Howard T. Odum and wetland ecology

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ABSTRACT

Howard Thomas Odum (1924-2003) was an important transitional figure in the development of wetland ecology in the United States. Although he was educated before wetland ecology became a recognized subdiscipline of ecology, his research during the first half of his academic career (ca. 1950 to 1975) was focused primarily on wetlands. By the early 1970s, he was self-identifying as a wetland ecologist, e.g., by establishing the Center for Wetlands at the University of Florida. Although Odum was interested in much more than wetlands, especially during the last half of his lengthy career, he contributed significantly to increasing the visibility of wetlands and to the development of wetland ecology in four principal ways: (1) his innovative and influential research on the trophic structure of Silver Springs, a riverine wetland; (2) his highly visible research on the use of Cypress Domes to treat waste water; (3) his establishment of a major academic, wetland research institute, the Center for Wetlands; and (4) his many graduate students who obtained influential jobs in academia, government agencies and private companies. When Odum started his academic career wetland ecology did not exist. Halfway through it, wetland ecology began to arise as a distinct discipline and Odum was one of the major reason why this happened.

FIGURE 1. Howard T. Odum in 1973 (HTO Papers Box 69, from Joslin 1973).

INTRODUCTION

The development of wetland ecology occurred unsystematically as a result of individuals making observations or doing research on wetland ecosystems or wetland organisms. Initially, these were natural-history observations that in retrospect dealt with some aspect of wetland ecology. The amateur naturalists who made them were proto-wetland ecologists (Egerton 2012). By the late nineteenth century, a new class of scientists arose within the universities and natural history museums who studied natural systems or organisms (van der Valk 2011). They initially identified themselves as botanists or zoologists and some later as ecologists. A few of the latter studied wetlands or wetland organisms, and I have called them antecedent wetland ecologists (van der Valk 2017, 2018). Wetland ecology as a distinct subdiscipline within ecology only began in the 1970s when scientists working on wetlands or wetland organisms began to self-identify as wetland ecologists. In this paper, I examine the career of Howard T. Odum who started his scientific career as an antecedent wetland ecologist, but who began to identify himself as a wetland ecologist in the early 1970s. Thus, Howard Odum is an important transitional figure in the development of wetland ecology.

Howard Odum (Figure 1) was a polymath, but a monomaniacal polymath. He was interested in and wanted to understand everything having to do with nature and man and the interactions between them, but primarily in the context of their energy acquisition and use. Although he used a systems approach, in his systems models, only energy flows linked their major components. Odum developed his systems worldview early in his professional career, starting with his stint in the military as a meteorologist and then during his early years as an academic ecologist studying the energetics (production, food webs) primarily in aquatic and coastal systems. For Odum energy was **the** unifying concept in ecology. He even created a new modeling approach and energy language that describes the storages and flows of energy in ecosystems (Odum 1983).

In this paper, I will examine only one facet of Howard Odum's career, his impact on the development of wetland ecology. Odum had about 300 publications during his career and only a small number of those deal with wet-

lands (Ewel 2003). For a more comprehensive overview of Odum's contributions to economics, systems ecology, and ecological engineering., see Hall (1995). Nevertheless, Odum contributed to the development of wetland ecology in four ways.

1. His classic paper on the energetics of Silver Springs (Odum 1957) raised the visibility of wetlands.
2. His study of Cypress domes for removing nutrients and other contaminants from polluted water demonstrated the economic benefits of wetlands.
3. He established the first wetland research institute, the University of Florida's Center for Wetlands.

His graduate students became important and influential wetland ecologists.

This paper is based not only on Howard Odum's published works, but also on my research in the Howard T. Odum Papers, which are housed in the Special and Area Studies Collections of the George A. Smathers Libraries, University of Florida, Gainesville, Florida. This collection contains correspondence, research files, manuscripts, publications, photographs, and personal papers. Information based on materials in the Howard T. Odum Papers used in this paper is cited by the box in which it was found, e.g., HTO Papers Box 21. Detailed information about the contents of each of the 93 boxes can be found on the Howard T. Odum Papers website (http://www.library.ufl.edu/spec/archome/MS130.htm).

