‘Potatoes Made of Oil’: Eugene and Howard Odum and the Origins and Limits of American Agroecology

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SUMMARY

Eugene P. Odum (b. 1913) and Howard T. Odum (b.1924) were at the forefront of the ‘new ecology’ of ecosystems, in the 1950s and 1960s. As part of their program the Odums were firmly committed to bringing both natural and human ecosystems into accord with the laws of ecoenergetics (the flow of energy through a system). American agriculture struck the Odums as a particularly egregious violator of all the laws of ecoenergetics and hence a dangerous paradigm for world development. By diagramming American agriculture as a simplified circuit of energy inputs and outputs, the Odums concluded that energy subsidies had created a dangerously unstable system. As a remedy they suggested an end to the Green Revolution and a modification of human society so as to better approach the steady-state of a mature natural ecosystem. To achieve their programme goals the Odums needed to enlist the support of their fellow ecologists and the government. In this attempt the Odums were largely unsuccessful, as the ecological community and the US government largely ignored their attempt to reform agriculture. While the Odums’ agroecological language and theories have persisted until the present, they have largely been divested of the brothers’ broader programme of bringing the entire human ecosystem into accord with natural laws. By re-examining the social and scientific context of the Odums’ early agroecology it may be possible to better evaluate agroecology as both a tool and a social programme.

INTRODUCTION

> This is a sad hoax, for industrial man no longer eats potatoes made from solar energy; now he eats potatoes partly made of oil.
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> Howard T. Odum, *Environment, Power, and Society*, 1971[1]

For the brothers Eugene and Howard Odum, understanding the relationship between humans and their immediate environment was something of a family

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tradition. Their father, Howard Washington Odum, was a leading American sociologist in the 1930s and 1940s, whose works on Southern regionalism sought to explain the environmental, racial, and cultural factors that made the South unique.[2] One of Howard W. Odum's primary concerns was the 'achievement lag', by which he meant that 'man has too often failed to apply his technical skills to prevent the social problems that have been created by the rapid expansion in technology'.[3] The father's interests seemed initially lost on the sons, as they went off to study ornithology and biogeochemistry; however, over time their work betrayed a continuing Odum tradition in its concern about the predicament of American agriculture. Agriculture struck the sons as a field that could be both explained and improved by applying the new methodology of 'systems ecology' (a term coined by Eugene) to overcome some of its technical problems. The Odums' attempt to understand the agroecosystem was reminiscent of their father's earlier attempts to understand how humans and the environment interact and, in doing so, improve the situation for both human and natural systems. A social role for the scientist in American society was ultimately the most important Odum family legacy.

The eldest brother, Eugene Odum (b. 1913), was initially trained in ornithology under Victor Shelford at the University of Illinois.[4] After receiving his doctorate in 1939, Eugene joined the faculty of the University of Georgia in 1940 where he remained for the rest of his career. His younger brother, Howard, was moving towards ecology via a similarly circuitous route, gaining a doctorate in biogeochemistry from Yale in 1951 and obtaining a post at the University of Florida at Gainesville. The two brothers saw their careers intersect in 1954 when both were hired by the Atomic Energy Commission (AEC) to study a coral reef at the Eniwetok atoll atomic test bomb site.[5]

Eugene's credentials as an ecologist at this point were the more impressive, as he had already published the first edition of his *Fundamentals of Ecology* (1953), the first textbook to be organised around A.G. Tansley's 1935 concept of the 'ecosystem'. Eugene had also been doing ecological field research for the AEC on the succession and productivity of abandoned farmland near the Savannah River nuclear facility. Howard, meanwhile, was busy studying fresh water springs in Florida. Neither ecologist had any particular background in coral reefs, but the 1950s was an important period of federal largesse as regards ecological programmes. Both ecologists had experience with federal funding and this was ultimately the experience that mattered most.[6] The six weeks spent at the Eniwetok Atoll were to have two important effects on the brothers. First, it was to link the brothers inextricably in the public mind as sharing a common paradigm of systems ecology. This was not an inaccurate perception since Howard was to contribute the chapters on energy in Eugene's textbook and both were fond of quoting and using each other's work in an almost symbiotic manner. The other result of the Eniwetok study was to convince the Odums that energy was the means to unlock the secrets of any ecosystem.

While at Eniwetok the Odums studied the entire reef as a system to determine its energy budget.[7] Strikingly, the results of the Odums' study seemed to show that most of the energy in a coral reef ecosystem was used to sustain the system. Energy for production (or photosynthesis) was nearly equalled by the energy respired – leading to their interpretation of a coral reef as a steady-state system. In the years that followed, the coral reef system was to remain an exemplar to the Odums of a mature ecosystem as a self-regulating, self-maintaining, steady-state system. As Howard went on to study the Puerto Rican rainforests, while Eugene studied marshes and woodlands, their ecosystem data confirmed their belief that conditions of stability were characteristic for all mature ecosystems.

In part, this concept was reminiscent of Clementsian succession where the climax community was the end of succession, thereafter maintaining a relatively steady state, barring some disaster such as fire or the mouldboard plough. The Odums shared with Frederic Clements a belief in evolution at the level of a system and a modified dynamics of successional stages culminating in a climax community, which the Odums defined as a 'steady-state' and self-maintaining condition.[8] However, the Odums' analysis differed in two important ways. First, the Odums always regarded their focus of analysis as arbitrarily determined by the ecologist. As Eugene liked to note in his textbooks, the ecosystem under study could range from a puddle to the entire biosphere depending on an ecologist's interests. For the Odums, all human systems also fell under the domain of the systems ecologist, a far cry from Clements' description of naturally occurring and recognisable plant communities. Second, the mode of analysis for the Odums was energy, not a flora or typological species as it had been for Clements. For the Odums, energy was the proper way to evaluate and analyse the ecosystem unit and, as a tool, ecoenergetics (the flow of energy through a system) allowed a meaningful comparison among units – something that had not been particularly easy to achieve with Clementsian communities. Most importantly, energy had a real meaning for human ecosystems and therefore provided an inroad for proactive ecologists, such as the Odums, to begin an analysis of human ecosystems along ecological lines. The Odums made this connection explicit in the introduction to their early Eniwetok coral reef study.

> Perhaps in the structure of organisation of this relatively isolated system man can learn about optima for utilising sunlight and raw materials, for mankind's great civilisation is not in steady state and its relation with nature seems to fluctuate erratically and dangerously.[9]

Moving beyond Clements was in keeping with the Odums' belief that previous attempts to study the agroecosystem were less than scientifically rigorous. The most famous attempts to study the agroecosystem ecologically had previously occurred within the Soil Conservation Service (SCS), a branch of government well-acquainted with the elder Odum's sociological work. Eugene, in his textbook and articles, was forever using the vast archive of SCS photos to demonstrate good and poor land-use practices and he even included a description of the agency's 'land-use maps' in all of his textbooks. These land-use maps were developed during the New Deal as a farm 'blueprint' so that SCS technicians could implement soil and water conservation projects.[10] Based on Clementsian ideas of agriculture as a disclimax and devoted to technological and engineering methods to protect the soil, the SCS offered few means of comparing various agricultural systems. Lacking energy analysis and any attempt to study the cycling and nutrient system on a farm, the SCS was hopelessly behind the atomic ecology of the 1950s, which was actively employing radioactive tracers to study the various cycles in every conceivable system. Even worse, the SCS had firmly tied itself during World War II to increasing production and a series of engineering projects – including reclaiming wetlands and straightening rivers – without any proper means of evaluating the environmental consequences.[11] Always focused on the key inputs of soil and water conservation, the SCS largely transformed itself into a narrowly technical 'agricultural corps of engineers' in the aftermath of World War II. Eugene's final verdict on the SCS was that it had become 'increasingly bureaucratic' and 'less responsive to the real needs' of American agriculture.[12]

The other important source of science on the farm lay in the state agricultural colleges and local extension agents. The extension system was rather single-mindedly committed to higher yields, even while crop surpluses were once again becoming a threat to the farm economy in the 1950s. Eugene dismissed extension agents as 'technicians who had great skill, but no understanding', while Howard described them as having 'forgotten how to farm without poisons' and who 'must go back to school as soon as the agricultural schools put courses in lower energy farming back into the curriculum.'[13] The extension service was described as moving in the opposite direction of more ecologically-based farming.

The final constituency with an interest in the agroecosystem arose in the post-World War II era, as increasing numbers of amateur alternative agriculturists took a non-traditional view of agriculture. Agrarian romantics – such as Louis Bromfield and the 'The Friends of the Land' – all sought to create some sort of 'balance' between humans and nature, while remaining tied to SCS ideas of how that balance might be achieved through soil conservation.[14] This was at odds with the Odums' claim that the human and natural systems did not need to be 'balanced', but rather the human ecosystems needed to more closely 'resemble' their natural counterparts.[15] The other important alternative agriculturists were the organic farmers, who in the 1940s began an American movement to bring agriculture more into line with what they saw as natural processes.[16] The organics eschewed chemicals and based their holy grail of the compost pile on the natural process of humus creation on a forest floor. In addition, the organics were intrigued by new developments in American environmental sciences (such as the early years of agroecology) which promised to validate their practices. Yet the organics could never completely shake off the aura of being health eccentrics.

