.

[13] G. E. Hutchinson, "Addendum" to R. Lindeman, "The Trophic-Dynamic Aspect of Ecology," *Ecology, 23* (1942), 417.

provided "a hint of some undiscovered type of mathematical treatment of biological communities."[14] Here was an early sign of Hutchinson's biodemographic approach; in fact, his interest in mathematical ecological theory had already led him to draw upon the work of Gause, Volterra, and Lotka.[15]

Hutchinson's search for a theoretical basis for ecology, coupled with his catholic interests, writing, and acquaintances,[16] had led to his participation in the Macy conferences, a series of interdisciplinary meetings from 1946 to 1953 sponsored by the Josiah Macy, Jr., Foundation. "Circular Causal and Feedback Mechanisms in Biological and Social Systems" was the original name of the meetings; later this was shortened to "Cybernetics."[17] The 1946 conference at the New York Academy of Sciences was, in effect, a Macy conference "open house."[18] The introduction was given by Lawrence Frank, a social scientist and an instrumental figure in the Macy conferences and in other interdisciplinary ventures. Frank was followed by Norbert Wiener, the "father" of cybernetics; then Hutchinson spoke. Warren McCulloch, initiator and chairman of the Macy meetings, concluded the conference. All these figures will contribute to my account in due course.

The Macy conferences had an enormous influence in many fields, popularizing the perspective that complex systems can be treated as self-regulating feedback systems. The impact extended well beyond the diverse and unresolved issues discussed during the meetings.[19] The conferences catalyzed the transfer to peacetime of an optimism born of the experience of wartime science: during the war, scientists, including many of the Macy participants, had worked under intense demands — but in a new environment of largely increased resources, cooperation among scientists, and social recognition.

Frank expressed this optimism at the New York Academy meeting: "[W]e are engaged, today, in one of the major transitions or upheavals in the history of ideas. . . . When the social sciences

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[14] Ibid., p. 418.

[15] Kingsland, *Modeling Nature*, p. 179.

[16] Hutchinson's "Marginalia," covering a wealth of topics, was a regular feature in *American Scientist* from 1943 to 1957.

[17] Steve Heims, *The Cybernetics Group (1946—1953)* (Cambridge, Mass.: M.I.T. Press, in press).

[18] "Conference on Teleological Mechanisms," held at the New York Academy of Sciences, October 21—22, 1946.

[19] Heims, *Cybernetics Group*.

accept these newer conceptions . . . and learn to think in terms of circular causal processes, they will probably make amazing advances."[20] Students of the many fields represented at the Macy conferences believed that it would be possible to construct a theory about complex systems. Moreover, such a theory might unify the physical, biological, and social sciences, allowing the success of physics to flow into other fields.[21] It was in this context of optimism about a scientific approach to society that Hutchinson was developing his views about ecology and systems.

ORGANISMS AND SYSTEMS

Hutchinson, concerned with the complexity of ecological relations, viewed systems thinking as a development in the theory of those relations. He was critical, as we have seen, of the organicist emphasis in ecology, wherein a community of different species was held to correspond to some complex organism that, like an individual organism, had unity, had interdependence of its parts, and developed over time. But his criticisms notwithstanding, Hutchinson and his community-oriented contemporaries shared a central precept: that nature was divisible into integrated wholes. Regardless of whether a community or a biogeochemical cycle constituted a whole, there were conceptual steps made in common, steps corresponding to both methodology and world-view. These ecologists had to propose boundaries to delineate a unity or whole and to articulate its components; for example, the plant populations making up a vegetation formation, or the stores of carbon in the global carbon cycle. The internal relations — that is, the relations they postulated among the components — were considered coherent and distinct from the external factors determining the behavior of the community or system. In this sense, Hutchinson's self-regulating systems constituted a small step from the homeostatic communities of his ecological contemporaries; circular causal paths were likewise a small step from groups of interspecies populations acting, reacting, and coacting to ensure coordination within the communities.[22]

In many other ways, however, feedback systems marked a departure from the prevailing idea of communities as organisms.

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[20] L. K. Frank, "Foreword," *Ann. N.Y. Acad. Sci., 50* (1948), 192, 195.

[21] G. Bateson, "Physical Thinking and Social Problems," *Science, 103* (1946), 717–718; G. E. Hutchinson, "Social Theory and Social Engineering," *Science, 104* (1946), 166–167.

[22] Clements and Shelford, *Bio-Ecology*.

In the systems view, living and nonliving feedback systems alike obeyed common mechanical principles, including their mode of evolution. Data could be used to elucidate directly the dynamics of systems. And, once scientists understood the dynamics of systems, those systems would be controllable, enabling society to become free from catastrophes. These were the themes of the new understanding of systems. I will draw on the papers of Hutchinson and the others at the New York Academy conference to explore each of these themes in turn.

Although vitalism was a defeated force in biology, it was nevertheless a radical step to unify the study of living and nonliving systems. The new theorists of feedback systems conceived of nature as a machine and, at the same time, acknowledged the purposive and regulatory character of that nature-machine. A theory of so-called "teleological mechanisms" could abolish not only vitalism but also the old cause-effect determinism.[23] Furthermore, the same terms could be applied to all systems, whatever their components;[24] living and nonliving could be intermeshed, eliminating the separateness of biological relations from physical factors. Hutchinson's ecology emphasized chemical and physical processes as much as biological, the geochemical as well as the demographic. It would not be long, as we shall see, before purely physical theories, such as those of thermodynamics — or, even more abstractly, of information theory[25] — would be taken up as organizing principles for ecology.

Communities as organisms evolved by natural selection. Organicist ecologists invoked selection's firmly guiding hand, improving the adaptation among different species. The coordination of species was necessary to ensure the existence of the community as an entity; in other words, species served a function in the maintenance of the community organism. Alfred Emerson, writing in *Principles of Animal Ecology* — the synthesis of organicist ecology — provided the mature expression of this view: "ecological evolution parallel[s] the evolution of internal physiological balance and control within the organism."[26]

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[23] Frank, "Foreword."

[24] N. Wiener, "Time, Communication, and the Nervous System," *Ann. N.Y. Acad. Sci., 50* (1948), 197—219. See Hutchinson's review of Wiener's *Cybernetics* (below, n. 28) in "Marginalia," *Amer. Sci., 37* (1949), 267.

[25] R. Margalef, "Information Theory in Ecology," *Gen. Syst., 3* (1958), 36—71; B. C. Patten, "An Introduction to the Cybernetics of the Ecosystem: The Trophic Dynamic Aspect," *Ecol., 40* (1959), 221—231.

[26] Warder C. Allee, A. E. Emerson, O. Park, T. Park, and K. P. Schmidt, *Principles of Animal Ecology* (Philadelphia: Saunders, 1949), p. 598.

Feedback systems, on the other hand, achieved self-regulation and stability by a process applicable to all systems, living and nonliving. In contrast with Emerson's superorganismic view, Hutchinson analyzed ecological metabolism so that actual ecological compartments and flows came into focus. Admittedly, the persistence of components of ecosystems was still dependent on the self-regulation of those systems. In Hutchinson's view the oscillations of systems that failed to self-regulate drove to extinction the components that were destabilizing.[27] While this formulation might seem like selection in another form, Hutchinson did not refer to it as such. It was not the intimately superintending natural selection invoked by organicists; the individual-in-system gained some autonomy relative to an individual fulfilling its function in a community. A shift in emphasis, not a conceptual break. After all, Hutchinson's system stability was no less powerful a criterion for persistence than was Emerson's group homeostasis; in fact, given its applicability to all systems, it was potentially more effective.