EDUCATION AND ACADEMIC CAREER

Although born in Durham, North Carolina, Howard Thomas Odum (1924-2003), Tom or HT to most of his friends and colleagues, grew up in Chapel Hill, North Carolina. His father, the sociologist Howard Washington Odum, was on the faculty of the University of North Carolina at Chapel Hill. The ecologist Eugene P. Odum was his older brother.

Howard Odum began work on his B. S, in Zoology at University of North Carolina at Chapel Hill in 1941 and finished it in 1947. During the Second World War (1943-1946), he served in the US Army Air Corps. While in the military, he volunteered for a meteorological program and then worked as a meteorologist. After he completed his B.S., he went to graduate school at Yale University (1947-1950) where he worked with G. Evelyn Hutchinson. He was officially awarded his PhD in June 1951.

Odum's first academic appointment in 1950 was as an assistant professor in the Department of Biology at the University of Florida. He left Florida for Duke University in 1954, but did not stay long. In 1956, he became the director of the Institute of Marine Science in Port Aransas, Texas, which is part of the University of Texas. From Texas, he moved to Puerto Rico in 1963 as chief scientist at the Puerto Rico Nuclear Center operated by the University of Puerto Rico. While in Puerto Rico, he directed a major study of the Loquillo tropical rainforest. In 1966, Odum moved yet again. This time to his alma mater, the University of North Carolina at Chapel Hill. There he finished his most widely-read book, *Environment, Power and Society* (Odum 1971*),* which he had begun in Puerto Rico. After 20 years as an academic gypsy, he moved back to the University of Florida in 1970 as a Graduate Research Professor in the Department of Engineering Sciences. Odum spent the rest of his academic career (more than 30 years) at Florida.

In his letter of resignation from the Department of Zoology at the University of North Carolina at Chapel Hill (HTO Paper Box 1), Odum outlined his vision for a new type of university curriculum. "The times are ripe for some university to foster world leadership in a new curriculum that starts in undergraduate levels with teaching, understanding, and management of all our systems from the molecular to the big environmental ones that include our survival issues of war, medicine, economics, food, and ecological stability, etc. To build new programs in times which require fast and effective new means, there has to be assigned enough authority, confidence, and budget in single individuals, free from the destructive elements of committee decision approaches " The University of Florida evidently was more amenable to developing his proposed new curriculum and giving him the resources and freedom needed to establish it.

As Odum demonstrated in his 1971 book, *Environment, Power, and Society*, he viewed systems analysis that focused on energy flows and storages as the best way to describe, model, analyze, and manage natural and human systems at all scales (Odum 1971). He initially developed energetic models of systems as part of his field and experimental (microcosm) studies of wetlands early in his career at Texas, North Carolina, and Florida. As Odum put it in his remarks on August 28, 1991 on retiring as director of the Center for Wetlands (HTO Papers Box 71): "You can't understand wetlands by studying only wetlands. You have to include the next larger scale systems, which means people and their economics." As his interests expanded from wetland systems to human systems (Figure 2), he increasingly focused on the costs of energy to human societies, i.e., to what is now known as ecological economics (Costanza 1995). In chapters written by Odum's students and collaborators toward the end of his career, Hall (1995) provides an overview of Odum's contributions to ecosystem modeling and simulation, ecological engineering, ecological economics, and "emergy" analysis. Several chapters also deal with his contributions to wetland ecology, most notably, Nixon's on his contribution to marine ecology and Knight's on wastewater treatment wetlands.

Another of Odum's fundamental beliefs was that natural systems benefit human societies. In retirement remarks (Box 73), he noted that "when I returned to [Florida] in 1970, there were bitter controversies nationally between environmentalists and engineers. My own background, … taught me that there was a middle way in which harmony of humans and environment were found in partnership (at that time a new idea)." His studies of how well cypress domes cleaned up sewage effluent demonstrated the utility of this new approach. That natural systems like wetlands can reduce or solve environmental problems created by human societies became one of the central tenets of what is now called ecological engineering (Mitsch 1995, 2003).

