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This report deals primarily with education in the biological sciences as a part of the training of the natural resource specialist and secondarily with the mathematics and physical science aspects of his training. The first part of the report presents the rationale for the proposed program. The proposal calls for a two-year core program. The first year is to include fundamentals of biology with equal emphasis on the study of plants and animals. The second year includes genetics, physiology and ecology using the concepts and principles of the first year as building blocks. Ecology is stressed as fundamentally important. A suggested outline for study in ecology is presented in the appendix. The report briefly discusses training beyond a two-year program. Recommendations for training in mathematics and the physical sciences are then presented with detailed outlines of the content to be covered in calculus, probability, linear algebra, and biometrics. (BC)

Report of the

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FOREWARD

In 1965 the Commission on Undergraduate Education in the Biological Sciences (CUEBS) established a Panel on Preprofessional Training in the Agricultural Sciences (PPTAS) to consider the following questions:

(1) What preparation in basic biology, physical sciences and mathematics is desirable for students planning careers in the agricultural sciences?

(2) To what extent can agricultural curricula include the same biology core program taken by other biological science majors?

The panel early recognized that it would be an Herculean task to evaluate adequately all the implications involved in the questions posed, especially when students in such divergent areas (e.g., forestry, wildlife, food science, agricultural engineering, preveterinary medicine) were to be considered. In an effort to obtain the broadest thinking possible, six action committees composed of scientists from universities throughout the country were created in cooperation with the Commission on Education in Agriculture and Natural Resources (CEANAR). Each action committee considered one of the following areas: animal sciences, plant and soil sciences, natural resources, food sciences, bioengineering, social sciences, and each was charged with the responsibility for studying and recommending desirable preparation in the biological sciences and cognate disciplines for undergraduates majoring in the committee's area of specialization. The committees were asked to think in terms of requirements for students who will be professional scientists and agricultural production workers in the 1980's.

The following report is from one of the action committees. The ideas expressed in the report are those of the action committee members and not necessarily those of either of the sponsoring Commissions. The PPTAS position paper itself is available as CUEBS Publication No. 17.

Martin W. Schein
Director, CUEBS

INTRODUCTION

Technological explosion, population expansion, increasing urbanization, changing land use practices and alterations in sociological demands are presenting vast new challenges to natural resource scientists and managers. In turn the task of training resource specialists to meet these challenges is now of major concern to both secondary and higher educational institutions. The biological sciences make up a major facet in the education of natural resources specialists. This report is concerned primarily with undergraduate training in biology. Secondary consideration is given to training needs in mathematics and the physical sciences.

Land Use Changes

Massive changes in the pattern and intensity of land and resource uses are currently underway and will unquestionably intensify. Improved technology now permits us to produce more food and fiber than ever before on fewer acres of land. In the past decade millions of acres of agricultural land have been converted from cultivation to grass production. Simultaneously, millions of acres of forest, range and agricultural lands are being diverted each year, sometimes irrevocably, from productive pursuits (in terms of food and fiber) to urban sprawl, to recreational interests and to transportation. Conversely, current trends indicate that we may have to "reopen" some of these previously cultivated lands and to utilize more of our resources to help feed less fortunate peoples.

Shorter work weeks, higher personal income and increasing urbanization indicate a repetition of the spectacular jump in participation in outdoor recreation and in the demand for more and better recreational areas, facilities and services. Increasing emphasis is being placed on the development of fish farms, game farms and picnic and camping grounds on private lands. Unquestionably more of our agricultural and forest-producing lands in the vicinity of the rapidly developing "strip" cities will be diverted to such uses.

