The Census of the Fishes: An Update 5 February 1999

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Background

In December 1996 the Board of Trustees of the Alfred P. Sloan Foundation endorsed two years of feasibility studies for a Census of the Fishes. The goal of the feasibility studies was been to explore whether the Foundation might catalyze a major new international observational program to assess and explain the diversity, abundance, and distribution of marine life, "The Census of the Fishes."

In practice observational strategies that will describe the fishes, in a strict taxonomic sense, will also see squids, jellies, turtles, and many other poorly described marine animal populations, and understanding the relations among these groups is key to understanding the diversity, distribution, and abundance of any of them. Thus, the scientific community has generally favored that the project be termed a Census of Marine Life. In this note I will retain use of the "Census of the Fishes," because it is a phrase stimulating a vision that the layperson immediately comprehends. The actual scope of the Census will of course best be determined by detailed consideration of priorities, strategies, and costs.

The premise for the exploration was that, because of the impermeability of water, the state of our knowledge of marine life remains substantially cruder than our knowledge of life on land. New technologies offer a chance for substantial improvement. For example, increased bandwidth in acoustical signal processing creates greatly increased potential for understanding the structure, shape, and motion of fish and schools of fish. The January 1997 Concept Paper which served as the point of departure for the feasibility studies outlines the premises more fully (http://phe.rockefeller.edu/fish).

The feasibility studies sought diverse expert views on three essential issues: a) the scientific and social value and motivations of a Census; b) its technical feasibility at a reasonable cost; and c) whether the diverse stakeholder communities, including marine researchers, commercial fishers, environmentalists, and government agencies, would support it. My comments below report first on value and motivations, second on technology, then on institutional aspects, and finally on some possible next steps.

Value and Motivations

Diverse motivations have converged on the value of a Census. I will illustrate with three: the chance for discoveries to complete our knowledge of the diversity of fishes, drastic reductions in commercially important fisheries, and finally the weak present ability to predict future changes, signaled in what I will call the mystery of the missing biomass.

Many of the world's leading icthyologists gathered at Scripps Institution of Oceanography in March of 1997 at a workshop to consider the knowledge of diversity of marine fishes. The meeting ranged over the world's oceans asking how many species were known to exist in each region and how many might remain to be discovered. Known species total about 15,000. The experts at the meeting concluded that about

5,000 remain to be discovered. The prospect of discovering 5,000 marine fishes is an exciting call to voyages of discovery in little explored regions of the Indian Ocean, along the deeper reaches of reefs, and in the mid-waters and great depths of the open oceans. Moreover, biodiversity now finds itself with an International Convention, but uncharted national obligations and resources. The Census could help draw the charts and build the understanding to allow international negotiations not only to keep government officials busy but also to serve marine Nature.

Changes in abundance and distribution add urgency to calls for scientific discovery. In August 1998 the Woods Hole Oceanographic Institution convened a workshop on the history of fished populations during recent centuries. From history, the assembled experts estimated that fish biomass in many intensively exploited fisheries (particularly demersal stocks such as cod) is about 1/10th the level pre-exploitation. That is, the fish in many seas such as the North Sea and Northwest Atlantic where commercial fisherman do their best (or worst) to make a living now weigh only 10% of the fish in those seas a few decades or hundred years ago. Diverse observations support this estimate. For example, the diaries of early European settlers describe marvelous fish sizes and abundance off New England in the 1600s. From Scotland to Japan, commercial records document enormous catches with simple equipment during many centuries. Even now, when fishers discover and begin fishing new places, they record easy and abundant catches, for example, of orange roughy on Pacific sea mounts. Also scientific surveys of fish stocks indicate fewer and fewer spawning fish, mothers, compared to recruits, their offspring. The ratio of spawners to recruits has fallen to 20% and even 5% of its level when surveys began.

This missing biomass creates a mystery. The mystery resides in the bookeeping models researchers have built to describe energy flows through marine food webs, from the microbes, to phytoplankton and seaweeds, to the herbivores, and then the several levels of carnivores that can prey on the herbivores and each other. Classically, marine biologists estimate five such trophic levels from primary production to fish. However, for the intermediate and higher trophic levels, we have relatively little quantitative information about biomass and production and indeed disagreement about the definitions of the levels. The result is ecosystem models precariously balanced to fit what data we have today. However, if the upper trophic levels once stored much more biomass, as suggested a moment ago, then either primary production was also higher or patterns of energy flows across levels have changed considerably. Required changes in primary production surely occur over geological time but seem unlikely within a few centuries. Fish might then have played a much larger role in the structure and functioning of the ecosystem than generally believed. To solve the mystery and have models that might reliably predict more than marginal changes, we need additional observations of the age and size composition of exploited stocks and on the species composition of affected systems.

