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A MARINE SCIENCE ODYSSEY INTO THE 21st CENTURY. *J.M. GILI, J.L. PRETUS and T.T. PACKARD (eds.)*

Conversaciones con Ramón: big questions for the millennium*

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SUMMARY: Ramón Margalef and I have enjoyed many years of conversation about ecology and my remarks will celebrate our relationship. My life has gradually shifted from the hustle of the market place and consumption of money and goods to a academic career devoted to students and ideas. Students ask how they can avoid becoming trivial, how they can contribute to solving the dreadful problems that face human society? Students want to know from me, their senior, what are the big questions of ecological science. That is the motivation for me to think about the challenging questions ecologists are asking today, that may change the subject tomorrow.

Key words: philosophy of ecology, ecosystems, evolutionary ecology, hierarchy of systems, Margalef personal remembrance.

INTRODUCTION

I became acquainted with Ramón Margalef when I was a graduate student at Michigan State University in the late 1950's. About this time I received in the mail a reprint of his landmark paper, **Information Theory in Ecology** (Margalef, 1957). The significance of this paper to our seminar discussions and to our research was that it applied a method, information theory, to express a broad, interacting, holistic point of view in ecology. We had not yet adopted ecosystem thinking. Eugene Odum's **Fundamentals of Ecology** had just been published (Odum, 1953) and while this text would change our way of thinking fundamentally we had not yet applied it effectively. Margalef's information theory showed us a way of thinking systematically about systems and it was connected to other advanced holistic scientific initiatives, such as Norbert Weiner's **Cybernetics** ,which I encountered as an undergraduate in the library of Purdue University, and N. Rashevsky's (1966) papers in the Bulletin of Mathematical Biophysics and the **General System Yearbook**.

Margelef's ideas was interesting to us mainly because information theory was oriented toward systems in general and to energetics specifically. His own focus was on combinometrics of spatial structure of populations and biodiversity. These issues were less relevant to our studies at that time. But his lectures and conversations with us at Georgia and at ecologist meetings and his latter papers and books were exciting because of his continued interest in synthetic questions. It was an exciting time to be an ecologist. New questions were being raised and many of us were challenged to apply theory from physics, chemistry, biology and the social sciences to answer them.

Later, I was fortunate to be asked to coordinate a course on ecology at the Institute of Mediterranean Agronomy of Zaragoza, Spain. Ramón Margalef was the Spanish coordinator of the course and we

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saw each other frequently. Over the years the course evolved and it is now concerned with rural planning and the environment. I still coordinate it, but now with Juan Bellot of the University of Alicante (Golley and Bellot, 2000). In those earlier times I had many conversations with Ramón Margalef. They were always stimulating because both he and I thought analogically, drawing connections from comments and ideas expressed across the table or desk and suggesting universals.

At one of these visits, in his office in the university at Barcelona, in the early 1980's, Ramón commented to me, "Frank, ecology isn't fun anymore." This is a rather arresting statement to make and at the time I thought that I understood his meaning but upon reflection I realized that I had not fully appreciated the comment. I had interpreted Ramón's comment to mean he recognized that the search for universal ecological concepts, derived from physics or other disciplines, was over. Students were no longer intrigued by analogies between toyshops and marine plankton. They were looking for experimental proofs, statistical designs, data and reductionism. The search for universals of the 40's and 50's was replaced with a focus on relativity, specificity,and individualism of the 60's and 70's. Modernism had become postmodernism. Ecology was affected by these intellectual movements just as were all the other sciences and humanities. By 1980 it was obvious that the grounds upon which we carried out our conversations and did our research were changed and "it wasn't fun anymore."

While fun related to an intellectual mood, I also feel that the concept of "fun" characterizes Ramón Margelef in a very special and personal way. I see him standing before us at the black board drawing a relationship between X and Y that is entirely unexpected, with a big smile on his face, as we register surprise and then amusement that X's and Y's may be connected in such a way. And we all laugh. And then our minds are stimulated to search out similar connections in other contexts. That is fun, all right! It is a kind of fun that is fundamental to intellectual work.

ECOLOGICAL SCIENCE, GROWTH AND CHANGE

I want to use this comment of Ramón's, made to me in a conversation in Barcelona, as a spring board to consider the nature of ecological science. Ramón was responding to a familiar feature of science; its capacity and tendency to grow and change. Our activity and the satisfaction we gain from that activity also changes as science grows. The "fun" of the early years, when ecological science began exponential growth, was a real phenomenon and is recalled with pleasure by those who shared in the time in some way. Growth leads to changes, which require new environments to maintain growth or sustain maturity. In this essay I want to explore some of the features of growth and change in ecology and environment in the twentieth century. Hopefully, these interpretations will help us to understand opportunity and challenges facing our science in the new millennium.

The first task is to describe the growth of ecology. Science, in general, has been growing continuously from its origins, when we express growth as increase in various quantitative measures, such as the number of practioners, published papers, citations to papers and so on. The historian of science, Henry Menard (1971), comments that "growth can be measured most easily by the increase in the number of scientific journals, all of which are cataloged and available in libraries." I am grateful to Stew Gillmor, Wesleyan University and Stanford University for drawing my attention to Henry Menard's publications.