Their personal commitment to farming with nature arose from pseudo-medical beliefs about the concentration of proteins in organic vegetables and the supposed health benefits of uncooked edibles. They frequently came across as one step removed from herbalists and hence were not seen as an effective spokesgroup or source of support for the new agroecology and were instead often spoken of condescendingly by practicing ecologists.[17]

All three agricultural interest groups sought the professed goal of the Odums, to stabilise and improve American agriculture. Yet the Odums felt each of these groups was flawed in their outlook. The SCS was primarily concerned about preserving soil and water on farm lands, believing that the conservation of these two most precious resources would trickle down to the preservation of American agriculture. The land-grant institutions, by the same standard, looked to increasing production and farm income as a panacea, while remaining relatively indifferent to the transformation of farmers and their farms into agricultural workers on agricultural factories. Finally, the alternative agriculturists sought personal redemption by a return to the land, while remaining largely suspicious of many scientists, blaming them for most modern agricultural problems. The Odums felt that all three groups had focused on only one segment of the problem and it was up to ecologists to focus on the big picture. This may explain the Odums' dismissive treatment of their predecessors.

The three agricultural interests dismissed by the Odums – the SCS, land-grant institutions, and the alternative agriculturists – had all produced precursors to agroecology which were ignored by the Odums. The SCS, for example, may have been the first organisation to present the term 'agroecology' to the American public.[18] In a 1938 article in the agency's official publication, *Soil Conservation*, Basil Bensin described 'agroecology' as the 'basic science of soil conservation.'[19] Bensin traced the term back to the Czechoslovak Botanical Society in 1928 and described the new science as emphasising the 'relationships between species and types of crop plants and their environment'. [20] Bensin's breakdown of the three main components of agroecology would not be out of place in a current agroecology text, as he emphasised: '(1) crop plants and their regional types, (2) regional environment as it affects crops, and (3) culture as a dynamic factor in agroecology, comprising the agrotechnique of the region'.[21] Bensin's primary omission was in any concept of 'energy' informing his study of agroecology. If the Odums ignored this early pioneer in bringing agroecology to America, so did the SCS, since there were no future references to agroecology until the 1970s and Bensin's methodology seems to have had little effect on SCS policies up to the present day. Still, the disappearance of this early article from traditional histories of agroecology is odd.

Likewise, buried in slightly less obscurity, there was an early article from an important land-grant university scientist, Alfred Transeau, about 'The Accumulation of Energy by Plants'.[22] This work seems to be a direct predecessor of the Odums' agroecology, as Transeau sought to calculate specifically the flow of energy in corn to determine whether agricultural crops might provide a future renewable energy source to replace limited supplies of coal, petroleum and natural gas.[23] Transeau concluded that corn was only able to convert about 1.6.% of available energy into usable energy (i.e., kernels) and hence crops were an unlikely substitute for traditional energy resources. [24] Although this particular line of reasoning may seem quaint in lieu of later attempts to limit the flow of fossil fuels *into* agriculture, the study's broader energy concerns, and attempts to understand agronomy via energy conversions, are reminiscent of present studies in agroecology. This makes the study's omission by the Odums all the more perplexing.[25]

Finally, the omission of all domestic organic farm work by the Odums seems unwarranted. The types of Asian and Indian agriculture lauded by Howard Odum in his comparative studies had already been transplanted on to a number of American organic farms through the information spread by Sir Albert Howard and J.I. Rodale. [26] While the organics continued to cover new agroecological advances in their periodicals, the organic farms in America remained an understudied resource for agroecologists, who persisted in looking to the developing world for their examples.

In contrast to these early examples of agroecological thought arising in fields the Odums dismissed, the Odums presented a history almost exclusively devoted to a pantheon of ecologists. In Eugene's attempt to describe the history of energy flow studies (and by extension agroecological studies) not a single non-ecologist appears, and the list is heavily weighted towards the Odums' work and the traditional heroes of American ecology (e.g., Stephen Forbes, Charles Elton, Raymond Lindeman).[27] The result of this revisionist history, written from the ecologist's point of view, was the omission of credit for early pioneering work in federal agricultural programmes, land-grant colleges, and alternative agricultural communities. The new field of agroecology was to be defined along narrowly scientific lines and to exclude all other inputs as extraneous. The Odums were certain that the reform of American agriculture would arise from the ecological community. In Eugene's words:

> If biologists do not rise to the challenge, who will advise on the management of man's environment – the technicians who have great skill, but no understanding, or the politicians who have neither?[28]

This attempt narrowly to define agroecology as a subdiscipline of ecology was to have ramifications for the development of the discipline in the 1970s and 1980s, when agroecologists sought to broaden their appeal. For the Odums, however, the key role of agroecology was management and previous attempts at agricultural management had removed themselves from the equation by virtue of their past failures.

The fact that agriculture needed managing seemed obvious to the Odums upon even the most superficial inspection. The return of some smaller dust bowls in the 1950s, the continuing decline of the farm population, the repeated agricultural booms and busts, and the pollutants arising from farmlands all pointed to a system dangerously unstable and unsustainable – the exact opposite attributes of a stable and self-maintaining mature ecosystem. If agriculture, with its unique status between the natural and the human environment, could not be effectively managed by ecologists, there was little hope for a meaningful role for ecologists in the management of other human systems. The Odums, continuing in their father's tradition, determined that a scientist's ultimate goal must lie in the human realm. Howard visualised the ecologist's role as wielding a 'macroscope.'[29] The goal of the ecologist was to look at all his data through a macroscope that would 'eliminate the details' of the tangled web of life and allow a simple diagram to be created (see Figure 1). This was all in keeping with the work of most ecologists in this period. But the final step in both Odums' conception of ecology involved the ecologist explicating the principles of the diagram and then 'managing with actions' the human system based on these ecological laws. Both ecologists were overcome with an excess of optimism in assuming ecologists would follow this banner. Howard predicted that in the future schoolchildren would be taught the 'three E's' ('energy, environment, and economics') and even helped to prepare a prototype of just such a textbook. [30] Eugene, meanwhile, predicted that ecology would become 'the link between the natural and the social sciences' and produced a textbook to show how this could

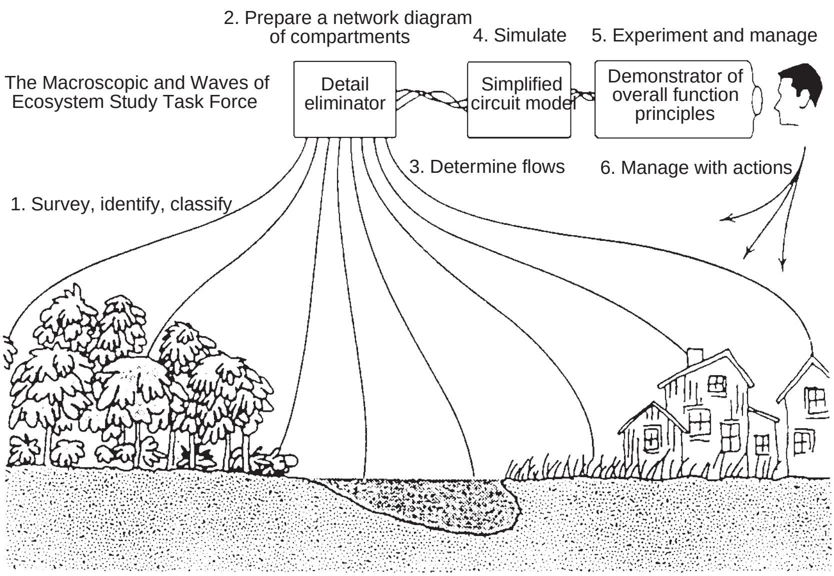

FIGURE 1. Cartoon of the 'macroscopic view' in which the detail eliminator simplifies by grouping parts into components of similar function. Once ths simplified model has been created it is the ecologist's role to 'manage' both the human and natural systems portrayed in the cartoon. (Howard Odum 1971: 10)

be achieved.[31] The path was laid for the reworking of American agriculture – the most obviously awry human ecosystem as regards natural ecosystem laws. Farm management was to be moved into the hands of the ecologists, while the farmers themselves were to be reduced to variables in an ecological diagram. With a working theory, a faith in the ecologist's role in human systems, and an important problem to tackle, the stage was now set for the Odums' analysis of American agriculture.

