

A Rationale for Standardized Curriculum and Professional Certification in Ecological Engineering

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Abstract

As the impact of human activities expand to global proportions the demand for engineering solutions to ecosystem level problems has increased. The science of restoration ecology has developed to address many critical ecosystem management issues, yet the high degree of complexity and associated uncertainty demands a more quantitative approach. Ecological engineering is the science-based quantification of ecological processes to develop and apply engineering-based design criteria for sustainable systems, consistent with ecological principles that integrate human society with its natural environment for the benefit of both.

There is little consensus on what distinguishes ecological engineering curricula from existing environmental, biosystems, or agricultural engineering curricula. We suggest that ecological engineering curricula should be offered only at the graduate level, and should require rigorous ABET-accredited (or equivalent) undergraduate preparation in the fundamentals of engineering. The graduate curriculum should provide the student with a core of courses in ecosystem theory including quantitative ecology, evolutionary ecology, community ecology, restoration ecology, trophodynamics, and ecological modeling, while strengthening the student's mastery of engineering theory and application. This curriculum should have a significant component to provide students with practical experience and inter-disciplinary contact. Additional courses in limnology, environmental plant physiology, ecological economics, and specific ecosystem design should be provided to address specific professional objectives of the student.

Finally, a professional engineering certification must be developed to insure the continuing credibility of this new engineering specialization. Several questions concerning acceptable standards of practice, codes of ethics, criteria for successful design, analysis of cost/benefit ratio, and safety factors must be addressed prior to development

of professional certification. Ecological engineering is in its infancy; careful guidance and direction is critical for this exciting field to grow to its full potential.

Introduction

Human civilization is dependent on ecological services extracted from Earth's biosphere. These ecological services are declining at increasing rates due to human management and exploitation (Vitousek et al., 1997). In the next 12 years the population of our species is expected to exceed 7 billion, representing a 33 percent increase from 1990 (Brown et al., 1997). In that same time period, *per capita* fish catch is expected to decline 10 percent, cropland area is expected to decline 21 percent, and forest area is expected to decline 30 percent (Brown, et al., 1997). According to a recent United Nations report, water use has been growing at more than twice the rate of the population increase during this century (United Nations, 1997). Currently, about one third of the world's population lives in countries that are experiencing moderate-to-high water stress partly resulting from increasing demands from a growing population and human activities; this number is expected to double in the next 15 years (Gleick, 1993).

The impact of human civilization on Earth's ecosystem is not clearly understood. Certainly the human species is changing Earth's ecosystem in a manner not planned, desired, or predicted. There is a growing concern that our demands for ecological services may not be met with current approaches to ecosystem management and conservation. There is also a growing opportunity to utilize advances in science and engineering to better understand and manage ecological processes. The emerging science of restoration ecology represents the current state of the art for rehabilitation of degraded ecosystems (Dobson et al., 1997). However, there is still significant debate among applied ecologists as to the viability of ecological management. Arthur Shapiro (Center for Population Biology, University of California, Davis) has described restoration ecology (and by extension, ecological engineering) as "a specialized form of gardening in which the ideal to which we aspire is our notion of what was there before we disturbed it" (Shapiro, 1997).

Ecological engineering is the design discipline for ecosystem restoration and conservation biology. The field of ecological engineering is currently broadly defined, without a consistent core body of knowledge, and is not clearly identified as a professional specialization in engineering certification programs. We propose guidelines for curriculum development and professional certification in ecological engineering.

What is Ecological Engineering?

Ecological engineering is not a new concept. Odum proposed the development of the field as early as 1963 (Odum et al., 1963). "Ecological Engineering: The Journal of Ecotechnology" has been in publication since 1992 (Elsevier Publishers, Oxford, England). There is little consensus on what distinguishes ecological engineering from

environmental, biosystems, or agricultural engineering. Ecological engineering has been defined as:

- the environmental manipulations by man using small amounts of supplementary energy to control systems in which the main energy drives are still coming from natural sources (Odum et al., 1963),
- the design of ecosystems for the mutual benefit of humans and nature (Mitsch and Jorgensen, 1989), and
- the design of sustainable systems consistent with ecological principles that integrate human society with its natural environment for the benefit of both (Bergen et al., 1997).

Bergen et al. (1997) suggested the following elements should be central to the profession of ecological engineering:

1. that the practice is based on ecological science,
2. that ecological engineering is defined broadly enough to include all types of ecosystems and potential human interactions with ecosystems,
3. that the concept of engineering design is included, and
4. that there is an acknowledgment of an underlying ethic.

Ecological engineering differs from civil, environmental, agricultural, and biosystems engineering in its reliance on ecological sciences as the basis for design. Certainly there is redundancy in certain applications of these diverse professions.