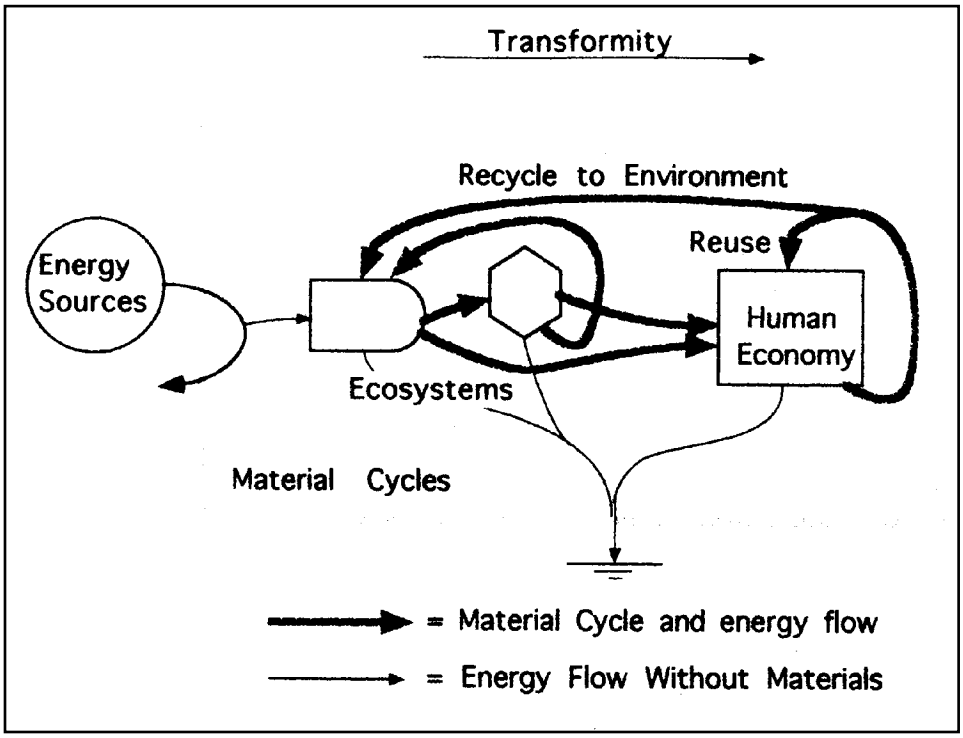
SILVER SPRINGS

Howard Odum began his PhD at Yale University in 1947. Five years earlier, Odum's major professor, G. E. Hutchison, had helped revise a theoretical paper on energy flow in a Minnesota bog by Raymond Lindeman (1915-1942): the trophic-dynamic aspect of ecology (Lindeman 1942). Lindeman had come to Yale in 1941 as a postdoctoral fellow after completing his PhD at the University of Minnesota. While working on this manuscript, Lindeman wrote a letter to William S. Cooper back in Minnesota. "I'm afraid you're going to say that I've hazarded a great deal of theory on very little information, and you may be right. I have a feeling, though, that at least some of the ideas are piquing enough to start some people making ecological studies on the basis of productivity and efficiency, and that would be quite gratifying even though some of the hesitantly proposed "principles" turn out to be wrong" (Quoted in Cook 1977). Howard Odum found some of Lindeman's ideas piquing, and, after taking a faculty position at the University of Florida in 1950, he began a study of energy flows and storages at Silver Springs, Florida.

From 1952 to 1955, Odum's attempts to quantify the storages and fluxes of energy in the Silver Springs ecosystem was unprecedented in its scope and detail. Silver Springs is one of a number of large freshwater springs in northcentral Florida. Immediately downstream from the "boil" (springhead), the spring runs are simply freshwater streams. Odum recognized that these spring runs provided an ideal system for studying ecosystem energetics in flowing water systems (Odum 1956, 1957). They have relatively constant flow volumes year-round and from year to year. Water temperatures are also nearly constant year-round. Their water chemistry does not vary seasonally. They were in his words "a ready-made natural laboratory … for studying the role of the factors that control productivity" (Odum 1957). In fact, he viewed them as natural chemostats. This view greatly influenced the overall design of the study. Because Odum viewed the Silver Spring ecosystem as in quasi equilibrium, he believed that it was not necessary to make simultaneous measurements of the various energy storage compartments or energy fluxes. This simplifying assumption allowed Odum to piece together a large number of small studies that he and others had made at different times or even years into his overall energy model of the Silver Springs ecosystem. Odum did recognize what he called "variation inherent in analytical procedures" and provided a table of standard deviations for carbon dioxide and oxygen measurements (1957). In the Silver Springs study, Odum used an important new method, diurnal changes in oxygen concentrations, to estimate overall ecosystem metabolism. He had, however, previously published a paper on this method (Odum 1956).