Another feature in the transformation to feedback systems was the power of data, or, at least, the promise of their power. In the place of descriptive and classificatory approaches to complexity, scientists could use long-time runs of data to detect feedback and expose the dynamics of systems. At least, that was the implication drawn from Wiener's theories about time series.[28]

> All we have a right to ask of the appropriate sciences are long-time runs of data. We know it will take years to collect these, but we must have them before we can determine whether the mechanism of negative feedback accounts for the stability and purposive aspects of the behavior of groups.[29]

With these concluding remarks to the New York Academy meeting McCulloch foreshadowed a new social science based on the analysis of data, a science that has subsequently flourished with the advent of high-speed computers. McCulloch's vision, self-confessedly utopian, was that "man should learn to construct for the whole world a society with sufficient inverse feedback to prevent another and perhaps last holocaust."[30] On a more prosaic

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[27] Hutchinson, "Circular Causal Systems," p. 221.

[28] Norbert Wiener, *Cybernetics* (Cambridge, Mass.: M.I.T. Press, 1948).

[29] W. McCulloch, "A Recapitulation of the Theory, with a Forecast of Several Extensions," *Ann. N.Y. Acad. Sci., 50* (1948), 264.

[30] Ibid., p. 264.

level, Hutchinson expressed a similar view in remarking that Lindeman's measures of energy content in the different levels of ecosystems and in the flows through those levels provided a basis for the abstract analysis of the dynamics of ecosystems.[31] In other words, the descriptive measures could be translated into dynamical models. This translation from data to dynamics would become important in systems ecology.

The vision of a cybernetic social science heralded by McCulloch also illustrates the last aspect of the transformation from community organisms to feedback systems. Freedom from holocaust, and from other social upheavals, might be achieved through the construction of an all-encompassing system of feedback. A systems approach to understanding nature moved easily into a systems approach for engineering society.

So, who would be the engineers of social systems? This question, not asked by the Macy participants, would find one answer in the developing work of Hutchinson's student, H. T. Odum.

CONCEPTUAL CONNECTIONS: H. T. ODUM

Howard Thomas Odum and his older brother, Eugene, who became an ecologist before him, are the sons of Howard Washington Odum. Their father, an influential sociologist, held profoundly organicist views and proclaimed himself the standard-bearer of Lester Ward's dynamic sociology.[32] H. W. Odum was best known for his work on Southern regionalism and the folkways of Southern blacks, and for his efforts to promote the cooperation of intellectuals and other social elements in the rebuilding of the South and its reintegration into the nation.[33] Of the two sons, Eugene Odum is the better known among ecologists. His textbook[34] and his founding of the Institute of Ecology at the University of Georgia have kept him in a central position in the academic discipline of ecology. Nevertheless, the conceptual and

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[31] Hutchinson, "Addendum," p. 418.

[32] Howard W. Odum, *Understanding Society: The Principles of Dynamic Sociology* (New York: MacMillan, 1947). The endcovers display the lineage from Ward to Odum.

[33] Wayne Brazil, "Howard W. Odum, the Building Years 1884—1930," Ph.D. diss., Harvard University, 1975.

[34] Eugene P. Odum, *Fundamentals of Ecology* (Philadelphia: Saunders, 1953, 1959, 1971).

practical developments that interest me, many of which are evident in Eugene Odum's writing, originated with the younger brother.[35]

H. W. Odum encouraged his sons to go into science and to develop new techniques to contribute to social progress.[36] H. T. learned his early scientific lessons about birds from his brother, about fish and the philosophy of biology while working after school for the marine zoologist Robert Coker,[37] and about electrical circuits from *The Boy Electrician*.[38] His college education was broken by three years of Air Force service as a tropical meteorologist in Puerto Rico and the Panama Canal Zone, after which he returned to complete his studies in zoology and chemistry.

After the war Hutchinson was looking for graduate students with a background in physics and chemistry and took on Odum in 1947, steering him into the study of the biogeochemistry of strontium.[39] Hutchinson's suggestion of this topic derived from his systematic study, following Goldschmidt, of the biogeochemistry of different elements; neither Hutchinson nor Odum anticipated the interest in strontium generated by later atmospheric testing of atomic weapons. Odum's dissertation, completed in 1950, indicated that the chemical composition of the oceans had not changed in the last 40 million years, at least insofar as it would alter the ratio of calcium to strontium — a finding in contrast to the prevailing wisdom. This result was labeled one of the top twenty scientific discoveries of the year in a *Life Magazine* feature on U.S. science.[40]

Odum's dissertation exemplified Hutchinson's biogeochemical approach and concept of systems as expressed in the "Circular Causal Systems" paper. Odum's approach was interdisciplinary; "any parameter that cuts through science boundaries is indeed

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[35] H. T. Odum wrote the chapter on "Principles and Concepts Pertaining to Energy in Ecological Systems" for the first two editions of E. P. Odum's *Fundamentals*. E. P. Odum's review, "Energy Flow in Ecosystems: A Historical Review," *Amer. Zool., 8* (1968), 11—18, indicates the extent to which H. T. influenced his thinking. By the 1971 edition the language of systems and energy pervaded the entire text.

[36] Author's interview with H. T. Odum, Gainesville, Fla., January 14, 1986. See also Brazil, "Howard W. Odum," p. 386.

[37] R. E. Coker, "Some Philosophical Reflections of a Biologist," *Sci. Monthly, 48* (1939), 61—68, 121—129.

[38] Interview with H. T. Odum.

[39] H. T. Odum, "The Biogeochemistry of Strontium," Ph.D. diss., Yale University, 1950.

[40] "U.S. Science Holds its Biggest Powwow," *Life Magazine* (January 9, 1950), p. 20.

welcome," he intoned.[41] Observations and data were drawn from a wide range of fields in an attempt to "connect isolated facts" into "one coherent and quantitative system."[42] Data about a system and that system's dynamics were closely connected: constancy of the *pattern* of distribution of strontium was interpreted as evidence of the self-balancing *dynamics* of the strontium ecosystem — an entity of "worldwide dimension."[43]

In expressing principles of systems Odum, like Hutchinson, made no distinctions between living and nonliving processes. For example, the "stability principle," which Odum attributed to Lotka, ensured that "nature is as a whole in a steady state or is in the most stable form possible and constitutes one big entity."[44] Furthermore, natural selection in inorganic systems and at higher levels of organization did not require differential survival in competition among variant entities, such as ecosystems. It was sufficient that "a system which has stability with time will exist longer than a system without stability."[45]

Odum, invited as a guest of Hutchinson's, attended one of the Macy meetings to talk about his strontium research. The discussion, as he recalls it, was unruly and unilluminating.[46] Nevertheless, his affinity with the Macy conferees' new, "teleological" view of mechanism was clear. In his dissertation he described ecology as one part of the study of "mechanisms of steady states in all types of system," quoting Wiener's definition of cybernetics. Odum adapted the marine ecologist George Clarke's picture of food chains as a set of cogwheels,[47] expanding this to a biosphere of cogwheels, "each constituent chemical cycle a cogwheel that is geared to other cogwheels, the whole system being interconnected."[48]

My tracing of conceptual connections would be incomplete without mention of Odum's many references to Lotka's work, in particular to *Elements of Physical Biology*.[49] Many ecologists,

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[41] Odum, "Biogeochemistry," p. 333.