Science can be defined as the material that is published in these journals. According to Menard, journals typically contain about ten articles per issue and thus about 120 per year. Price (1961) has shown that about 6 million scientific papers have been published since they were invented in 1665. After an initial startup period of a century, growth of scientific papers has been exponential with a doubling time of 15 years. Of course, there are individual sciences that grow more slowly. Glacial geology is an example (Menard, page 34-35). In this case dynamic growth began in 1837 when Louis Agassiz published on the existence of an ice age in western Europe. By 1858 growth became exponential with a doubling time of ten years, which continued until 1900 when the moraines of repeated glaciation were mapped in North America. Afterwards a slower growth period began with an average doubling time of 27 years. This rate has continued.

Menard proposes that the doubling time of scientific papers is connected to other measures of science. For example, each scientific paper is written by a scientist and, again according to Menard, a typical rate of production of papers by a productive scientist is three papers per year. Thus, he calculates one journal is equivalent to the output of about 40 scientists. Since a doubling time of 15 years is equivalent to an annual interest rate of between 4 and 5 percent and the doubling time for the population of the United States is about 50 years or one percent per year compounded, the consequence is that the number of scientists in the population has increased rapidly. More than 87 percent of all scientists that have ever existed are alive today. Obviously this situation cannot continue indefinitely. Menard finds evidence that resources are beginning to be limited and the capacity to support science is slowing down. Clearly, this is the reason for the repeated efforts in the US Congress, Academy of Science and other bodies to stress the importance of adequate funding to maintain science productivity. Complex, growing, modern societies need science to address new associations of problems.

These observations of Menard provide a context within which to consider ecological science. Ecology is a relatively small discipline which is usually placed within the biological sciences. In 1980, the National Science Foundation (NSF) of the United States reported on the number of scientists in the country (NSF 80-308). Of a total of 274,000 scientists, 41,000 were biologists, 15,000 agricultural scientists and 53,000 medical scientists. Each of these categories could contain ecologists but probably most ecologists would be included among the biologists. At this time the total number of ecologists was about 6,000.

The problem of determining numbers of scientists is definitional. The term “ecology” was coined in 1866 by the German zoologist Ernst Haeckel and published in his textbook on general morphology. Haeckel defined ecology as the study of the relationships between animals and their environment. If we extend this definition to include plants and microbes, it will serve as the general definition of ecology in the current textbooks. The ecologist focusing on the animal, plant or microbe part of the definition is clearly a biologist, as well as an ecologist. His or her explanations of the patterns observed in nature will be grounded in the basic biological subfields of anatomy, morphology, genetics, physiology and behavior. But if the ecologist is concerned with the environment he or she might be a physical scientist, such as a geologist, hydrologist, chemist or geographer. And further, if we consider that organisms and environments may be created and managed by humans, an ecologist might be an agricultural scientist, an environmental designer or other alternative discipline.

In an actual example of this problem, in 1916 when the Ecological Society of America (ESA) held its inaugural meeting, the membership was made up of 88 plant ecologists, 86 animal ecologists, 43 foresters, 39 entomologists, 12 agriculturalists, and 14 marine ecologists of a total of 307 individuals. The formation of this society attracted scientists from a variety of disciplines. This means that the boundaries of the discipline are fuzzy. Rather than create a precise definition for this heterogeneous group, even if the definition is based on the words of Ernst Haeckel, and then use it to interpret man power statistics of a government to estimate the number of ecological scientists, it is probably more accurate to use the membership of the national ecological societies to estimate the size of the population of these scientists. After all, professional societies are voluntary organizations and the membership is usually made up of self identified individuals who are willing to pay dues and participate in the societies business. Fortunately, we have good information on the membership of the Ecological Society of America and the British Ecological Societies, the two largest societies of ecologists in the world and we can use these to determine the growth of the population of ecologists.

Ecology became an active scientific field around the turn of the 19th into the 20th century; although, of course, Ernst Haeckel invented the term “ecology” in 1866. The British Ecological Society was the first professional ecology society to be established. It was formed in 1913 and the Ecological Society of America was formed a few years, later in 1916. If we arbitrarily assume that the beginning of ecology was the time of formation of discrete professional societies, that is about 1915, then the first doubling would be expected in 1930 at a doubling rate of 15 years. The second doubling would occur in 1945, the third in 1960, the fourth in 1975 and the fifth in 1990.

