AN OCEAN SCIENCES AGENDA FOR THE 1990s

A J McKernon Lecture

In Marine Affairs

By Barry D. Brewer

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The Idea of an Agenda

SETTING AN AGENDA is generally the first step in defining and eventually coming to terms with problems. The point holds for individuals, institutions, and even groups and collections of each. The term, agenda, means a list, outline, or plan of things to be done. The task at hand is true to these meanings in that I have tried to identify and sketch out several topics that the ocean sciences, as a diverse collection of individuals and institutions, need to address in the decade to come.

It would be extremely presumptuous to expect my list to be either widely accepted or highly accurate as actual events in the 1990s unfold. Indeed, one of the main purposes an agenda serves is to call attention to new problems and opportunities and to do so in settings already quite filled with old and demanding examples of each. Any claim to precision must, likewise, fade in the face of the stunning complexities those in the various ocean sciences ordinarily confront. But making precise forecasts is not the object of an agenda; stimulation, provocation, and discovery are much more to the point.

Several aspects of agenda setting stand out for comment.

First, there is almost never one agenda, but usually several of them operating and competing at the same time. Gaining attentions, forging a broad consensus, and acting in concert are all highly problematic tasks as a consequence. That they are also essential tasks only emphasizes the importance of an agenda.

Second, only a limited number of items or issues can be considered. Simon and others refer to this as a "bottleneck of attention," whose practical consequences include

disproportionate focus on immediate, clear, simple, and threatening matters at the expense of longer-term, uncertain, complex, or innocuous ones.[1] The number seven has even been identified as being magical—a common limit on the number of items an agenda might contain.[2]

Third, as attentions home in on highest priority agenda items, seemingly less demanding matters are necessarily neglected and may accumulate. Clear indications here are chaotic and authoritarian managerial tendencies and decision-making styles. Numerous crises—or nonstop crises—are likewise symptomatic. None of this is usually desirable.

Fourth, gaining time to recognize and analyze problems is perhaps the most compelling reason to set an agenda. Crisis decision making, by definition, means that there is not enough time—to access various sources of information, to translate each into meaningful portraits, and then to figure out reasonable courses of action. All this takes time, and when problems are large, complicated, and messy, there is seldom enough time.

The requirement to identify and "work" problems analytically and politically as early and often as possible is a high priority, especially in a democratic system, where a thinking consensus as to appropriate, best, or necessary courses of action must be created to energize and legitimate decisions.[3]

The main points of the following discussion are simply stated, although their various implications are exceedingly difficult to grasp or work out. Indeed, my purpose is to begin exploring such implications to identify problems to be worked over and in time resolved.

- The ocean sciences have diversified and grown in size and importance, nationally and around the world.
- Demands to link ocean sciences to atmospheric and terrestrial ones are intense, appreciated, and increasing. The label "Global Change" is indicative, and expectations of a looming scientific revolution are common.

1. Herbert A. Simon, "Human Nature in Politics," *American Political Science Review*, vol. 79 (December 1985): 293-304, at 302.
2. George A. Miller, "The Magic Number 7, Plus or Minus 2," in his *Psychology of Communication* (New York: Basic Books, 1967).
3. This is perhaps the most striking lesson to be learned in the wake of the 1970s energy crises. Martin Greenberger et al., *Caught Unawares: The Energy Decade in Retrospect* (Cambridge, Mass.: Ballinger, 1983).

- Intellectual, practical, and technical challenges to a successful revolution exist, but are inadequately respected.
- Financial constraints on scientific prospects are scarcely acknowledged. Excessive "wishful thinking" blocks out thought about coping in a time of austerity.
- Demands to link Global Change to people, institutions, and policy processes are, by comparison with scientific ones, less intense or poorly conceived, or hardly exist at all.
- Accustomed linkages of the ocean sciences to the military are changing in substantial ways. Conflicts are emerging and may grow far worse.

The exploration begins with a recollection of the not-too-distant past for points of reference and emerging trends.

The Ocean Sciences In Broad Historical Context

Scientists professionally interested in the sea have never been numerous. The fraternity of physicists, biologists, chemists, mathematicians, and engineers comprising the ocean sciences was, prior to about 1950, extremely small indeed. Everyone knew everyone else, many routinely went to sea together, and nearly all had served the country in or for the U.S. Navy during World War II.[4] To do science meant going to sea in close quarters and for long periods of time, and this merely strengthened the personal bonds as it reinforced a dominantly naval culture.

Beginning early in the 1950s, the ocean sciences entered a period of growth and change that continues to the present. Prior to 1951 less than $200 thousand per year was spent on oceanography by the federal government. By 1951 this figure had increased to more than $2 million, and it reached $20+ million per year in the scientific run-up immediately after Sputnik was orbited into space by the Soviets. By 1967 the rate topped $215 million each year, about half of which was coming from the U.S. Navy.[5] In the following 20 years order-of-magnitude

4. H. W. Menard, *The Ocean of Truth* (Princeton, N.J.: Princeton University Press, 1986), is one recent first-hand account which gives substance to these general points.
5. The precise figures are less useful here than the overall message of logarithmic growth over the period 1950 to 1970. Roger Revelle, "A Short His-

increases each decade abated, although growth in the collective enterprise continued. fiscal year 1989 budgets for the National Science Foundation's Ocean Sciences Division alone amounted to more than $220 million.[6]

Because there are multiple funding sources—governmental and private—and because questions about how and what to count as ocean sciences persist, precise budget figures are hard to determine. What concerns us here, however, are the general pattern of substantial growth in support and the military's central role.

Nostalgia buffs may one day look back on the 1960s as the ocean sciences' "Golden Age," if not in the world then certainly in the United States. And if there is any one plan or grand conception of that era, it is most likely the National Academy of Sciences Committee on Oceanography [NASCO] report, "Oceanography 1960-1970." Interestingly enough, the prominent role the Navy played (in the report and in all that followed) seemed natural, appropriate, and constructive—at least in the context of the times. Sputnik was then the bright symbol, not Khe Sahn or the Tet Offensive.

Even without a terribly divisive war to distance the young scientists of the late 1960s and early 1970s from the security establishment, other changes in the ways ocean sciences got done would undoubtedly have occurred—perhaps not so soon nor with such impact on the science-security link.

With increased funds came increased numbers and varieties of ocean scientists. The close fraternity yielded to a whole Greek Council, with chapters in all the old and many of the new centers of ocean research.

The Navy itself began to grow its own, identifying bright officers and sending them to advanced training at the Naval Post Graduate School and in the best research universities in the country.[7] By 1985, the Oceanographer of the Navy commanded nearly four thousand persons on ships, in an observatory, oceanographic and regional centers, and other lesser locations around the world. With a budget on the order of

tory of Oceanography in the National Academy of Sciences" (unpublished paper, August 22, 1985), p. 6, is my point of reference.

6. Advisory Committee on Ocean Sciences, *A Unified Plan for Ocean Science* (Washington, D.C.: NSF, May 1987): p. 70.

7. Rear Adm. R. Seesholz, Oceanographer of the Navy, earned his Ph.D. at MIT, just as the Joint MIT/WHOI program was launched.

$350 million, a decidedly self-contained and -reliant capability had been achieved. The Navy was spending as much on its own ocean sciences as the entire federal government, from all other sources, combined.[8]

Two basic consequences of a turn to self-reliance stand out: (1) the service needs independent research centers less, or at least the Navy can make such a case; and (2) many in the new generation of ocean scientists believe they can operate independently of the Navy. Considering how unpopular a war Vietnam had become by the late 1960s, such thinking probably served understandable but immediate ends. In the longer term, and certainly by 1988, the separation and estrangement have persisted long enough to deserve reconsideration. Financial exigencies may even soon prevail to force accommodation.

Two other changes enter the story. Anglo-American domination of the ocean sciences began to yield to a trend toward internationalization. Recent revealing facts contained in the Bromley-Packard report on science and engineering manpower in general suggest just how far this trend has progressed.[9] By the early 1970s, concern about limiting nuclear weapons proliferation had already revealed another side of the coin: the futility of trying to control or restrict scientific knowledge at all.[10] A pragmatic side limits efforts at control, too. Nearly two-thirds of all engineering graduate students currently enrolled in American universities are foreign-born. "Almost one out of three doctorate engineers employed in industry is foreign-born, and that number is increasing."[11]

Other realistic pressures to broaden and diversify the ocean sciences into several nonmilitary arenas emerged and grew. Fishery management in a new regime of the sea brought the National Oceanic and Atmospheric Administration (NOAA) and the states via Sea Grant and the Magnuson Fisheries Conservation and Management Act to new prominence. Oil and gas in

8. Briefing by Rear Adm. Brad Mooney to the National Academy of Sciences, Ocean Studies Board, August 1986.

9. White House Science Council, Panel on the Health of U.S. Colleges and Universities, *A Renewed Partnership* (Washington, D.C.: OSTP, February 1986).