[42] Ibid., p. 1.

[43] Vernadsky's concept (see above, n. 6).

[44] Odum, "Biogeochemistry," p. 9.

[45] Ibid., p. 8.

[46] Interview with H. T. Odum.

[47] G. L. Clarke, "Dynamics of Production in Aquatic Populations," *Ecol. Monogr., 16* (1946), 321—335.

[48] Odum, "Biogeochemistry," p. 308.

[49] Alfred Lotka, *Elements of Physical Biology* (Baltimore: Williams and Wilkins, 1925), reprinted as *Elements of Mathematical Biology* (New York: Dover, 1956).

including Hutchinson, referred only to Lotka's mathematical models. Odum, however, grasped the intent of Lotka's title, namely the analogy of physical biology with physical chemistry. In one of Odum's few references to organisms he called them "ecocatalysts," able to "lower the free energy of activation" of each step in a cycle so that the system would reach a different equilibrium than it would without them.[50] Odum's intellectual debt to Lotka will appear even stronger in my later discussion.

Two aspects of the systems thinking of Hutchinson and the Macy conferences were, it might be noted, missing from Odum's dissertation. The first was the inclusion of humans in biogeochemical systems and their possible reordering of those systems. The second was Hutchinson's enthusiasm for the energetic analysis of ecosystems. These themes would emerge, however, in the next decade of Odum's career.

ECOSYSTEMS AS ENERGY CIRCUITS

In 1951 Odum published a short article based on his dissertation emphasizing that stability was the fundamental property of the strontium cycle.[51] This stability, and the fact that the cycle included both living and nonliving components, led Odum to call the strontium cycle an ecosystem. Significantly, in his paper he elevated a minor comment in his dissertation[52] to a prominent introductory position: biogeochemical cycles were "driven by radiant energy."[53] From that point on, energy drove Odum's development of the biogeochemical approach to ecology.

Odum's first research project as a young professor at the University of Florida at Gainesville was a study of the trophic structure and productivity of the Silver Springs, a series of springs of different mineral composition along the Silver River in central Florida. This project continued Lindeman's research program of measuring the efficiencies of energy transformation from plants to herbivores, to carnivores, to higher carnivores. In addition, Odum advanced several suggestive hypotheses about biological communities and the partitioning of energy; for example, that the ratio of

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[50] Odum, "Biogeochemistry," p. 325.

[51] H. T. Odum, "The Stability of the World Strontium Cycle," *Science, 114* (1951), 407–411.

[52] "[It] should be emphasized that these cycles are not energetically closed" (Odum, "Biogeochemistry," p. 311).

[53] Odum, "Stability," p. 407.

total community production to total community respiration determined the character of the biological community.[54] Odum placed this research within the systems perspective,[55] stating his aim as the determination of the control mechanisms by which the states and flow of energy are sustained.[56] Nevertheless, as noted earlier in the case of Hutchinson, Odum also retained many terms and emphases of organicist ecology. For example, in another passage he reexpressed his goal as the study of "mechanisms by which the community metabolism is self-regulated."[57] Certain of his organicist perspectives would later lead many systems ecologists to distinguish their work from Odum's and his brother's, but not before H. T. Odum had made several innovations that were a basis for all systems ecology.

During his Silver Springs project, Odum began to draw energy flow diagrams (Fig. 2a) — an obvious step, he claims, for someone with biogeochemical training.[58] With Odum's background in electrical circuitry, it was a small step to convert these energy flow diagrams to actual electrical circuits, an analogy that Odum would explore until the analogy dissolved into equivalence.[59] Variable resistors could be adjusted until the current flow in an electrical analogue circuit (Fig. 2b) became proportional to the measurements of energy (or its biomass equivalent) flowing between trophic compartments in the actual ecosystem. Voltage drop between compartments suggested to Odum the analogous "ecoforce." Among the hypotheses stimulated by his manipulation of electrical circuits, he advocated that ecologists think about avail-

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[54] H. T. Odum, "Trophic Structure and Productivity of Silver Springs, Florida," *Ecol. Monogr., 27* (1955), 59.

[55] H. T. Odum in E. P. Odum, *Fundamentals* (1953), p. 67.

[56] Odum, "Trophic Structure . . . of Silver Springs," p. 59.

[57] Odum, "Trophic Structure . . . of Silver Springs," p. 56. Odum's Silver Springs research and, we might suspect, his organicist perspectives were encouraged by W. C. Allee, who had at just this time moved to Florida from Chicago to head the Zoology Department at Gainesville (interview with H. T. Odum). See Gregg Mitman, "From the Population to Society: The Cooperative Metaphors of W. C. Allee and A. E. Emerson," *J. Hist. Biol.*, this issue, for a discussion of Allee's organicism.

[58] Interview with H. T. Odum. The first flow diagram appeared in H. T. Odum, "Primary Production in Flowing Waters," *Limnol. Oceanog., 1* (1956), 102–117.

[59] H. T. Odum, "The Use of a Network Simulator to Synthesize Systems and Develop Analogous Theory: The Ecosystem Example," in *Proceedings of the Cullowhee Conference on Training in Biomathematics*, ed. H. L. Lucas (Raleigh: North Carolina State University, 1962), pp. 291–297.