'EXPLANATION, PREDICTION AND CONTROL'

> The diagram of energy flow might be referred to by some as an 'Odum' device…
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> Eugene Odum, 'Energy Flow in Ecosystems: A Historical Review', 1968.[32]

The first thing the Odums required, to create a meaningful comparison of human and natural ecosystems, was a means to reduce both to a common language – in this case, it was energy, their preferred ecosystem language since the groundbreaking Eniwetok study. Ecoenergetics was to be the great unification model for human and natural systems. Initially a wheat field, a natural grassland, or a forest shared little resemblance to one another. The difficulty in dealing with human environments had led Clements to dismiss all agricultural systems as 'disclimaxes'.[33] This sense that human environments were beyond the pale of ecological investigation continued well into the 1950s. However, the Odums felt that by reducing all systems to energy and, then, by further reducing this energy analysis to a simple model, meaningful comparisons could be made. The details of both a natural and a human ecosystem could be overly distracting, what was needed were simple models to act as 'detail eliminators' that would 'extend the capacity to see the wholes and parts simultaneously'.[34] In Howard's words the energy diagrams would serve the three roles of 'explanation, prediction and control'.[35] By extending the explanatory weight given to their ecoenergetic models, the Odums made them the key to their own (and future) agroecological comparisons. They also risked allowing their models to develop an explanatory power greater than the facts might bear. The Odums were to transform their energy diagrams from a merely visual representation of energy transformations in an ecosystem, into a heuristic device for discerning new connections, deriving new theories, and making long-term predictions.

In the collaboration between the two brothers, it was Howard who was the more gifted modeller. Since his dissertation on 'The Biogeochemistry of Strontium', Howard had always taken a keen interest in physical ecology. Well-versed in both biochemistry and biophysics, it was natural that Howard's interests drifted towards energy – a common denominator in most chemical and physical experiments. Energy circuits had been common in the physical sciences for decades but they were virtually unknown in the biological sciences, particularly ecology which still had a strong bent towards natural history and applied botany while the Odums were being trained. Howard's spiritual mentor in unifying the physical and the biological was Alfred Lotka, a physical chemist whose 1925 work, *The Elements of Physical Biology*, predicted that all of biology could be reduced to matter and energy exchanges. Although Lotka did not mention how these exchanges should be depicted, some type of energy diagram was a reasonable way to present these exchanges for a visual field such as ecology. Howard's first diagrams of ecoenergetics in the early 1950s showed the various mass and energy amounts as they decreased from one trophic level to the next, while much of the energy was dispersed in heat (see Figure 2). These diagrams were effective visual aids and largely based on his study of Florida springs and estuaries. These early diagrams, according to Joel Hagen, continue to be published in textbooks up to the present. [36] However, these large masses

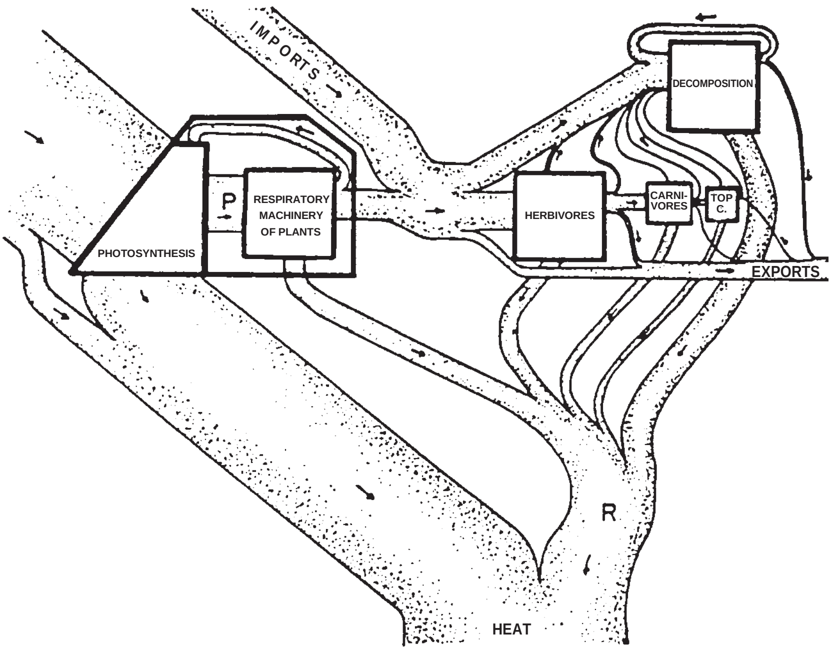

FIGURE 2. Energy flow diagram for an ecosystem. The diagram represents data obtained in 1956 from Howard's study of warm mineral springs in Florida. The various trophic levels are labeled in the boxes and the amount of available enegry declines at each stage (represented by changing width of energy bands) as respired energy goes to the 'heat sink' as a result of energy transformation. This particular diagram was reprinted in a number of ecology texts in the 1960s and 1970s. (Howard Odum 1960: 1)

gradually shrinking into higher trophic levels tended to confuse issues of energy and matter exchange and Howard, at an early stage in his diagramming, sought to move to the next level – energy circuit diagrams.

Energy circuits were a traditional way for physical scientists to demonstrate the transfer of at least one form of energy – electricity. Although Howard's early energy circuit diagrams, presented in 1959 before the Ecological Society of America, did not look especially auspicious to the attendees (see Figure 3), they had several things in their favour as far as the Odums were concerned.[37] First, Howard quickly abandoned the strictly analogous energy circuit diagrams of the electrical engineer for a more symbolic energy language he developed himself which combined some of the best design elements of his trophic diagrams – directional arrows, discrete stages, ease of visual analysis – with the traditional language used in electrical engineering. The other advantage, not immediately realised with the earliest energy circuit diagrams, was that it provided a gateway for the addition of both positive and negative feedback loops.

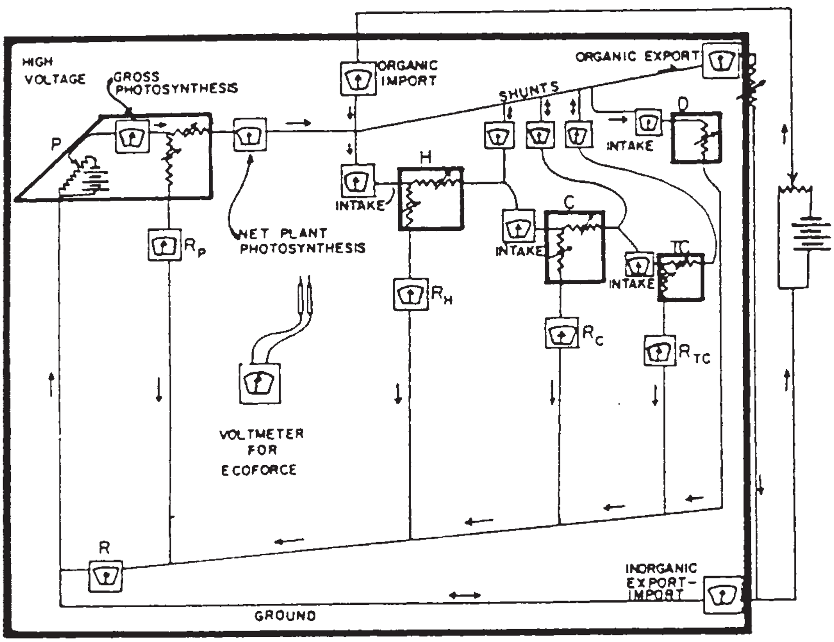

FIGURE 3. Howard's first presentation of a electrical analogue circuit. In this diagram of a steady state ecosystem, the flow of electrons corresponds to the flow of carbon. These strictly analogous diagrams were poorly received by ecologists and by the late 1960s Howard had replaced them with a more symbolic representation of energy flows through a system. (Howard Odum 1960: 4)

The promise of cybernetics in World War II had yet to fully manifest itself in ecology, prior to the Odums.[38] Physiology had incorporated homeostasis into its discipline and computing had adapted many cybernetic concepts, but the transition to ecology remained elusive. Howard's energy circuit diagrams, however, offered a way into cybernetics as his representations turned back upon themselves through feedback loops in a visually impressive and immediately apparent manner. These modeling devices quickly came to dominate a fair bit of the literature on ecosystems, in part, through the Odums' dominance in the field of American ecology in the 1950s and 1960s. Eugene's textbook, *Fundamentals of Ecology*, went though three editions (1953, 1959, 1971) and this definitive work in the 1950s and 1960s was filled with Howard's views on energy and with both brothers' energy diagrams, which derived from Howard's new energy models. Furthermore, the two brothers helped to train a new generation of college instructors through an advanced course in ecosystems biology at the Woods Hole Marine Biological Laboratory from 1957-1961. Together, the brothers enjoyed a quick trajectory of fame, winning three high prizes in ecology from three nations in three different decades as they shared the Mercer Prize in 1956 from the Ecological Society of America, the French Prix de l'Institute de la Vie in 1975, and the Crafoord Prize in 1987 from the Swedish Academy of Science. Eugene also went on to assume the presidency of the Ecological Society of America from 1964-1965. In the late 1950s and early 1960s the two ecologists were well-poised to introduce a new field of study in agroecology, enjoying secure research institutions, graduate students, and renown.

