Closing the Ecological Cycle: The Emergence of Integrative Science

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INTRODUCTION

A new century/millennium provides an opportune time to reflect on how the science of ecology evolved during the 19th and 20th centuries, and to predict how it is likely to change during the 21st century (at least to reflect on how it might evolve in order to best serve societies during the decades ahead). This viewpoint article will attempt to: (a) provide an overview regarding the emergence of ecology from a subdiscipline of biology to a discipline of its own during the past century (Odum 1977); (b) discuss the academic fragmentation of ecology into numerous subdisciplines of study; and (c) argue that a new field of transdisciplinary science is urgently needed that will not only integrate these emerging fields of the ecological sciences, but will interface with the humanities and the social sciences as well (i.e., similar to C. P. Snow's "third culture," Snow 1963). Earlier we termed this 21st century field of study "integrative science" (Barrett & Odum 1998; Barrett & Kress 2001).

Should this integrative and transdisciplinary field of study continue to evolve, this emergence will greatly increase our knowledge and understanding of the natural world. This emergence will also increase the ecological literacy necessary for humankind to understand the benefits and services that are supplied to societies by natural ecosystems and landscapes (Daily *et al.* 1997). Thus the concept of a "sustainable society" (Barrett 1989; Rapport *et al.* 1998a) will be more fully realized. This approach and, hopefully, its success could be viewed as "closing the ecological cycle" regarding the earlier view that scientists had of natural ecological systems (i.e., the emergence of the ecosystem concept), which led to investigations addressing questions at greater temporal/spatial scales. Later in this article, I suggest that this integrative approach be based on the noosystem, rather than the ecosystem, concept as discussed by Barrett (1985), including the multitude of cultural influences on these systems.

Transdisciplinary education, research, and service missions are urgently needed to advance the frontiers of science in a revolutionary manner during the 21st century (i.e., if Snow's "third culture" is to become a reality). The emergence of "integrative science" should result in a novel worldview of problem solving, political decision making, transdisciplinary education, and sustainable development. The field of ecosystem health is expected to play an important role in contributing to this emerging paradigm, which increasingly needs to focus on larger scales and higher levels of organization (Rapport *et al.* 1998b). As Odum (1995) notes, to be effective, new interfaced or integrative efforts should not only enrich the disciplines (or subdisciplines) being interfaced, but also result in new principles and/or procedures that are applicable to human predicaments. Otherwise, the effort merely adds to the already excessive fragmentation as discussed below.

DISCIPLINARY FRAGMENTATION

Although the science of ecology mainly evolved as a subdiscipline of biology during the latter half of the 20th century (Figure 1), it was of practical interest early in human history. For example, the writings of Hippocrates, Aristotle, and other philosophers of ancient Greece clearly contain references to ecological topics. However, it was not un-

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til the mid-1850s, perhaps closely associated with the Industrial Revolution, that the natural sciences exhibited an intellectual revolution. For example, the word ecology, taken from the Greek *oikos* (meaning "house") and *ology* (meaning "study of"), was first proposed in 1869 by the German zoologist Ernst Haeckel. From 1850-1945 (i.e., to the end of the Second World War), the natural sciences were dominated by the biological and physical sciences, including mathematics and engineering, with increased interest on natural ecological systems (Figure 1). It was not until 1935, however, that the term "ecosystem" was proposed by the British ecologist A. G. Tansley (Tansley 1935).

Numerous major contributions in evolutionary biology played important roles in the early development of the biological sciences between 1850 and 1945, beginning with Charles Darwin's *Origin of Species* (Darwin 1859) and culminating with Ernst Mayr's *Systematics and the Origin of Species* (Mayr 1942) and George Gaylord Simpson's *Tempo and Mode in Evolution* (Simpson 1944). The ecological sciences, although widely viewed as a study of natural history during this period, also began to gain stature on their own. For example, the American S. A. Forbes wrote his classic essay on the lake as a microcosm (Forbes 1887) and Charles Elton published *Animal Ecology* during this time (Elton 1927). The "ecosystem" became the integrating concept and system that emerged during the latter part of this period that began to unite evolutionary and systems ecologists. The emerging science of ecology, however, remained a subdiscipline of biology during this period.

The end of World War II resulted in an explosive growth in higher education in the United States, fueled by the GI Bill and the fear of global domination by the Soviet Union following the launching of Sputnik in 1957. This universal growth in science and engineering between 1945 and 1960 was accompanied by a fragmentation in the science of biology; large biology departments were divided into botany, zoology, and microbiology—a process that discouraged plant, animal, and microbial ecologists from addressing ecosystem-level questions in an efficient and cost-effective manner. This process might be viewed as "disciplinary" or "academic fragmentation".