This theoretical pattern fits the growth of membership of the Ecological Society of America rather closely (Fig. 1). The ESA started with 286 charter members (Burgess, 1977). The first doubling to 600 members occurred in 1930, as expected. But little growth occurred in the next 15 years due to the Great Depression and the Second World War. There was even a slight decline to 546 members at the height of the depression in 1934. After the Second World War ended, growth in members of ESA increased rapidly, reaching 2000 in 1960. This growth rate continued to 1973, when membership reached 5000. Burgess commented that the doubling

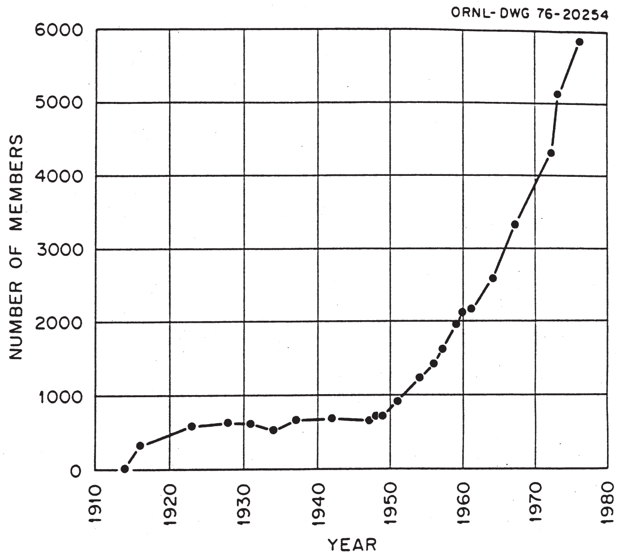

Fig. 1. – Growth in Membership of the Ecological Society of America from its start in 1914 through 1976 (from Burgess, 1977).

time for the ESA during this postwar period ranged from nine to 13 years. At present (1999) the membership of ESA is about 7400, and it has remained at this level for several years. It appears that the ESA has reached maturity and is no longer doubling each 15 years.

These data for the ESA may be compared to data for the British Ecological Society (BES) presented by John Sheail in his 75th anniversary history of the BES (Sheail, 1987). In 1913 there were 47 members present at the inaugural meeting of this new society. By 1917 the BES slightly exceeded 100 members. Of course the BES also suffered from the two world

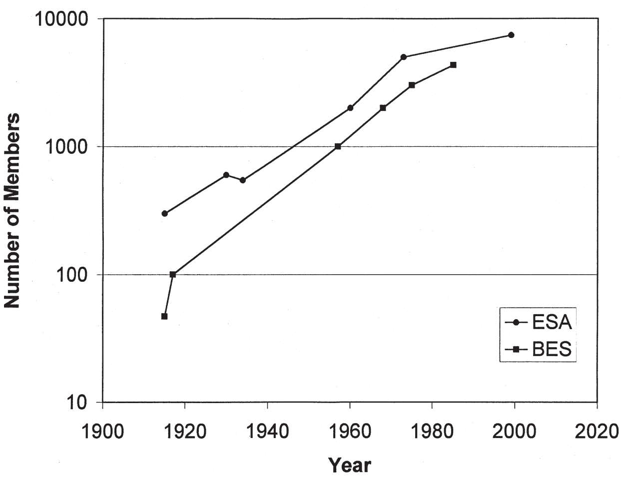

Fig. 2. – Growth in membership of the British Ecological Society, as compared to the Ecological Society of America. ESA is indicated by solid circles and BES by open circles. Note the change in number from the mid1970's to the present for ESA.

wars and the depression but by 1957 it had reached 1000 members. Growth was sustained. There were 2000 members in 1968, 3000 in 1975 and 4322 in 1985. The doubling rate of growth of the BES (Figure 2) is somewhat faster than 15 years. Of course the population base of the UK and the USA are quite different and the ESA is about twice as large as the BES. And, unlike the ESA, the BES is continuing to grow in size.

These comparisons suggest that Menard's model of doubling of 15 years fits ecological science rather well. It also shows that the growth process can be impacted by world wars and depressions. Finally, it demonstrates that the rate of growth of professional societies isn't the same for all societies. One society reaches maturity and stops growing, while another continues growth. Since the total numbers of members are different in the ESA and the BES, we do not know if the BES will reach an asymptotic level of about 8000 members in 2005 and then stop growing. But we will watch for this prediction.

Menard makes the point that these observations are not merely academic exercises. Conditions of life for an ecologist during these phases of growth are very different, indeed. Early in the growth period young individuals can contribute directly to development of the theory of the subject and advance rapidly. At maturity individuals may have difficulty becoming recognized at all and it may take many years to obtain the expected rewards. If we could determine where in the growth cycle a subject is, probably we could improve our career decisions. I have set Ramón Margalef's comments into this context to show that he was making a highly personal comment, in conversation, that reflected his perception of a real phenomenon - the doubling time in science and its impact on practioners.

What about the world population of ecologists? We do not have precise data on the size of ecological societies in other countries. Of course, many foreign ecologists are members of the BES and ESA, but financial exchange problems, languages, national loyalties and other factors have caused ecologists to form societies throughout the world. Presumedly all of these will go through a growth cycle similar to the BES and ESA, but many are quite small and financially unstable and for these, growth is problematical.