Interestingly, Odum (1957) presents his overall energetic model of Silver Springs (his Figure 7 on

FIGURE 2. Odum's general model of energy and material linkages between natural ecosystems and the human economy. (HTO Papers Box 68, Notes for the talk, Century of General Systems Ecology, that was given at Syracuse University, April 14, 1998).



page 61) before he gives a detailed description of the components of the Silver Springs ecosystem, any field data collected during the study, or even a description of his sampling methods. In effect, readers got the main take-home message of the paper (Figure 3) after the first 7 pages and could ignore the next 50 pages, which were primarily of interest to limnologists specifically interested in the methods used or the data collected. He had even published a skeletal version of this model the previous year in *Limnology and Oceanography* (Odum 1956). As Odum admits in a long footnote in the legend for Figure 7, the energy flows were estimated very roughly for purposes of indicating their order of magnitude. In spite of this caveat, this figure presented the most detailed estimate of the energetics (gross and net primary production, secondary production, trophic fluxes) of any ecosystem then published. The data-rich Silver Springs paper provided actual data that could be used to test Lindeman's (1942) principles of ecosystem energetics. Odum's paper stimulated increased interest in ecosystems and their energetics.

Silver Springs is a riverine wetland, and Odum (1957) raised the utility of wetlands as ecosystems worth studying and thus their visibility outside wetland circles. Figure 7 became one of the most widely known figures in the rapidly developing field of ecology in the 1960s and 1970s. It was reproduced in Eugene P. Odum's second edition of *The Fundamentals of Ecology* (Odum 1959), the dominant ecology textbook of this era. (I used it as a student in three different ecology courses in the late 1960s.) Howard Odum himself (Odum 1971) also made extensive use of it (see pp. 2-3 and pp. 22-23) in *Environment, Power and Society*.

CYPRESS DOMES

By the 1960s, it had been demonstrated repeatedly that wetlands could remove a variety of contaminants in water passing through them. Käthe Seidel (1907-1990) had done much of the pioneering work on this topic. Seidel's original interests and training were in horticulture. She was particularly interested in the cultivation of bulrushes, which were used in caning furniture seats and backs by local artisans in Germany. After the Second World War, she did graduate work at the University of Kiel in limnology and microbiology and obtained a research position at the Krefeld substation of the Hydrobiological Institute in Plön, Germany. At Krefeld, her research interests increasingly shifted to the use of bulrushes

FIGURE 3. Summary of energy flows of the Silver Springs ecosystem. (HTO Papers Box 68. Notes for the talk, Century of General Systems Ecology, that was given at Syracuse University, April 14, 1998). This is a version of Figure 7 in Odum (1957).