10. Harold C. Relyea, "Shrouding the Endless Frontier—Scientific Communication and National Security," in Relyea, ed., *Striking a Balance: National Security and Scientific Freedom* (Washington, D.C.: American Association for the Advancement of Science, 1985).

11. National Research Council, "Foreign Engineers: Assets or Liabilities?" *News Report*, vol. 38, no. 2 (February 1988): 11-14, at 13.

the off-shore assumed unheard-of importance in the wake of the dramatic oil shortages of 1973-74 and then again in 1979. At the same time, deep seabed mining rose and fell in suspected importance, only to rise again quite recently. Forecasting the weather and ultimately linking atmospheric and ocean sciences moved from an untouchable dream to something rapidly approaching reality by the early 1980s. In the last 15 years, recreation, waste disposal, and dozens of other possible uses for the sea have all surfaced.[12] Their common denominator is the research each demands to clarify the possibilities and to illuminate the way toward better use and exploitation. Their common consequence, as concerns the ocean sciences generally, is to enlarge, diversify, and fragment the corporate activity. We have come a very long way and very quickly from the good old days when everyone knew everyone and lived mainly for the next great cruise.

This tale is hardly told, although that task requires thoughtful attention, and soon. Many of the principal players of the era have retired or died. Writing a thorough and disinterested history of the ocean sciences in the span between about 1940 and 1980 could shed light on, among other things, the exceptionally successful role the Office of Naval Research used to play in basic "small" science.[13]

Gone, also, are the natural and easy links and associations of small size that allowed the ocean sciences to achieve a remarkable degree of interdisciplinary integration.

Twin Demons—Specialization and Fragmentation

Progress in our sciences proceeds as many different individuals learn and know more and more about less and less. Specialization is necessitated by the sheer vastness and bulk of what there is to discover and know. Paradoxically, the dreamed-of payoffs from Global Change and Earth Systems

12. A special issue of *Oceanus*, vol. 25, no. 4 (Winter 1982/83), was devoted to "Marine Policy for the 1980s and Beyond," and provides a very solid accounting of problems and opportunities as appreciated by ocean professionals at that time.

13. James R. Killian, Jr., tantalizes but hardly satisfies with his "Brief Analysis of University Research and Development Efforts Relating to National Security, 1940—1980," in Committee on Science, Engineering, and Public Policy, *Scientific Communication and National Security* (Washington, D.C.: National Academy Press, 1982), Appendix D.

Science (as the general scheme is also known) require extraordinary integration of the sciences, a task only a very few have identified and comprehend.[14] Doubts consequently exist about realizing scientific success absent unaccustomed efforts to pull the bits and pieces of its relevant specialties together.[15]

The demons of specialization and fragmentation extend beyond the sciences to include political and economic institutions and processes, whose connection to forthcoming new scientific knowledge is essential to sense problems and secure wise choices. Such connections are rare.

For instance, observing and measuring global biogeochemical processes hold out hope for a substantial improvement in our capacity to monitor and know the consequences of human acts, now and into the future. The efforts are worthwhile and are commonly rationalized by scientists on the grounds that destroying or even harming such processes could threaten human existence. But a striking aspect of this fact gathering is the near absence of connections between it and social, economic, and political persons and concerns. The Marine Policy and Ocean Management Program at Woods Hole Oceanographic Institution is one exception and is, at the moment, focussing on economic and political matters related to the ocean sciences. Other programs exist, to be sure, but they are few, not well financed, and not prominent.

The problem seems rooted in lack of interest and an incapacity of individuals in the social science disciplines and related institutions to engage or contribute. John Dryzek, in an important and critical new book, accuses economists and political scientists with a *Titanic* metaphor:[16]

> Many ecologists are aware of icebergs in the vicinity, and seek to avoid them. Most economists would be more concerned with ensuring a utility-maximizing arrangement of deck chairs. Most political scientists would worry about whether their methods for analyzing the voting behavior of the people in the deck chairs

14. John H. Steele, *Forward Look—1986-1995* (Woods Hole, Mass.: Woods Hole Oceanographic Institution, October 1986), is directly to the point.

15. Warren S. Wooster, "Immiscible Investigators," *BioScience*, vol. 37, no. 10 (November 1987): 728-30, sees cultural differences as being responsible for the oil-and-water relationships that exist between oceanographers, meteorologists, and fishery scientists. Specific constructive recommendations are presented.

16. John S. Dryzek, *Rational Ecology: Environment and Political Economy* (London: Basil Blackwell, 1987), p. ix.

were scientific. The trouble is that the iceberg-avoidance task is left to those with scant knowledge of political-economic systems, who consequently produce naive, sweeping, and erroneous analyses. Icebergs merit more serious attention.

The images are vivid and perhaps a bit unfair. However, they make the basic point clear.

Gradual but cumulative effects of disciplinary specialization and professionalism have had many unhelpful consequences, not the least of which are the severe disconnections that exist within the sciences and between the sciences and the socioeconomic institutions and political leadership they must learn to serve. Thus, the first item becomes:

AGENDA ITEM #1: CREATE INCENTIVES, MEANS, AND PROCEDURES to counter fragmentary effects of earth systems sciences, to communicate better and sooner what composite scientific signals say and findings mean, and to involve decision makers and their constituents to the greatest extent possible.

Incentives, means, and procedures together point toward issues of human institutions, management, and control.

Global Change Is About Human Beings

Knowing that sea levels will continue to rise over the next 50 to 100 years is not the same as perceiving this fact from the perspective of a wealthy property owner on North Carolina's outer banks or a desperately poor Egyptian or Bangladeshi farmer.[17] The point here is to raise a question about what a "fact" might be and mean, and to whom, and under what circumstances. In the first instance the fact could well result in one's searching for insurance relief from government, and in the second it could mean death, migration, and war.[18]

17. Garry D. Brewer and Martin Shubik, "Shore Builders and Taxpayers," *Christian Science Monitor* (January 12, 1988): 14, 15. James M. Broadus et al., "Rising Sea Level and Damming of Rivers: Possible Effects in Egypt and Bangladesh" (Woods Hole, Mass.: WHOI, Marine Policy Center, n.d.).

18. James G. Titus, "Greenhouse Effect, Sea Level Rise, and Coastal Zone Management," *Coastal Zone Management Journal*, vol. 14, no. 3: 147-71, is an unusual and concise compilation of the science-based literature in that various human implications are discussed. R. J. N. Devoy, ed., *Sea Surface Studies* (New York: Methuen, 1987), is a recent survey of the various contributing scientific disciplines and provides an extensive bibliographic guide to the subject.

Fearing that the oceans and the atmosphere will interact to produce abrupt changes in climate, as they have done in ancient times, is a legitimate scientific concern, but one whose significance is hard to fathom.[19] Is the problem caused by excessive combustion of fossil fuels? If so, then human intervention is conceivable and may even be required to sustain life.[20] Or, is the problem driven by forces outside human control? If so, how much time do we have and what needs to be done to adapt or cushion the blow? Or, is the problem so difficult that it defies understanding? Or, conversely, is it difficult but so critical to human beings that all research efforts possible must be launched to crack it?

The issue is hardly helped by the confusing and confused array of agencies and organizations that exist and deal piecemeal with problems newly demonstrating unity and coherence. The National Oceanic and Atmospheric Administration (NOAA) has the ships, except when they come from one of the oceanographic centers (with the Navy's blessing); the National Aeronautics and Space Administration (NASA) has the satellites, except when the launch vehicles self-destruct or the military preempts them; the National Center for Atmospheric Research (NCAR) has the computers, and the basic models to run on them, except when the ruling administration is angered by studies such as Nuclear Winter and threatens to withhold funds; and the Environmental Protection Agency (EPA) funds studies of sea-level rise for reasons only a bureaucratic genius can describe.

Existing institutions represent (are monuments to) past problems and old solutions. There is little reason to believe or expect them to be responsive to new problems or to be creative in finding new solutions.

Merely identifying problems based on their scientific accessibility and intrinsic attractiveness is not the same as also thinking nonstop about a problem's human implications. Indicative here would be biogeochemical inquiries coupled to de-

19. Richard A. Kerr, "Linking Earth, Ocean, and Air at the AGU," *Science*, vol. 239 (15 January 1988): 259-60. Kerr pursues the topic in "Is the Greenhouse Here?" *Science*, vol. 239 (5 February 1988): 559-61, by emphasizing the difficulties of making a definitive scientific case for global warming.