Our estimate of the size of the world population of ecologists is based on two different studies made for purposes of assisting international organizations. The first was a census of tropical ecologists (Yantko and Golley, 1978) carried out for the International Society of Tropical Ecology, headquartered at Benaras Hindu University, Varanasi, India. Based on over 4000 census forms mailed world-wide, with a return of about 2000 censuses, we determined that the countries with the largest number of tropical ecologists were the USA, Brazil, India, the UK, Australia, France, Colombia, Venezuela, Canada, Japan, Mexico, Germany and Indonesia, in that order. More than 30 responses were received from each of these countries. We did not ask a question about national ecological societies since we were representing an international society but the data showed that tropical ecologists were distributed world-wide, including in small countries with a relatively small science establishment. Many of these scientists carried out research and published in international journals. In an approximate way, the data suggest that at this time about twenty percent of the world ecologists were studying the tropics.

A few years later we calculated the numbers of ecologists in each country based on the authorship of ecological papers abstracted in *Biological Abstracts*, 1981 to 1982, by BIOSIS (Golley, 1983). We are grateful to BIOSIS for providing us this data set. This survey of publications (Table 1) showed that there were approximately 17,000 ecologists world-wide, with 6000 addresses in the USA, 1500 in the USSR, 1100 in the UK, 1200 in Canada, 700 in Australia, and 500 both in India and in the combined Germanies. The total publications by ecologists was about 10,000 titles annually, where ecology was the primary designation, and 25,000 titles, where ecology was the secondary designation. The publication rate was about two titles per ecologist per year.

INTERPRETATION OF THE GROWTH OF ECOLOGY

Interpretation of the growth curve of the ecological societies must be speculative. Hopefully these speculations will stimulate other ecologists to examine the growth of the discipline and describe and explain the patterns more quantitatively. I feel that

TABLE 1. – Number of ecologists by country, derived from data on published papers classed as ecological in Biological Abstracts, 1981-1982. The author acknowledges the generous contribution of BIOSIS in providing the data for this table

Algeria	3	Hungary -	51	Poland	286
Argentina	27	Iceland	9	Portugal	12
Australia	699	India	510	Puerto Rico	1
Austria	73	Indonesia	12	Rumania	23
Bangladesh	28	Iran	11	St. Christopher	1
Barbados	4	Iraq	13	Saudi Arabia	14
Belgium	70	Ireland	37	Senegal	13
Bermuda	1	Israel	134	Singapore	1
Botzwana	1	Italy	212	South Africa	253
Brazil	96	Ivory Coast	9	SW Africa	3
Bulgaria	50	Jamaica	14	Spain	137
Burma	2	Japan	930	Sri Lanka	16
Burundi	1	Kenya	14	Sudan	2
Cameroon	1	Korea, South	51	Sweden	253
Canada	1,170	Kuwait	12	Switzerland	91
Chile	50	Madagascar	1	Syria	1
China	86	Malawi	1	Taiwan	18
Colombia	8	Malaysia	33	Tanzania	5
Costa Rica	17	Mauritius	1	Thailand	21
Cuba	6	Mexico	36	Trinidad-Tobago	1
Czechoslovakia	135	Monaco	4	Tunisia	4
Denmark	73	Nauru	1	Turkey	12
Dominica	2	Netherlands, The	255	Uganda	1
Ecuador	4	New Caledonia	2	USSR	1,512
Egypt	32	New Zealand	216	UK	1,145
Ethiopia	2	Niger	2	USA	5,917
Fiji	4	Nigeria	34	Upper Volta	3
Finland	147	Norway	185	Venezuela	30
France	465	Oman	3	Vietnam	1
Fr. Polynesia	5	Pakistan	23	Yemen	4
Germany, East	90	Panama	24	Yugoslavia	52
Germany, West	458	Papaa-New Guinea	12	Zaire	1
Ghana	10	Paraguay	2	Zambia	1
Greece	18	Peru	1	Zimbabwe	16
Hong Kong	17	Philippines	17		
Total	16,579				

there are at least four major factors which help explain either the period of exponential growth or the period of maturation in the growth of ecology in the twentieth century. These are intrinsic elements of population increase, change in the resources available to the science, fragmentation of the science, and changes in the theoretical structure of the subject. I will consider each of these factors below.

Henry Menard suggests that growth and change in science, represented by social organizations made up of individual scientists, follows the familiar pattern of growth of organismic populations. Ecology textbooks describe the classic pattern in which three phases can be recognized. First, the population becomes established and begins to grow. The rate of growth at this time is slow. Once establishment occurs, the population begins growing rapidly, at its physiological capacity. This period is analogically similar to the period of doubling described by Menard. For the ecologist, it is the period when the population is growing at its intrinsic rate of natural increase. Eventually, the population begins to experience resistance from the environment, resources begin to limit growth, and growth slows. Following the period of growth the population may exceed its carrying capacity and decline to low numbers or go extinct. Or, the population may pulse around the carrying capacity, increasing and then decreasing over time. Or, new resources or new members may become available and start a new growth cycle. A similar pattern occurs for the individual organism, expressed in terms of weight or volume. In this case, there is a set point where genetic information tells the cells when to stop growth. Growth ends and the organism is mature.

