Marine Sciences in the Coming Decades

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The period since 1945 has been one of immense progress in understanding the sea. Oceanographic knowledge led to the compelling evidence for plate tectonics, the discovery of sea-floor vent biological communities, and the nascent ability to predict El Niño, to cite only a few examples. The scientific community was able to exploit the technological revolution in electronics, materials sciences, and instrumentation, as well as the increase in basic scientific understanding of fluid dynamics, chemistry, and biology to make great advances in understanding how this immensely complex and interesting system operates.

Looking back, it is clear that most of the advances took place in the context of pure curiosity-driven basic science, as funded initially by the Office of Naval Research (ONR), and later joined by the new National Science Foundation (NSF) in the early 1950s. It is inescapable, however, that much of marine science was funded implicitly for its perceived military implications. In particular, the existence of a Soviet submarine fleet generated an extensive U.S. antisubmarine warfare program. In support of that effort, the U.S. government used research grants and contracts to transform the small number of tiny, prewar civilian oceanographic institutions into a much larger number of major laboratories, both university-operated and independent. The ONR took the enlightened view that across-the-board understanding of the ocean would ultimately redound to the national security, even when the immediate application to military needs was not even dimly perceivable.

Like all of science, the oceanographic community in the United States is now facing the question of how and why support will be provided in the future. The country is grappling with finding a rationale and mechanisms for support of science in a time of peace, for the first time since before 1940. There is no U.S. experience with large-scale federal support of marine science in the absence of a perceived external threat.

With such strong roots in the Cold War, oceanographic science is particularly vulnerable to shifts in national priorities. To help understanding of the implications of the changing context in which marine sciences will operate, the Ocean Studies Board of the National Research Council recently published a review and discussion of the state of marine sciences in the United States, and the future outlook (*1*).

The report notes that compared to many scientists, oceanographers have the advantage of being able to describe the real and potential application of their work to a multitude of societally important problems. An abbreviated listing of those applications would include weather forecasting; climate change; sea-level rise and related shorefront processes including water supply, fisheries management, and pollution trajectories; and the ever present military issues. But such applications represent a two-edged sword for the field.

The social applications are built on the foundation of basic science, which ONR and NSF supported. The report points out that much of the knowledge that is being used today in applications was developed 20 to 30 years ago by scientists simply following their own interests. With the rise in concern over such issues as global change, the federal players in the field are not just agencies interested in basic research—NSF and ONR—but also an array of agencies dominated by short-term applications and regulatory requirements: the National Aeronautics and Space Administration (NASA), the Department of Energy, the Department of Commerce [through the National Oceanic and Atmospheric Administration (NOAA)], the Army Corps of Engineers, the Geological Survey (USGS), the Environmental Protection Agency (EPA), the Department of Energy, and various parts of the Navy. If the roles of NSF and the Department of Defense in supporting basic science should change as some have proposed, and marine science is left to the mercies of narrowly focused mission agencies, who will make the investments so that our successors will have the basic understanding upon which useful political, economic, and social policies can be based?

It is no longer obvious that the organizational structures on either the federal or nonfederal sides are as effective as they might be. Nonfederal research exists in a spectrum of laboratories at least as complex as the varying structure of the federal agencies. Nongovernment organizations include large, private, nonuniversity laboratories (for example, Woods Hole Oceanographic Institution), large, private, and state-funded laboratories at least nominally connected to universities both private and state (for example, Texas A&M University, University of Miami, and Scripps Institution of Oceanography), and faculty in conventional academic earth sciences departments. The types of nongovernmental laboratories are so diverse that it makes the full description of the workforce nearly impossible. The nonfederal institutions and their employees are often labeled "academic," although only about 10% of the scientists are involved even peripherally in teaching.

The nonfederal institutions have focused, at the behest of ONR and NSF, on individual, peer-reviewable science. The success of this collective enterprise can hardly be doubted: U.S. scientists assumed a leadership role in many of the most important intellectual and technical advances of the last decades.