The agroecosystem was an overriding concern for both brothers when it came to trying out their new modeling system of energy. In many ways the American farm became the exemplar for the Odums' system of energy modelling for human ecosystems, just as the coral reef had served as the exemplar for natural ecosystems. Eugene's revolutionary 1964 article 'The New Ecology' had as its first illustration an SCS photo of a healthy farm, and he included lengthy sections in all his textbooks elucidating the basics of the agroecosystem. Howard, likewise, tended to introduce his energy diagrams using the agroecosystem in both popular books (e.g., *Energy Basis for Man and Nature,* 1976) and scientific texts (e.g., *Systems Ecology*, 1983). For both ecologists the agroecosystem was to be an important test case for the modelling and predictive powers of the new energy flow diagrams.

Howard first unveiled his new symbolic method of following energy flow in an article prepared for the Panel on the World Food Supply. In the published proceedings of the Presidential Commission, *The World Food Problem* (1967), Howard introduced his new energy diagrams specifically as a means to compare different agricultural systems around the world (see Figure 4). In the opening sentence of the article Howard immodestly declared that: 'The problem of world food production and the population explosion is one of system design.'[39] The rest of the article proceeded to lay out energy flow diagrams as a means of comparing different agricultural systems and evaluating them.

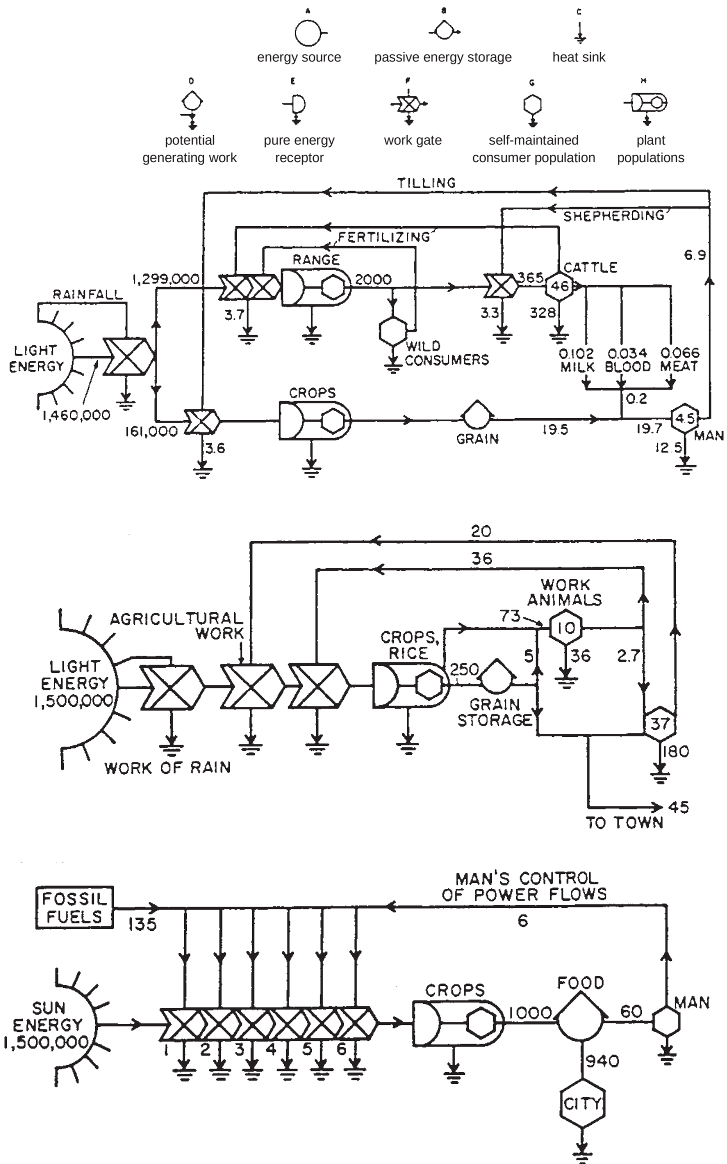

FIGURE 4. Energy circuit diagrams for: tribal cattle system in Uganda (top); unsubsidised monsoon agriculture in India (middle); and fuel-subsidised industrial agriculture of the United States (bottom). The purpose of juxtaposing these systems was to show how the high yields of American agriculture were based on large inflows of fossil fuels which (1) replace the work formerly done by man and animals and (2) do away with the more diverse network of animals and plants preserved in the two non-Western systems. (Howard Odum 1967: 72, 74, 76, 82)

For the models of both natural and human ecosystems to be of any predictive or theoretical value they had to follow certain laws. Early on, Howard described the three ecoenergetic laws which would play a role in interpreting all such diagrams.[40] The first law was the familiar one of conservation of energy, which required that in each diagram all energy be accounted for somewhere in the model. The second law was a variation on the entropy law, which required the necessary degradation of energy at each stage of transformation, usually into a heat sink (or respiration). The final law was variously described by both Odums as the Darwin-Lotka law or 'the maximum power principle'; this law stated that natural selection selected for maximum effectiveness in the use of available energy resources. This third law was variously interpreted as working at the system level and the individual level, but in effect almost all the Odums' examples derived from the level of systems (i.e., rainforests, lakes, estuaries, coral reefs). Of the three explicit laws which constrained each energy diagram, the first two laws required a careful accounting of every kilocalorie taken into a system and used up in the process, while the third law required a smooth flowing system in which successful systems were shown to make the maximum efficient use of energy resources.

In addition to the three explicit energy laws, there were a number of tacit assumptions made by the Odums. The first tacit assumption went back to the Odums' coral reef study, where they had learned that a mature ecosystem tended to have production equal to respiration, with minor oscillations. Consequently, mature systems were modelled as relatively stable, self-maintaining units where production (i.e., photosynthesis) roughly equalled respiration. Following a period of unrestrained growth, maximum power and efficiency were assumed to arise from increasing complexity and stability within the ecosystem. In addition, the Odums' focus on the system level, rather than the individual, led to an analysis which, both implicitly and occasionally explicitly, described selection occurring at the system level. The maximum energy use and the steady-state of the mature ecosystem were often described in terms of natural selection occurring at this higher level. Likewise, when it came time for the Odums to investigate the agroecosystem, it was at the level of national systems that most of their examples were derived. They would frequently diagram a prototypical 'American farm', but the examples that followed were inevitably drawn from different nations and cultures so as to make the comparisons more striking. This larger system analysis became important as the Odums sought definitively to tie industrialised farms into the larger industrial society. Finally, both ecologists assumed that all inputs into the ecosystem could be converted into energy. In Howard's earliest diagrams in the 1950s, the cycling of nutrients and the cycling of energy had often been portrayed in separate models. But with the beginning of Howard's more symbolic energy circuit models in the 1960s, all inputs – nutrients, labor, respiration – were reduced to common energy units (usually kilocalories). By the 1970s, even more problematic inputs such as money were occasionally being converted to energy units (i.e., dividing the gross national product in dollars by the total energy production in a nation).[41] The cumulative effect of the Odums' tacit system assumptions was the increasing reduction of all important inputs to energy, the necessity of examining many conversions at the larger system level (i.e., GNP only had relevance at the level of a national agroecosystem), and the further removal of the diagrams from any observed data, as they sought to encompass more elements deemed crucial to understanding the system.

With this combination of explicit laws and tacit assumptions, the Odums proceeded to outline the key characteristics of human ecosystems in general, with particular attention being paid to the American agroecosystem. From their earlier work on stable ecosystems, it seemed clear to the Odums that the key to understanding the agroecosystem lay in discovering how energy flowed through the basic trophic levels of a farm, with crops as producers and urban humans as the ultimate consumers. If all inputs and outputs on the farm could be reduced to kilocalories then alternative forms of agriculture could be examined and compared. Both Odums were particularly interested in the comparative aspects of agroecology, in part because of dominant political interests in the 1960s. The International Biological Program (1968-1974) and various food panels convened by the United States and the United Nations during this period were preoccupied with the question of how to feed the world's burgeoning population.[42] The Green Revolution offered one possible answer to fears of overpopulation.[43] However, Howard, through his work in Puerto Rico and with the White House Panel on World Food Supply, had become increasingly convinced that developing nations' agricultural systems were poorly understood and might contain hidden efficiencies unknown to American experts.[44] In particular, Howard was struck by the stability of millennial-old cattle raising practices in Uganda and monsoon agriculture in India. Never one to evade a telling catch phrase, Howard quoted Gandhi's statement that in India 'cows are sacred because they are necessary' to frame his own analysis about the protein and manure returns provided by cattle in India.[45] While experts were just beginning to study the systems of agriculture in the developing world, both Odums felt that the American agricultural system had also been largely unexamined from an energy perspective and had been widely misunderstood as a result.

According to the Odums, the myth of American agriculture was predicated on a common belief that increasing crop yields were the result of more efficient use of solar energy. This belief, the basis of the Green Revolution, claimed that fertilisers and pesticides had allowed any natural disasters and nutrient bottlenecks to be overcome, while hybrid seeds allowed for increasingly efficient use of all the solar energy received in a field. Both Odums referred to these common conceptions as 'energetic fallacies' for, like perpetual motion, they seemed to imply that something could be constantly increased without any compensatory costs.[46] The only way to combat these misconceptions involved detailing all the agroecosystem's energy inputs and outputs.