The most dramatic changes in the American landscape are occurring at the urban fringe, as the urban agglomeration expands into the rural hinderland. In this process, scant attention is being given to the opportunities or constraints offered by the natural resource components, so that we are often as reckless with our resources on this new frontier as we were on the "Old Frontier." This is happening because natural resource scientists and managers are not ordinarily being admitted to the planning process, and resource-use decisions are being made by land developers, engineers, politicians and others who lack ecological awareness. If the environment of the seventy percent of our population which lives in urban centers is to be pleasant, safe and efficiently utilized, natural resource scientists must be involved. In order to make a contribution, however, these scientists need the kind of education which will enable them to assist planning boards, local governments, highway departments and other planning groups. This requires not only a basic understanding of biological processes of the urban zone of influence, but also, greater familiarity with the social sciences. The ecosystem has a legal, institutional, economic, historic and cultural "climate" as well as a biological regime.

Multiple Use

The concept of "multiple use" is being applied at an increasing pace on our timber and range lands, both public (including military) and private. Many of our forest lands which were once used almost exclusively for timber production are now providing multiple goods and services--open space, recreation, watershed protection--and are supporting an aesthetically important bird population, wild game and domestic livestock. Although total livestock production on our vast acreage of public range has steadily declined, use by game and wildlife has increased. Many ranchers and farmers are combining cattle and sheep production with game and wildlife "farming." Increasing efforts are being directed to natural resource management on private lands--agricultural, range and forest lands.

Quality of the Environment

Our natural endowment of resources and our research in agriculture and natural resources (largely biologically oriented) has made us rich. We are required to spend less of our time and money for the necessities of life and consequently have been able to devote more of our total resources to industrial development. Consequently, our natural resources have been relatively neglected.

However, a major effort is underway to improve the quality of our environment, not only from the standpoint of eliminating water and air pollution but by roadside beautification and the establishment of green belts. The preservation of wilderness, natural areas, open space, wild rivers, seashores and lake shores is being actively undertaken. Many of our so-called wilderness areas have ceased to be such due to heavy invasions by man. Management of wilderness and controlled use of such areas will be necessary in the immediate future. Similarly, floodplains susceptible to high-cost damages must be maintained in their natural state in some cases and rezoned in others to low-damage recreational use.

World-wide Responsibilities and Challenges

There is a growing awareness of human environmental relationships and the importance of harmonious adjustments between human societies and their natural resources within the regional ecosystems of the world. We are entering a new era of human ecology in which education will play a major role in providing improved standards of living and more satisfying environments.

The opportunities for development of natural resources curricula are international in scope. Foreign countries are presently sending students to American universities for education in the various specialties of natural resources. Similarly, resources specialists from the United States are serving abroad in educational and research capacities. As the effort of aiding the emerging nations with programs in management of natural resources gains momentum, demands for educational opportunities will grow. American universities will be requested to increase their activities in the development of schools, training programs and research in natural resources.

Demand for Professional Workers

The need for large numbers of well educated personnel at all professional levels, as well as sub-professional levels, is extremely urgent today; the demand will increase in years ahead.

The opportunities for challenging professional positions within the United States and abroad in human ecosystem biology and resource management will attract more and better students as the urgency of world problems increases. Success of the international effort will depend upon attracting good students and providing sound yet imaginative biological study. Concentration is needed at levels of biological organization from human to microbial systems. Offering a challenging curriculum is as important to attracting students as is the opportunity for employment.

Challenge to Education

Until relatively recently, biological research has often been qualitative and descriptive. New techniques, computers and other hardware, as well as the results of past research, have permitted the rapid quantification of this science. And, as in several of the sister sciences, the last decade has witnessed a tremendous research output in biology which has, and is, rapidly altering old concepts and ideas. Marriages with mathematics, engineering, physics and chemistry have given birth to such new and challenging fields as biochemistry, biophysics, biostatistics, radiation biology and bioengineering. The computer has proven its capability to handle vast amounts of data in short order--often however, we lack sophistication in determining biological input.

Despite these advances, we have only started to scratch the surface in terms of the challenges ahead in agriculture and natural resources. In the field of water resources we have developed few solutions for the problems of loss and waste in irrigation and in pollution control. In forestry we still leave a substantial volume of wood in the forest. Forest products research is needed to reduce this waste and to find uses for the so-called "weed species."