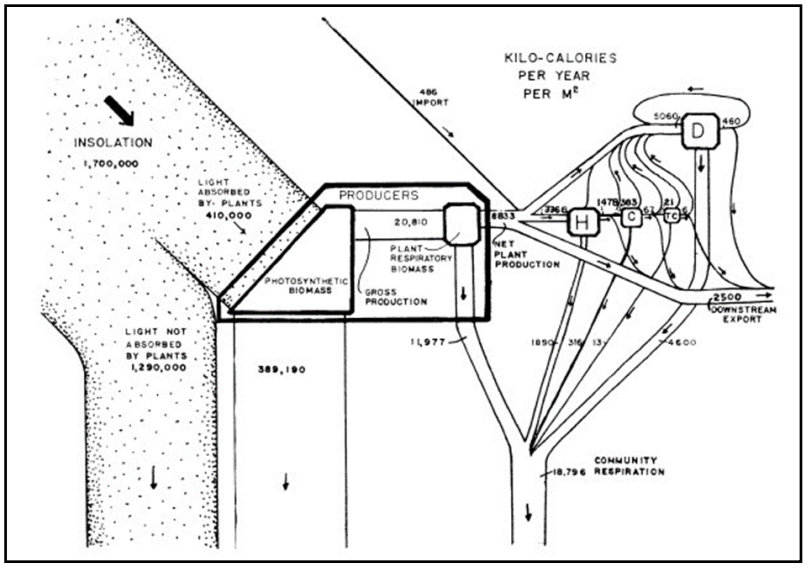
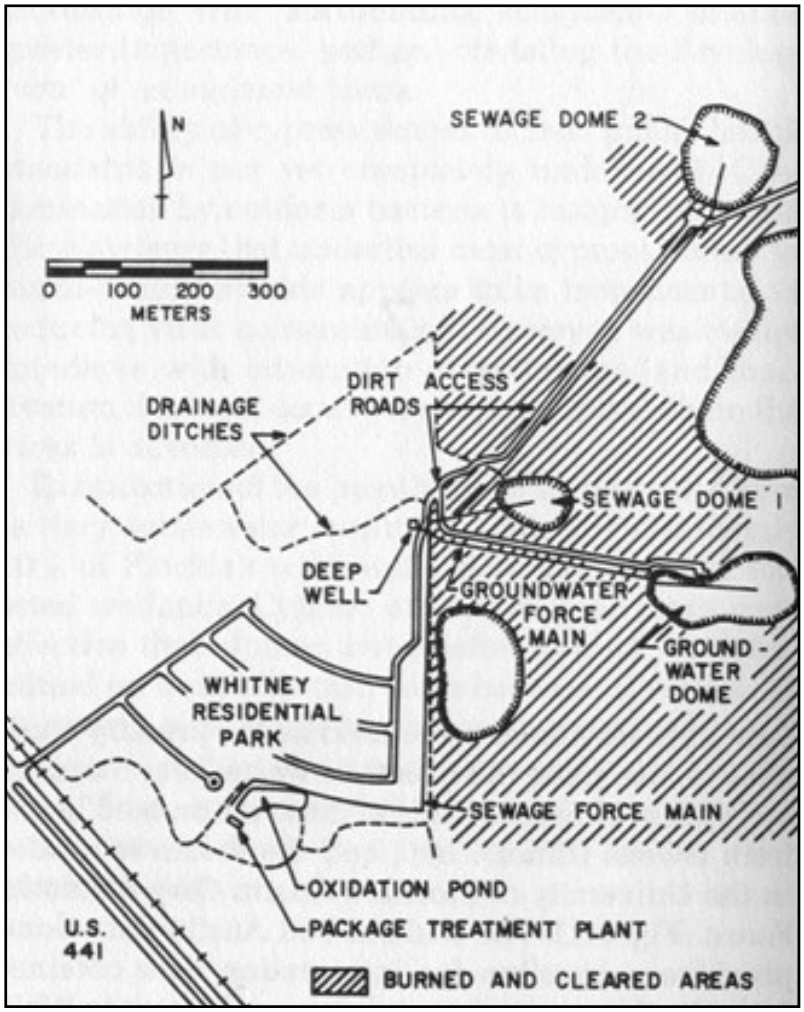


FIGURE 4. Map of the Cypress Dome wastewater application study site (Ordway 1984).



and other aquatic plants to clean up polluted water. Starting in the 1950s, she began to build small sewage treatment wetlands planted with emergent wetland species. She eventually showed that treatment wetlands could remove nutrients, heavy metals, phenols, etc. from contaminated water passing through them. In fact, Seidel became increasingly convinced that wetlands were capable of cleaning up any kind of polluted water and she promoted the use of treatment wetlands for the rest of her life. Because her work demonstrated that wetlands were valuable to society, her classic 1966 paper, *Reinigung von Gewässern durch höhere Pflanzen* (*Purification of waters by higher plants*) has had a lasting impact on the history of wetland ecology. Her work directly or indirectly resulted in many other studies of wetlands and water quality in Europe and North America. By the mid-1970s, nearly 20 studies of nutrient removal by natural wetlands had been published (van der Valk et al. 1978), among them was the Cypress Dome study by Howard Odum and his associates in Florida.

In the United States, water pollution had become a major political issue by the 1960s. In 1972 the Federal Water Pollution Control Act (Clean Water Act) was passed by the US Congress to address the problem. This new environmental mandate to reduce water pollution stimulated a variety of research projects to study novel ways to clean up polluted waters, including the use of wetlands (Knight 1995).