Menard is suggesting that there is a fundamental process of growth that is generally true of any entity made up of living organisms, including social organizations. I think that this suggestion is accepted in most disciplines in the social sciences (Teitelbaum and Winter, 1989). However, its value is mainly analogical. It does not help us understand change in patterns of growth or differences in growth rates among organizations.

The second factor useful to explain growth of science is a change in the resource base supporting growth. Menard deals with this factor extensively. By analogy with natural populations and from a political point of view it is an obvious candidate to be considered. Sustained growth requires increase in the rate of financial support and, because science is highly technical, an increase in scientific laborers. Few countries are able to balance financial and manpower requirements with the result that we observe crises of insufficient manpower and migration of scientists from one country to another and excessive production of graduate scientists who can not find a position. But overall, science has been well supported since it began. A sustained rate of doubling numbers of products or producers over centuries of time testifies to this fact. Nevertheless, individual disciplines have grown slowly or not at all. How is resource supply related to the change in the rate of growth for an individual scientific discipline?

In the case of ecological science in the United States there is publicly available information that is helpful in understanding patterns of support. Basic ecological science is supported by the National Science Foundation within its Division of Environmental Biology (DEB), in the Program on Biological Oceanography in the Division of Ocean Science and in a few other small programs. Environmental Biology is the main source. In 1980 DEB support of basic ecology was about $25.3 million and in biological oceanography was about $7.5 million (Golley, 1981). In contrast, applied ecology is supported by a variety of agencies, depending upon the problem needing attention. Obviously, the Environmental Protection Agency (EPA), the Department of Energy and the Department of the Interior are important sources for applied ecology. In 1980 the EPA provided 60% of the funds for applied ecology or $90.7 million. During the decade the ratio of applied to basic environmental science support was 4.6 dollar applied support to 1 dollar of basic support.

I served as the Director of the Division of Environmental Biology from 1979 to 1981. This time period was an especially significant period because it included the transfer of the presidency from Jimmy Carter, a Democrat, to Ronald Reagen, a Republican and was the end of a decade, labeled the Decade of the Environment. During the 1970's a number of notable environmental activities took place. These included the United Nations Stockholm Conference on the Human Environment, the formation of the Man and Biosphere Program within UNESCO, in the United States the establishment of the Environmental Protection Agency and the Council for Environmental Quality within the office of the President and the end, in 1974, of the International Biological Program of the International Council of Scientific Unions (ICSU). The decade also saw an outpouring of public interest in the environment and while ecological science was recognized as directly relevant to solving the environmental problems, the media soon scrambled the meaning of the term “ecology” and confused it with environment and environmentalism. As a consequence, many notable ecologists lamented their fate and even suggested abandoning the word entirely.

This explosion of interest in the environment inevitably led to increased support for environmental research and services. For example, in DEB the ecological science support increased 51% in dollars corrected for inflation from 1970 to 1980 (Golley, 1981). However, the rate of increase was not constant over the decade (Table 2). Highest support occurred in 1972 and after 1975 the level of support was essentially constant. Considering the total federal support of basic environmental biology research (not only NSF support shown in Table 2), the increase from 1969 to 1979 was 88% in dollars corrected for inflation. The increase for nonbiological environmental research, that is research on water, atmosphere and earth sciences, during the same period was 173%. For comparison, the budget for all federal research functions increased 20 % in constant dollars from 1970 to 1980. Clearly there was substantially increased support for environmental studies during the 1970’s, although increase in physical and chemical project support was twice that for biological projects.

Evaluation of these data in the context of our interest in changing rates of science activity, suggests some potential connections. Ecological science funded by the NSF, the main source of support for ecology, increased during the decade of the environment but the increase was not constant. During the last half of the decade support in dollars corrected for inflation was constant. Further, during the decade there was a bias toward support of the physical aspect of environment in comparison with the biological aspect. Constant funding in an expanding subject area can translate into lower support for graduate students and postdoctorate students, into smaller individual research grants, and delayed maintenance of equipment and facilities. The impact of constant support will be felt years later when students seek jobs and facilities and services have to be rebuilt. There is no way to trace cause and effect in these numbers but the convergence of funding patterns on the change in rate of numbers of ecologists is suggestive of a relationship.

TABLE 2. – NSF support of ecological and other biological sciences in Systematic Biology, Support of Systematic Collections, Physiological, Cellular and Molecular Biology, Neurobiology and Psychobiology. Constant dollars in millions.