That is not to say the standard beliefs about American agriculture did not hold some truths. American agriculture was magnificent at increasing crop yields and all the diagrams of international agroecosystems tended to have the United States or Japan at the top of the list for crop yields per acre.[47] The misconceptions arose from equating yields with efficiency. In economics, the equivalent would be equating the gross national product with each individual worker’s efficiency, regardless of other inputs such as mechanisation. Similarly, the Odums felt that the actual energy costs of American agriculture had been significantly underestimated, due to a lack of accounting for fossil fuel subsidies. Every ounce of fertiliser, pesticide, and diesel fuel used to run a piece of farm machinery was a fossil fuel energy input, and had to be accounted for in the energy ledger in accordance with the first law of thermodynamics (and ecoenergetics) – that energy is neither created nor destroyed. That this had not been previously attempted was partially due to difficulties in conversions. The units of energy for food were traditionally kilocalories, and those for fossil fuel were joules or watts. However, the conversions did exist and could be made increasingly with calculators and computers in the 1960s and 1970s. Another reason for the lack of analysis was the result of United States Department of Agriculture (USDA) being primarily interested in yield per acre, regardless of energy inputs.[48] The Odums argued the most important figure was not the *gross energy* produced (as measured in total crop yields of American agriculture frequently touted by the USDA) but rather *net energy* was the figure that counted in evaluating the agroecosystem. Net energy was a fairly slippery commodity in the Odums’ hands, but a common sense one. Since solar energy was a free and continuous input into an open system, one could ignore it for the purposes of determining net agricultural energy.[49] But any energetic inputs – such as fossil fuel, labour, and chemical additives – had to be added up and compared to the amount of energy made available in kilocalories of food. When defined this way, there was an interesting evolution in the history of agriculture toward declining net energy yields. Hunting and gathering and subsistence farmers tended to have small net energy yields, while highly industrialised farming of the Western variety tended to have a net energy loss. In fact, there was a strong correlation between auxiliary energy inputs (that is anything but solar energy) and decreasing net yields.[50] The fact that human cultures had moved away from net energy yields over their history might have made it appear evolutionary advantageous. However, Eugene explained this phenomenon as being a result of humans being stuck in a type of ‘pioneering stage’ in which it was advantageous to maximise the use of energy resources, even while the human population and its complex modern civilisation required a transition to a steady-state climax stage.[51] The job of ecologists, such as the Odums, was to increase the human understanding of their current agroecological stage and help humans modify their policies in accord with it.

The first stage in increasing public understanding involved laying out the details of American agriculture. A distressing tale of the decline of American agriculture, as regards net energy, emerged from the Odums' breakdown of all the inputs that went into that agriculture. The Odums, in a rather uncharitable assessment of the general public, believed that most people saw sunlight and hybrid seeds yielding larger crops and never went beyond this type of superficial analysis. The ecologist's job was to pull back the curtain and expose, via energetic models, that the Great Oz of American agriculture was hardly as powerful and stable as it appeared. The key to the Odums' analysis of American agriculture revolved around what they termed *auxiliary* sources of energy. As opposed to a natural system, human systems could modify evolutionary tendencies by adding auxiliary sources of energy. A stable ecosystem in nature was forced to expend a fair amount of the system's energy providing for the maintenance of the flora and fauna. In fact, many ecosystems enjoyed a noticeable shift over time from pioneer species (those that used energy resources with profligacy), to more stable species (those which were more economical in their demands). Clements referred to these generalised species as pioneer and climax species; MacArthur and Wilson, in their 1967 work *Island Biogeography*, referred to them as r-selected and K-selected species; and the Odums referred to them as C4 and C3 plants.[52] Although the names changed with the changing ecological paradigms, they all referred to two classes of species: the former being adapted to quick, fast growth, the latter being adapted for stability and maintenance of a complex system.

According to the Odums, this natural evolution towards climax species was precluded in agriculture because farmers sought to maximise production via quick-growing species of plants (such as C4 varieties). The use of pioneer species and monocultures prevented the appearance of a well-developed climax community and, by all ecological laws, these stands of plants should have been prone to large boom-and-bust cycles. However, it was painfully obvious that the opposite had occurred in the United States, where crop yields kept on consistently increasing, with only periodic fluctuations during particularly adverse weather conditions. According to the Odums, American farmers had achieved this feat by using fossil fuels to bypass the evolutionary cycle. Plants that should have evolved to be more stable and self-sufficient (or been replaced by others that were) persisted in agricultural fields because virtually all maintenance functions were replaced by fossil fuels. Pesticides killed predators, fertilisers decreased the need for deep and efficient roots, feedlots decreased any energy expenditures cattle might require, and air-conditioned hen houses reduced the need for chickens to maintain their own temperature-regulating mechanisms. Farmers had been able to maintain highly productive pioneer-type species, that were inherently unstable, by releasing all the pioneer's energies for the production of increasing yields. These fossil fuel farms were populated by seemingly monstrous hybrids, bred not for any efficiency as regards sunlight, but rather for their symbiotic potential with fossil fuel auxiliaries:

> We now have chickens that are little more than standing egg machines, cows that are mainly udders on four stalks, and plants with so few protective and survival mechanisms that they are immediately eliminated when the power-rich management of man is withdrawn. Such varieties are complementary to the industrialised agriculture and cannot be used without it.[53]

With this analysis, the Green Revolution came across as a 'cruel hoax' since these hybrid species would have little hope of survival in a non-industrialised society without the requisite fossil fuel subsidies.[54] Equally important, this analysis boded ill for the sustainability of American agriculture. According to Howard: 'Nothing about man's present system [of agriculture] is balanced, for his inputs come from geological storage and from energies that used to go to balanced systems'.[55] Considering that one of the primary attributes of mature ecosystems was stability, American agriculture seemed at odds with all natural systems laws.

The Odums, in re-examining the American agroecosystem, had moved themselves to the forefront of a contemporary political debate on Third World development. Paul Ehrlich's 1968 polemic *The Population Bomb* had largely stigmatised people of the developing world as breeding themselves into poverty.[56] Ehrlich and population ecologist Garrett Hardin both raised questions about the efficacy of the Green Revolution to meet the needs of a burgeoning world population.[57] The Odums had previously entered the debate on the Green Revolution, yet they approached the problem from the opposite end. The Odums argued that American agriculture had been a vast experiment, replacing natural ecosystems with heavily dependent monocultures. The result of these policies had been a costly and unstable agriculture whose export to the rest of the world seemed dangerous and misguided. This confluence of political and scientific issues of the 1960s caused the Odums to examine international agroecosystems, but their primary interest remained the United States. They felt that a necessary first step involved understanding the domestic agricultural situation, before beginning a heedless export.

This analysis of the domestic agroecosystem led to a critique of the American economy ranging far beyond the Green Revolution. Once begun, the analysis of human agroecosystems called into question every aspect of human ecology and economy. As their ecoenergetic diagrams began to encompass cities (as the ultimate processors and consumers of agricultural products) both Odums began to question the energetic foundation of American society. Eugene, in an important 1969 article for *Science* entitled 'The Strategy of Ecosystem Development', attempted to explain two centuries of American history using the laws of ecosystems succession:

> In the pioneer society, as in the pioneer ecosystems, high birth rates, rapid growth, high economic profits, and exploitation of accessible and unused resources are

> advantageous, but, as the saturation level is approached, these drives must be shifted to consideration of symbiosis (that is, 'civil rights', 'law and order', 'education', and 'culture'), birth control and the recycling of resources. A balance between youth and maturity in the socio-environmental system is, therefore, the really basic goal that must be achieved if man as a species is to successfully pass through the present rapid-growth stage, to which he is clearly well-adapted, to the ultimate equilibrium-density stage, of which he as yet shows little understanding and to which he now shows little tendency to adapt.[58]

According to Eugene's prescription, the human ecosystem needed to approach more closely a mature equilibrium system where production and respiration are nearly equal. Some of the solutions Eugene directed at American agriculture included: the use of more 'detritus agriculture' (including oyster beds along the entire East Coast), less dependence on fossil fuel inputs on the farm, and a halt to the Green Revolution. In addition, Eugene argued for diverse homesteads, both for aesthetic reasons (he felt most heterotrophs prefer to have both grass and trees) and because they offered more stability from ecological perturbations.[59]

Howard went beyond these rather timid goals to envision more broadly what the entire human ecosystem would look like if it followed all natural ecosystem laws. First, Howard reaffirmed the equivalence of all natural and human systems by diagramming history and religion as ecological feedback loops in *Environment, Power, and Society* (1971) – his first attempt to make accessible to the general public the explanatory, predictive, and control aspects of his new energy diagrams. From this analysis, Howard proceeded to offer a prescription for bringing the entire human ecosystem into a more stable accord with natural laws. For a human ecosystem to approach a natural mature ecosystem required achieving an equilibrium between production and respiration, and growth must give way to self-maintenance. Obviously, the large energy subsidies for agriculture would have to cease and instead, more efficient use of decomposers, animals, and human labor would have to occur to maintain production. Howard's speculations in *Environment, Power, and Society* were relegated to the final chapters in an otherwise rather sober scientific treatise; however, the future outlined in the final chapters of that work was revisited in Howard's later, post-OPEC oil crisis writings, including his prototype of a textbook for the three E's – *Energy Basis for Man and Nature* (1976). In this later work, an emboldened Howard envisioned American agriculture in the near future as approaching the steady-state of traditional Asian agriculture, 'where the nutrients are recycled and most yields reinvested in work back on the land' and where the primary energy inputs involved human and animal labour.[60] Howard predicted that travel agents, luxury dealers, international traders, and other occupations at the top of the fragile, production-driven, fossil fuel economy would have to be transferred to the farm economy to meet the needs of a newly labour-intensive agriculture.[61] The resulting human ecosystem would be self-sufficient, regional, and less prone to non-local fluctuations. The loss of Florida oranges available year-round would be compensated for by the sustainability of the new system and the end of agricultural booms and busts. Howard presented this future as 'a happy place' and an optimistic alternative to the unnatural *Future Shock* (1970) previously described by Alvin Toffler.[62] Like a natural ecosystem, the human ecosystem at that point would be geared toward the sustaining of diverse regional units at a steady-state.