While he was still at the University of North Carolina, Odum had collaborated in a study that used man-made ponds filled with estuarine water to treat sewage and to evaluate the impact of increased nutrients on estuarine production. This was one of the first studies to use estuarine systems to treat wastewater (Knight 1995). Shortly after returning to Florida in 1970, Odum put together a grant proposal to study how effectively a local, isolated wetland type - cypress domes - could remove or store contaminants from sewage entering them (Figure 4). Odum's Cypress Dome project was funded by a million-dollar grant, "Cypress wetlands for water management, recycling and conservation," funded jointly by the Rockefeller Foundation and the National Science Foundation's Division of Research Applied to National Needs (RANN). The size of this grant was unprecedented, and it marked a quantum leap in the funding of a wetland research project. Odum's Silver Springs study was done for about $5,000 (HTO Papers Box 68, Notes for a talk, Century of General Systems Ecology, given April 14, 1998 at Syracuse University).

The overarching goal of the Cypress Dome project was to elucidate the relation between human society and the wetlands (swamps); i.e., "to explore the concept that a symbiosis between humanity and nature would maximize the vitality of both the economy and wetlands" (Ewel and Odum 1984). If wetlands could be shown to benefit society by reducing the cost of cleaning up polluted water, this would obviously benefit local economies as wells local wetlands by ensuring their conservation. This large project was co-directed by Katherine Ewel, also of the University of Florida. During this project, wastewater from a facultative sewage lagoon that treated waste from a trailer park near Gainesville was applied to cypress domes at a low hydraulic loading rate (Figure 4). The goal was to add only as much wastewater as would be lost through evapotranspiration over a given period. This was done to prevent the domes overflowing. The study ran from 1974 to 1977.

The book, *Cypress Swamps*, which was edited by Katherine Ewel and Howard Odum (1984), summarizes much of the research done by a small army of graduate students, Florida faculty, and off-campus collaborators during the project as well as other research on cypress swamps in the Southeastern US in the 1970s. Specifically, Part II, Effects of Wastewater on Cypress Domes, contains 19 chapters based on the Cypress Dome project, including chapters on hydrology, nutrient mass balances, ecology of cypress, invertebrate faunas, microbes, and economics. The final chapter in Part II examines the possibility of using Florida's cypress wetlands for tertiary waste treatment: its authors conclude that cypress wetlands are excellent nutrient traps and that they potentially could be used as tertiary treatment systems at about 35% of the wastewater treatment systems in Florida (Fritz and Helle 1984). Knight (1995) provides an evaluation of the Cypress Dome study, as well as the earlier estuarine pond studies, on the development of the use of treatment wetlands.

The Cypress dome study had one major flaw. Odum had assumed that it was acceptable to use natural wetlands to clean up polluted water. After the Clean Water Act, it was, however, no longer acceptable to let point sources of polluted water contaminate aquatics systems, i.e., lakes and streams. Why was this acceptable for natural wetlands? Although a number of similar studies were done on the use of natural wetlands to clean up polluted water in the United States during this period, the use of natural wetlands for this purpose eventually fell into disfavor. Instead, constructed or treatment wetlands that were specifically designed and built for this purpose became the norm (Knight 1995; Kadlec and Knight 1996).

CENTER FOR WETLANDS

The Center for Wetlands was established in 1973 as part of the Rockefeller-RANN grant that funded the of the Cypress Dome project. Its main function initially was to coordinate the many studies that were part of this grant (see Ewel and Odum 1984). Howard Odum was its director for 18

years (1973-1991). Its original mission was to understand "wetlands and their role in the partnership of humanity and nature" (HTO Papers Box 33, Odum, Best and Brown (1985) Center for Wetlands). Wetland projects done through the Center include work on sewage treatment, phosphorous mine reclamation, productivity, energy analysis, environmental planning, and public policy. With time, however, the Center's research projects began to emphasize how "the patterns of humanity and nature may generate maximum economic vitality defined as the landscape's carrying capacity for humanity."