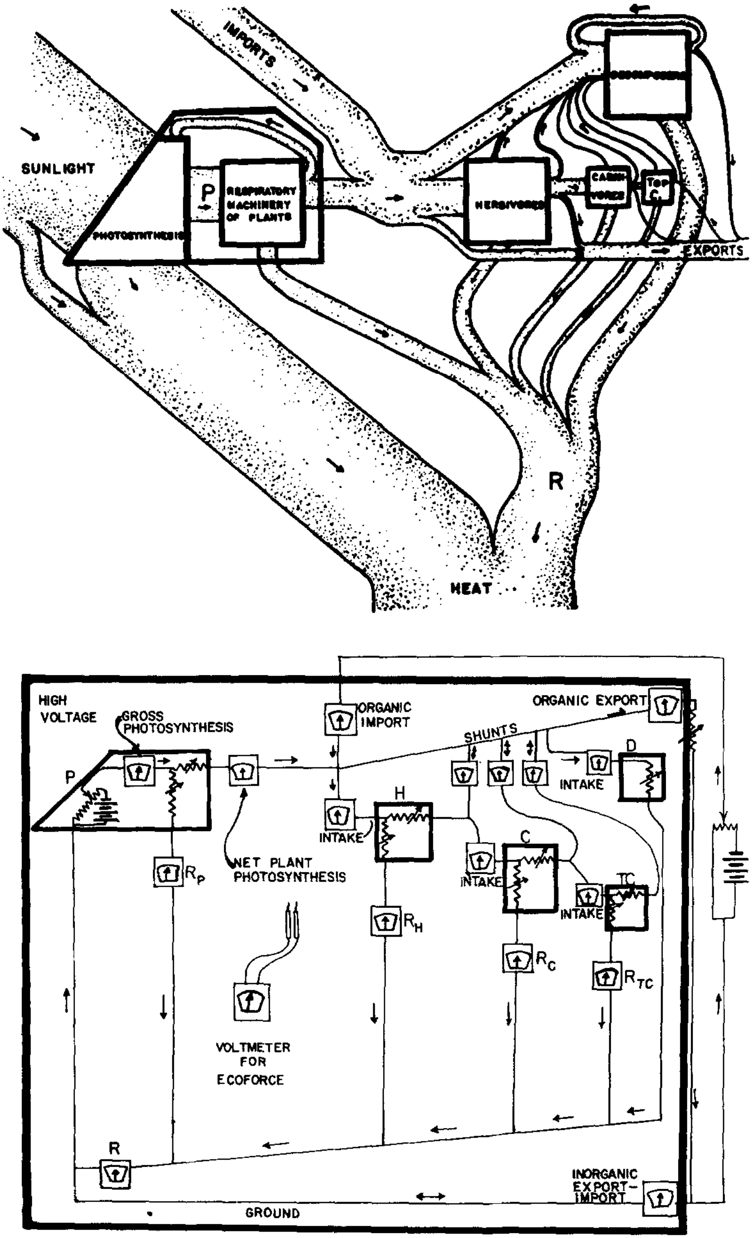

Fig. 2. (a) Energy flow diagram for an ecosystem. (b) Electrical analogue circuit for the steady-state ecosystem in (a). (From H. T. Odum, "Ecological Potential and Analogue Circuits for the Ecosystem," *Amer. Sci.*, *48* [1960], 1 [reprinted from H. T. Odum, "Primary Production in Flowing Waters," *Limnol. Oceanog.*, *1* (1956), 113], 4.)

able "food by its concentration practically forc[ing] food through the consumers."[60]

The use of electrical circuits, in turn, inspired Odum to develop a set of symbols that he hoped would provide a common language for ecologists to use in discussing energy flow and would enable electrical systems theorists to convey their synthetic insights to ecologists. The symbols, refined during the 1960s, would become his hallmark in subsequent publications.[61]

Odum's energy circuit diagrams were readily generalized. During the 1950s he had taken the necessary measurements from a coral reef at Eniwetok Atoll in the Pacific,[62] microcosms and ponds in North Carolina, estuaries in Texas,[63] and a tropical rain forest in Puerto Rico. In summarizing the functioning of these different ecosystems, Odum hoped the energy diagrams would indicate where there was similar function despite the taxonomic differences between ecosystems, or between sites within an ecosystem. He emphasized general principles instead of the particularities of the organisms and their interactions — a "functional ecology," popularized in his brother's textbook. For H. T. Odum, measurement in a common unit — energy — might make it possible to discover universal principles of ecosystem "design," including the energy transformations not only of living matter but also of purely physical processes such as erosion, which moves the sedimentary cycle, or wind, which influences evapo-transpiration from the leaves of trees.

Measurement was central to Odum's ecology, as it was to the systems ecologists who followed him. By collecting data for an entire system and summarizing them in flow diagrams, the systems ecologist could act as if the diagrams represented the system's dynamic relations. This approach, it should be noted, might require some arbitrary internal aggregations, such as species being summed into trophic compartments. The flow diagrams, when transformed into computer models, could be used by systems ecologists to generate predictions about the future or about

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[60] H. T. Odum, "Ecological Potential and Analogue Circuits for the Ecosystem," *Amer. Sci., 48* (1960), 5.

[61] See frontispiece of H. T. Odum, *Systems Ecology: An Introduction* (New York: John Wiley, 1982).

[62] H. T. Odum and E. P. Odum, "Trophic Structure and Productivity of a Windward Coral Reef Community on Eniwetok Atoll," *Ecol. Monogr., 25* (1955), 291–320.

[63] H. T. Odum and C. M. Hoskin, "Comparative Studies of the Metabolism of Texas Bays," *Publ. Inst. Marine Sci. (Univ. Texas), 5* (1958), 65–96.

responses to perturbations. Data have retained a powerful hold on the imaginations of Odum and other systems ecologists. Redescription, or bookkeeping, of the measurements on an ecosystem has frequently been used as if it provided a representation of the ecosystem's dynamics — that is, of the ecological relations that generated the observed data.

While other systems ecologists would come to measure variously biomass, population sizes, energy, or essential elements such as nitrogen, Odum converted everything to energy. This currency had a special status: all organisms require energy, and, following Lotka's lead, Odum expected theoretical generalizations in ecology to take the form of biological additions to the thermodynamic principles of physical chemistry.[64] By 1955 Odum had formulated the "maximum power principle,"[65] which he would later describe as the "fourth law of thermodynamics,"[66] applicable to open systems. The principle was the complement of the energy/electrical-circuit analogy; together, they formed the physical basis of Odum's ecology.

The maximum power principle was a hybrid of a theoretical suggestion made by Lotka about energy and natural selection, and the stability principle mentioned earlier, which Odum also attributed to Lotka. Lotka had suggested that evolution "proceeds in such direction as to make the total energy flux through the system a maximum compatible with the constraints." This could be "derived upon a deductive basis" using the principle that, all other things being equal, "in the struggle for existence, the advantage must go to those organisms whose energy-capturing devices are most efficient."[67] Competition among organisms disappeared, however, in Odum's version. Instead, the maximum power principle was stated in terms of persistence, that is, as a variant of the stability principle: survival of the fittest meant "persistence of those forms which can command the greatest useful energy per unit time (power output)."[68]

Odum's ecological theory relied on the universality of the

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[64] See H. T. Odum in E. P. Odum, *Fundamentals* (1953), p. 67.

[65] H. T. Odum and R. C. Pinkerton, "Time's Speed Regulator: The Optimum Efficiency for Maximum Power Output in Physical and Biological Systems," *Amer. Sci.*, *43* (1955), 321–343.

[66] H. T. Odum, "Ecological Potential," p. 1.

[67] A. J. Lotka, "Contributions to the Energetics of Evolution," *Proc. Nat. Acad. Sci.*, *8* (1922), 147, 149.

[68] Odum and Pinkerton, "Time's Speed," p. 332.

maximum power principle. In his original paper on the principle, written with chemist Richard Pinkerton, he applied the same general formulation to many cases: a water wheel driving a grindstone, one battery charging another, food captured by an organism for its maintenance, primary production in a self-sustaining climax ecological community, and the growth and maintenance of a civilization.[69] The maximum power principle covered any open system having self-reproduction and maintenance, irrespective of its scale, the placement of boundaries, or the internal aggregation into compartments. Models from population, community, and systems ecology alike could be reexpressed in energy diagrams; the maximum power principle implied that this was the natural way to develop such a synthetic and comparative reduction of otherwise bewildering complexity.