Increased intensity of land use and increased demand for resources will multiply socio-economic and legal problems in natural resources. An example is provided in conflicts in water use between recreational interests and power and irrigation demands. Training and research in these areas are essential if we are to satisfy competing demands.

While it is quite apparent that by 1980 agriculturalists, resource scientists and technicians will be facing many new and complex challenges, the challenges to educational institutions to train and retrain personnel qualified to cope with the problems of the future are equally formidable. A major step has been taken by the biological science community with the creation of the Biological Sciences Curriculum Study (BSCS) and its introduction of updated curricula into the nation's high schools. It is estimated that about 30 percent of our high schools are participating in this program. Within five years it is anticipated that the majority of all graduating high school students will have been exposed to this new curriculum or its equivalent. Since this program is in many aspects superior to many of our present college freshman level biological sciences courses, universities are faced with a major curriculum reorientation.

RECOMMENDATIONS FOR EDUCATION IN THE BIOLOGICAL SCIENCES

A Two-Year Core Program

In view of changing demands in natural resources use and development and the rapid growth and sophistication in the biological sciences, marked changes in biological science training are inevitable. It is urged that at least a two-year core program in the biological sciences be available for all students in natural resource disciplines, whether research or management oriented. In the preparation of this program, two important assumptions have been made. First, entering university students will have had a biological background at least equivalent to the present BSCS program. The first year course will build upon this foundation, permitting greater depth in instruction than is presently practical. Second, during the next five or ten years, high school instruction in mathematics will improve markedly.

The first year of such a core program should be concerned with fundamentals of biology. Outlines for such a course may be found in many modern textbooks, so an outline has not been included here. It is recommended that an ecological approach should be stressed in the course wherever and whenever practical. Biology staff teaching natural resources students should realize student interests. Subject matter should not be treated in an abstract physio-chemical realm; rather, illustrations should be drawn from higher (preferably economically important) plants and animals as well as microorganisms. Equal emphasis should be given to plants and animals.

The second year of the minimum two-year core should include genetics, physiology and ecology. Instruction in these areas should utilize the concepts and principles in the first year course as building blocks. It is recommended that genetics emphasize fundamental concepts, population genetics and quantitative inheritance. Instruction in physiology may be plant or animal oriented or may be an integrated course.

A thorough understanding of the principles and concepts of ecology is particularly important for all natural resources disciplines. A suggested outline for the material offered in ecology is given in Appendix A. The intent of the outline is to present the principles of ecology in the framework of the ecosystem. Some disciplines may require further courses in some of the subject matter areas covered in this course. In particular, the sections headed "Responses of organisms to environment" and "Classification and description of ecosystem" should be expanded with courses in autecology, synecology, advanced ecology or in professional courses. The section entitled "Man in the ecosystem" should serve as an introduction to applied ecology.

Training Beyond a Two-Year Core Program

Beyond the subject matter described above for the first two years of the common core program, there are many other areas of biological science that are particularly pertinent to training in natural resources. These include biochemistry, biophysics, pathology (parasitology, mycology), entomology, systematics (taxonomy, classification), developmental biology (anatomy, morphology) and microbiology as well as some of the applied professional courses which often are largely biological.

It is anticipated that in the future as well as at present both breadth and depth of training will vary substantially beyond the second year with the various disciplines and according to the student's professional goals. A student in fisheries biology will undoubtedly receive specialized training in microbiology, aquatic biology, icthyology and limnology, while students in forest science will be oriented more to training in systematics, pathology and entomology. Students who plan careers in research and who expect to enter graduate school will undoubtedly receive additional training in basic biological sciences courses including biochemistry, physiology and ecology as well as coursework oriented to his specific discipline. With the rapid advances in the biological sciences, it is evident that training in biochemistry would be highly desirable for all natural resources and may, if fact, be a necessity in the near future.

