Limnology, as Seen by Limnologists

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Introduction

The science of inland waters is structurally amorphous because it has evolved as a loose collaboration of self-conscious disciplines that have overlapping scope. Disciplines such as hydrology, aquatic ecology, and fisheries science are complementary in an intellectual sense, but have retained their identities through distinctive histories, separate tracks for graduate education and training, and professional societies that serve their interests.

The fortunes of the disciplines that work together do not always rise and fall in unison. Intellectual advances, societal priorities, and a variety of other factors may invigorate or expand a particular discipline while a sister discipline declines in vigor, size, or recognition. Given that science is now supported to a large extent by national governments, invigoration or redirection of a discipline can sometimes occur through a collaboration between governmental support systems and the members of a discipline. For this reason, disciplinary self-analysis can play a major role in the maintenance of a scientific discipline. The field of hydrology provides a current example. A distinguished committee of hydrologists organized by the National Research Council concluded that hydrology has been too much dominated by an applications perspective and needs to be stimulated with initiatives that address basic hydrologic phenomena in the broadest way, thus strengthening the foundation of hydrology (NRC 1991). The National Science Foundation responded to the recommendations of the NRC Committee by the creation of a modest support program, which provides a basis for future expansion, for basic advances in hydrology.

Limnology

Limnology is one of the oldest disciplines contributing to the study of inland waters. Its foundation is typically attributed to F.A. Forel and S.A. Forbes. Forel studied the physical, chemical, and biological attributes of Lake Geneva from an integrative perspective that is characteristically limnological (Forel 1898). Forbes, in a classic paper on lakes as microcosms (Forbes 1887), outlined not only the premise that a lake is an integrated system (ecosystem) with emergent properties, but also that lake ecosystems can be studied through analysis of biogeochemical cycles, system metabolism, food webs, and physico-chemical gradients.

Limnology often has been defined as the study of inland waters; its scope indeed encompasses many dimensions of inland water science. More pertinent than any formal definition, however, is that limnology deals with inland waters as ecological systems. This requires the use of information on all components of the system. Limnology thus might be considered an umbrella discipline supported by information from all other disciplines contributing to the science of inland waters. Limnology has strong affinities with fisheries science, hydrology, oceanography, and some branches of geology, botany, zoology, and environmental engineering.

Limnology has entered a phase of self-analysis within the last several years. Distinguished limnologists and members of other disciplines who are familiar with limnology have written a series of articles and commentaries that raise questions about the present and future of this discipline, and the need for change. This commentary has dealt with a range of subjects, including education of limnologists in universities, support for basic research in limnology, and recognition of limnology by other disciplines.

The ASLO Challenges Report

Widespread interest in the status of limnology has been reflected in discussions of the Board of Directors of the American Society of Limnology and Oceanography, which is the largest of the societies representing limnological interests in North America. Members of the ASLO Board have shared concerns of the Society's membership that limnology is losing its unity and sense of direction, and that scientific societies representing it should seek some beneficial change. This matter was also discussed by the membership, which passed a resolution calling for the U.S. National Science Foundation to establish a designated program in limnology in order to improve and consolidate support of limnological research (Lewis et al. 1995).

In 1991, the ASLO President and Board of Directors authorized the formation of a committee, which was designated the Challenges for Limnology Committee, that was charged with producing an analytical report assessing the status of limnology in the 1990s with a focus on the U.S. and Canada. The Committee consisted of nine individuals of varied backgrounds (see reference section for names: Lewis et al. 1995). Following a meeting at the Institute of Ecosystem Studies in Millbrook, NY, the Committee prepared a report that was subsequently reviewed broadly within the Society. The final report is scheduled for publication as a special issue of the ASLO Bulletin in the first half of 1995. The Challenges Report is partly devoted to an analysis of the present situation for limnology and limnologists, and partly to the development of recommendations for the future. This article gives a synopsis of the Challenges Report.