Ecological engineers may be competent to address any number of biological and environmental engineering problems, including bioremediation, composting, and biological treatment of wastewater. However, ecological engineers should also be applied ecologists, able to collaborate with theoretical scientists to develop, design, and construct solutions to complex ecological problems. Ecological engineers should be able to address issues such as terrestrial and aquatic ecological restoration, integrated pest management, biodiversity conservation planning, watershed sustainability analysis, and ecological risk assessment. Developing and protecting the credibility of ecological engineering as a profession requires clear definition of the body of knowledge a practicing ecological engineer must master prior to being certified.

Need for Standardized Curriculum

Many universities offer degree programs in ecological engineering, some more comprehensive than others. Even within the several competent graduate programs in ecological engineering there are varying degrees of emphasis on engineering design. The graduate programs in *Engineering Ecology* at the University of California at Berkeley and *Ecological Engineering* at the University of Maryland represent two competent yet different approaches to curriculum development in ecological engineering.

The University of California at Berkeley offers graduate degrees (M.S. and Ph.D.) in Engineering Ecology with a focus on aquatic ecosystems. The graduate program is designed to “provide the quantitative information needed for engineered solutions to ecological problems. The backbone of Engineering Ecology is applied limnology and

oceanography and encompasses the ecology of all types of aquatic systems. It includes toxic and bio-stimulatory properties of domestic, industrial and agricultural wastewater, and urban runoff as they affect surface waters” (Environmental Quality Program, 1998). The core curriculum required of all students focuses on four major areas of engineering ecology: hydrodynamics, water chemistry, environmental engineering, and aquatic ecology. This is an applied ecology program and does not require undergraduate preparation in engineering, but has a very strong core curriculum.

The graduate program in Ecological Engineering at the University of Maryland at College Park offers graduate students an “interdisciplinary approach to solving societal and environmental problems through the use of designed natural systems” (Department of Biological Resources Engineering, 1998). The program is heavily weighted to restoration ecology and ecosystem management, including projects in flood prevention, restoration of damaged ecosystems, creation of new habitats, water treatment using vegetation-based systems and wetlands, and use of wastes to fertilize agricultural land and natural habitats. Undergraduates from any field may enter the graduate program, provided they have completed 49 semester hours of core courses in engineering design. This is an engineering program with a strong ecological science and design component, but no explicit core curriculum.

The difference in emphasis between the two programs is significant. The Berkeley program may produce engineer ecologists with sufficient design training and experience to employ the engineering method to problem solving, but the curriculum is not constructed to insure it. While the University of Maryland program does require all incoming students to have a common base of knowledge in engineering design, the graduate program does not have a core curriculum requirement for ecological engineers, resulting in a less focused program.

Ecological Engineering Curricula

The fundamental tenant of ecological engineering should be that it is a specialization within professional engineering, and should require accreditation of programs and certification of practitioners. However, the vision of ecological engineering presented here is a substantive hybridization of science and engineering. The scientific method differs significantly from the engineering method. Undergraduate students are prepared to be either engineers or scientists; scientists are not engineers, nor are engineers scientists. Landscape or aquatic ecologists are not engineers, and therefore not ecological engineers; by the same logic, environmental, agricultural, or biosystems engineers are not ecologists, and therefore not ecological engineers. Ecological engineers must be competent in the scientific *and* engineering methods; they must be proficient in ecological theory *and* engineering design.

Developing the professional credibility of ecological engineering will require a significant shift in pedagogy. As previously alluded to, an undergraduate degree program is inadequate to prepare ecological engineers. Undergraduate engineering programs

nationwide are experiencing pressure to reduce credit hour degree requirements. There are insufficient hours in current degree programs to provide the diverse skills necessary to design complex ecological systems. Undergraduate preparation in engineering should not reduce fundamentals in statics, strength of materials, dynamics, thermodynamics, electrical science, fluid mechanics, and design to provide competent preparation in ecology and biology. An advanced degree is required to obtain these additional skills.

An ecological engineering curriculum should be composed of an undergraduate degree (or equivalent) from an Accreditation Board of Engineering and Technology (ABET)-accredited engineering program, and a Master of Science or Doctor of Philosophy degree in ecological engineering. The undergraduate degree should provide a substantive understanding of physical, biological, and chemical processes. Students from non-engineering undergraduate programs should be admitted provided they complete a pre-determined curricula in engineering design to meet ABET criteria for engineering certification. The graduate degree in ecological engineering should incorporate an ecological sciences core curriculum integrated with ecological design experience. Ecological engineering curricula must prepare students to identify and analyze ecological design constraints, characterize engineering solutions in ecological time, and incorporate ecological economics in design evaluation.