CONCLUSION

The OPEC oil crisis of 1973 seemed to vindicate the Odums' predictions about the instability of American energy use. Both Odums took the crisis as proof of their analysis and claims and prepared, in vain, for a more general acceptance of their ecoenergetic analysis of society. The Odums did succeed in attracting some adherents to their beliefs; unfortunately they were the wrong sort of disciples. The Odums' work began to attract attention from some of the same amateur groups whom systems ecology was meant to supersede. Organic farmers and environmentalists, in particular, found many points of intersection between the Odums' solutions and their beliefs. Organic farmers found an unlikely ally in the Odums' agroecology.[63] The organics' shunning of herbicides and pesticides need no longer be based on vague misgivings about industrialised farming, but could now be justified as the avoidance of unstable expenditures of geological resources – using the Odums' analysis. The organic farms and ideology also seemed to fit best into the mode of a low-energy and high-diversity ecosystem, toward which mature natural communities were constantly striving.[64] Even the rhetoric of the Odums at times seemed to echo that of organic farmers and alternative agriculturists when, for example, Howard claimed that 'agribusinesses' will be replaced by 'agrihumanity'.[65] The Odums discussion of local food producing regions echoed the organic Rodale Institute's later work on 'foodsheds' – both ideas self-consciously building on SCS concepts of ecologically important agricultural watersheds. The organics could now find agroecological support for their agrarian nostalgia and health concerns.

In a similar manner, the type of society envisioned by Howard Odum in the steady-state future struck an appealing note with many environmentalists. Howard's 'Ten Energy Commandments' to replace anthropocentric religion, reflected the growing environmental belief in 'the rights of nature'. The final commandment declared 'Thou must find in thy religion, stability over growth, organisation over competition, diversity over uniformity, system over self, and survival process over individual peace.'[66] The fiercely biocentric 'deep ecologists' of the 1980s found much to admire in the Odums' human ecology.[67] In addition, certain pseudo-scientific organisations like Biosphere 2 (the ill-fated attempt to re-establish a sustainable and self-sufficient human ecosystem in southern Arizona) quoted approvingly from both Odums to support their research.[68] The Odums predicted a future steady-state human ecosystem that would be more agrarian, regional, stable, and diverse – all terms that have become buzz words of environmentalists in the last twenty-five years. In addition, the Odums, unlike most ecologists, were firmly committed to bringing the human ecosystem into line with ecological laws, since they saw no clear demarcation between them. This fitted in well with the modern American environmental movement's attempts to ensure a political role for ecologists and ecology.[69]

Unfortunately, scientifically suspect organic farmers and environmentalists had not been the intended audience for the Odums' agroecology. The Odums had hoped to move beyond amateur groups to create a working theory of human ecology that would follow its laws as inextricably as the coral reefs followed their ecoenergetic laws. The Odums assumed that ecologists would lead the way in the rationalising of the human ecosystem. The Odums needed to appeal to the ecology community and the federal government to achieve their goal of rationalising the human ecosystem. With these two groups, however, they were not particularly successful.

Ecologists were the first to pull back from some of the more unorthodox speculations of the Odums. These speculations were a natural outgrowth of the Odums' type of ecosystem analysis which constantly spoke of natural ecosystems having 'strategies' and 'goals' which were achieved via 'feedback loops' in the system. If natural ecosystems did indeed have such strategies then it made perfect sense for human ecosystems to be brought into accord with similar goals – especially agriculture, which was perceived by the Odums as an ecosystem in which all natural feedback loops and controls had been eliminated in order to maximise productivity. Unfortunately, the Odums' rather injudicious use of such anthropomorphic terms tended to scare off a new generation of ecologists. By the late 1960s, fewer and fewer ecologists were finding the search for ecosystem strategies and goals a particularly fruitful area of research. Instead of the Odums' purposeful ecosystems and system strategising, a new generation of ecologists was becoming more interested in the interworkings of selfish individuals to fulfill their Darwinian strategies. The next generation of ecologists, in the 1970s and 1980s, found their most fruitful paradigms in the evolutionary transformations of populations. The effect of the Odums' attempt to blend the natural and social sciences was that their work was attacked as anthropomorphic and teleological by the very ecologists they sought to empower. Agroecology was gradually marginalised as a hybrid anthropological ecology, with no effective base or adherents in American agricultural colleges throughout the 1970s and 1980s. In spite of its origin as an attempt to analyse American agriculture, agroecology was pushed to the edges of academia, as a tool to study 'other' systems or to understand the effects of the Green Revolution. Although their values were often sympathetic to developing nations, agroecologists largely took on the colonial role of studying other peoples from a Western perspective. Ecologists, by and large, gave up the human ecology work of the Odums, and restricted agroecological analysis to an academic niche most often found studying developing nations or primitive tribes, not the agricultural system that supported their universities.

Scientists associated with land-grant institutions either ignored the Odums or actively attacked their ideas. One of the great advantages of the diagrams pioneered by Howard was their ability to reduce all inputs to an interconvertible unit of energy. The Odums felt that this allowed meaningful comparisons to be made between human and natural systems for the first time. Unfortunately, the Odums' theories were vulnerable to charges of privileging energy above all other causal factors. This became especially obvious in the Odums' one sustained analysis of a human systems – the agroecosystem – which did not in fact revert to the type of nineteenth century farm communities predicted by energy flow models. Yet both Odums continued to make these type of generalised predictions about human systems well into the 1990s, based largely on their all-encompassing energy analysis. Agricultural economists were rather quick to attack this type of analysis, on the basis of two claims. First, agricultural economists had their own definition of energy as equivalent to its cost in dollars as an input. This was at odds with the Odums' conversion of all elements to energy. The issue among agricultural economists was whether you wanted to reduce everything to energy or money – a debatable point. [70] More problematic was the claim (again led largely by aggrieved land-grant economists) that the Odums' models did not mirror what actually occurred on American farms.[71] Here the critics seized upon the relatively small data base available to the Odums and the rather sweeping generalisations arising from this data.[72] The economist critics' general claim was that the agroecologists had not effectively demonstrated how their analysis was more 'useful' in policy decision-making than more traditional economic analysis. The economists argued that the agroecologists' scientific credentials and powerful use of physical laws effectively shrouded some of the utilitarian flows of their analysis. By exaggerating the utilitarian flaws in net energy analysis, the agricultural economists largely sidestepped the issue of whether net energy analysis held any explanatory power. Because flaws could be discerned, the argument went, agroecology need not be considered as a serious policy tool.

In part, the Odums' ineffective policy efforts were the result of their own personal and occupational limitations. The Odums' reductionist techniques and holistic claims allowed for an exciting research agenda in the 1950s and 1960s, while largely remaining above the mundane level of everyday practicalities in American agriculture. This allowed the Odums to examine American agriculture in a wholly new way and to detect heretofore unknown long-term instabilities in American agriculture. Unfortunately for the Odums, agricultural policy has always been formulated in the mundane present. Since the advent of large federal agricultural subsidies in the 1930s, American agricultural policies have been driven by a combination of historical, political, and economic factors. None of these translated particularly well into energy units. The Odums were, from the beginning, more interested in rewriting the history of agroecology than in studying the history that gave rise to American agriculture. This prevented the Odums from enlisting support from outside groups who had long sympathised with the types of dire agricultural warnings presented by agroecology. The Odums' political naiveté and disinterest also limited effective federal implementation of their programme. They could not reduce to kilocalories the effect of having federal subsidies controlled by powerful Senators with strong rural constituencies. In addition, the *long-term* nature of the 'predictions' implied by the Odums' energy diagrams made them politically problematic and a less than perfect policy instrument. Economically, crop values, with their historical, social, and political contingencies, were not necessarily the equivalent of their energy value as related to a barrel of crude oil. The Odums were relatively uninterested in why energy values did not function on the farm as they did in the ecoenergetic diagrams. The Odums always focused on two of the three E's (energy and environment always took precedence over economics), and the Odums' economist critics pointedly seized upon the gap between the energy diagrams and what actually was happening on American farms. Not surprisingly, recent environmental transformations in agriculture – such as no-till farming – owe more to the development of new pesticides and herbicides than ecoenergetic diagrams. The Odums' broader programme of a planning role for agroecology faltered on the irreducible human constructs of history, politics, and economics which drove, and continue to direct, American agriculture.