Year	Ecological Science	Other Biological Science	Total Biological Science	Ecological Science as a % of Total
1969	9.7	41.4	51.1	19
1970	13.8	40.4	54.2	25
1971	20.5	40.9	61.4	33
1972	30.0	49.9	79.9	38
1973	26.1	49.1	75.2	35
1974	23.7	46.6	70.3	34
1975	25.5	48.7	74.2	34
1976	21.1	45.3	66.4	32
1977	20.6	52.5	73.1	28
1978	19.3	55.9	75.2	26
1979	20.6	56.0	76.6	27
1980	20.9	57.9	78.8	27
1981	21.7	57.1	78.8	28
% Increase				
1970-1980	51%	43%	45%	

The third factor that may be involved in change in the rate of doubling of ecologists could be fragmentation or splintering of the subject. Ecology is a highly diverse subject to begin with. Even in a spatially restricted habitat we might identify a thousand species, all of which play some role in the ecosystem. Beside the intrinsic problem of biodiversity, there has been two distinct fault lines across ecological science. The first involves the division of the subject into aquatic ecological sciences and terrestrial studies. Aquatic ecologists formed their own professional society, the Limnological Society of America in 1936, which was joined in 1948 by the Oceanographic Society of the Pacific to form the American Society of Limnology and Oceanography. Of course, some aquatic scientists are members of both this society and the ESA but the different methods, habitats, problems and approaches result in a deep divide. The second division is that between basic and applied ecology. There has always tended to be a line drawn between those who did hands on work and those who did not work or worked with the mind. In the university this prejudice might be important but overall Americans have respected applied science. A celebrated example of the pure and applied fault line within the ecological society involves the well known University of Illinois ecologist, Victor Shelford. Shelford was concerned that disturbance by humans was impacting many of the sites where ecologists worked. He formed a committee within the ESA, the preservation committee, that considered this problem and proposed that it was essential to purchase and maintain biological reserves and field sites. It was suggested that ESA be the organization to serve this need. The Ecological Society of America has always been a peculiar professional society. The membership elect the president and its officers annually but the management of the ESA is done through a Council, chaired by the President. Members of the Council are sometimes elected, appointed or are members by the law of the constitution of the society. Members meet once a year at a business meeting to approve the budget and to debate and vote on various proposals placed before them by the officers and Council. While ESA has an office and staff today, in Shelford's time the day to day activity of the society was carried out by the Secretary, who's tenure was frequently a number of years. In this kind of structure political power is in the hands of the President , the Secretary and the Council. At the time Shelford's committee made its proposal there were other powerful ecologists in the leadership of the society who thought that the ESA should focus on scientific research and instruction of graduate students. They were opposed to the preservation committees conservation proposal for solving applied problems. In their minds ecology was a theoretical or basic science, not an applied science. Shelford was not to be detoured and at his own expense he wrote and distributed to the members of ESA a questionnaire asking their opinion about the proposal of the preservation committee and the role of the ESA in conservation. He found that many members supported his position. In this standoff, the President and Council decided to abolish the preservation committee and several other ad hoc committees. The consequence was fragmentation, with Shelford and his supporters in 1946 organizing The Ecologists Union separate from the ESA. The Ecologists Union became the Nature Conservancy in 1950. The Nature Conservancy in 1989 listed more than 535,000 members and 300 corporate associates and managed 1000 nature sanctuaries (Coker, 1991).

Differences of opinion, new opportunities in research and training, new ways to solve problems can result in fragmentation of a society or community. Ecologists tend to be private, individual scientists, who are pleased to have a society that manages technical journals and an annual national meeting efficiently and cheaply. They welcome recognition and support but they feel uncomfortable about speculating from their data and experiences in the public arena. They tend to label that sort of thing unrigorous, which is an ecologists term of disparagement. But, ecological societies can rise above the individualist approach. In the BES Sheail (1987, pp 262) says "Through its very existence, the Society had denied the high ground to any particular aspect or grouping of ecologists. No matter what prominence was given to a topic or a person at a meeting or in one of the Societies publications, the term of others would assuredly come." But, of course, the BES is also smaller in size than the ESA and so has not had quite the same problem of numbers of members to manage and service.

The fourth factor I want to suggest might play a role in explanation of change in the rate and direction of growth of a science concerns theory. Cohesion is especially strong when a community of scientists are all addressing a single theoretical issue. The community will be in close communication, there will be considerable competition between its members and progress may occur rapidly and unexpectedly. The subject is hot and students and others can be drawn into the subject easily. Ecology has tended not to have many of these hot topics. This is probably because ecology is faced with an enormous diversity of subjects and habitats. Ecology did experience a time of active theoretical concentration from the late 1940's to the early 1970's, focused on the ecosystem. This concept was operationalized by Raymond and Eleanor Hall Lindemen in their study of Cedar Bog Lake in Minnesota (Lindeman, 1941 and 1942) a few years after the word was coined by Arthur Tansley (1935). Eugene Odum gave the ecosystem concept the central theoretical position in his textbook, **Fundamentals of Ecology** (Odum, 1953). Odum's text had an enormous influence in training ecologist during a period of rapid increase in manpower. It was rewritten in three editions and translated into many languages. Later the ecosystem concept was a central foundational idea for the International Biological Program, the UNESCO Man and Biosphere Program and the Long-term Ecological study projects and it remains an active organizing principle of the science today.