But the changes in the world at large suggest that whatever their successes, only one prediction is secure: the ways in which science in the United States will be conducted and supported in the next several decades will differ from the ways to which we have become accustomed. Several trends are already visible. Many, if not most, of these problems are shared by all sciences. But the

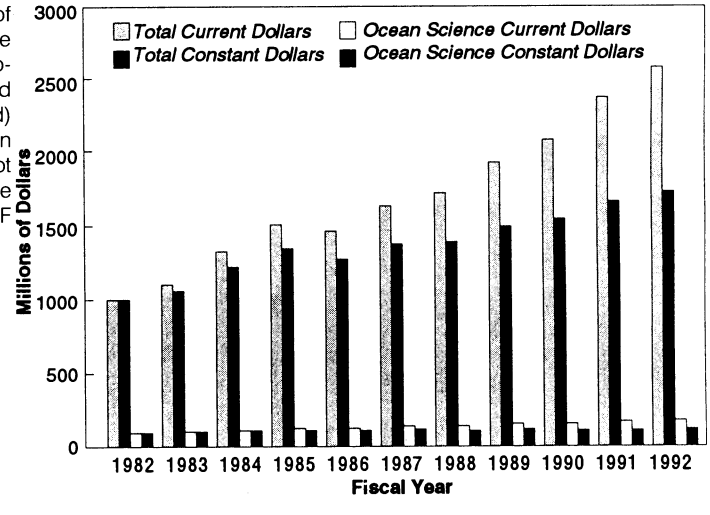

Fig. 1. Budget history of the total NSF and of the ocean science component in both current and constant 1982 (deflated) dollars. Overall growth in the NSF budget was not reflected in the marine sciences. [From NSF data]

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special history and organization of oceanographic science, as well as the problems of working at sea, lend a special flavor and urgency to understanding them.

Budgets for basic marine science have been nearly flat, in real terms, for a long time (Fig. 1). In contrast, the number of people entering the field at the doctoral level continued to rise, growing by nearly 50% over the same interval (Fig. 2). That complaints over increasing difficulties in funding have emerged is hardly surprising. Clearly, the marine community must grapple with what is an emerging scientific steady state or worse in basic science funding.

Nonetheless, the continued growth in numbers of marine scientists is not necessarily an unwelcome development. As noted, there are wide applications of oceanographic knowledge to a host of problems of serious societal concern. If one reviews the policy decisions being made concerning this vast array of problems, the best oceanographic knowledge has not often been used. With the growing numbers of marine science–educated people, this knowledge could become more widely disseminated to government agencies, students in universities, and scientists in neighboring fields (for example, meteorology), which would be a welcome trend.

Marine science shares with the wider scientific community an inexorable inflation in the costs of maintaining the state of the art. Twenty years ago, at-sea science was conducted by small teams and involved measurement durations of weeks to a few months at most; the numbers of instruments deployed at sea were modest. Today, particularly with the rise in demand for understanding the climate system, the science often dictates multiyear deployments of hundreds to thousands of instruments. The resources that even a single principal investigator must command to do serious work at sea have become daunting. Other activities, such as global-scale modeling, require organized efforts sustained over many years and in continuous, immediate contact with the latest scientific knowledge. No organization anywhere within our system is equipped to deal with large-scale, long-duration marine problems. Instead we have a series of ad hoc arrangements and subcritical efforts for whose possible ultimate failure no one is actually responsible.

Oceanographic vessels have rising capital construction costs, now in the range of $30 million to $120 million (the latter a projected cost of a proposed Arctic research vessel) with operating costs of $3 million to $10 million per year. Construction and operating costs are supported by a kaleidoscopic amalgam of NSF, the Navy, NOAA, USGS, EPA, and the states. The investment represents a significant part of U.S. spending on earth science. Oceanographic fleets are operated by various government agencies and different arms of the same agencies, as well as the academic institutions, often in a semi-competitive mode. Sustenance of this infrastructure has not been a serious issue in the past. But proposals to spend $1 billion to rehabilitate the NOAA fleet, to maintain an at-sea capability in the Navy, EPA, and so on, and to provide large seagoing vessels to all the science institutions that historically have operated them will outstrip the available resources.