Conclusions of the Challenges Committee

The Challenges Committee concluded that the societal context for advancement of limnology is more compelling than at any time in the history of the United States. Within the last 20 years, the US and Canada have committed vast new resources to the protection of inland waters. For the United States alone, the U.S. EPA estimates that the annual cost of water pollution control, which is primarily for inland waters, totals approximately $50 billion per year and is escalating rapidly (U.S. EPA 1991). This commitment and the underlying legislation are a societal acknowledgement of the value of inland waters, including streams, rivers, reservoirs, natural lakes, wetlands, and groundwaters, to human welfare.

The thread that unifies limnology is water itself, rather than any specific scale of space or time or any particular commitment to physics, chemistry, geology, or biology. Because limnology is comprehensive in its treatment of aquatic processes, it is often relevant to the protection and management of inland waters. Recent examples of the broad applicability of limnological knowledge derive from such problems as eutrophication, acidification of inland waters, and maintenance of aquatic biodiversity. Active fields of inquiry for limnologists include biological productivity, biogeochemistry, land-water interactions, optics and physical dynamics of natural waters, biological community composition, and adaptations of aquatic organisms. These subjects are directly relevant to maintenance of the integrity and usefulness of aquatic systems.

The Present Status of Limnology

The Challenges Committee concluded that limnology shows many signs of intellectual vigor and appropriate focus on problems of conceptual and societal importance. For example, present research fronts include nitrogen cycling and responses to nitrogen enrichment of aquatic systems, microbial processes in inland waters, origin and processing of organic matter in surface waters, effects of ultraviolet radiation on aquatic biota and aquatic processes, and principles governing the structure of aquatic communities. Publication of limnological research continues to increase in volume and becomes ever more competitive, and scientific societies are growing in number and composite membership.

Despite the numerous positive indications given by present-day limnology, the Challenges Committee identified a number of needs for change within the discipline as related to educational programs, the ecosystem perspective, subdisciplinary balance, interaction with other disciplines, connection to applications, and support of research.

The education of limnologists presently emphasizes the production of Ph.D.s for academic positions. While some graduates pass into government agencies or the private sector, the clear priority of most leading institutions is to produce individuals who will take tenure-track positions at institutions of higher learning. This traditional emphasis may be outdated in the sense that it seems to ignore growth in demand for limnological knowledge outside universities. Change in this focus might require considerable reorientation of limnological education. A high degree of specialization in a particular subdiscipline or subject within limnology is not necessarily consistent with the production of individuals who will assume responsibilities outside academia. Limnological education may need to be broader, and to be better unified through some sort of certification or disciplinary convention that ensures a reasonable degree of breadth and commonality among graduates with advanced degrees.

Ecosystem science is the root of limnology. Within the last few decades, however, limnology has become more specialized and increasingly fragmented into subdisciplines that focus on specific components of ecosystems (Peters 1990). Such studies are essential to the framework of limnology, but their utility is greatly weakened without integration at the system level. Limnologists need to find solutions to this dilemma.

Because limnology is a blend of topics that are biological, physical, geological, and chemical, specific areas of inquiry must be under development at a sufficient pace to support advances in other areas. Limnology has developed a serious imbalance of components (Wetzel 1991). At present, physical limnology is especially weak in North America, and chemical limnology is underemphasized. Zoological studies have traditionally outnumbered botanical or microbial ones, despite the pivotal importance of photosynthesis and decomposition. These imbalances are perilous to a science that draws much of its significance from integration.

Limnology is not well connected to some of the disciplines whose specialists would best be able to work with limnologists. Some ecologists have even come to view limnology as irrelevant to their interests (Hairston 1990). For example, hydrology may at present have weakening connections to limnology (NAS 1991). In contrast, the connection to oceanography appears to remain strong, although a number of oceanographers have expressed concern about a coming decline in the vigor of limnology (Jumars 1990, Banse 1990).