Since the maximum power principle was universal, then, Odum advocated that we should pay special attention to systems isolated and undisturbed for sufficiently long to adjust so as to achieve optimum power. We should examine, for example, tropical reef[70] and rain-forest ecosystems. Mankind could learn from these systems "about optima for utilizing sunlight and raw materials"; nature could teach us how to design "systems of man and nature."[71] Whether it was desirable or not, humans were intervening in previously undisturbed ecosystems: "the old systems and the new are being joined into an overall network including factories and towns, reefs and grass flats, and the flows between them."[72] In 1957, therefore, Odum initiated, with funds from the Rockefeller Foundation, an ambitious project intended to show how a mature natural system — a tropical rain forest in Puerto Rico — evolves or modifies its own design in response to a massive input of energy, and from this study to derive a model for humans to follow.

The goal of designing systems of man and nature was leading Odum outside the boundaries of the academic discipline of ecology. The Puerto Rican rain-forest project, nevertheless, became a practical model for subsequent systems ecology. In 1962 the Atomic Energy Commission, desiring a study of the "consequences

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[69] Ibid., pp. 337 ff.

[70] Odum and Odum, "Trophic Structure . . . on Eniwetok Atoll."

[71] H. T. Odum, "Biological Circuits and the Marine Systems of Texas," in *Pollution and Marine Ecology*, ed. T. A. Olson and F. J. Burgess (New York: Interscience, 1967), pp. 99—157. See also H. T. Odum, "Ecological Tools and Their Use; Man and the Ecosystem," *Bull. Conn. Agr. Sta.*, *652* (1962), 57—75.

[72] Odum, "Biological Circuits," pp. 99—100.

of nuclear warfare or major reactor accidents,"[73] committed $360,000 to the project. Under Odum's scientific direction, this project brought to the study of one ecosystem a wide variety of scientists, collaborating somewhat loosely to piece together a picture of the forest before and after exposure to three months of irradiation — in Odum's terms, an input of additional energy. Odum had pioneered the highly managed, collaborative, integrated ecosystem research project, commanding significant government support. Ecology had entered the domain of "big science."

Since the rain-forest study, Odum has continued to be a successful and productive scientist — recognized, though not always understood as he would like, well beyond the boundaries of the academy.[74] He has written over 200 articles and has advised, since 1970 when he returned to Florida, more than forty master's and Ph.D. theses. His research projects, including further large-scale interventions into ecosystems, have continued to attract funds from a variety of sources.

In many respects the new discipline of systems ecology followed Odum's leads. For example, during the International Biological Program, a massive ecological research endeavor that began in the late 1960s, ecologists undertook large, integrated research projects to accumulate measurements on entire systems, appropriately bounded and divided into compartments.[75] Storages of biomass or specific nutrients in the compartments, and flows between those compartments, were translated into computer models — that is, data were directly converted to dynamics. Ecological complexity seemed to be reducible in a systematic manner; systems ecologists could move from system to system, collaborating in making measurements that might reduce the need for intimate knowledge of the range and flexibility of particular species' behavior. In these features, systems ecology and Odum shared a similar technocratic orientation.

In other ways, however, the mainstream of systems ecology did not follow Odum's approach. Most systems ecologists were skeptical about systems' evolving to achieve optimum function

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[73] J. C. Bugher, "Project Foreword," in *A Tropical Rain Forest: A Study of Irradiation and Ecology at El Verde, Puerto Rico*, ed. H. T. Odum and R. F. Pigeon (Oak Ridge, Tenn.: U.S. Atomic Energy Commission, 1970), pp. vii–viii.

[74] See, for example, "Odum's Law," *Newsweek* (January 13, 1975).

[75] E. B. Worthington, *The Evolution of the IBP* (Cambridge: Cambridge University Press, 1975).

(that is, maximum power). Odum's extensive use of the stability principle seemed unnecessary, his focus on energy overly restrictive. General theoretical principles were of less importance than organizing and completing projects on a huge variety of systems using the same overall methodology. (In recent years the lack of general theory has haunted systems ecology, and a school of hierarchy theorists has attempted to remedy this shortcoming.[76]) At times, proponents claimed that systems ecology would lead to sound environmental management. Nevertheless, in practice, it focused on basic science;[77] the more ambitious project of developing a theoretical basis for human interventions in nature was postponed. Such a pragmatic separation was untenable for H. T. Odum.

FROM ORGANICISM TO TECHNOCRATIC OPTIMISM

Odum's project of designing systems of man and nature should remind us of the vision of a new social science announced by McCulloch at the New York Academy meeting: freedom from holocaust and other social upheavals might be achieved through the construction of an all-encompassing system of feedback. Raising the possibility of controlling complex systems marked a development in ideas about social organization and, simultaneously, in ideas about the representation of nature. Nature and society shared a universal feedback logic, a logic consciously and dramatically materialized in the wartime technology of antiaircraft missile guidance.

The naturalization of social discourse is a familiar theme among U.S. historians. It is, however, less straightforward to support the reciprocal interpretation, that scientific categories reflect social relations. The reality of the natural world would seem to filter out arbitrary social impurities; where, in any case, is the conduit from society into scientific theory? One response to such objections is to analyze how social and natural theorists responded to social and technological developments that changed their social status, sometimes threatening, sometimes enhancing the modes of social action with which they identified most strongly. The transformation of social/natural theory from community-organisms to feed-

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[76] Robert V. O'Neill, D. L. DeAngelis, J. B. Waide, and T. F. Allen, *A Hierarchical Concept of the Ecosystem* (Princeton: Princeton University Press, 1986).

[77] *U.S. Participation in the International Biological Program* (Washington, D.C.: National Academy of Sciences, 1974), p. 5.

back systems, when read as the theorists' attempt to make sense of their experience as social agents, supports the contention that it is the distinction between inside and outside of science that is arbitrary.[78] In the richest sense of metaphor, ideas and actions regarding nature, machine, and society animated each other.

In Howard Scott's words, technocracy alone offered life.[79] Technological development had made the Technocratic social order possible — vast increases in energy utilization allowed Technocracy to promise a short work week for all. At the same time, technological change had made a new order necessary: industrial production had become so complex and interdependent that the failure of any one component could disrupt the entire "machine." In fact, the Great Depression and idle productive capacity proved to the Technocrats and their supporters that the organization of industry had broken down. Only a cadre of engineers using scientific principles could solve the technical problem of restarting and running the industrial machine at maximum efficiency.

In many respects the Technocrats' polemic simply expressed an extreme current of the organicist mainstream. Many social theorists viewed the broken machine as a sick organism; interdependent components of the machine translated readily into parts of the social organism functioning in a natural division of labor. In the early 1930s the social organism was out of balance. The organicists' diagnosis of this crisis was, like the Technocrats', one of "social lag": the pace of scientific discovery and technological innovation had become so rapid that the necessary adjustment of social institutions and sentiments lagged behind.[80]

Social balance had been the central problem for organicists even before the crisis of the Great Depression. The Progressive period and World War I had advanced the cause of State regulation and planning, opening up the possibility of new administrative and managerial roles. Organicism was to a large extent a discourse of leaders and administrators defining their roles in the post-Progressive period, responding to social and political forces that were not easily balanced. Immigration, for example, was viewed as

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[78] See D. J. Haraway, "Teddy Bear Patriarchy: Taxidermy in the Garden of Eden, New York City, 1908–1936," *Social Text, 11* (1984/1985), 53.