The ecosystem concept bridges the gap between living organisms and environment by focusing on the interaction between these entities. That is, the ecosystem concept operationalizes Haeckels' definition of ecology. It stresses that there is a system of interactions in nature. These systems are fuzzy, in that their boundaries are weakly defined and are changing in space and time. The ecosystems evolve and change because the organisms within them evolve and adapt to environmental factors which are changing for physical reasons.

A second theoretical step in modern ecology occurred in 1980 when the Dutch Society of Landscape Ecology held the first international congress in Veldhoven, Netherlands (Tjallingii and de Veer, 1982). This meeting brought the concept of landscape ecology to the ecological community in general. The significance of the landscape concept is that it recognizes that the ecosystems studied by ecologists, a lake or a patch of forest, is embedded in a larger scale system called a landscape. The landscape is the environment of the ecosystem. Ecosystem behavior has a significance within the context of the landscape. Landscapes may be treated as entities, that is, a watershed is a landscape, and they may be scaled at multiple levels leading eventually to the planet Earth which is embedded in the Solar System. Thus, the landscape concept leads us to apply the hierarchical theory of Allen and Starr (1982) and O'Neill et al. (1986) to ecosystem theory in a space and time continuum. This is a very significant achievement because it links interactions across multiple scales of space/time.

The third theoretical concept that grows out of the ecosystem and landscape concepts involves human ecology. Ecologists tended to ignore humans as subjects of ecological study. Study of humans have been located in the social sciences and not only are ecologist untrained in the social sciences but they tend to think of themselves as natural scientists, as biologists. But if the scale increases so that the study involves entire landscapes then we cannot ignore human activity. Zev Naveh and Arthur Lieberman (1984) termed this the total human ecosystem. As an approach it brings into the research every thing that is relevant to the question being asked. Where human action is important, then human motivation, human technology, human history are all relevant. This approach transforms ecology. It becomes the bridge science that links the natural and social sciences into a single endeavor.

Unfortunately it is not clear how we can implement the total human ecosystem concept. Human ecology, which has existed since the 1930's, at least, has not developed bridge concepts that link across the social sciences. Many people are studying this problem and one finds interested colleagues through the social sciences, in environmental history, cultural anthropology, historical ecology, ecological economics, social ecology, environmental ethics and so on. But a break-through has not occurred.

Viewers of the scene have identified other factors causing change in the success of ecological sciences. For example, Francesco Di Castri and Malcolm Hadley (1985, 1986 and 1988), who led and managed the Man and Biosphere project which was established in 1971, viewed the period of the 1980's as a time of trouble. They asked, "was ecology a science in crisis? These authors attributed the trends to lack of scientific rigor, a weak predictive capacity and underuse of modern technology. They suggested that causal reasons for the trends were the fragmentation of ecology, proliferation of programs, a contraction of research especially in developing countries, low budgets, lack of recruitment opportunities and the rarity of concerted action between ecologists and planners. One has to take seriously the opinion of colleagues who have ten years experience in managing an international program involving thousand of scientists in every country of the United Nations. The experience of such people far surpasses the experience of most of us. Therefore, it is pleasing that there is so much overlap between our analyses. Where there are differences of opinion, I suspect that they represent the consequences of a change in growth rather than being a cause of the change. I do not think that ecology is a science in crisis. Rather, I suggest that ecology is a science ready for a new takeoff in development.

MILLENNIAL QUESTIONS

My remarks so far focus on the trends of growth and change in ecological science. That is, I have presented data which suggest certain patterns in ecology have changed and I have related our interpretation of these changes to the familiar growth curve of the population, and other concepts familiar to all ecologists and social scientists. I showed that the manpower of the ecological sciences based on the membership of the worlds two largest ecological societies, which make up almost one-half of the world's ecologists, increased exponentially through the twentieth century. But this rate of increase has slowed in the last decades of the century. I then speculated about the cause of such patterns, exploring the intrinsic character of population growth, change in funding the sciences, fragmentation of ecological societies and the role of theory in creating cohesion of a science. I concluded that there are probably multiple reasons for the observed patterns. Now I want to turn and look from the past toward the future. I want to address the question of the application of ecology to the millennial question of our time.

I recall being a graduate student living in the forests of western Washington, studying the blacktailed deer, in the early 1950's, and my growing concern about the state of the natural environment. I was introduced to the books of Paul Sears, William Vogt, and Aldo Leopold through the professional requirements for the degree of wildlife biologist at Washington State University. My personal experience of almost ten years of hiking and camping in the eastern deciduous forest of the United States as a young student provided a practical grounding for my concern. Human population growth was out of control and seemed unstoppable. Forests were being clear cut for no other reason than they were there. Rivers were being polluted. I was deeply troubled; clearly conservation and nature protection deserved our concern.