20. National Research Council, *Atmosphere-Biosphere Interactions: Toward a Better Understanding of the Ecological Consequences of Fossil Fuel Combustion* (Washington, D.C.: National Academy Press, 1981).

mographic ones to place the likely human costs and consequences of natural changes into focus. But where are the demographers and economists or the professionals from public health and epidemiology? Calls for global risk assessment studies, such as those contained in the 1987 Bruntland Commission report, seem pointed in this direction.[21] But where are the Bayesians, game theorists, psychologists, and other decision scientists specialized to the topics of human behavior and risk? Continuing to fund dozens, if not hundreds, of uncoordinated research endeavors—all in various ways pursuing information about the state of the biosphere, but with inadequate weighing in of human causes and implications—is wasteful and unacceptable. And this leads to:

> AGENDA ITEM #2: ASSESS AND REDESIGN. Numerous institutional frameworks, histories, and purposes make the science task confused, fragmented, and unresponsive to the emerging realities of the 1990s. Who has the "big picture," if anyone? Who ought to have it?

The basic idea here is that authorities are seldom well matched to the current realities or to anticipated human needs. This is especially true when the "rules of the game" change, as with the worldwide extension of jurisdictions to 200 miles. Think only briefly about the numerous institutional problems EEZs provoked in oil and gas developments offshore, minerals exploitation, coastal zone management, and fishing. The Commerce Department, through the National Marine Fisheries Service, is responsible for fisheries management, but most enforcement of fisheries regulations in the Exclusive Economic Zone (EEZ) is a job for the Department of Transportation's Coast Guard. Interior controls and regulates oil, gas, and minerals offshore, except when exploration for them upsets the Department of the Navy or someone on the National Security Council enough to classify NOAA's maps and charts of the outer continental shelf. And so the story goes. Local, state, federal, and international roles and responsibilities are likewise snarled and tangled.

Fine-grained divisions of responsibility among too many different committees of the Congress mirror the institutional mess in the Executive branch. A thorough overhaul is long overdue.

21. The topic of "Human Response to Global Change Programme" was featured at a June 11-13, 1987, Toronto meeting of IFIAS. See IFIAS Working Paper #87-04 of this title and date.

But now think about the dearth of serious inquiry into these same institutional problems. Indeed, Agenda Item #2 could not be more neglected, challenging, and essential. Unless one compares it to the list of fundamental scientific, practical, and social tasks that merging land-air-sea sectors engender.

Global Ecosystem Dynamics

Integrating marine sciences with those oriented toward the land and air is a far from trivial undertaking. The basic matters are cogently presented by Steele in the following:[22]

> We have entered a period where the study of the earth as a total system is within the reach of our technical and scientific capabilities. Further, an understanding of the interactions of earth, sea, and air is a practical social necessity. These interactions encompass physical, chemical, and biological factors. The biological or ecological components are critical not only as parts of these processes but as a major and direct impact on man of the consequences of global changes in the system. Yet, the possible nature and direction of ecological change are the most difficult aspects to predict and to relate to the other, physical and chemical processes.

General problems of fragmented approaches to the subject matters discussed earlier are reinforced by the very different time and spatial scales encountered in studies of the sea, land, and air. That satellite-borne instruments will erase such differences in terms of measurement does not automatically answer many difficult theoretical and practical questions that exist independent of the measurement.[23]

> AGENDA ITEM #3: CONVENE SMALL PLANNING GROUPS of marine and terrestrial ecologists and marine and atmospheric scientists to identify observations and data sets commonly required to connect land-sea-air aspects of the biosphere. Determine and rank a critical set of field studies whose conduct would foster improved

22. John H. Steele, "Global Ecosystem Dynamics: Comparison of Terrestrial and Marine Systems" (Woods Hole, Mass.: WHOI, 11/23/87), draft.

23. Boosterism is much in evidence and fashion; it is also misplaced. Robert McC. Adams, "Smithsonian Horizons," *Smithsonian*, vol. 18, no. 12 (March 1988): 10, cites most of customary benefits imagined to flow from increased satellite observation and measurement. Few of the costs or difficulties balance his opinion.

and more efficient long-term monitoring and assessment.

The task is aimed at getting better agreement about "what counts" rather than just counting everything in sight. This apparently simple matter is in fact quite difficult, which may account in part for its neglect.[24] The importance of Item #3 is accentuated in the urgent need to tame the satellite-created monster of "data glut."

Data Glut—A Monumental Technical Challenge

Being overwhelmed by the data that technology can provide has plagued researchers since the earliest days of satellite-based intelligence collection. The problem of data glut is massive and only getting worse. Furthermore, it is at least as much a collection of difficult intellectual questions and puzzles as it is something liable to a technological fix—such as bigger super computers. There is little evidence that those in the ocean science communities responsible for the coming decade's massive, satellite-based data gathering projects are taking data glut seriously enough.

> AGENDA ITEM #4: JOIN FORCES WITH INTELLIGENCE ANALYSTS AND SPACE RESEARCHERS to define the most critical research and institutional problems associated with data acquisition, fusion, and reduction. Then fix them.

In an excellent, unclassified investigative report in *The Wall Street Journal,* Dennis Kneale discovered the following about data gleaned from space exploration:[25]

> The U.S. has spent billions on space exploration the past two decades, searching out the secrets of the moon and Venus, or Mars, Jupiter and Saturn and galaxies beyond. But the little known secret is that scientists have looked at only 10% of the data that spacecraft have sent back to earth. They have closely analyzed only 1% of the mountain of tape.

24. Yu. A. Izrael and R. E. Munn, "Monitoring the Environment and Renewable Resources," in William C. Clark and R. E. Munn, eds., *Sustainable Development of the Biosphere* (New York: Cambridge University Press, 1986), chap. 13, is an excellent example of what is required here.
25. Dennis Kneale, "Into the Void," *The Wall Street Journal* (January 12, 1988): 1, 33.

The bulk of the data is recorded on tapes and then stored in what Kneale refers to as "tape landfills." Simple cataloguing has not even been done: "Over 60% haven't even been located or catalogued." One sad consequence, among too many, was the nearly decade long lag between the initial satellite readings that ozone in Antarctica was rapidly depleting and someone's recognition of the facts. "The hole in the ozone . . . showed up 10 years ago in raw data from the Nimbus 7 satellite. Yet no one ever sifted it out of the tangle of tape."

As poorly as the data-handling tasks have so far been done, matters are only getting worse—and at an accelerating rate. NASA's short-lived 1978 SEASAT I produced more data points in its 104-day life than had been collected in the previous 100 years of ship-borne measurement. Usual data transmission rates from a single spacecraft in 1974, for example, were some 1,000 bits per second. By 1980 this benchmark had increased to 50,000 bits per second, and by 1995 and the space station, the figure could exceed 200 million bits per second. The benchmark does not account for increased numbers of satellites and instruments, nor does it factor in problems associated with joint, shared, and international data-gathering arrangements. As if the "simple" data-handling problems were not enough, the blurring of distinctions between scientific and security requirements figures in as well. The tension between science and security is hardly limited to the United States.[26]

> [France's] two new earth-observation satellites SPOT-3 and SPOT-4 . . . are widely acknowledged as being looked upon by the French government as stepping stones toward military observation satellites.

Data glut is to some extent a political problem, which means that leadership might be brought to bear to address and perhaps even manage it. "Glitz," or political sexiness, has so far prevailed.[27]

> Congress . . . is quick to spend billions on the gear that spits out numbers. . . . Big pieces of iron such as spaceships and satellites create good publicity and thousands of jobs. Software, on the other hand, doesn't rank very high on the glitz index.

26. David Dickson, "Europe in Space: The Program Is in French," *Science,* vol. 238 (18 December 1987): 1645-46. The title does not "say it all," but it certainly fingers a big part of the problem.
27. Kneale, "Into the Void."

Data glut is also created by classification barriers that insulate the intelligence community from the open, scientific ones. One must presume that the general problem has been faced and dealt with by those responsible for the nation's highest security priorities, such as timely warning of ICBM launches and treaty violations discernible only via satellite verification. Rediscovery of that which has already been painfully and expensively learned seems less sensible than joining forces in appropriate settings and on secure terms.

This hopeful thought must be tempered, if not discounted entirely, by taking account of the changing relationships between ocean scientists and those who provide the nation's security.

Security and the Ocean Sciences—SOS

As large and complex as the topic of security and the ocean sciences is, there are two general issues within it that stand out as problems: the unstable roles and relationships that define and guide civil and military science, and the restriction of science caused by security classification.

Civil and Military Science

The respective roles of science and the military in American society are worth detailed and dispassionate inquiry. The nature of the relationships has always been complicated, but what is striking today are the fundamental changes they are undergoing, and the rate at which this is taking place. The impetus grows stronger, it seems, as traditional sources of support for science, such as private foundations, the National Science Foundation, and nonmilitary operating agencies of government, level off or dry up. Where else is there to turn, especially as military research budgets burgeon in response to initiatives for strategic defense?