The Odums' legacy was ultimately a narrower one than they would have liked. Although their policy goals largely failed, the Odums' diagrams proved a useful heuristic device for comparing differing agroecosystems by reducing them to their most basic energy inputs and outputs, while allowing the viewing of the whole and the parts simultaneously. Their diagrams and personal popularity persisted, while their importance within the ecological community waned after the 1960s. The power of the Odums' combined work lay in equal measure upon their own scientific prestige and the usefulness of their diagrams. As a dominant force in the American ecological community in the 1950s and 1960s, their work was understood and replicated across the nation and hence was profitable as regards publications and research programmes. Both Odums were quite successful in setting up a number of ongoing ecological institutions at their home universities. In addition, their models were an important tool for the burgeoning field of ecology after the 1950s. Although Howard understood the mathematics probably as well as any ecologist in the field, his diagrams did not require specialised mathematical knowledge. The Odums (when they listed them at all) placed the equations for their models far away in the appendices of their papers and texts. As Howard noted, the energy circuit diagrams were 'a form of mathematics with emergent theorems and perceptions that extend the capacity to see the wholes and parts simultaneously'. [73] The models may have been mathematical in derivation, but their comprehension required no special mathematical skill and this may have accounted, in part, for their continuing popularity in introductory texts and among certain mathematically averse ecologists. Finally, the visual appeal of the models themselves almost certainly played some role in the continuing Odum legacy. As opposed to mere numbers or graphs, the Odums' models actually seemed to represent the way nature works and hence were reminiscent of an older tradition of natural history. In a field such as ecology, whose roots were largely observational, it is not surprising that the visual ecology of the Odums' models enjoyed a lasting popularity in texts and presentations – long after the research programme of most ecologists had abandoned the Odums' energy reductionism and system dynamics. The science of agroecology itself retained a large share of both the Odums' methodology and modeling techniques, while initially narrowing the scope of its focus largely to 'other' agricultural systems beyond the developed world's boundaries. As the science of agroecology began to define and delineate itself more strongly along these lines, it moved further from the Odums' social role and left the way open for a new generation of political ecologists to take over the social half of the Odums' programme.

The political ecologists largely took up the more extreme programme of a critique of American society that had been inherent in many of the Odums' more encompassing energy diagrams. Rachel Carson was the most important early populariser of some newly discovered agroecological dilemmas. Her environmental wake-up call, *Silent Spring* (1962), helped to present American agriculture for the first time as a system dangerously at odds with nature and capable of endangering the broader populace. Barry Commoner went on to re-evaluate the entire American agricultural system in the 1970s and concluded that the system was dangerously unstable both economically and environmentally.[74] Commoner attributed this to the cheap inputs of energy and its by-products which, he claimed, made it pay to pollute. Agriculture played an important role in Commoner's broader critique of capitalism as anti-environment. Yet, reminiscent of the Odums, Commoner was likewise unable to expand the domestic constituency for agroecology. Certainly, part of the domestic failure of agroecology can be attributed to the politics of the farm bloc. Since the 1930s, a coherent political interest group has emerged based on federal subsidies of agriculture and consisting of land-grant institutions, farmers, and federal agricultural agencies. This powerful force has consistently and effectively mobilised counter-attacks to any critique of current agricultural policies. But the failure to mobilise a larger share of environmental activists or ecologists surely cannot be attributed solely to the farm bloc. Rather, both environmentalists and ecologists seem unwilling to accept human ecology as a *natural* field of study or activism. Until human environments are incorporated into the same privileged realms of study and protection which natural systems enjoy, programmes such as agroecology must surely falter on the prejudices of their chosen constituency.

NOTES

[1] Howard T. Odum 1971: 116.
[2] Howard W. Odum's two seminal works on regionalism were *Southern Regions of the United States* (1936) and *American Regionalism* (with Harry Estill Moore in 1938).
[3] As quoted in Eugene Odum, 'The Attitude Revolution', 1970: 14.
[4] Biographical details about the Odums are from: Hagen 1992: 101-145; Taylor 1988: 213-244; McMurray 1995: 1501-1503.
[5] Eniwetok was a two-square-mile circular atoll in the Marshall Islands chain in the western central Pacific. Captured by the U.S. in 1944, it had been an atomic test site since the end of World War II.
[6] The best treatment of the importance of the Odums' work in the 'atomic age of ecology' is found in Hagen 1992: 101-121.
[7] H.T. Odum and E.P. Odum 1955: 291-320.
[8] Eugene Odum was well-versed in Clementsian theories, having studied zoology at the University of Illinois in 1937 under Victor Shelford, who was then collaborating with Frederic Clements on *Bio-Ecology*. As regards evolution at the level of systems, Howard defined it as such: 'By systems selection, Lotka, Tansley, and the theories in this volume refer to self-organisation choices that contribute to the systems resources for meeting contingencies. Darwinian selfish selection is regarded as a secondary priority for survival.' (H.T. Odum 1983: 453)
[9] H.T. Odum and E.P. Odum 1955: 291. The introduction went on to ask about the connections between productivity, energetic efficiency, and a steady-state equilibrium.
[10] The most common SCS techniques to hold soil and water in their proper places included: plouging along contour lines, terracing steeper hillsides, intercropping strips of grasses or trees to retain soil and moisture, crop rotations to restore soil nutrients, and various drainage projects designed to better control water runoff and prevent soil erosion. The heyday of these projects occurred from 1933-1937, when an influx of youthful Civilian Conservation Corps labour allowed large-scale implementation of these projects on endangered farmlands.
[11] The SCS in 1937 began to organise all the nation's farmers into Soil Conservation Districts. The SCS was committed to providing technical support and land-use maps to all farmers participating in the districts. In spite of the districts, it became apparent during World War II and immediately afterward that farmers felt free to drop out of any soil conservation plan whenever market conditions made it lucrative to do so. Faced with a growing dropout rate and a farmer-based agenda within the districts, the SCS after World War II began to focus more on land drainage, flood prevention, and efforts to increase crop production. For a more detailed discussion of the Soil Conservation Service during and immediately after World War II, see Madison 1995: 157-172.
[12] E.P. Odum 1993: 140. Eugene in the 1950s originally thought the SCS might play a useful role as a provider of technical support along the natural boundaries of watersheds. However, the SCS's inability to develop a coherent theory-based science, its dubious reclamation efforts, and its political ties to the farm bloc all helped to disillusion Eugene about the potential of the SCS.
[13] E.P. Odum 1964: 16; Howard Odum and Elisabeth Odum 1976: 7.
[14] The group I labelled as 'agrarian romantics' all had close ties with the Soil Conservation Service. For example, one of the founders of the Friends of the Land was Hugh Hammond Bennett, Director of the SCS. The editor of the Friends of the Land journal, *The Land*, was

a former writer of SCS pamphlets, Russell Lord.
[15] E.P. Odum 1969: 262-270.
[16] In 1942, J.I. Rodale began publication of *Organic Farming and Gardening* magazine. For the first two decades of its existence, American organic farming was largely dominated by Rodale's publications.
[17] Olds 1969: 66-71. In this article, Barry Commoner speaks patronisingly of organics stumbling onto ecological laws. The Odums for their part rarely, if ever, mentioned the organics although many of their proposals – such as low-input farming, compost heaps, and detritus agriculture – could likely be traced to them. Instead, the ecological histories produced in Eugene's textbooks and articles scrupulously avoided mentioning any organic predecessors.
[18] In an interesting historical footnote, the official SCS publication, *Soil Conservation*, actually discussed a new science of 'agroecology' at least twenty years before the Odums first became interested in the topic. The article discussed the new European science of agroecology which sought to quantify appropriate agricultural plants based on the environment and particular farm culture of a region. The agroecology described in the article resembled a mixture of plant botany and social anthropology. It did not involve energy or any ecological concepts nor was it an important factor in shaping the American version of agroecology. Characteristically, the technical and engineering-based SCS paid no attention (besides the one article) to the new science. Bensin 1938: 138-141, 152.
[19] Bensin 1938: 138-141, 152. Bensin was an agricultural scientist who occasionally taught at the USDA Graduate School in Washington, D.C.
[20] Bensin 1938: 138.
[21] Bensin 1938: 138.
[22] Transeau 1926: 1-10. Transeau was a scientist at Ohio State University and President of the Ohio Academy of Science.
[23] Transeau 1926: 1.
[24] Transeau 1926: 10. Transeau did his energy conversion by converting glucose to calories and using calories as the standard for comparing various energy efficiencies. Transeau, unlike the Odums, did not consider the inputs of fertilisers, pesticides, mechanical fuels, or labor into his equations, in part, perhaps because they played a much smaller role energy-wise in the American agriculture of 1926 than they did in 1966.
[25] Transeau seems to have also fallen out of later histories of agroecology. The only agroecologist to mention Transeau as a pioneer in the field was Stanhill 1984: 3.
[26] Sir Albert Howard, an agricultural scientists in colonial India, introduced the Indore method of composting to American farmers in the 1940s through J.I. Rodale's magazine *Organic Farming and Gardening*.
[27] E.P. Odum 1968: 11-18.
[28] E.P. Odum 1964: 16.
[29] H.T. Odum 1971: 9-11.
[30] H.T. Odum and E. Odum 1976: 13. Every chapter in this book had questions at the end to provoke either the high school or undergraduate readers to envision the links between the three E's. In reality all of Howard's books after 1971 had this goal of uniting the three E's.
[31] E.P. Odum, *Ecology: The Link Between the Natural and the Social Sciences*, 2nd ed. (New York: Holt, Rinehart and Winston, 1975). The first edition came out in 1963 and although the theme was the linkage between the two sciences, the subtitle was only added to the second edition. The Odums' book titles were often an explicit call for a link between

the natural and human sciences: Howard Odum, *Environment, Power, and Society* (1971), and Howard Odum and Elisabeth Odum, *Energy Basis for Man and Nature* (1976). Even Eugene's earliest textbook, in 1953, strongly supported this linkage in its content.