We advocate a core curriculum composed of six courses, assembled to provide continuity-based education in ecological principles (Table 1). The core curriculum is critical to developing a credible profession. Ecological engineers must have a uniform body of knowledge to establish professional direction, identify areas of need within the profession, and to insure that the practitioner is well based in ecological theory. The core curriculum should provide a sound foundation in ecological theory integrated with applied ecology and ecological design. Each of the six core courses should integrate ecological theory and design when possible:

Quantitative Ecology - Introduction to ecological systems, energy pathways, organism processes, population dynamics, homeostasis, and community structure. Engineering design should be incorporated in the quantitative component of the course, with varying criteria for design success. This course should be taught in a traditional ecology program, with a multi-disciplinary student body.

Evolutionary Ecology - Theory of life-history strategies in plants and animals (reproductive rates, life cycles, sex ratios, breeding and mating systems) and the co-evolution of animals and plants (pollination, dispersal, and herbivory). This course should be theory-based, with a multi-disciplinary student body.

Community Ecology - Introduction to the link between community structure and community function. Theory of community adaptation and succession should be presented in the context of niche size, shape, and time. Productivity and nutrient/resource cycling should be introduced. This course should be taught in a traditional ecology program, with a multi-disciplinary student body.

Restoration Ecology - Applied ecology course with a summer internship or intensive laboratory component. This course should be designed to provide students with an opportunity to work with students from other disciplines (botany, wildlife ecology,

agronomy, forestry, hydrology, and geology, for example) to analyze, design, and remediate a degraded ecosystem. The obvious constraints of a three hour course will require that these projects be small in scope, but should expose the students to the complexity and diversity of specific ecosystems.

Ecological trophodynamics - Systems Ecology, with emphasis on energy flows through ecosystems, carbon and nutrient cycles, and *emergy* (ala H. T. Odum) as a concept for sustainable design.

Ecological Modeling and Design - Introduction to model design, development, calibration, and validation. Ecological models should be developed for at least three biomes. Students should use current models that incorporate physical processes, biological productivity, and uncertainty analysis.

Ethics and Standards of Practice - Provide explicit code of ethics for ecological engineering, including professional responsibility to future generations, sustainability criteria, and identification of exploitation processes.

Technical Electives - Approved courses in focus areas. These courses should enhance depth in the applied ecology core curriculum. These can include Biochemistry, Environmental Plant Physiology, Soil Chemistry, Limnology, Aquatic or Wildlife Toxicology, among others.

Table 1: Proposed Master of Sciences Ecological Engineering Curriculum (Semester-based).

Course Description	Classification	Credit Hours	
		Design	Total
Quantitative Ecology	Core Course	1	3
Evolutionary Ecology	Core Course	0	3
Community Ecology	Core Course	0	3
Restoration Ecology	Core Course	2	3
Ecological Trophodynamics	Core Course	1	3
Ecological Modeling and Design	Core Course	3	3
Thesis Research	Design and Research	3	6
Ethics and Standards of Practice	Seminar	0	3
Optional Courses of Special Interest	Technical Electives	4	9
Total Hours		14	36

Professional Certification Development

Professional certification is required if ecological engineering is to be a recognized engineering profession. The process for creating certification for any type of professional engineer is meticulous, time consuming, expensive, and requires a great deal of planning before the legal process of establishing certification can begin.

Procedures for certification (licensing) of professional engineers vary between states. However, a typical pathway to obtaining a P. E. license includes:

1. graduation from an ABET accredited undergraduate program (or taking undergraduate courses to meet said requirements as a graduate student),
2. passing the *Fundamentals of Engineering* (F. E.) examination,
3. then after the appropriate engineering experience (four or five years under the supervision of a licensed professional engineer), successful completion of an examination on the *Principles and Practice of Engineering* (the Professional Engineering Exam, or P. E.).

At this point, the licensee will be certified and can claim to be a professional engineer.

The professional certification process will need to be sponsored by a professional engineering society, as the process is resource intensive and requires an enormous contribution of time by volunteers. The first step of professional certification is to form a professional group of practitioners. This group will need to develop a working definition of the practice of ecological engineering and clearly state the added benefits this new profession offers to the public, i.e. what ecological engineering adds over and above current capabilities of other engineering branches. The professional society then must define a core base of specific knowledge required to practice ecological engineering over and above the knowledge required to pass the F.E. exam. Once the knowledge base is defined, the critical intersections of engineering practice and public safety, health and welfare need to be determined. The final outcome is the definition of critical competencies required of the ecological engineer in order to perform their duties while having the technical capability to protect the public welfare. These competencies will comprise the body of knowledge required to pass the P. E. exam for ecological engineering, and provide a foundation for continuing education requirements.