[79] Howard Scott, *The Mystery of Money* (New York: Technocracy, 1938).

[80] William F. Ogburn, *Social Change with Respect to Culture and Original Nature* (New York: B. W. Huebsch, 1922). See also S. J. Cross and W. R. Albury, "Walter B. Cannon, L. J. Henderson, and the Organic Analogy between the Wars," *Osiris, 3* (1987), 165–192.

a threat to the dominant status of these primarily Anglo-Saxon American men. Immigrants brought with them different cultures, religions, and, it was claimed, diseases, and differential reproductive rates. They had to be assimilated into a "traditional" American way of life, or contained without provoking revolt. Class conflict had to be averted, and this called for some restraint of industrial capitalism or for mitigation of its excesses. With the crash of 1929 this issue became urgent.

The language of organicists was not, of course, so explicit about their interests; their silences are instructive. Progress or social change was a force curiously external to the social organism. Capitalism and science as prime movers of social change were afforded, therefore, a privileged existence. Although social lag was viewed as a result of the rapid development of science and industry, it was society and its components that needed to adjust. Terms such as "adjustment," "adaptation," "integration," and "function" dominated the discourse of the organicist or functionalist social sciences. Cooperation among the specialized parts of the social organism was viewed as essential to the survival of the whole, which, in turn, would ensure the welfare of the parts.[81] Yet the cooperation sought by organicists could equally well have been described as subordination to a hierarchical division of labor.[82] In the discourse of organicism, management had moved to the realm of necessity; natural spontaneity must be subjected to some social control; regulation of social processes was a precondition for free and individual life. Individuals who were well adjusted would recognize their responsibility to work in harmony and to ensure stability and order. Some degree of control was not only compatible with traditional democratic values, it was necessary for their defense.[83]

Those holding a common vision of a managed society disagreed about the degree of social control needed. The Technocrats, whose leaders were marginal figures politically, fantasized a radical redesign of society, and nominated engineers (themselves) to run the new industrial organization. The predominant organicist

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[81] Mitman, "From the Population to Society," has shown that this was similarly the case when Emerson, W. C. Allee, and others advanced biological bases for ethics in response to World War II.

[82] For example, Howard W. Odum in *Man's Quest for Social Guidance* (New York: Henry Holt, 1927), pp. 470 ff, discusses the "misunderstandings" that stand in the way of cooperation between laborer and capitalist. See also D. J. Haraway, "Signs and Dominance: From a Physiology to a Cybernetics of Primate Society," *Stud. Hist. Biol.*, *6* (1983), 129—219.

[83] Cross and Albury, "Walter B. Cannon."

discourse, on the other hand, was sustained by leaders in the academy, industry, and government. It was more pragmatic, advancing an administrative or a therapeutic model informed, in the notable cases of L. J. Henderson and Walter Cannon, by work in physiology.[84] Change would not be revolutionary, but would be planned. Organicist commentators implied a role for themselves as rational, practical administrators or, as Odum senior expressed it, leaders in "man's quest for social guidance."[85] Nevertheless, organicists were not of one voice about the degree of intervention required, paralleling the wider social debates about government intervention. The Hooverites emphasized private voluntary planning and coordination, and Henderson used case studies of concrete problems to train administrators, men who would become intuitively skilled in the redirection of human relations. Cannon, on the other hand, tentatively advocated a "biocracy," a noncentralized set of agencies to regulate the processes of commerce;[86] the New Deal increased in measured steps federal planning, regulation, and intervention to stimulate "national recovery."

Ironically, given the success of the New Deal in legitimizing rational management in place of "laissez-faire," there was no New Deal science. Government support and long-range planning in science met successful resistance from many influential scientists. They feared that science would lose its perceived independence from politics in a "planned economy." Their insistence on the method of "private initiative" frustrated physicist Karl Compton's vigorous advocacy of a federal science advisory agency with broad responsibility for funding science.[87] World War II would change all that.

Late in 1944 President Roosevelt asked Vannevar Bush, a protégé of Compton and director of the wartime Office of Scientific Research and Development, for advice about government involvement in the extension of wartime science to peacetime. The response — *Science: The Endless Frontier* — set many of the terms of postwar science policy and led eventually to the establish-

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[84] Ibid.

[85] H. W. Odum, *Man's Quest.* In Emerson's writings the powerful administrator became naturalized in the role he gave selection, guiding the improvement of the whole and ensuring group homeostasis; see Mitman, "From the Population to Society."

[86] W. B. Cannon, "Biocracy: Does the Human Body Contain the Secret of Economic Stabilization?" *Tech. Rev., 35* (1935), 203—206, 227.

[87] R. Kargon and E. Hodes, "Karl Compton, Isaiah Bowman, and the Politics of Science in the Great Depression," *Isis, 76* (1985), 301—318.

ment of the National Science Foundation.[88] Compton's frustrated plan had been reborn; some form of alliance between government and science was now taken for granted. Any resistance lingering from the thirties had succumbed to the wartime experience of science generated by the federal government and serving the national interest.

The war had not, however, swept away the prewar organicist themes of social lag and adjustment. Lawrence Frank, the social scientist who would become a leading figure in the Macy conferences, made this clear in his report of a 1944 symposium on "Research after the War." Frank insisted that a national policy of scientific research would, among other things,

> recognize that the very progress of research in physical science and technology made it imperative that research in the social sciences and the humanities, especially into the traditional American patterns of thinking and action, be further developed and improved, since the growing discrepancy between our advancing technology and our established practices and organizations is one of the major threats to our free, democratic social order. The need for the exercise of critical thinking upon our folkways and our historically derived social, economic and political beliefs and patterns is no less than the need for critical thinking upon our industrial processes and technical equipment and practices.[89]

Nevertheless, the preeminent role afforded to science, albeit enmeshed with the military, was transforming organicism. In particular, the scope of scientific intervention in society could be increased. Previously, when either nature or society was viewed as an organism, the scientist's role was to describe and classify the natural order and the natural mechanisms of integration; perhaps the scientist could also advise on how the organism might be healed or might heal itself.[90] Systems, in contrast to organisms, could be constructed, or so McCulloch claimed; systems were constructs in which scientists could intervene and exert control.

A social feedback system implied the existence of systems scientists under whose controlling hands the system would run for

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[88] Vannevar Bush, *Science: The Endless Frontier* (Washington, D.C.: United States Government Printing Office, 1945). Hutchinson applauded Bush's report and gave it a detailed review in *Amer. Sci., 33* (1945), 262–269.

[89] L. J. Frank, "Research after the War," *Science, 101* (1945), 433–434.