Turning to the military need not mean compromise with core and essential scientific values, although it often does. Helping defend one's nation from outside threats need not mean eroding its capacity to adapt, evolve, and survive, although it might. And becoming more concerned with operational, not basic, research may improve the utility of one's scientific efforts, but only until the intellectual capital has been exhausted.

Most of these cares and concerns can be stated clearly enough to begin work on their resolution. Is greater dependence on the Department of Defense for research support likely to be

"costless" in terms of fundamental importance to science? How much control over defining acceptable research topics, allowing ideas to flow freely without classification, and employing foreign colleagues are scientists willing to accept to get DOD's money? What longer-term consequences for the university as an institution do the new military-industrial arrangements portend?

The institutional aspects are compelling, and so are the financial ones. The total amount and relative proportion of military research and development (R&D) funding have increased since 1981. Of the total $45 billion spent in FY 1984 for R&D by the federal government, $29.9 billion—about 65 percent—was military. The amount has increased but the proportion has held ever since, to the point where in FY 1989, the military's two-thirds share is projected at $38.7 billion, out of a total federal R&D of $62.5 billion. Careful dissection of other R&D line items increases the military share, as nuclear weapons design and development by the Department of Energy (at $2.5 billion) are treated as "non-military."[28]

Of more immediate concern during the next few budget cycles is how scientists are going to absorb slashes in the Defense Department's category 6.1 basic research funding. All military research is not equally important. And even Pentagon managers are being forced to set and order priorities in the face of budget exigencies. It is hard to believe that they will set basic research above nearly or currently operating programs. Indeed, of the several billions in cuts just proposed for military spending, a disproportionately large share is aimed at RDT&E (research, development, test, and evaluation) not related to the Strategic Defense Initiative (SDI). So-called "Technology Base" funding decreased 4.0 percent in the FY 86-87 period and rose only 2.0 percent in the FY 87-88 one. Contrast this with the budgeted 40 percent increase in "Advanced Technology Development" (translated: "SDI") in the same RDT&E overall account.[29]

There is an essential individual aspect of the problem one needs to plumb to place the institutional and financial parts in context. A set of questions suggests what is involved here: Under what circumstances would scientists be willing to withhold

28. "Congress's Handiwork on the R&D Budget," *Science*, vol. 239 (19 February 1988): 857. Also, Mark Crawford et al., "R&D Budget Faces High Hurdles," *Science*, vol. 239 (26 February 1988): 965-68.

29. Congressional Budget Office, *An Analysis of the President's Budgetary Proposal for Fiscal Year 1988* (Washington, D.C.: CBO, February 19, 1987), p. 54.

their services from the military? And how many would be willing to do it? Or, how willing is the military to let scientists determine the course of new research? Or the priorities to assign current projects, including eliminating or cutting some of them?

The point of raising such issues is to pose as questions, rather than accept as givens, the prevailing institutional arrangements to do science. After all, institutions are but stable patterns of interaction, subject to appraisal, modification, and replacement. Human beings created them, and have power to change them.

> AGENDA ITEM #5: CREATE A HIGH LEVEL WORKING GROUP to assess and recommend changes in the prevailing relationships between civil and military components of the sea (ocean)-land-air sciences. What are the costs and benefits, in financial and many other terms, of past, prevailing, and future arrangements (both likely and imaginable)?

The general requirement calls for a careful and nonpartisan treatment, something on the order of a Hoover Commission or a Brownlow Committee. Among other urgent tasks such a group needs to consider is the redefinition and refinement of a socially useful role for presidential science advice. And that role ought not be limited to only one of the elemental science groups (sea, land, or air), but instead should integrate them, as they are in nature and as they are becoming as a consequence of Global Change initiatives.

Still, it is useful to focus on just the sea. There appear to be several distinctive features that condition and account for the special relationships ocean scientists have with the military.

- A productive relationship between these scientists and the military began during World War II and has existed ever since.
- The ocean community is multidisciplinary and inherently includes a range of scientific topics and styles of operation.
- A rich assortment of funding sources, within government and without, has been drawn to support the ocean sciences over the years.

Each of these elements merits discussion, especially since past and prevailing arrangements are under such strong pressures to change. The overall task is to determine what has worked best, so as to adapt and retain it, while eliminating that which is no longer needed or which works poorly. The "what" in each case refers to working arrangements between the security establishment and individual scientists, their various disciplines, and respective institutions. The presumption is that ocean scientists and their military clients and sponsors have devised many useful means to serve both science and security. There are positive lessons to be recorded, learned, and perhaps applied elsewhere.

Agenda Item #5 aims to take good advantage of the planned budgetary perturbations facing the country. It is expected that the coming period of austerity will affect scientific research in special ways and that the larger these shocks, the greater the changes to be observed, particularly those favoring military sources, standards, and requirements.

The Classification of Scientific Information

The tension that exists between the scientific ideal of an unrestricted flow of all knowledge and the realistic security demands to guard certain information closely is old, persistent, and apparently increasing. Stressful symptoms are occurring in many fields, and the ocean sciences are hardly immune.[30]

The "classification problem," as it is generally called, is large and more complex than what can be covered here and concisely. Accordingly, what follows is brief and aims to discuss only several of the problem's main contributing elements. Discovering means to manage the problem will require extended and serious thought and discussion.

Advancing the ocean sciences while sustaining the nation's security is a very high priority which, until lately, has been met to a very large extent. Walter Munk's exemplary slogan makes the historical point: "Classification through achievement, not through concealment." There is little reason to fear that resumption of this past success is not possible. But at the moment, many seem dubious, and the "Sea Beam" debacle provides ample reason to doubt.

In 1983, President Reagan issued Presidential Proclamation 5030 and thus established an American Exclusive Economic Zone out to 200 miles from our coasts. Some 3.9 billion acres,

30. Committee on Science, Engineering, and Public Policy, *Scientific Communication and National Security* (Washington, D.C.: National Academy Press, 1982); and, U. S. Congress, Office of Technology Assessment, *The Regulatory Environment for Science* (Washington, D.C.: U.S. Government Printing Office, February 1986), respectively establish the persistent issues and detail some of their more recent manifestations.

more than the total land area (2.3 billion acres) of the United States, were claimed in the process, although basic mapping of the claim was yet to be done. The undersea technology for mapping the claim was well known, unclassified, and used both here and abroad. Considering it had the ships and the technological means, it seemed self-evident that NOAA would be given the job. And it was. But then the trouble began.[31]

Sea Beam consists, in essence, of an array of sonar transducers that cut a wide swath through the ocean as a ship "plows" along a "furrow" under the precise guidance of a navigational satellite (GPS in this case). Knowing one's location is as important as getting a clean echo off the bottom, at least for the purposes of accurate map making. Fine-grained details are reliably recorded by this system.[32] Therein lies the snag, for according to one observer:[33]

> Much to the chagrin of NOAA officials, who expected their maps to be widely available to the public, the Navy and the Defense Mapping Agency have argued that NOAA's detailed EEZ bathymetry data should be classified secret. Just as the *Red October*'s [reference to the popular thriller by Tom Clancy] navigator was able to guide his submarine with gravity charts, NOAA's extensive and detailed bathymetric maps, the Navy contends, would be extremely useful tools for an enemy submarine wanting to target missiles and to navigate without being detected.

Knowing precisely where one's submarine is also helps in initializing the sub's missile guidance systems.

The initial reluctance to release NOAA maps and data prompted a flood of correspondence and several hastily called meetings between scientists and various government officials. It also resulted in a momentary compromise, worked out under the care of the National Research Council's Naval Studies Board: raw data points would be filtered by NOAA to preclude high resolution mapping of the EEZ by other nations, and

31. Public airing of the problem occurred as early as winter 1984. See Colin Norman, "Classification Dispute Stalls NOAA Program," *Science*, vol. 227 (8 February 1985): 612-13.

32. Resolution of details 4 by 4 meters in size has been achieved in depths to 25 fathoms with computer-enhanced Sea Beam raw data by William Kruse of Kruse Imaging in Palo Alto, California.

33. Stefi Weisburd, "Secrecy and the Seafloor," *Science News*, vol. 129, no. 11 (March 15, 1986): 170-173, at 170.

release of the data for scientific use would be considered on a case by case basis. The compromise came quickly unglued, and the issue remains unresolved to this day.

In the meantime, Great Britain, France, West Germany, Japan, and presumably the Soviet Union all possess and are using the technology—it's that accessible. Not so available, but even more troublesome, are satellite-based systems, quite like those to be used in the earth system science and global change projects.[34]

> As technological advances such as satellite instruments expand the scope and accuracy of earth-science data collection in general, those interested in surveying and studying the earth may find that dealing with security issues in one form or another is becoming a way of life.