As noted above, advanced courses in biological sciences as well as applied professional courses should utilize the core courses as building blocks. Such practice will eliminate what is often today unnecessary duplication and will permit a higher level of presentation than is now possible.

The Committee urges that consideration be given to a course in Systems or Systems Ecology which would be required of all students in natural resources at the senior level. This should be a philosophical course, integrating concepts in social, physical and biological sciences with an introduction to the quantitative synthesis of ecological systems by computer simulation. Such training should help students in all natural resource areas overcome the shackles of their specialization by providing them with a total view of resource use and management. This training must provide an opportunity for interplay with the social science aspects of resource management as well as with the physical and biological sciences. The type of material which may be covered in such a course is indicated in Appendix B in an outline developed by Dr. A. M. Schultz at the School of Forestry, University of California.

Additional education and experience in quantitative ecology and computer simulation of ecosystems should be required of those advanced undergraduate and graduate students who are preparing themselves for positions as "analysts" or resource managers who are charged with making decisions regarding alternative uses of natural resources.*

RECOMMENDATIONS FOR EDUCATION IN MATHEMATICS AND THE PHYSICAL SCIENCES

Mathematics

Increasing sophistication and quantification in all aspects of biological sciences and in professional courses dictate a major revision in training in mathematics for students in natural resources. "New" biology will require the application of calculus and probability techniques. Improved inventory methods require a knowledge of statistical tools and computer technology. Similarly, recommended training in systems analysis which will undoubtedly become a tool of both the researcher and manager will require a substantial increase in mathematical competence.

The present training norm in mathematics for most students in natural resources areas include college algebra, trigonometry and a course in statistics. Based on present efforts to improve instruction at the secondary school level, it is assumed that within the near future entering college students will have attained a substantially higher degree of competence in mathematics.

The Committee recommends that mathematics instruction include (1) introductory calculus, (2) probability, (3) linear algebra and (4) biometrics. Subject matter content should be comparable to the recommendations of the Mathematical Association of America, Committee on the Undergraduate Program in Mathematics.**

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* See also: Patten, B. C. 1966. Systems Ecology: A Course Sequence in Mathematical Ecology. <u>Bioscience</u>. September 1966.

** <u>A General Curriculum in Mathematics for Colleges</u>. The Committee on the Undergraduate Program in Mathematics, P.O. Box 1024, Berkeley, California 94701.

Subject matter in biometrics should utilize biological illustrations and should include an introduction to computer science.

Mathematics courses may be the same courses as those taken by mathematics and engineering students or may be specially designed courses in mathematics for biologists. For students contemplating graduate study or research careers it is especially important that these be such that they can continue on in additional mathematics training.

<u>Calculus</u>

- The integral and derivative
- Differential calculus of polynomials and rational functions
- Anti-derivatives and integrals of polynomials
- Logarithms and exponentials
- Trigonometric functions
- Applications and extensions

<u>Probability</u>

- Probability as a mathematical system
- Random variables and their distributions
- Limit theorems
- Topics in statistical inference

<u>Linear Algebra</u>

- Linear equations and matrices
- Vector spaces
- Linear mappings
- Determinants
- Quadratic forms
- Vector cross product
- Differential calculus of inner product and cross product
- Groups of symmetrics

<u>Biometrics</u>

- Populations and parameters; samples and statistics
- Measures of central tendency and variation
- Frequency distributions (binomial, poisson, normal, other)
- Sampling (different distributions, infinite and finite populations, transformations, optimum allocation, stratification, multi-stage sampling, cluster sampling)
- Comparison of two sample means (paired and unpaired observations, linear additive model, equal and unequal variances, testing hypothesis of equality of differences, confidence limits, sample size)
- Enumeration data (Chi-square, one-way classification, contingency tables, goodness of fit to theoretical distribution)