In a memorandum announcing his resignation as the Center's director dated August 31, 1991 (Box 71) that is addressed to the staff, students, alumni, and friends of the Center, Odum outlines its major accomplishments during his tenure as director: 80 theses and dissertations, 220 research reports, and 135 journal papers and book chapters. He notes that only about half of the work done dealt with "wetlands and ecological engineering" and the other half with "environmental systems, resources evaluation, energy comparisons, and global futures." In short, as Odum became more interested in developing his energy theories and models and applying them to political entities at a variety of scales, wetland research at the Center for Wetlands became less of a priority. Consequently, the Center's visibility as a major center of wetland research declined as Odum's term as director progressed. Odum gradually ceased to be a wetland ecologist and his direct influence on the development of wetland ecology waned. The Center's last major wetland publication while he was still director was Ewel and Odum (1984), *Cypress Swamps*.

The Center for Wetlands was the first such academic institute in the United Stated. It greatly increased the visibility of wetland ecology. Its establishment demonstrated that such a center could attract major funding for wetland research and could be a congenial home for faculty, graduate students, postdocs and visiting scientists interested in wetlands. The Center for Wetlands was an important milestone in the development of the wetland ecology in the United States.

GRADUATE STUDENTS

Odum's academic family tree is found in Hall (1995, see figure P.1) that shows his collaborators and graduate student in chronological order up to January 1994. There are a lot of them, and you need a magnifying glass to make out their names. Of those who worked primarily on wetlands, a significant number became major figures in wetland ecology, including Robert Beyer, Ariel Lugo, John Day, Scott Nixon, Tom Fontaine, Scott Leibowitz, Robert Knight, Pat Kangas, and Bill Mitsch. Odum's wetland legacy lives on through the work of his graduate students who obtained positions in academia (Day, Nixon, Kamgas, Mitsch), government agencies (Fontaine, Leibowittz) and consulting firms (Knight). It continues today through the graduate students of Odum's graduate students.

Odum held strong views about the self-organizing nature of ecosystems. Given a specific set of boundary conditions (hydrology, nutrient input, energy inputs, organisms, etc.) a specific ecosystem would develop that maximizes gross production and total ecosystem energy consumption. Self-organization makes ecosystems "competitive and useful" and able to "capture and feed energy back into useful processes" (HTO Papers Box 43, Odum (1973), Principles for interfacing wetlands with development). Odum identified Fredeic E. Clements, an early American plant ecologist whose views of vegetation development were highly deterministic (van der Valk 2014), as an important contributor to the development of systems ecology (HTO Papers Box 68, Notes for a talk, Century of General Systems Ecology, given April 14, 1998 at Syracuse University). For Odum, Clements' theory of succession to climax was an example of self-organization. For the first half of the twentieth century, Clements' deterministic views dominated ecological theory in the United States, but by the 1970s they were on the wane. Odum gave them new life. Odum's deterministic view of ecosystem development and functioning would become widespread in wetland ecology after the 1970s as it was spread by Odum's students in their papers, reports and books. For a detailed examination of Odum's deterministic approach to ecology, see Taylor (1988).

SUMMARY

Howard T. Odum did much to raise the visibility and value of wetlands, both among his fellow scientists (the Silver Springs study most notably) and among policy makers and the general public (the Cypress Dome study). His work demonstrated that wetlands were important ecosystems whose study would reveal new scientific insights and would establish the importance of wetlands to human society. He was, however, much more than just a wetland ecologist. He developed a new approach to describing and modeling energy flows and storages in ecosystems. After the publication of *Environment, Power and Society* (Odum 1971), his intellectual interests became increasingly fixed on societal and economic issues and on applying his insights from work on the energetics of ecosystems to human societies at a variety of scales.

For a new scientific discipline to develop, recruiting and training additional scientists in the discipline is essential as is institution building. Odum's lab at Florida was a major center for training wetland ecologists. Many of Odum's graduate

students went on to become important and influential figures in wetland ecology during the last quarter of the twentieth century. Odum also raised the visibility of wetland ecology through the establishment of the Center for Wetlands at the University of Florida. In short, although Odum was a wetland ecologist only during the first half or so of his lengthy professional career, his work on wetlands helped transform wetland ecology from an antecedent science to a new, self-conscious scientific discipline. ■

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