Now, fifty years later, my judgment is that we have not had an improvement in the global environment. Indeed, we see an environmental situation that has become more serious over time. All the trends identified earlier have continued over fifty years and the costs to nature and human well-being have mounted. By tripling and quadrupling the numbers of scientists and environmentalists, organization of green political parties, expanded nongovernmental organizations of all types, and expenditures of vast amounts of money these trends have not changed. Of course, for those who want to put a good face on it, one can identify successes. They are enough to justify our whistling in the dark. But an evaluation that takes a holistic perspective, over fifty years, leads me to another conclusion. The problem of environmental deterioration and destruction is increasing everywhere and has become critical in some places. Human habitation of the earth is being compromised. We try to get ahead of the problems, yet they increase around us beyond our capacity to deal with them.

What are we to do? The issue is exceptionally complicated, involving history, philosophy, science and culture.

In this context it seems unfortunate that the size of the community of ecological scientists may be increasing at a slower rate. But maybe the data are misleading. What is likely is that our definition of ecology has changed, with a continued increase in applied scientists concerned with environmental problems and a lesser rate of increase of basic ecological scientists. For example, at our Institute of Ecology at the University of Georgia I have noted that more students are choosing to do their thesis in applied ecology. This is partly because we have created a Masters program in Conservation and Sustainable Development within the Institute and we have reestablished a Service Program, with the purpose of applying ecological knowledge to environmental problems. Further, many students come to our graduate programs having developed a strong experience in applied ecology at the undergraduate level. While we have administratively declared all these students to be ecologists, students continually force us to stretch our definitional boundaries of the discipline as they follow their creativity and research directions. The field is changing rapidly and there is no question that ecology represented by graduate training is different now from what it was ten to fifteen years ago.

A second change I consider of special significance for interpretations of the century long trends is the change in theoretical approach in ecology. In the past we were searching for universal theory that would explain many individual cases. Very few so called theories could stand the scrutiny of ecologists. Gradually we recognized that all theoretical development was contingent upon the methods used, the definitions selected, and the local features of biodiversity and habitat. Each species is different from other species, each habitat differs and the environment changes in time creating continually new opportunities for evolution and adaptation of organisms. Just as in human society we have learned that it is counterproductive for us to lump individuals in categorical groupings, so it is essential in ecology to pay attention to the specific local and individual systems of concern. This change in focus brings us closer to the world but it makes our task immensely more immediate and local. In the world of politics and the media simple solutions to problems that can become slogans for advocates of point of view and the identification of leaders who can represent these points of view are important. Our scientific approach doesn't fit this scenario and ecologists interested in politics must find some middle ground where they simplify and generalize enough to make an argument that is convincing but where they do not ignore the data. This is difficult, as we know.

CONCLUDING REMARKS

At the beginning of a new millennium we recognize a state of change in the human species and in the environment that causes our concern. It is not change that is a problem; change is universal. Rather trends move us toward states that are ecologically problematic. For example, extinction of species is increasing globally. While extinction is a familiar process in nature, the rate of extinction exceeds any known rate in the history of the Earth. Evolution represents unique genetic properties that make organisms fit. Loss of genetic fitness is tragic. Destruction of mature communities and their replacement with plantations or with spontaneous regeneration has increased world-wide. In my country it is difficult to find mature nature anywhere. We no longer have a basis of comparison of natural processes, except for small fragments of nature in marginal places. Our rivers are filled with sediment and toxic substances. These materials accumulate in the river deltas killing the organisms and creating dead zones that are enlarging. Rivers which were a dynamic part of the landscape have become sewer pipes. These trends converge signifying that we are in an environmental crisis, which is already affecting our system through increasing economic costs, social disruption and health problems.

Yet, since we are part of nested hierarchical systems, our personal life may be quite comfortable and positive and environmental problems seem remote. It is a good strategy to maintain ones personal space at as high an environmental quality as one can. This strategy will produce health and well being which will buffer one against the trends. If one can combine with a group of like-mind individuals it may be possible to protect a part of the land and create ecologically healthy environments for the group. Experience may stimulate members of the group to train others and to demonstrate how it is possible to work against the trends and transform society and the environment into sustainable systems. It is really a matter of will to study the ecology of place and then live within the constraints of those environments.

All of our deliberations turn out to have similar patterns. All are a function of scale. All concern small scale, individual phenomena which are embedded into local, self-defined systems - of science, of nature, of the environment. This is the arena where we can function and have an effect. The hope that we can move up the scale and from some superior position order everyone to function in an environmentally positive way, to discover a principle that is so simple and so convincing that everyone will be motivated to change their way and be transformed, the hope that some God, some leader, or some organization will overcome the complex behaviors of more than six billion people and will create a global village are, in my opinion, all dreams. Reality and the future is in the hands of each individual. Individuals organized into effective groups, such as societies of ecologists, are important because creativity, which only comes from the individual human mind, can be recognized, supported and extended by the human group. Our challenge is to be creative and to apply our creativity to solving the human environmental problem. One can be optimistic about that opportunity.

From one perspective this conclusion is quite amusing. Who would have thought that we might solve problems through focus on details. Clearly, one has to approach the future with a laugh. It is fun, in Ramón Margalef's language, to grapple with such questions. Probably some unexpected connections will emerge out of the apparent chaotic behavior of the present and we will be able to use these connections to leap ahead or to maintain our balance.

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