Principles of experimental design
Linear regression
Linear correlation
Analysis of variance (one-way and multi-way classification, factorial experiments, split-plot designs, unequal subclass numbers, separation of means)
Use of computers in biometrics
Multiple and partial regression and correlation
Analysis of covariance
Nonlinear regression
Multivariate analysis
Stochastic processes
Curve fitting
Experimental designs

Physical Sciences

Based on the assumption that undergraduate programs in the immediate future will continue to be essentially four-year programs, the following recommendations are considered minimal for all students in natural resources. If future undergraduate programs become five-year programs, an expansion of subject matter in the physical sciences would be indicated.

Chemistry - 1 year (one-third to one-half to be organic chemistry). A course in biochemistry is highly recommended.

Physics - at least one-half, preferably one year with primary emphasis on heat, light and mechanics. A course in biophysics is highly recommended.

Geology or Physical Geography - one-half year.

Soil Science - one-half year.

Atmospheric Science (Meterology and/or Climatology) - one-half year.

Depending upon the student's major, additional course work in the physical sciences may be required or recommended as elective courses. Particularly germane to natural resources disciplines would be courses in soil science, geomorphology, hydrology, oceanography and earth science (geophysics).

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APPENDIX A

GENERAL ECOLOGY

Ecosystem Concepts and Operation

- Definition, interdisciplinary nature, kinds, boundaries
- Controlling factors (state factors, including temperature, parent material, etc.)
- Dependent factors (soil, vegetation, etc.)
- Ecosystem change
  - Temporal
    - Directional (successional)
      - Progression (increasing complexity, diversity and stability)
      - Regression
    - Principle of self-regulation through compensatory fluctuations
    - Replacement and intercommunity cyclic nature
    - Long term change (polygenetic ecosystems and paleoecology)
  - Spatial
    - Patterning along environmental gradients
    - Continuum vs. discrete ecosystem
    - Ecotone and edge effects

Living Organisms

- Adjustment to the environment
  - Limiting factors
  - Carrying capacity
  - Genetic adaptation (biotypes, ecotypes, gene pools, introgression, etc.)
  - Stratification
  - Periodicity
- Relationships within populations
  - Population growth
  - Population structure
  - Reproductive potential (natality, mortality, survivorship)
  - Cycles
  - Dispersion patterns
  - Oscillations
  - Dominance
  - Tolerance
  - Density dependence
- Relationships between populations
  - Neutral
  - Positive (commensalism, mutualism, protocooperation)
  - Negative (competition, predation, parasitism, amensalism)

Appendix A

Ecosystem Change

- Ecosystem metabolism
  - Energy flow
  - Primary and secondary production
  - Gross and net productivity
  - Ecological efficiency
  - Food chains - trophic levels
  - Food webs
  - Biomass
  - Population energetics (pyramids of biomass)
  - Second law of thermodynamics
  - Entropy (pyramids of energy)
  - Negative entropy of living systems
- Biogeochemical cycles
  - Hydrologic cycles
  - Other cycles

Responses of Organisms to Environment

- Microclimate, organism climate, local climate, and macroclimate
- Environmental factors
  - Heat
    - Nature and properties
    - Effects (physical, biochemical, cellular, organism, ecosystem)
  - Water
    - Nature and properties
    - Effects
  - Soil
    - Nature and properties
    - Effects
  - Atmosphere
    - Nature and properties
    - Effects
  - Fire
    - Nature and properties
    - Effects
  - Gravity, pressure and sound
    - Nature and properties
    - Effects
  - Ionizing radiation
    - Nature and properties
    - Effects

Appendix A

Classification and Description

- Community classification
  - Methods
  - Levels (terrestrial, marine, aquatic, extra terrestrial)
- Habitat
  - Methods
  - Levels
- Ecosystems
  - Methods
  - Levels

Man in the Ecosystem

- As a part of the ecosystem
- As an observer
- As a manipulator
  - Exploitation
  - Environmental pollution
  - Environmental engineering
  - Manipulation of ecosystem factors in forest management, range management, watershed management, wildlife management, fisheries ecology and recreation

APPENDIX B

NATURAL RESOURCES ECOSYSTEMS

Introduction

Reasons for offering the course. Proposals for course title. Objectives. Organization of course. Reading list.