Take, just for instance, TOPEX, (for The Ocean Topographic Experiment), a satellite scheduled for launching in late 1989 as a joint project of NASA and the European Space Agency. TOPEX will carry a precision altimeter and tracking system designed to measure ocean surface topography, with a 20 kilometer resolution (20 km x 20 km grids), for wave heights resolved to 14 centimeters (approximately 5.5 inches) for entire ocean basins or to 2 centimeters for local observations. NROSS, the Navy Remote Ocean Sensing System, an on-again-off-again system because of budget and classification concerns, is reputed to be even more capable.

The classification problem has only just begun, but the tension between science and security need not be debilitating or inhibiting. Indeed, honest confrontation of it, in its many aspects, has considerable constructive potential. Not the least benefit is reducing evident harm to America's scientific and technological competitiveness caused by excessive and restrictive classification.

Evidence here is far from complete, although what has lately surfaced is not encouraging. A security restriction on satellite photographic resolution of less than 10 meters apparently existed even prior to President Carter's formal 1978 directive and codification of it. Consequences of this technological impediment mean, among other things, that French and Soviet commercial satellites are now better enough than our own to cause the ban to be lifted "to encourage the development of a U.S. commercial system competitive with or superior to for-

34. Ibid., 173.

eign-operated civil or commercial ones."[35] We shot ourselves in the foot, in other words. Accordingly:

> AGENDA ITEM #6 becomes CONVENE AND EMPOWER A SPECIAL STUDY AND DECISION GROUP to oversee and arbitrate existing and proposed requirements to classify ocean (and other global) data. Such a body should operate from the premise that freely flowing information is generally most beneficial to the nation's security; therefore, the burden to apply classificatory restrictions must weigh most heavily on its proposer. Or, "when in doubt, don't."

Without making a case, one can only wonder about the competence or good sense of the existing National Operations Security Advisory Committee (NOSAC), a body ostensibly given some discretion in these matters. Opinion about the National Security Council's personnel and operations, a group where Sea Beam and related matters ran aground, is more readily formed in the wake of 1987's Iran-Contra hearings.

Items #5 and #6 are superficially closely paired. As I envision them, however, they are distinctive. The former is broader and more strategic. The latter is more sharply focused and tactical. It also must be controlled as closely as is humanly possible, for there are always legitimate needs for classification, which if invoked must be guarded to the utmost.

It is time to switch gears and to emphasize workaday, managerial concerns. They are important and within the reach of any of us who take responsibility for training and research. Let me add, however, that my positive opinion about the possibilities is advanced cautiously.

Cautious Creativity

Taking the genuine complexity of our resource and environmental systems seriously makes one cautious. In just one instance, where several concerned and thoughtful souls tried to identify the requisite management measures in post-EEZ fishery regimes, the enormity of the task nearly overwhelmed them. Simple management objectives or quick fixes were quickly set aside as the enormity and seriousness of the matter

35. William J. Broad, "U.S. Ends Curb on Photographs from Satellites," *New York Times* (January 21, 1988): A-1, A-23.

emerged and took hold of them.[36] That shared experience continues to reverberate in research and writing several in the group have produced since.[37]

Cautiousness also marks the work of those pioneering in the new field of "adaptive management," a foremost example of which is located nearby in efforts by the Northwest Power Planning Council to restore salmonids to the Columbia River Basin.[38] The ideas underlying this approach are easily described, although their execution is challenging: Systems complexity exceeds our capacity to know and predict accurately. Decisions will, in any event, be made, even though no one of them can be counted on to accomplish what one hopes for. Circumstances and contexts change, to the extent that a good decision today might be a tragic one, in the same setting, but tomorrow or next year. The relinquishment of hubris comes in one's willingness to try out many plausible "solutions," but to monitor them carefully so as to learn from each and to cut losses when matters go awry.

Decision making is treated explicitly as mistake making and error correction. The creative aspect comes in one's willingness to dream up many plausible approaches and solutions, not just the one "best answer" we commonly employ. The cautiousness comes in not believing very much in any particular "answer" as much as in one's capacity to know, sense, and adapt to changes in one's specific operational setting. The approach is context-dependent. At the extreme, cautiousness turns into thoughtful consideration of the costs and benefits attached to undoing choices earlier put into place. In financial jargon this is known as downside risk minimization. In Las Vegas it is known as hedging a bet.

As intriguing as adaptive management is, there are limits to it. Not the least of these is a weakness of concern for institutional, political, economic, and human behavioral factors. This is most definitely not a criticism. The approach is deeply rooted in the soil of ecology, as displayed prominently in work produced by C. S. Holling and his students and colleagues at the

36. U.N. Food and Agriculture Organization, *Report of the ACMRR Working Party on the Scientific Basis of Determining Management Measures* (Rome: FAO, Fisheries Report No. 236, 1980).

37. Colin W. Clark, "Bioeconomics of the Ocean," *BioScience*, vol. 31, no. 3 (1981): 231-37, is illustrative.

38. Kai N. Lee and Jody Lawrence, "Restoration Under the Northwest Power Act," *Environmental Law*, vol. 16 (1986): 431-60.

University of British Columbia.[39] My point here is rather to show where a possible productive joining of similar work in the social and behavioral sciences—generally labeled "social experimentation"—might take place. The limitations of it, incidentally, are the strengths of adaptive management.

It is also coming clear that managers of the future must know much more than we've usually taught them. They also have to know many different things, as suggested by my urging to join ecology with some of the social sciences. I'm most encouraged, in this vein, by some sophisticated plans for change that are now being discussed by those in the University of Washington's School of Fisheries and its Institute for Marine Studies. Not the least of my interest here owes to the evident relationship of current efforts and those expended by the star-crossed FAO working party ten years ago.[40]

Likewise becoming apparent in many different places and institutions around the world is a need to infuse traditional legal and business training and practice with more information and awareness of sea-land-air realities. Recent convulsions at the World Bank to reorient and reemphasize environmental consequences of investment decisions are indicative. Much more is needed.

Creative new procedures are being imagined and tried out, as for instance in the areas of computer assisted negotiations (without which the Law of the Sea Convention would have turned out differently, if at all[41]), mediation, modeling and gaming,[42] and communication—oral and written presentation above all.

> AGENDA ITEM #7 encourages both the National Academy of Sciences and the U.S. Department of Education to CONSIDER THE CREATION of special research and training programs in the management of emergent problems of global change environmental sustenance.

39. An early labeling of the approach is contained in C. S. Holling, ed., *Adaptive Environmental Assessment and Management* (New York: John Wiley & Sons, 1978).
40. U.N. Food and Agriculture Organization, *Report of the ACMRR Working Party*.
41. James K. Sebenius, "The Computer as Mediator: Law of the Sea and Beyond," *Journal of Policy Analysis and Management*, vol. 1, no. 1 (1981): 77-95.
42. Garry D. Brewer, "Methods for Synthesis," in Clark and Munn, eds., *Sustainable Development of the Biosphere*, chap. 17.

Existing institutions are monuments to problems of the past and may or may not be appropriate for dealing with newly emergent and future problems. In any case, it is reasonably safe to say that none exists to deal with environmental catastrophe on a global scale. But dealing with localized environmental distress is certainly conceivable, and it appears to be more necessary. It is equally apparent that conventional disciplinary understandings of ecosystem function will not suffice. Rather than accepting just an ocean sciences or an atmospheric sciences general rendition of systems undergoing change or in distress, very much more stands to be gained by combining forces in specific locations at given points of time.

Joining of the sciences (land-sea-air)—as represented in Agenda Item #3 Global Ecosystems Dynamics—opens up similar joinings on the managerial front. Sadly, though, a most likely collection of responsibilities will be to put ecosystems back together or in some semblance of order in the aftermath of their degradation or demise. Chesapeake Bay, the Mediterranean and Caribbean seas, depleted fisheries, coral and marine mammal die-offs, and many more events point to the problem. While a new speciality in "restoration ecology," including its own lobbying organization, Restoring the Earth (RTE), has called attention to the problem, the following discussion extends well beyond RTE's narrower objectives.[43]

After the Fall—
Resource Reconstitution

Whether resources are harmed in one stunning event, such as an oil tanker spill, or simply misused over long periods of time, such as overexploitation of a fishery, it is becoming increasingly clear that decisions about resource restoration or reconstitution are important but poorly understood.[44]

Several questions help frame the task. Is the stressed, threatened, or destroyed resource likely to regenerate spontan-

43. "Making Nature Whole Again," *Newsweek* (January 18, 1988): 78-79. Daniel H. Jansen, "Tropical Ecological and Biocultural Restoration," *Science*, vol. 239 (15 January 1988): 243-44, is more in keeping with the present discussion, particularly in his stress on man-environment interactions.
44. I first used this title in a "Lecture on the Environment" at Fairfield University on November 4, 1987, one of a three-part series on *Ethics and the Environment* sponsored by the Olin Corporation Charitable Trust. A full text of the lecture, here only sketched, will be published in the *Fairfield Management Review* (Fall 1988, in press).

eously, or only with human intervention, or not at all? What institutional rearrangements or creations need to be considered to help reconstructive efforts? Are there professional training requirements? Are public awareness and education essential? The list of relevant questions is long and daunting. The task here is to ask them in the context of what appears to be a general, widespread, and growing problem. That context is resource management, whose traditional goals and simple means often underlie, if not cause, the problems.