Before the certification process can begin, practitioners of ecological engineering must reach a consensus on the core goals and methods of the profession. The following questions on certification topics specific to ecological engineering must be addressed:

What are acceptable areas of practice for gaining the required experience in ecological engineering before the P. E. exam can be administered? The applicant must have both general technical engineering experience, and specific experience applying engineering to ecological systems. Currently, all or part of this experience might be gained through employers such as state and federal environmental regulatory agencies, equipment manufacturers and developers, consulting firms, municipalities, agriculture based companies, public works projects, animal and human waste management and treatment companies, and other groups involved with engineering projects that utilize and/or affect ecological processes. The development of professional certification for ecological engineering needs to include all of these groups. This will avoid having a specific industry control certification and the potential for conflicts of interests, where the best interests of a specific industry may conflict with the best interests of specific ecological functions, or the best interests of another industry or the public.

Which aspect of the public welfare is the engineer to hold paramount? The ecological engineering profession must consider the spirit behind professional certification, which is

to ensure its practitioners “in the fulfillment of their professional duties, shall: Hold paramount the safety, health and welfare of the public in the performance of their professional duties” (National Society of Professional Engineers, or NSPE, code of ethics). It is this fundamental canon of the NSPE code of ethics that may be a source of confusion and discourse surrounding the practice of designing ecosystems for the benefit of both humans and nature. There have been age-old arguments pitting the welfare of ecology against the welfare of the public: Trees versus jobs; municipal water supply versus endangered species; short term food supply or cash crops versus long term sustainability. Therefore, the profession of ecological engineering may need to consider specific codes of professional practice for properly addressing conflicts between the needs of specific public communities and specific ecological communities.

What are the criteria for acceptable standards of practice in ecological engineering?

The engineering profession is based on objective science; professional standards of practice or ethical guidelines must be based on scientifically valid evidence of the direct, reproducible, corollary effects between ecological function and human health, safety and welfare. The practice of ecological engineering should to be based on sound technical competence and objective reasoning of the practitioner, not politically popular or trendy environmental attitudes. Accepting this premise, the temptation is to then establish standards of practice based solely on technical engineering calculations and raw data while disallowing any judgmental conclusions or predictive modeling and thereby avoiding the difficult engineering art questions that arise as a result of the practice of ecological engineering. This approach is flawed because it limits the prerogatives of engineers, thus not allowing them to do what they do best: create systems to function in ill-defined and complex environments.

What currency is to be used in cost/benefit ratio analysis? The profession must establish within the professional guidelines and standards of practice clear definitions of what results are undesirable. Obviously, a design cannot directly cause the illness, injury, or death of a human, but beyond this, how does the practitioner account for the sustainability of a project? How is the impairment of an ecological service assessed and quantified? Since ecological services are typically held in common trust, cost/benefit analysis cannot be viewed in terms of dollars alone. All humans in the present and in the future own these services, so how does the profession establish what is a successful engineering design and what is a design failure? How does this relate to standards of practice? In designing these systems, which is paramount: the health of the ecosystem or the people currently occupying it?

How do we incorporate the responsibility of ecological engineers to future generations into acceptable safety factors for design of ecological systems? If an engineer is working for a specific company, any design they implement can fail and cause the company fiscal loss. As long as the public is not harmed by the failure of the design, and the design was carried out in an ethical manner, standards of practice for engineers do not address the tolerance for risk to the company. That is a risk voluntarily accepted and determined by the members of the company. However, if an ecological design fails, those affected may

not be voluntarily assuming the risk. These questions indicate that acceptable risk levels within ecological engineering may be significantly lower than in other branches of engineering practice. Aspects of small-scale ecological testing need to be addressed so that standards of practice can be developed to guide the engineer in the proper methodology for testing ecological processes in an isolated setting prior to implementation.

Conclusions

We recognize that neither a curriculum nor a certification program make a professional engineer. However, there is a certain body of knowledge that must be assimilated and mastered to be competent in a profession, and there are standards of practice that must be adhered to if a profession is to establish and maintain credibility with the public. There is still significant debate within applied ecology regarding the viability of designing an ecosystem. The credibility of ecological engineering will be measured by its successes, and more critically, by its failures. A common body of knowledge that is founded in theoretical ecology and engineering design, wedded with clearly defined professional codes ethics and standards of practice, will provide substantive footing for this new and exciting profession. Ecological engineering may become the single greatest tool developed by the human species, or it may become advanced horticulture. The outcome is dependent on the vision of its practitioners.

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