The ecosystem approach and concept, however, continued to flourish during this period championed by Aldo Leopold's *A Sand County Almanac* (Leopold 1949) and Eugene P. Odum's *Fundamentals of Ecology* (Odum 1953). Interestingly, the growth and fragmentation of biology was accompanied by the maturation and integration of ecology as a holistic science.

Between 1960 and 1980 (Figure 1), the biological sciences continued to grow (and fragment) into new departments or schools of learning, especially in molecular biology and the biomedical sciences. Ecology became a "stand-alone" discipline during this time fueled by the "environmental" movement during the 1970s—a time frequently referred to as the "Decade of the Environment." Policy makers increasingly turned to ecologists for answers to problems/challenges related to environmental degradation, resource management, food production, and decreased biotic diversity. The environmental movement was accompanied by the emergence of new state and federal agencies necessary to administer a plethora of environmental laws and regulations. It was during this period that ecology emerged as a new integrative discipline (Odum 1977).

Just as the biological sciences continued to fragment into numerous fields of investigation between 1980 and 2000, the ecological and environmental sciences began to fragment in somewhat the same manner. Figure 1 depicts several of these emerging interfaced fields of investigation that can be divided into the areas of medical and perturbation sciences, planning and management, ecological health and restoration sciences, and policy and education. Most of these new interfaced fields of study are promoted by professional societies, new journals, and national/international meetings necessary to exchange information and to conduct the business affairs of each society. Although this disciplinary fragmentation resulted in a better understanding of ecosystem and landscape dynamics, such as the effects of pollution and increased subsidies of ecological systems and new approaches to restore or rehabilitate perturbed systems (e.g., Hildén & Rapport 1993; Yazvenko & Rapport 1997), this fragmentation process also reduced or divided resources (human and financial) necessary to address questions and solve large-scale (real-world) problems in a transdisciplinary manner. Fortunately, there exists an increasing receptivity to ecosystem and landscape health approaches to large-scale environmental management (Rapport *et al.* 1999). Only time will tell which of these relatively new fields of study will become paradigms (Kuhn 1970), which will transmit its needs and disappear, or which will evolve into yet another field of investigation. Interfaced disciplines will likely persist if the merger