Limnology in the United States is poorly connected to applications (Kalff 1991). Assessments of aquatic systems often are conducted without the participation of limnologists, even where a role for limnology is obvious. This is ironic, given the particular attention that limnology has given to problems of anthropogenic origin (eutrophication, acidification). Poor connections may be in part the legacy of past societal attitudes that have emphasized extraction and exploitation of specific resources, rather than a concern for sustainability of ecosystem functions and multivariate management. The old perspective is changing, as reflected in federal agencies by recent introduction of the concept of ecosystem management (Lewis 1994, Kreiter 1994). Limnology is preadapted for this change in perspective, but must make itself known if it is to contribute fully.

Most disciplines can justify additional support for research, as can limnology. The Challenges Committee concluded, however, that support for research in limnology is small when taken in appropriate context with the societal need for knowledge about inland waters. Opportunities for postdoctoral training have been few, although recent changes at the U.S. EPA may help reverse this state of affairs. There are no designated training grants, except for limnology of the Great Lakes, nor any federal programs specifically designed to strengthen limnology. Infrastructure, which is particularly expensive for studies of integrated systems, is often absent in universities. University research programs have in many ways not been able to keep pace with government research laboratories; this handicaps the national research effort as well as the education of graduate students.

Factors Influencing Limnology

Federal support is an important part of the picture for any scientific endeavor in the United States. At the same time, analysis of federal support can be misleading because it reflects both the cause and effect: while support nurtures science, particular branches of science must persuade the federal support system of the merit of additional support.

The context for support of research and development in limnology is summarized in Table 1. Federal environmental

R&D totals about $3.9 billion, of which approximately $1 billion can be attributed to oceans, $1 billion to inland waters, and the remainder to other categories. The numerical data must be interpreted cautiously, however, because federal definitions of research and development are very generalized.

Table 1 shows a breakdown of the billion dollars attributable to research on inland waters. Much of this is focused on hydrology and toxicology, and is only remotely related to limnology. The U.S. EPA has the largest portion of the research budget for inland waters, but only 6% of the total, or $25 million , is designated as research related to water quality. The balance goes for research related to drinking water, hazardous waste, pesticides, multimedia problems, toxic compounds, or superfund, and thus is not limnological; a portion of the water quality research is also nonlimnological.

Support of research on inland waters by the National Science Foundation is not explicit; it is subtly imbedded in the Division of Environmental Biology and other divisions and is difficult to extract, although Table 1 provides an estimate.

It is difficult to estimate support for limnological research from the federal budget, but an approximation is possible. Recent tabulation of limnologically related proposals supported by the National Science Foundation provides one basis for an estimate. According to Firth and Wingard (1993), In FY 1991 NSF supported 195 proposals that had some limnological component. Assuming that approximately one-third of the total emphasis of these proposals is limnological, and given $60,000 per award, the total investment in limnology by NSF would be approximately 3 million dollars annually. A wide variety of other sources, including the US Geological Survey, support basic limnological research amounting to perhaps twice as much as that of NSF, as judged from their program descriptions. This would make a total of 9 million dollars per year. If the ratio of applied to basic research can be estimated as approximately equal to the national average (1:4; AAAS 1994), the total national support for limnology would be approximately 45 million dollars. This estimate checks reasonably well against the numbers and average research expenditures of limnologists. The total number of U.S. limnologists is approximately 8,000, which would account for approximately 50 to 100 million dollars per year in research, of which 10 to 20 million would be for basic research.

Private sector investment in research and development in the US is 2.8% of the GNP, an amount that is widely considered too low (OECD 1989). If pollution control is the base of societal justification for limnological research, the EPA's estimate of 50 billion dollars per year combined with a 2.8% designation for research on inland waters would correspond to approximately $1.4 billion per year, of which limnology would be a significant component. The total investment as shown by Table 1 ($1 billion) is not so far from the mark as one might expect, but the limnological component seems far too small.