[90] Cross and Albury, "Walter B. Cannon."

the benefit of the rest of society. The implications of abdicating control to a cadre of scientists were not a major concern to the Macy participants (though some of them were skeptical on technical grounds about the possibility of social feedback systems[91]). The new theories about feedback systems were liberating for arms race enthusiast John Von Neumann, and alike for humanists such as Hutchinson, Margaret Mead, and Gregory Bateson. In 1946 Bateson, calling on physicists and other natural scientists to help prevent atomic war, proposed a mission for the social sciences inspired by the Manhattan Project. In retrospect, it is a telling irony that the project that had spawned the danger of a final holocaust could, at the same time, stand as a model of the potential of science. Bateson wrote:

> We have not enough basic knowledge of the mechanics of individual aspiration and large-scale political interrelationships to plan the steps which must be taken to adjust human societies to the availability of atomic weapons. . . . It is possible that a small number of carefully selected men with experience in the modern handling of natural science problems might, after intensive training in psychological and anthropological methods, make outstanding contributions in the field of social science.[92]

Bateson, like Frank, was concerned with social lag and adjustment, but these organicist themes had taken a technocratic turn. Selected scientists could be granted a special role: using modern scientific methods they could provide the necessary perspective on society as a whole in order to plan its development. Yet, if anything, these early systems theorists perceived their science to be antitechnocratic. The organicist view emphasized subservience of the individual to the larger group, or, at least, adjustment of the individual to a society composed of an integration of specialized groups. Feedback systems, in contrast, appeared to relieve the individual from total subservience to the function of the group (or to the decisions of the technocrat). Frank, speaking about the social sciences at the New York Academy meeting, described this possibility forcefully:

> Economists, political scientists, and sociologists . . . impute to the individual the motives and desires which they derive

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[91] Wiener, *Cybernetics*, p. 162.

[92] Bateson, "Physical Thinking" (above, n. 21).

> deductively from statistical studies of group activities . . . ignoring what the study of individual personalities has revealed about human behavior. . . . They will find it fruitful to recognize that the regularities of social life arise from the social-culture patterns and institutional practices into which the individual's activities are channeled. They will then realize that the dynamics of social life arise from individual actions, re-actions and interactions, not from mythical "forces" which they assume operate and control the social "system."[93]

We see Frank even rejecting the term "system" in favor of "field" in order to dissociate himself from connotations of impersonal forces responsible for the development of some social "whole."

For Frank and other Macy participants the individual in a feedback system appeared to gain in autonomy because systems theory addressed communication and information flow between individuals.[94] Communication was a favored theme of the Macy conferences. Furthermore, the conferees could see in the prospect of scientifically managed systems new social roles and a pluralization of social influence relative to the domination of labor by paternalistic management serving the owners of capital. The new managers, trained in cybernetic science, could institute more efficient systems of feedback, systems responsive to the needs of interacting individuals.

Nevertheless, appearances notwithstanding, the possibility of enhanced autonomy for the individual was problematic. Communication systems were also command-control systems; command-control engineers would be required to ensure that the systems operated according to new criteria — for example, minimizing information loss or preserving circuit stability. The technocratic implications of systems thinking were scarcely discussed and perhaps invisible at this time to the Macy scientists. The implicit common endorsement of the systems engineering role by these people, who differed considerably in their attitudes to politics, the military, and technology, revealed a shared wartime experience of social facilitation as scientists. (Wiener, who refused to undertake research for the military after the war ended, stood as a possible exception.) The prospect of scientifically managed systems had transformed the discourse about science and society; a technocracy, even though the term was not used, seemed both realizable

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[93] Frank, "Foreword" (above, n. 20), p. 195.

[94] Wiener, "Time, Communication" (above, n. 24), and *Cybernetics*.

and acceptable. The ambiguous implications for individual freedom were obscured by a triumphant optimism: the social order that had triumphed over fascism in the war was basically good; in fact, it was the best. "Technocratic optimism" supplanted organicism as the dominant metaphor for social theory.

SYSTEMS AS ALLEGORY

Norbert Wiener in *Cybernetics* (1948) cautioned against his colleagues' "excessive optimism." From believing in the necessity of control over the social environment, he said, "they come to believe it possible."[95] Making ecological and social engineering possible was precisely the task to which the young Odum applied himself.

The postwar alliance of government and science, and its attendant optimism, provided fertile ground for Odum to begin his scientific career. As we have seen, he complemented the progressive organicism of his father with the systems thinking of Hutchinson and the Macy conferees. The ecology that he built upon those foundations was "macroscopic."[96] Using data derived from a system, the ecologist could stand back and model the overall functioning of that system. Knowledge of the system's structure was more important than its particular details for predicting the system's future behavior. The same approach could guide intervention into any system, whether its components were ecological, electrical, or social.

However, as important as these conceptual developments were, they constitute only one-half of the story. Odum also derived support for his early ecosystem research from the major institutions of postwar science: the Office of Naval Research, the Atomic Energy Commission (AEC), the Rockefeller Foundation, and the National Science Foundation (NSF). The funding was by no means exhorbitant, but it stood out in the era before Sputnik led to increases in funding for basic research in areas outside medicine and the military. Science in the postwar decade was, in fact, "big" only where it intertwined with the military.[97] Odum and his

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[95] Wiener, *Cybernetics*, p. 162.

[96] H. T. Odum, *Environment, Power, and Society* (New York: Wiley-Interscience, 1971), p. 10.

[97] David Dickson, *The New Politics of Science* (New York: Pantheon, 1984); R. Kargon, "The Future of American Science: An Historical Perspective," in *The Future of American Democracy*, ed. M. E. Kahn (Philadelphia: Temple University Press, 1983), pp. 141—161.

brother were among the few ecologists who found themselves a place in this enterprise. E. P. Odum's study for the AEC of the site for the Savannah River nuclear facility led in 1954 to the Odums' joint study of the coral reef ecosystem at Eniwetok Atoll, the site of the Pacific H-bomb tests. Other contracts followed, including NSF funds for studies of ecological microcosms, constructed to investigate directly Odum's proposed techniques for ecological engineering.[98]

Odum's project of designing systems of man and nature surfaced in his 1955 monograph on the Eniwetok coral reef; its prominence in his ecological writings increased until, in 1971, his first book for a general audience, *Environment, Power, and Society*, was published. The book reads in parts as an allegory for his style of doing science. When Odum discussed a future in which power — that is, energy available per unit of time — might be expanding but would more likely be constant or receding, he concluded that a

> bright possibility is ecological engineering. Adequate knowledge about the natural solar-energy based system [if power is limited] may allow a small concentrated loopback of energy to guide the systems of fields, forests and seas to stabilize and produce for man. . . . Loopback focus of relatively small energies may be able to hold world organization. . . . Greater work expenditures are required to create novel structure than to maintain it. The preparations need to be made now for this contingency of receding power.[99]

H. T. Odum, like Howard Scott before him, had a vision that reduced the complexity of social and ecological relations to a single energy dial for the social engineers to adjust. In his high-quality, low-energy circuits Odum had found "in nature" a special role for systems engineers, working in the service of society.

Yet by this time an edge to Odum's optimism can be detected. If power were receding, he warned, we would need to plan for the necessary transition. He had also turned his attention to the "disordering" effects of war, which drain energy away from "the maintenance of the structure of whole countries." In the early 1970s he constructed analogous models of the effect of hurricanes on a mangrove swamp and the disordering (war-losing) U.S.

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[98] Odum, "Ecological Tools" (above, n. 71).