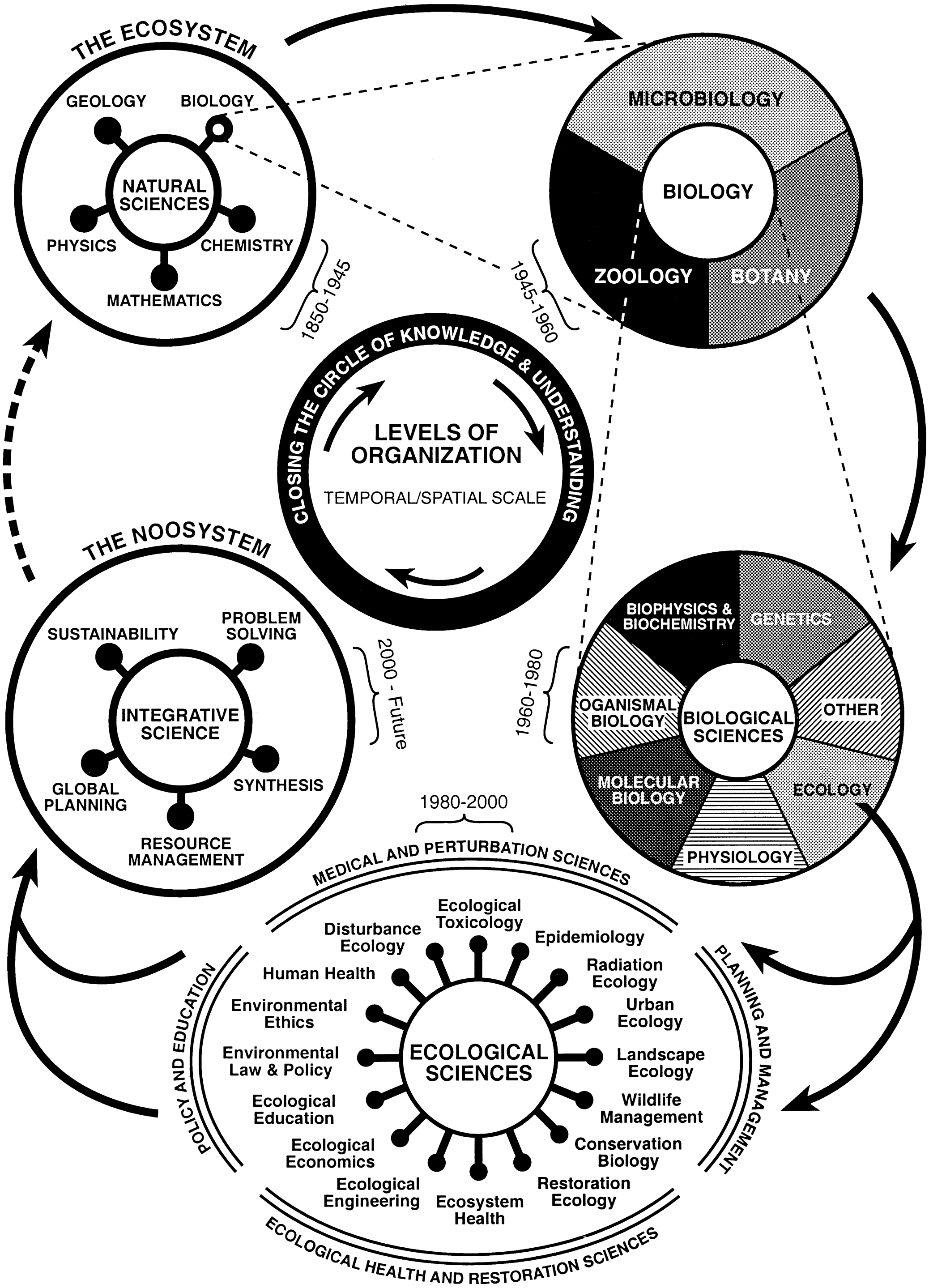

FIGURE 1. A historical perspective (1850–2000) depicting the evolution of ecology and the ecological/environmental sciences. Starting with the diagram section (ecosystem) in the upper left corner, the fragmentation of biology and ecology is shown in clockwise fashion hopefully leading to a more unified and integrated science.

produces new principles and concepts such as the concepts of eMergy (Odum 1996) and the importance of nonmarket goods and services (Costanza *et al.* 1997) in the field of ecological economics.

How will this academic fragmentation process move forward and be administered within our colleges and universities? Will resources be provided to meet these needs? Which state or federal

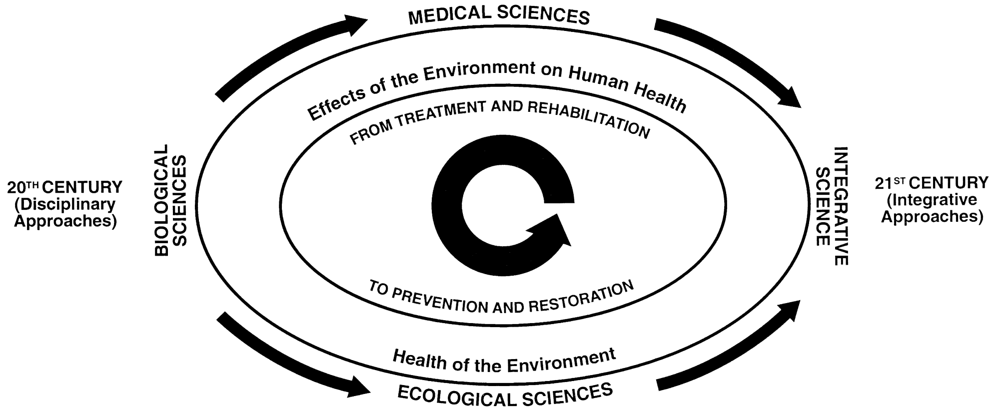

FIGURE 2. A model illustrating the need to wed the medical and the ecological sciences during the twenty-first century into transdisciplinary integrative science.

agencies are best equipped to evaluate the number and quality of these emerging fields (subdisciplines) of investigation? Interestingly, the science of ecology—that science perhaps best equipped to investigate "the home" or "total environment" in a holistic approach—now faces a challenge regarding how best to structure its "academic, disciplinary-based home" to meet these functional needs. The same concern and challenge apply to emerging interfaced and integrative fields of study such as ecological economics, sustainable development, and ecosystem health. In most large research universities, ecology has moved out of biology into a separate department, institute, or resource school. Colleges and universities of higher learning, which evolved from disciplinary cornerstones, now face the need to administer these emerging and integrative programs in a cost-effective and intellectually efficient manner.