Relationships Between Disciplines

Hybrid, multi-, and interdisciplines. Practical aspects of the interdisciplinary movement. Ecology as a field of inquiry. Ecology and economics. Ecology and sociology. Human ecology. Epidemiology. Engineering. Agriculture, forestry, range management and recreation. Appropriateness of the ecosystem as a unifying concept.

Philosophical Background

The Holistic philosophy. Gestalt perception. Logical Positivism. The laws of the integrative levels of organization. Principle of emergence. Mechanism and purpose. Invariance principle. The organismic-transectional view of physical nature and human society. Scientism.

Ecological Background

Before and after Tanslay. Clements and the organismic community. Ecosystem contrasted with community concept. Ecosystem and population ecology. Ecology as a point of view. Systems ecology. Ecosystemology as a separate science. Contemporary ecosystem research: energy flow, nutrient cycles and radioecology.

Background from Organization Theory

Organization theory and theory of organizations. Science of administration, production management and operations research. Analytical concepts from economics and sociology.

Systems Analysis and Synthesis

The general systems approach. Machines and communications systems. Information theory. Cybernetics and feedback systems. System models. Network theory. The strategy of synthesis in scientific inquiry. Classification of systems. The ecosystem as a special case.

Characteristics of Ecosystems (Definitions)

Ecosystem components and subsystems. Ecosystem boundaries. Definition of state of a system. Open and closed systems. Concept of equifinality. Equilibrium systems and steady state. Initial states and flux potentials. Independent (state) factors and dependent factors. Sequences and functions.

Appendix B

Ecosystem Properties (Emergent Qualities)

Trophic structure. Productivity. Carrying capacity. Stability. Cyclicity. Diversity. Entropy. Order.

The Organism in the State Factor Equation pFFFp

Flora and fauna as independent state factors. Vegetation and animal populations as dependent factors. Succession and climax theories in the ecosystem framework. "Natural" ecosystems.

The Component Man in the Ecosystem

Man's three roles: (1) Dependent--top of food chain; (2) Independent--planning agent; (3) Indifferent observer--researcher and philosopher. Reciprocity between culture and environment. Population dynamics and demography. Technology and culture. Research and management: observations, measurements, manipulations. Perturbations. Brittle ecosystems and the investigator effect. Conservation.

Approaches to Resource Management Problems

Simple casual trains and the symptom-cure approach. New methods for handling "all possibilities." Facilities for studying "total environment." Handling of factual and normative problems. Qualitative versus quantitative aspects of management.

Principles of Ecosystem Management: Simulating Nature

Examples of cultural practices that do or do not stimulate nature. Monoculture. Organic farming. Use of fire in silviculture and forest management. Balancing inputs and outputs in "preservation management." Biological control versus chemical control of pests. Multiple use management of wildlands. Crop rotation and fertilization practices.

Principles of Ecosystem Management: Creating Order

The notion that man can create more order than disorder if he wants to. Concept of randomness. Landscape architecutre and regional planning. Building systems with homeostatic controls.

Problems of Evaluation

Three standards of good architecture. Economics and theory of value. Pareto's sociology. Criteria for rating natural phenomena, cultural practices, institutions and policies on a goodness-badness scale.

Evolution of Ecosystems

Evolution of systems at lower levels of organization. Comparison of theories and concepts at organismic and supraorganismic levels. Mechanism and purpose again; adaptive behavior. Problem solving as natural selection. Evolutionary explanation of hierarchy. Evolution in planned ecosystems.

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