[32] E.P. Odum 1968: 16.

[33] Disclimax stood for 'disrupted climax community.' Clements also used the term proclimax to describe agricultural systems. Clements and Chaney 1936: 48.

[34] H.T. Odum 1971: 10.

[35] H.T. Odum 1983: 579.

[36] Hagen 1992: 142.

[37] Howard's presentation before the ESA was reprinted in: Howard Odum, 'Ecological Potential and Analogue Circuits for the Ecosystem,' *American Scientist*, 48, No 1 (1960), pp. 1-8.

[38] Norbert Wiener's influential book *Cybernetics* came out in 1948.

[39] H.T. Odum 1967: 55.

[40] Howard's laws were laid out quite early in the chapter on energetics he wrote for his brother's textbook. E.P. Odum 1959: 43. Originally these thermodynamic laws were supposed to be superseded by something called the 'ecoforce,' which Howard introduced along with his energy circuit analogues in 1959. But the power of the ecoforce to 'force' energy through the various trophic levels was quickly abandoned and the thermodynamic laws returned to the forefront of Howard's model-making.

[41] H.T. Odum 1971: 297-298.

[42] E.P. Odum 1968: 17. In this overview of systems ecology, Eugene explicitly tied the new energy flow diagrams to the International Biological Program and other attempts to grapple with the food problem.

[43] By the Green Revolution I refer to attempts, beginning in the 1960s, to dramatically increase food production in the developing world using high-yield hybrid seeds, pesticides, herbicides, and large-scale mechanical farming.

[44] Howard was given funds from the Rockefeller Foundation in 1957 to study the Puerto Rican rainforests and their response to a massive input of energy. From this natural system, Howard began to devise models for humans in response to massive inputs of fossil fuels.

[45] H.T. Odum 1967: 60.

[46] H.T. Odum 1971: 128.

[47] Examples of such diagrams include: E.P. Odum 1971: 412; E.P. Odum 1993: 85; H.T. Odum 1971: 132. These diagrams were generally presented as straw men to be followed by analysis demonstrating that gross yields were not the crucial measure for agroecology, but rather net yields (in which the United States and Japan did not fare so well) were the important figure.

[48] The USDA still does not have any breakdown for the energy costs of crops.

[49] H.T. Odum and E. Odum 1976: 79. Howard succinctly defined net energy as 'the energy yielded over and beyond all the energy used in processing it.' According to his diagrams and analysis, solar energy was not a 'processing' energy but all other energy inputs were tabulated.

[50] H.T. Odum 1983: 253.

[51] E.P. Odum 1969: 262-270.

[52] H.T. Odum 1983: 373.

[53] H.T. Odum 1971: 128.

[54] H.T. Odum 1971: 128.
[55] H.T. Odum 1971: 288.
[56] Ehrlich 1968.
[57] Hardin's two most provocative discussions of the issue appeared in 'The Tragedy of the Commons' (1968) and 'Lifeboat Ethics: The Case Against Helping the Poor' (1974).
[58] E.P. Odum 1969: 269.
[59] E.P. Odum 1969: 267.
[60] H.T. Odum and E. Odum 1976: 145. In looking to Asian agriculture, Howard was following a long tradition in American agrarian conservation going back to F.H. King, a turn of the century USDA employee, and culminating in Howard's contemporary the organic farming publisher J.I. Rodale.
[61] H.T. Odum and E. Odum 1976: 250-251.
[62] H.T. Odum and E. Odum 1976: 250-251. Howard presented his 'steady-state future' as a retreat from future shock back to an earlier simpler life. In many ways this was reminiscent of the way certain agrarian Romantics (Louis Bromfield comes to mind) nostalgically recalled an earlier agricultural era.
[63] In the 1960s the organic farming journal was taken over by J.I. Rodale's son, Robert Rodale. Robert had a keen interest in keeping up with the latest ecological trends (including agroecology) and he created the Rodale Research Center to bring together ecologists and agronomists to create new agroecological studies. R. Rodale 1968: 19-21; R. Rodale 1982: 22-26; R. Rodale 1983: 15-20.
[64] Olds 1969: 66-71; Cox 1973: 90-94.
[65] H.T. Odum and E. Odum 1976: 7.
[66] H.T. Odum 1971: 253. The first nine commandments were: '(1) Thou shall not waste potential energy; (2) Thou shall know what is right by its part in survival of thy system; (3) Thou shall do unto others as best benefits the energy flow of thy system; (4) Thou shall revel in thy systems work rejoicing in happiness that only finds thee in this good service; (5) Thou shall treasure the other life of thy natural system as thine own, for only together shall all survive; (6) Thou shall judge value by the energies spent, the energies stored, and the energy flow which is possible, turning not to incomplete measure of money; (7) Thou shall not unnecessarily cultivate high power, for error, destruction, noise, and excess vigilance are its evil wastes; (8) Thou shall not take from man or nature without returning service of equal value, for only then are thee one; (9) Thou shall treasure thy heritage of information, and in the uniqueness of thy good works and complex roles will thy system reap that which is new and immortal in thee.' As to the inevitable question—was Howard serious about this?—the answer seems yes. As part of his attempt to outline a means of bringing human systems more into line with natural systems, Howard specifically targeted anthropocentric religion and proposed teaching this energy ethic (with its ten commandments) in schools and churches as an alternative.
[67] For an example of American deep ecologists' treatment of the Odums see: Devall and Sessions, *Deep Ecology*, 1985: 85. In this popular American book, Eugene Odum and several other ecologists are praised as a small group of scientists who 'were to develop in their own philosophies some version of a biocentric perspective on the equality of all nonhumans and humans.'
[68] Allen 1991: 3, 57. In spite of finding support for their project in the Odums' writings, Howard, at least, was quite skeptical of the project predicting only 20% of the species in the habitat would survive. Howard had been advocating experiments resembling Biosphere 2 since 1971, because he sought to determine how to create the perfect steady-state

human system for the future. In contrast to the current project (with its eyes on the stars) Howard sought to use such an experiment to radically rework the human systems on earth so as to make them better adapted to the environment. H.T. Odum 1971: 287.

[69] Both Eugene and Howard explicitly reached out to a broader popular audience. Howard, as already noted, published a series of books aimed at a more general audience. Eugene contributed articles to popular magazines. A particularly interesting example of the latter is Eugene's 'The Attitude Revolution' an introduction to a series of articles on ecology collected by The *Progressive* magazine. In his introduction Eugene described systems ecology as uniting the disparate forces of the day including: Howard W. Odum's technological 'lag time,' the youth-oriented ecology movement, and the need for a scientifically rigorous national environmental policy. E.P. Odum 1970: 13-15.

[70] Some of the earliest volleys in the critique of agroecology came after a 1974 Congressional act mandating the use of 'net energy analysis' in the assessment of new energy sources. Many agricultural economists attacked the net energy enthusiasts both for their dismissive attitude toward traditional economics (often derided as 'contingent') and for their attempts to replace economic values with energy values. For a typical example of this critique see: David Huettner, 'Net Energy Analysis: An Economic Assessment,' Sc*ience*, 192, No. 4235 (1976), pp. 101-104.

[71] An important survey by Stout et al. in 1984, seemed to confirm the relatively minor role of energy in domestic agricultural policy. Whether this was the result of the failure of the Odums' programme to educate the public and transform agricultural policy, or the inevitable working of agricultural economics was left unexplored—though the implication was toward the latter. Stout et al. 1984: 167-189.

[72] Connor 1977: 669-681; Pasour and Bullock 1977: 683-693.

[73] H.T. Odum 1983: ix-x.

[74] Barry Commoner's most sustained examination of agroecological issues occurred during his study of agrochemical pollutants in the water supply of Decatur, Illinois. From a careful examination of the conditions that led up to this disaster, Commoner concluded that the economies of agriculture made it efficient to overload the soil with fertilisers and pesticides. See: Commoner 1971: 81-93.

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