AN INTEGRATIVE SCIENCE

Earlier (Barrett 1985) I suggested that the noosystem should be recognized as the basic unit of study for integrating biological, physical, and socioeconomic parameters within a holistic systems framework (see Vernadsky 1945; Teilhard de Chardin 1966; Naveh & Lieberman 1984; Serafin 1988 for a review of the noosystem concept). *Webster's Collegiate Dictionary* defines noosphere (*noos* Greek for "mind") as how the sphere of mental (human) activities influences the biosphere, whereas natural science is defined as any of the sciences (e.g., physics, chemistry, or biology) that deal with matter, energy, and their interrelations and transformations. The ecosystem, perhaps, best represents the system in which these transformations occur. However, socioeconomic factors and noosphere influences (Naveh & Lieberman 1984) increasingly have affected the rate of energy flow, and the quality of matter and materials that function within the system. Therefore, I suggest that the noosystem be considered the integrative unit of investigation, based on a transdisciplinary (Jantsch 1972; Rapport 1997), integrative science (Barrett & Odum 1998) approach to higher education needed to address these challenges and opportunities. The noosystem concept and approach would also enhance our knowledge of the ecosystem concept, as espoused by Tansley (1935), Evans (1956), and Rowe (1961), which led to the emergence of systems ecology during the last half of the 20th century (see Brown 1981 for an overview of the "ecosystem ecologists school" that concentrated on the flow of energy and matter through the ecosystem as a whole, as opposed to its "evolutionary ecologists school" that concentrated on understanding community organization and species diversity). It's important to note that this suggested "noosystem approach" during the 21st century (Figure 1) will help to close the circle of information needed to understand the natural world that was and remains paramount to not only the natural sciences, but also to the social and health sciences as well.

Interestingly, the concept of a more unified and integrated science was proposed in 1969 following a symposium of the Council of Unified Research and Education (Haskell 1972). Wilson's (1998; 2001) use of the term "consilience"—meaning the interlocking of cause-and-effect explanations across disciplines—again reflects the need for a unity of knowledge among disciplines. Recently, Barrett and Odum (2000) noted the significance of timing for an idea or approach to be accepted. Evidently in 1969 the time was not right for the concept of a unified science to be accepted. Just as we argued that the time is now right to integrate ecology and economics (Barrett & Farina 2000; Barrett & Odum 2000), I feel that the time is now right to initiate programs in integrative science.

In summary, the biological sciences have provided an intellectual basis for both the medical and ecological sciences (Figure 2). Whereas the medical sciences have traditionally focused on the effects of the environment on human health (e.g., the effects of anthropogenic pollutants on rates of cancer), the ecological sciences have been concerned with creating a quality environment in which human and all organisms reside (e.g., the importance of habitat quality on rates of species survivorship). See Soule (1985) for a model depicting the multitude of disciplines related to the interface between conservation biology and cancer biology (i.e., the interface between the "basic" and "applied" sciences). The medical sciences, because of the transmission of deadly diseases, human warfare, and worldwide malnourishment, among others, have had traditionally to target resources toward treatment and rehabilitation, whereas the ecological sciences have increasingly focused on ecosystem health and the restoration of a quality landscape. There now exists an increased need to wed the medical, ecological, and social sciences as an integrative science (e.g., Odum 1995; Rapport *et al.* 1998b).

Integrative research, education, and outreach missions must accompany this new science. This research, education, and service triumvirate must be administrated in a cost-effective and creative manner if change, rather than the *status quo*, is to emerge. This means that disciplinary, cross-, and interdisciplinary educational missions need to be transformed into transdisciplinary educational programs (Rapport 1997), that basic and applied research approaches need to "blur" as questions focus on processes that transcend all levels of organization (Barrett *et al.* 1997), and that outreach and service functions must promote and underpin the concept of a "sustainable society" (Barrett 1989; Rapport *et al.* 1998a). These needs and challenges will be difficult for colleges and universities of higher learning to achieve (Uhl *et al.* 2000). This new transdisciplinary science will mean not only restoring but, perhaps, inventing sustainable landscapes (Turner 1994). This must include the establishment of a fair and equitable reward system for young investigators who desire to explore questions of a transdisciplinary nature (Barrett 1994) and will necessitate the creation of new schools and colleges of integrative science. This will represent a major paradigm shift from a reductionist science and a fragmented one problem/one solution technology to an ecological world view that will provide a more holistic and long-term approach to dealing with our increasingly fragmented *oikos* (Orr 1992; Goldsmith 1996; Odum 1997). I predict that the ecological sciences, including ecosystem health, will contribute greatly to C. P. Snow's third culture. However, an even greater paradigm shift is needed if humankind is to achieve an optimum, rather than a maximum, carrying capacity functioning within a sustainable environment during the 21st century (Barrett & Odum 2000)—an environment constrained by rates of energy and material flows from a finite earth, constrained by the absorptive capacity of ecosystems and landscapes, and constrained by the requirements necessary for maintaining ecosystem health in its biophysical, social, and human health dimensions.

ACKNOWLEDGMENTS

I thank David J. Rapport for inviting me to share my vision of the future, Eugene P. Odum for constructive comments pertaining to the content of this article, and Terry L. Barrett for the preparation of this manuscript.

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