[99] Odum, *Environment*, p. 309.

intervention in Vietnam (Fig. 3).[100] War planners — and by extension, engineers in general — could produce disastrous results. Odum hoped to make them recognize what they overlooked. Society, like all systems, must ultimately submit to the maximum power principle, a natural law applicable to mangroves and economies alike, a law we neglect at high cost. Odum, who was finding himself misunderstood and unappreciated by the new systems ecologists, implied that there existed a role above systems engineer in the enterprise of designing systems of man and nature. At the close of his 1971 book he made this role explicit:

> While there is energy, we need to stimulate religious evolution. We may encourage faster religious change even now by injecting large doses of systems science into the training of religious leaders. What a glorious flood of new revelation of truth God (the essence of network) has handed man in the twentieth century through sciences and other creative endeavors. How false are the prophets who refuse even to read about them and interpret the message to the flock. Why do some inhabitants of the church pulpits fight the new revelations simply because the temporary prophets are a million spiritually humble little people in laboratories and libraries, only vaguely aware of their role? Why not open the church doors to the new religion and use the preadapted cathedrals and best ethics of the old to include the new? Let us inject systems science in overdoses into the seminaries and see what happens. Why should we fear that deviation from rigid symbols of the old religion is deviation from morality? A new and more powerful morality may emerge through the dedication of the millions of men who have faith in the new networks and endeavor zealously for them. Prophet where art thou?[101]

Clearly Odum saw himself as the prophet. His personal allegory, although eccentric, highlights how scientists can build their experience of social relations and social action into their science. We should remember that Odum was and continues to be a successful scientist. Furthermore, and what is more important for

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[100] H. T. Odum, M. Sell, M. Brown, J. Zuchetto, C. Swallows, J. Browder, T. Ahlstrom, and L. Peterson, "Models of Herbicide, Mangroves, and War in South Vietnam," in *The Effects of Herbicides in South Vietnam, Part B, Working Papers* (Washington, D.C.: National Academy of Sciences, 1974).

[101] Odum, *Environment*, p. 310.

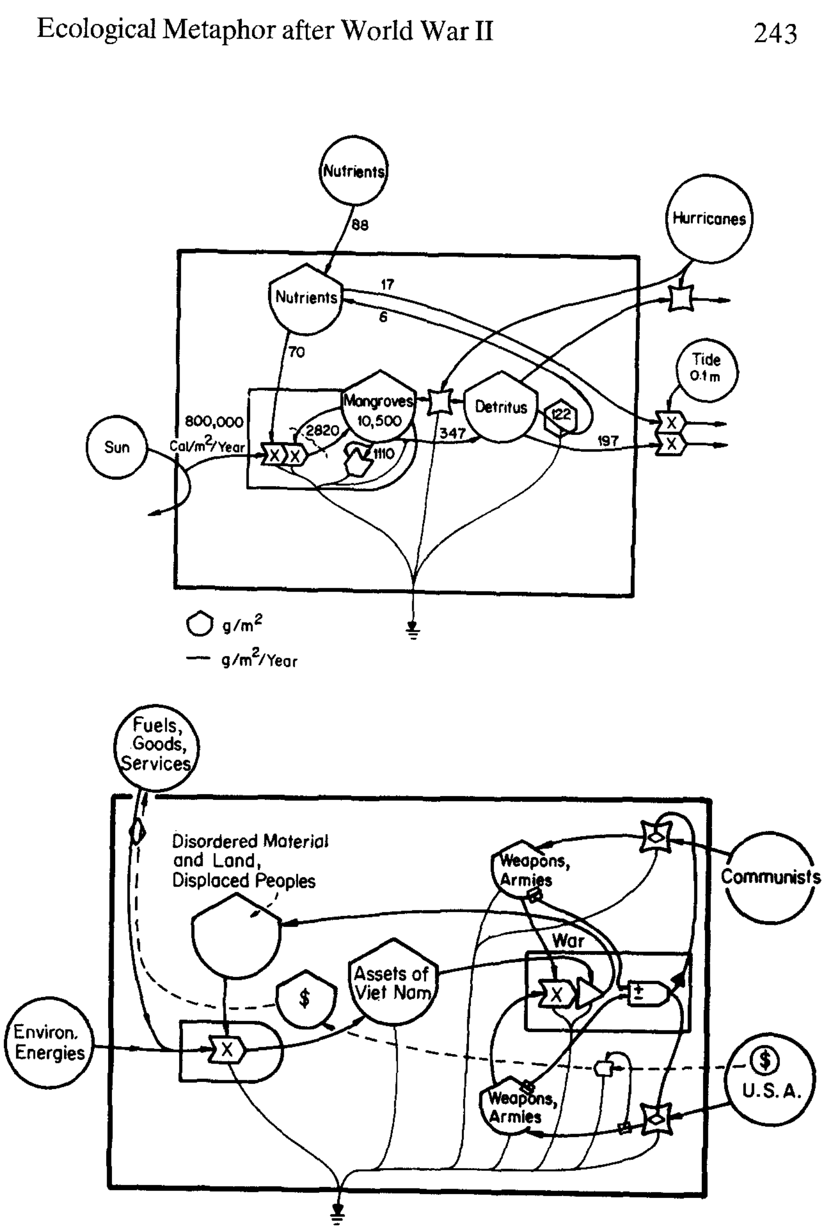

Fig. 3. (a) Simulation model of tide and hurricane effects on nutrients of a mangrove swamp. (b) Simulation model of the Vietnam war zone in 1970. Solid lines represent energy flows; dashed lines in (b) represent flows of money. For the Vietnam analysis, B-52s and so on were converted into energy at a rate of 14,000 Calories per dollar. (From H. T. Odum, *Systems Ecology: An Introduction* [New York: John Wiley, 1982], figs. 21—37a and 25—27a. Copyright © 1982 by John Wiley & Sons, Inc.; reprinted by permission of John Wiley & Sons, Inc.)

this paper, in the research that pioneered the important features of systems ecology — in particular, its technocratic orientation — Odum was already "making science" of his place in society. His vision of designing systems of man and nature gave him access to resources, both institutional and personal, for pursuing prodigious amounts of ecological research. Society facilitated his work — in the broadest sense, and in a way not possible before World War II.

Since the 1960s H. T. Odum has attracted an international following of environmentalists, energy policy analysts, and, more recently, economists. Ecologists and evolutionary biologists, on the other hand, have in general turned their attention away from the discussion of groups or systems evolving toward improved feedback and coordination; instead, most theory focuses on individuals in the pursuit of self-interest.[102] This shift in predominant metaphor speaks both to the postwar fulfillment and to the subsequent eclipse of technocratic optimism. A diversity of roles for scientists in social management has indeed opened up since World War II. At the same time, the influence of any single scientist has been diluted; fewer scientists can now identify as closely with social leadership as could Odum or his father. In society more generally, the individual's ties of personal dependence within the family and community have been loosened: the individual is freer to consume and to seek personal fulfillment. At the same time, the individual is more vulnerable to decisions about social organization that are increasingly made on a scale that eliminates the details of local interests, and at a distance that removes the decisions from the individual's influence. In fact, in feedback systems of energy or information the individual is potentially obsolete — all processes, whether physical or biological, are substitutable. The exercise of a technocratic rationality that Odum helped to naturalize has diminished the grounds, even for the privileged, for feeling secure or optimistic about one's place in the changing world.

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[102] Keller, "Demarcating Public from Private Values"; D. J. Haraway, "The High Cost of Information in post-World War II Evolutionary Biology," *Phil. Forum, 13* (1981—82), 244—278.