Spacecraft have become a major method for conduct of marine science. Any research mission costs a minimum of about $100 million, and many cost far more. In the United States, spacecraft have been a monopoly of NASA. Decisions made about flying specific missions obviously affect the health of the field as a whole. Where should the debate about the appropriate mix of spacecraft take place? Shouldn't the debate involve the entire community?

What is the role of the large oceanographic institutions in the emerging era? Is it to retain mainly their focus on individual-driven science? Which institutions should develop the capability for carrying out large, complex, evolving, long-lived observational and modeling programs that climate-related problems appear to require? Should this responsibility be lodged in the federal government, perhaps in transformed weapons laboratories? If so, where will their expertise come from and how will scientific responsibility be maintained? Or should our large academic laboratories move to take that role? If the latter, how does one arrange stable funding, and can it be reconciled with conventional academic reviews and their deep commitment to "small science"? Will the mission agencies have the foresight and the flexibility to sustain the funding for basic understanding by scientists in these organizations, although the payback is possibly many years in the future?

The many federal agencies have diverse and conflicting problems facing them. *Oceanography in the Next Decade* briefly outlines some of the special problems in a few government agencies. Among the examples is NOAA, which was created in response to the recommendations of the Stratton Commission of the late 1960s. Few observers would conclude that, weighed down with an array of political and bureaucratic baggage, it has ever been the effective agency envisioned by the commission. NASA has become fixated on enormous pieces of hardware (the shuttle, the space station, and the so-called Earth Observing System), and in recent years seems to have deliberately shed much of the marine expertise it had, even as spacecraft have emerged as central to the science. The Department of Energy is charged with the narrow problem of understanding the role of oceanic carbon in the climate system, but no one actually believes that such a problem can be studied in isolation from the rest of the science.

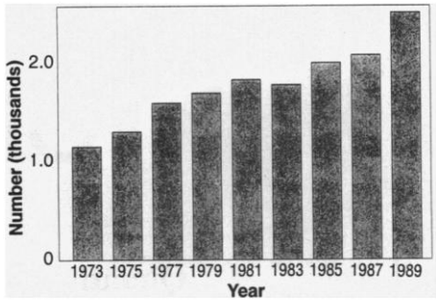

Fig. 2. Employment in ocean sciences (in broad definition) through time. [From NSF data]

There are obviously more questions than available answers. If we are truly entering an era of steady state or even declining support, what mix of federal, academic, and state laboratories is most sensible? How do we maintain the health of basic scientific research in the teeth of demands for short-term societally important answers? Should we maintain separate seagoing infrastructures for the nongovernmental and governmental sectors?

Existing mechanisms are inadequate to maintain the quality of the science that has hitherto been taken for granted. In the past, the general rising tide of federal funding could readily accommodate inefficiencies and irrationalities. Some mechanism for discussion, oversight, and the ability to act is required. None of the existing consortia or coordinating bodies is remotely adequate. Various federal coordinating committees do exist, but only sporadically function effectively—quickly lapsing into torpor—because in no single federal agency is marine science an important enough element to capture sustained attention at high levels.

Whatever new mechanism is found, it must be one that will permit rational discussion and allocation of resources across the multitude of agencies involved. The resources involved include people and their education; ships for scientific and regulatory purposes, inside and outside the government; spacecraft for long-term observations; investments in the technologies essential to progress in the science; and above all, the maintenance of the investment in basic understanding that will be the foundation on which the policy decisions of our successors will be based. Is the construction of such a mechanism beyond the imagination and powers of our scientists and the new Administration?

REFERENCES AND NOTES

1. *Oceanography in the Next Decade: Building New Partnerships* (National Academy Press, Washington, DC, 1992).
2. I have had useful comments from E. Frieman, W. Merrell, D. J. Baker, and M. Freilich. The opinions here are my own and are not necessarily shared by the members of the Ocean Studies Board or the National Research Council.