Simple Pursuits and Unwanted Outcomes

As individuals became aware of the need to manage, not merely use, resources, a succession of increasingly sophisticated and complex ends have been sought. However, from simple and naive all the way to complex and sophisticated, managerial goals and the institutional regimes created to pursue them often end up harming the resources they were meant to sustain or husband. The following illustrations help make this point.[45]

Maximum sustainable yield (MSY) is a clear example. As a management goal, MSY owes to a biological presumption that existing natural populations must overproduce themselves in the long term, else they cease to exist. The production rule is "harvest the excess over the stock needed for maintenance of the population." The concept provides deceptive precision in an equilibrium package, neither of which is realistic. Natural variation, poor understanding of species interactions or other constraints in dynamic contexts, thresholds and attendant explosions and crashes, and assorted human foibles all conspire to limit management regimes tied to the MSY concept.

Different economic ideas have been advanced to get around these limitations. Discounting, stabilizing, and other forms of market operation and government intervention have, at one time or another, all guided resource planning and management, but widespread successful applications of these kinds of ideas have not occurred.

Calculating a resource's discounted value is a tried and true economic tool and management approach. A low discount rate

45. This basic idea came up in April 1984 during discussions with Carl Walters at a Dahlem Konferenz, in Berlin. Reported as Robert M. May, ed., *Exploitation of Marine Communities* (New York: Springer-Verlag, 1985): 227-44. Walters has recently elaborated the main points. Walters, *Adaptive Management of Renewable Resources* (New York: Macmillan, 1986): 20-30.

"means" that today's decisions account for future needs in terms of the resource being valued. A high rate means just the opposite and can often be discovered underlying decisions to "cut and run" or to use up resources as quickly as possible. Selecting the rate is the problem. Ought one set the rate at the current cost of capital, equal to the renewal rate of the resource, or to some ethically and politically determined level?[46] Easy calculation does not remove the need to answer these questions or for someone to set the rate. Indeed, the rate is "set," implicitly as the consequence of prevailing policy processes—phenomena so complex no one could possibly do the calculations.

Explicit political goals of dampening economic fluctuations or providing employment are more up-to-date rationales for resource management. Trying to break out of a boom-and-bust cycle is common to many economies, as illustrated by the creation of the infrastructure and broadening of the tourist industry in Mexico and lately in Alaska. The welfare goal of providing employment is most visible in support of investments and operations of many national fishing fleets around the world. Concern for the short term and the level of employment overwhelm thoughts about long-term resource vitality. The future is so heavily discounted, it is mortgaged to the hilt. "Bankruptcy," with attendant restructuring, becomes all the more likely.

The particulars in each case are less important than these two general points:

- Traditional management approaches are based on simplistic views of the resources they are meant to manage.
- Longer-term and larger-scale consequences from such approaches are seldom considered by anyone until notable, often irreparable, damage is done.

At issue are the cumulative effects of human interventions in resource systems complex beyond imagining. In the extreme, these effects entail ecological collapse, instances of which serve notice on traditional practices and signal needed change.

46. This techno-economic matter is thoroughly covered in James P. Quirk and Katsuaki L. Terasawa, *The Choice of Discount Rate Applicable to Government Resource Use* (Santa Monica, Calif.: The Rand Corporation, R-3464, December 1987).

Cumulative Effects

Cumulative effects happen as numerous small decisions that affect a resource or environmental system, but whose combined consequences are slow in coming, show up only as thresholds are crossed, or are spread over space. The ecologist W. E. Odum captures the idea in the label, "The Tyranny of Small Decisions."[47]

Dump sewage and toxic wastes in an estuarine habitat, such as Boston and New Bedford harbors or the Hudson River. Little seems to happen until water quality deteriorates and surpasses the adaptive and resilient capacities of the system's life forms. Continue disposing plastics throughout the world's oceans, and the destructive toll mounts slowly until local catastrophes begin adding up, as mountains of garbage on Caribbean beaches or as dead birds, fish, and mammals on the shoreline surrounding the New York Bight.[48]

Continue loading the environment with human wastes and industrial byproducts. Eventually there must be environmental consequences from such contamination. Consider just the hundreds of new compounds modern chemistry develops and releases each year. Then consider the unusual and large-scale die-offs of porpoises on New Jersey beaches. The root problem is rather straightforward, however complicated precise details about it may turn out to be. Nor does it take complex analysis to realize that Long Island, New York, will not much longer accept the contaminant and refuse loadings being placed on it. The touring garbage barge that was featured in numerous news reports in 1987 was a stinking mess for those responsible for it and a danger signal for those whose lives are at deadly risk.

But even thoughtful and well-intended exploitation can cause surprises. Trying to maximize sustainable yields of fish often fails because harvesting rates and population densities are seldom linear, and crossing a critical threshold can lead to a total population crash. Many fear longer-term harm because of reduced genetic diversity—species are disappearing at an accelerating rate because of human activity.[49]

47. W. E. Odum, "Environmental Degradation and the Tyranny of Small Decisions," *BioScience*, vol. 32, no. 4 (1982): 728-29.
48. Clifford D. May, "Waterways, Declining, Focus of Laws," *New York Times* (January 5, 1988): B-1, B-2.
49. Office of Technology Assessment, *Technologies to Maintain Biological Diversity* (Washington, D.C.: U.S. Government Printing Office, March 1987).

This brief excursion into cumulative effects does not exhaust the topic, as much as it reminds us all that man is an integral and especially potent component in the environment. Our decisions and actions are capable of producing serious ecosystem stress, of the magnitude found in each instance just listed.

Intelligent and effective management could be devised according to natural boundaries and definitions of living systems. The idea of ecosystem-based authorities needs elaboration.[50] The wholesale destruction of tropical ecosystems in which existing boundaries mean little, diminution of marine wetlands and nursery habitats, and elevated concern about likely and widespread climatic effects all suggest that we should reconsider powerful arrangements from an unaccustomed ecosystem point of view.[51]

"Internalizing the externalities" (to borrow economics jargon) by empowering regional authorities over local ones is another fresh idea. Laudable as it appears, restoring the Atlantic salmon in New England's rivers makes very litte sense if management controls cannot be extended to Iceland, Denmark, and the United Kingdom where the fish spends much of its adult life. Indeed, a general first step toward reconstitution appears to be an assessment of the authority systems needed to resolve the problem.[52]

Air and water conservation and management are likely targets for a regional reallocation of decision-making powers. Coping with the political and institutional complexities of the Puget and Long Island sounds or the Chesapeake and San Francisco bays points directly to this needed change.

The demise of an ecosystem forces social and economic responses.[53] Close connections between natural failures and institutional terminations exist, but seldom are they closely studied. The crash of the Peruvian anchoveta in the aftermath of El Niño in the early 1970s was no doubt hastened by previous

50. Kenneth Sherman and Lewis M. Alexander, eds., *Variability and Management of Large Marine Ecosystems* (Boulder, Colorado: Westview Press, 1986), can be viewed in this light. A parallel terrestrial, account is contained in Tim Clark and Ron Westrum, "Paradigms and Ferrets," *Social Studies of Science*, vol. 17, no. 1 (February 1987): 3-33.
51. Jansen, "Tropical Ecological and Biocultural Restoration," illustrates what is required.
52. Maynard B. Fiering and C. S. Holling, "Management and Standards for Perturbed Ecosystems," *Agro-Ecosystems*, vol. 1, no. 2 (1982): 301-21.
53. J. Cairns, Jr., *The Recovery Process in Damaged Ecosystems* (Ann Arbor, Mich.: Ann Arbor Sciences, 1980).

gross overcapitalization of the fishing fleet.[54] Resulting questions about what to do with idle human and other capital were nearly as complex as trying to determine when or even whether the fishery would ever recover.[55] Comparable questions attend nonrenewable resource consumption (oil and gas) despite prior knowledge of their eventual exhaustion or diminished worth because of technological or economic substitutions. Curiously, though, environmental impact assessments of oil and gas drilling offshore seldom address any of this.