It has become increasingly important that disciplines be named in the budgets of federal agencies in order to maintain an appropriate share of research support. No federal agency in the United States or Canada names limnology in its budget. Within NSF, limnology is subsumed under other names, including especially ecology. It may be important that limnology receive federal budgetary recognition, even though in principle it is supported under other headings.

Robust fields of basic science frequently have two or more designated sources of federal support. As pointed out by Jumars (1990), oceanography has benefited from the availability of substantial support from both NSF and ONR. Many branches of animal science receive joint support from either NSF or NIH. Support for basic research in limnology is heavily dependent on NSF, although there are some opportunities through other agencies. Recent changes in the U.S. EPA, through the expansion of competitive grants programs, suggest a possible remedy to this problem.

Weak support may be at the root of some of the present trends in limnology. The NSF support system, without organized alternatives in other agencies, puts the bulk of investigators under pressure to conceive projects that are short-term, highly specialized, and that stand only a modest probability of continuation. For their own part, limnologists have been reluctant to propose integrated or comprehensive, long-term programs that are well aligned with national research priorities. They have been successful participants in a few long-term efforts, such as some of the Long-Term Ecological Research Program of the National Science Foundation, but have not proposed their own initiatives, as have oceanographers and atmospheric scientists.

Scientific societies could play a major role in consolidating and improving limnology. The American Society of Limnology and Oceanography, which is the largest of several societies that represent limnological interests in North America, has devoted itself almost exclusively to the communication of scientific advances in limnology and oceanography, and much less so to practical matters related to education, research support, and welfare of the discipline. The societal combination of limnology and oceanography in ASLO is immensely beneficial intellectually, but may have handicapped the ability of limnologists to consolidate their interests through ASLO. Also, ASLO has not fulfilled, and perhaps does not attempt to fulfill, the professional needs of some major branches of limnology. Other societies, including the North American Benthological Society, the North American Lake Management Society, the Ecological Society of America Aquatic Section, and the Society for Wetland Science have drawn the primary allegiance of numerous limnologists. Thus the voice of limnology is not well unified, particularly by contrast with some other disciplines such as geology, zoology, and botany.

Remedies

The Challenges Committee proposed a number of remedies for undesirable trends in limnology, and has consolidated these recommendations under six headings as follows: (1) reform of educational programs, (2) development of cooperative studies, (3) designated federal support of basic research in limnology, (4) development of a coordinated interagency support plan for research, (5) increased support of selected limnological field stations, and (6) expanded responsibilities for limnologists.

Pursuit of these recommendations may unify and strengthen limnology in the future. As always, only human effort can make this happen.

Table 1. Support for three specific categories of R&D by the federal government in 1995 (partly extracted from AAAS 1994; expected or proposed).

Budget Items	Millions of Dollars
Federal Environmental R&D by Agency	
Department of Defense (Oceans, Basic, via ONR)	122
NationalScienceFoundation(Bioenvironmental73, Bio global change 21, Engineering environmental 28, Geo environmental 23, Geo global change 134, Oceans 208)	487
Department of Energy (Biological & Environmental)	427
National Aeronautic and Space Administration (Mission to Planet Earth)	1200
U.S. Department ofAgriculture(NaturalResources & Environment)	27
National Oceanic and Atmospheric Administration (Operations, Research & Facilities)	490
U.S. Geological Survey	367
National Biological Survey	177
U.S. Fish and Wildlife Survey	0
National Park Service	20
Environmental Protection Agency	570
Total	3887
Inland Water Resources R&D	
U.S. Geological Survey	193
Bureau of Reclamation	12
National Biological Survey	69
Bureau of Mines	24
Environmental Protection Agency	444
National Science Foundation	104
U.S. Department of Agriculture	140
Other	2
Total	988
Limnological Research	
Applied	36
Basic	9
Total	45

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