The main points are clear. Many ecosystems are being stressed to thresholds beyond which new patterns of response are likely to occur. Such discontinuities from accustomed behavior are extremely difficult to forecast, but the risks are generally assumed to be large.[56] Not so commonly acknowledged are the opportunities a natural break or even a collapse presents. Destruction yields to creation; termination opens up opportunities just as it presents difficulties.[57]

Caring for Future Generations

One of the most challenging analytic tasks I can imagine is figuring out changes in the power relationships and institutional frameworks after a resource is depleted or a cumulative-effect crisis occurs. As with most instances of termination, thoughtful consideration of the options beforehand is rare because of the associated anguish and disruption.

But even after the fact there may be advantages to seize. Once a collapse occurs, vested interests are no longer a problem and rational management can be imposed with less political difficulty or interference. If, for instance, the original problem resulted from domination by local authorities, a collapse may permit broader authorities to assert control. Once there is little left to lose, opportunities to consolidate control in institutions with appropriate scope, competence, and power may be greater than ever. Rehabilitation of the Great Lakes under the guidance

54. Michael H. Glantz, "Science, Politics, and the Economics of the Peruvian Anchoveta Fishery," *Marine Policy*, vol. 3 (September 1979): 201-10.

55. John H. Steele and E. W. Henderson, "Modelling Long-Term Fluctuations in Fish Stocks," *Science*, vol. 224 (1984): 985-87.

56. C. S. Holling, "Resilience and Stability of Ecological Systems," *Annual Review of Ecology and Systematics*, vol. 4 (1973): 1-23.

57. Garry D. Brewer and Peter deLeon, *The Foundations of Policy Analysis* (Chicago: The Dorsey Press, 1983): chaps. 13 and 14.

of a joint U.S. and Canadian commission illustrates the general idea. Assumption of authority by the court to clean up Boston Harbor is another, comparable approach. However, by this line of reason, persistent inability to consolidate authorities or make headway in cleaning up the Chesapeake Bay suggests that the overall problem is not yet perceived to be "bad enough" or "out of control."

The inertia of economic arrangements to change is similarly least after a collapse. The collapse of the sardine immediately after World War II ruined the fishing industry of Monterey, California, in the short term, while it created "space" and impetus for alternative tourist, educational, and retirement-based industries in the 1950s and beyond. None disputes the substantial additions to social welfare that switching resource bases eventually allowed.

But suppose the worst does happen, and a resource-dependent industry simply folds. Whose responsibility is it to serve as salvage specialists or receivers to reallocate investments in ruined or even declining industries? Who ought to be worrying about and paying the price of rehabilitation, should that be the policy choice? What cooperative institutional arrangements are needed to distribute reconstitution and rehabilitation costs and benefits equitably and effectively? These questions are not usually considered by those of us who train resource managers for the future.

Likewise, we seldom raise questions about policy choices that concentrate the benefits of resource exploitation and use in the near term and for a select few while spreading the costs broadly and mainly into the future. The political calculus recited here is as simple as it is mischief making. The broad issue of equity between the generations is at stake. But how much emphasis do we place on it? Not much and certainly not enough if reconstitution is a problem large enough to cause concern.

The insoluble dilemma in all this revolves around the impossibility of knowing the preferences of our progeny while simultaneously making decisions on their behalf. The thoughtless simply are not fazed while the rest of us seem confused. We all need to do better.

AGENDA ITEM #8 thus follows: STUDY, LEARN ABOUT, AND TRAIN all resource and environmental managers in the new field of ecosystem and resource-system reconstitution.

Many environmental changes, including damaging ones, can be foreseen. A few can even be repaired, but perhaps not to their original state of nature. Repair, or reconstitution, demands unusual amounts of imagination to appreciate its importance and then to figure out its means. It presumes uncommon responsibility on the part of political leaders. Its success hinges on an ample supply of great good luck. And it requires money, toward which we next turn.

Living Within Reason—Austerity and Retrenchment

Undeniable Change

Not since World War II have there been so many forces at work to change the fundamental roles operating and relationships underlying scientific work in this country. Until now the magnitude and dynamic of science, taken as a vast collection of activities, have provided a dependable certainty along with momentum. Change has occurred slowly, mainly at the margin, but usually upward in the last four decades. More than a generation of scientists has learned to expect continuity in society's demands of them—as suggested by stability or growth in their budgets—if not year to year, then certainly over the longer haul.

But past experience now seems a doubtful basis for reliably anticipating the future. Huge budget deficits, a revolution in the popular consensus that enables anyone to govern, a shifting of attentions to strategic threats and preparations, and wrenching economic challenges here from abroad all figure in. These are interesting times, to say the least. Determining how precisely various factors affect science, or how science may affect them in return, will provide grist for the scholarly mills for years to come. What one can count on soon, however, is that accustomed stability and growth are no longer possible.[58]

Austerity has seldom, if ever, been factored into any of the discussions, plans, or actions of those currently responsible for

58. John Walsh, "Dividing the Pie at NSF," *Science*, vol. 239 (19 February 1988): 862. "The painful evidence seems to suggest that NSF's recent comfortable ride on the budget growth curve may be over."

the ocean sciences. Individual and collective unwillingness or incapacity to consider retrenchment is evident, although reminiscent of the small boy whistling loudly as he passed the graveyard.[59] And because there is little experience, no one knows how or what to do. Certainly, no one wants to cut back. Nonetheless, those leading the U.S. Coast Guard must figure out how to absorb a $115 million reduction fiscal year 1988. Essentials will be saved, and lower-priority items will be sacrificed. But one wonders if fishery enforcement will be as "essential" to the Coast Guard as it is to the National Marine Fisheries Service, the Regional Fishery Management Councils, and the states? The question acquires added weight when the deep cuts proposed for NOAA and NMFS are taken into account.[60]

Another consideration complicates coming to terms with an era of austerity: the increased scale of the ocean sciences. Twenty—or even ten—years ago, the ocean sciences would have registered as small to medium in size in any reckoning of different kinds of scientific endeavor. No more. The coming decade looks increasingly like a time of big science, with relatively fewer, but larger-scale and expensive, investments needed to continue the work. This presents an unaccustomed problem of what economists refer to as "lumpy investments," whose indivisibility sometimes demands "all-or-nothing" decisions about what to pursue and what to forgo. To an outsider viewing the array of truly wondrous satellite missions planned for the 1990s, it is very hard to imagine which ones to scale back much less which ones to scrub. But that is precisely what budgetary considerations now demand.

The issue is trade-offs. How much is one willing to pay for the benefits of getting into space as opposed to the lost opportunities of not pursuing many other valuable goals elsewhere?

Policy Termination

Change is an essential element of policy or of strategic planning. And when resources are limited, changes in programs or policy direction require the termination of some activities to make way for new ones. Benefits to some are reduced while

59. Noteworthy mostly for its detachment from reality is the Advisory Committee on Ocean Sciences, *A Unified Plan for Ocean Science*.

60. Crawford et al., "R&D Budget Faces High Hurdles," p. 968. FY 89 budget cuts of nearly 50 percent in NOAA's research programs are being proposed in the spring of 1988.

those to others are increased. Believing themselves entitled, the beneficiaries of the old programs carry an effective veto over termination, and therefore over strategic or policy change. Consequently, explicit attention needs to be focused on the problems of policy termination.

Termination is not fun. It is often equated with failure, and it is nearly always tied up in high emotions and considerable irrationality—at just the time when clear thinking and solid analysis are most needed. Understandably, most of us would just as soon not think about it, a habit of mind which translates directly into demands for exceptional leadership and unusual community-wide discipline.

Leadership and Discipline

Neither leadership nor discipline is evident in several other scientific fields where the budget crunch has already hit. Instead, one is dismayed to see end-runs to individual members of Congress to earmark R&D funds for specific projects. Besides encouraging a mean, beggar-thy-neighbor style of operations, nonscientific criteria usually determine whose pork barrel to fill. It is also noteworthy that the Departments of Defense and Energy are the most common sources of the handouts.[61]

Until recently, leadership in the ocean sciences was well and tightly held by the small cohort that established the field in World War II and continued to shape and direct it afterward. Succession to the next generation has been uneven and difficult, problems not helped at all by the relatively few eligibles in today's 45-to-55-year-old group, the increasing number of foreigners now in the field of ocean sciences, and the lingering disaffection for the military felt by many 35-to-45-year-olds most touched by the Vietnam War. Nor is there much evident a true sense of wholeness or integrity for the community-wide enterprise, a likely penalty for allowing the "twin demons" of specialization and fragmentation to flourish.

Beyond recognizing and calling attention to the leadership and succession crises, it is difficult for one not intimately involved with the ocean science community (or tribe) to know what to do. The issue does seem important enough, however, to put on the agenda as:

61. Mark Crawford, "'Earmarking' at DOE, DOD Rolls On," *Science*, vol. 239 (22 January 1988): 344-45.

> AGENDA ITEM #9: CONVENE THE ELDERS to diagnose in detail and to map out strategies to overcome the serious leadership and succession problems facing the ocean sciences. At the same time, ESTABLISH RULES AND SANCTIONS for any in the tribe who break ranks or otherwise flout community discipline.

Community survival in times of external threat or distress nearly always requires extraordinary measures. But challenges also often bring out the best in individuals and institutions, and the discussion next turns to several opportunities austerity presents.

Opportunities and Challenges

If hard choices must be made about satellite-borne instruments, why not open the matter wide, to consider alternative and cheaper launch vehicles for instance? Officials of Hughes Communications, it has been reported, are doing precisely this by inquiring about availability and costs to launch on Soviet and Chinese "BDRs" (Big Dumb Rockets) now that space shuttle operations have become so unreliable and costly.

Hard choices should also mean some hard questions about which instruments and what data the community truly needs, not just wants to fly and collect. Benefits here accrue directly to relieve the data glut problem at the same time as they focus research priorities.

If austerity, quite like the prospect of death according to Samuel Johnson, "wonderfully concentrates the mind," it may result in the U.S. Navy's having to decide whether to maintain its independent oceanographic and basic science research capabilities. An interesting prospect would be the consolidation of all military support for the ocean sciences into a common pie to be administered by a new civil science authority for Global Change. As radical as such a thought may seem, stark alternatives to it seem even less appealing.

Reconsider the current dilemma before the U.S. Coast Guard: If cutbacks mean less time for fishery management, as they may, then how else might the task be performed? Could state agencies be "deputized" and empowered to enforce fishery regulations out to the 200-mile limits of the EEZ? Placing shipriders with expanded enforcement powers on board fishing vessels would avoid the expense of ships and would put managers in closer touch with their resources.

Bringing up these possibilities is not the same as advocating any of them. Rather, my point is that times of stressful change, such as the one we are now entering, offer opportunities to think creatively and to take bigger risks than simpler and more dependable times. Indeed, collective survival often depends closely on such thinking and risk taking. The status quo or business as usual can be quite harmful.

One obvious challenge is to attract and hold the public's attention better so that the ocean sciences can compete with other exciting fields, such as high energy physics (SSC) or SDI. Developing the sea and land linkages, as suggested in Agenda Item #3, seems important scientifically, but it also has a public aspect worth exploiting: More and more citizens (and voters) are moving to the coasts. Tapping into widespread health concerns of the sort that sustain environmentalism and politics, by publicizing the importance of toxics, estuarine processes, and harbor and ecosystem reconstitution, is a positive means to connect the sciences to the citizens. Etzkowitz explains why this is so in terms of human-caused disaster:[62]

> Whether experienced at first or second hand, it is the most salient factor in developing environmental consciousness. [Futhermore, and contrary to popular belief], environmental consciousness has not declined. Indeed, it is broadly spread across the social spectrum and comes close to constituting a consensus.

As hard as it is to attract and hold attentions, one need not pander to promote the importance of the work. Nevertheless, it seems worthwhile to think explicitly about the public face the ocean sciences present. Exploitation of offshore oil and gas readily excites political passions, but focussing them to foster the relevant sciences is uncommon. Plate tectonics, on the other hand, may excite geologists, but to the average guy on the street the concept is about as interesting as watching paint dry. The topic of "Telling What We Know," which this point suggests, is important and concludes the discussion.

Telling What We Know—Knowing What to Tell

The general problem of pulling bits and pieces of knowledge together in ways that convey meaning—to other scientists, to decision makers, and to average people—is extraordinarily difficult. It is also vitally important, which suggests that many able minds need to be working on it.

62. Henry Etzkowitz, "Environmentalism and Equity," *Science*, vol. 235 (20 February 1987): 914-15.

For instance, how does one create an institutional or corporate memory about emerging problems associated with Global Change, civil and military science (including matters of classification), resource reconstitution, and the like? How does one guide attentions to aspects of such complex problems that demand special care and effort? How does one then go about putting new knowledge to constructive use? How, in short, might one imagine improving the business as usual of contemporary science?

At the moment the "twin demons" rule. Journals are proliferating to the point that libraries cannot afford to subscribe to many of them; no one can claim to read more than selectively in most fields. Small, highly specialized associations have become more prominent, at the expense of large, general purpose, and integrative ones, such as the American Association for the Advancement of Science. Conferences tend to stress crises, such as AIDS, but at the expense—in terms of decision-maker or public attentions—of longer term and less evidently urgent matters. Congressional hearings, when focused on matters scientific, highlight existing investments and programs and thus devalue new and challenging problems of the longer run.[63] Earmarking and pork barreling of specific science projects are symptomatic.

None of this is healthy. We must collectively work to establish and assemble what various scientists know, in forms and in time, to alert decision elites and the public to emerging concerns of land-sea-air, Global Change, and sustainable developments of the biosphere.[64] Problems must be placed on various agenda earlier, with sufficient lead times to allow less costly and less risky corrections and accommodations to be imagined and to occur. Recall the opening arguments of this lecture.

Also not healthy is a slighting of intellectual pursuits aimed at discovery, as opposed to the predictive ones celebrated in science. We are engaged in a changing global enterprise such as

63. As for the "Task Force Hearings on Science Policy," conducted by the House Space, Science and Technology Committee in 1985-86.

64. The final chapter in Clark and Munn, eds., *Sustainable Development of the Biosphere*, is a lengthy plan and argument on just this point. Garry D. Brewer, "Methods for Synthesis," chap. 17.

has never been experienced before. There are at present more than 5 billion souls living, consuming, and depending on this planet. All too soon, by best estimates, this number may well double, and with it will come intensification of life, consumption, and dependence. The ideas of trying out new means to cope, as in the cases of adaptive management and social experimentation, acknowledge our limitations to know definitively as much as needed to predict and manage with great certainty. Efforts to rebuild or reconstitute can be seen either as symbols of such incapacity or as creative responses promising considerable hope.

How do we communicate in forms that are more accessible? The issue is technical and practical, as in working diligently to pick, assemble, and interpret "tons" of data about the world, and the issue is also philosophical, as in allowing individuals the chance to be well enough informed so as to make their own decisions for their own preferences and for their own reasons. The spectre of a Platonic, guardian elite assuming greater control here is worrisome. Words, pictures, maps, charts and other simple, broadly appealing forms to present our science all must figure in as means to these different ends. Developing technologies, such as computer teleconferencing, provide other avenues of hope.[65] But, instead of calling particular attention to the task, by making it one final agenda item, allow me to invite everyone to take to heart such matters as "Telling" and "Knowing" that which we do.

Indeed, instead of concluding this lecture, allow me to invite one and all to consider the array of agenda items and tasks, to select (add to or modify) those of most interest, and then to get down to work.

There is so much to be done.

65. U.S. and Soviet scientists concerned about global warming are, for instance, about to embark on a one-year experiment in computer teleconferencing. American leadership is being provided by Walter Orr Roberts and Rusty Schweickart (President emeritus of the University Center for Atmospheric Research and former astronaut, respectively). Many comparable efforts are conceivable for ocean science aspects of global change.

The McKernan Lectures

This lecture series was created to honor the memory of Donald L. McKernan, who died in Beijing, May 9, 1979, while participating in a U.S. trade delegation. Professor McKernan's last job was that of Director of the Institute for Marine Studies, University of Washington. Before that, he had several distinguished careers—as fishery scientist, fisheries administrator, Director of the Bureau of Commercial Fisheries, and special assistant to the Secretary of State for fisheries and wildlife in the U.S. Department of State.

Professor McKernan's interests encompassed the entire range of marine policy studies, and this lecture series, as reflected by the following titles, has been designed to incorporate the same breadth of interests.

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* This lecture was published in the *Bulletin of the American Meteorological Society*. Reprints may be ordered from Washington Sea Grant Communications at the address above.

Garry D. Brewer holds the Frederick K. Weyerhaeuser professorship at Yale University, with appointments in the Schools of Organization & Management and Forestry & Environmental Studies. The chair was endowed as a family memorial to Mr. Weyerhaeuser, a 1917 Yale graduate and early environmental advocate, to foster integration of environmental science into public and private management.

Professor Brewer earned an A.B. in economics at the University of California at Berkeley, an M.S. in public administration from San Diego State University, and a masters and doctorate in political science from Yale. His interest and background in the oceans come from his boyhood by the sea, service in the U.S. Navy, and early professional involvements such as the FAO Law of the Sea Study Group. A member of the Woods Hole Oceanographic Institution's Corporation and the National Academy of Sciences' Ocean Studies Board, Brewer also is author of seven books and more than 150 articles in several policy areas.

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