The 5000 conjectured fishes, the estimated loss of 90% of many commercially important stocks, and the problem the missing biomass makes for our models indicate the sketchy nature of what is known, how much is unknown about marine animal populations, and the timeliness of learning more. Worried by climate change and the ocean's capacity to absorb atmospheric carbon dioxide, ocean research during the last two decades has tended to assess life in the oceans in gigatons of carbon. Yet, we care very much what forms the carbon takes. Because the upper trophic levels have been rather neglected, the initial focus of the Marine Census might be on these levels, although the decadal goals of the Census could embrace more.

Technology

Here I quote from a statement prepared by experts associated with the International Council for the Exploration of the Seas (ICES), an intergovernmental group concerned with Atlantic fisheries:

> There is absolutely no doubt that much existing acoustic and optical technology has yet to be developed and deployed in the fisheries and ecosystem field, and the challenge of describing and estimating open-ocean populations could be the necessary stimulus for huge developments.... Suggestions include the use of lidar to detect pelagic fish from aircraft, PIV and sheet laser methods, acoustic tomography; long-range, low frequency back-and forward-scattering sensor systems; horizontal multi-frequency sonars operating in a variety of propagation modes (e.g., convergence zone or bottom bounce); and multi-beam acoustics. The relatively new field of 'acoustic daylight' may be relevant. Ultra-high resolution, sub-meter spatial scale measurement sensors exist for non-fisheries uses and may be applicable in the water column and for the benthos. Doppler-effect systems are under-utilized. Side-scan sonar technology exists over a wide range of acoustical frequencies but is not yet widely used in fisheries or plankton work. An entire subset of underwater acoustics, signal processing and code-design has been largely ignored in traditional fisheries applications. The entire field of passive acoustics is under-utilized for species that generate noise (e.g.reef fishes, croaker, and marine mammals). Methods developed two decades ago, such as size estimation via swimbladder resonance and Doppler measurement should be re-evaluated in the light of advances in computing power which may make them more cost effective. Bistatic and multi-static methods, as well as absorption and forward scattering acoustical methods are under-utilised.
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> The above list is only a sample of what could be discussed, and it makes no reference to the equally fertile fields of bio-optics or electromagnetics, nor does it address modern data processing and synthesis methods (e.g., Bayesian network theory, neural nets, relational data bases, and data mining approaches). Neither does it contain multi-disciplinary approaches that would combine two or more sensor or data-processing/synthesis technologies to achieve better measurement resolution, accuracy, or the advantages predicted for sensor 'nesting'.
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> Significant advantages could come from simply modifying the mode of deployment of existing sensors using for example open-ocean moorings, bottom-mounted moorings, constant depth or yo-yo'ed towed sensors, neutrally-buoyant floats, drifters, single-ship/multi-ship bases for AUV's and ROV's, and air-deployment. Many such approaches, already available or in development, could become practicable due to improved two-way communications, or due to cost savings if instrumentation were to be deployed in significant numbers.

Along with this list molecular and chemical as well as tagging techniques have places as well. Like many fields of activity favored by miniaturization of electronics and reductions in power demand, tagging is undergoing a revolution. Animals are brilliant, hungry and thus motivated samplers of their environments and may provide efficient and cheap pictures of the distribution of marine life that could both guide and check other approaches. The benefits of all technologies soar if integrated. For example, acoustics, optics, and molecular and chemical methods can combine in several ways to enable reliable remote identification of species.

Scientific Questions, Outcomes, and Cost

During 1997-1998, we vetted the idea of a Marine Census in a series of nine scientific workshops as well as other consultations with the broad range of concerned constituencies. About three hundred experts from about 20 countries and dozens of different universities and research institutions have now seriously participated in the discussions. The workshops addressed:

1) State of knowledge of diversity of fish populations (Scripps Institution of Oceanography)
2) State of knowledge of diversity, distribution, and abundance of marine animals beside fish (non-fish nekton, such as squids, jellies, and turtles)(New England Aquarium)
3) State of knowledge of diversity, distribution, and abundance of marine animals in the deep ocean (benthos) (Institute for Marine & Coastal Sciences, Rutgers)
4) Technologies for assessing fish populations (Scripps Institution of Oceanography)
5) Tagging of marine animals as a way to assess populations (New England Aquarium and Marine Technology Society)
6) State of the art for the remote identification of species, without capturing them (Monterey Bay Aquarium Research Institute & University of Washington)
7) History of fish populations since human predation became large (Woods Hole Oceanographic Institution)
8) Overall goals and feasibility of a census of marine life (US National Research Council at Monterey Bay Aquarium)
9) Overall goals and feasibility of a census of marine life, emphasizing European perspectives (Southampton Oceanography Centre [SOC] and International Council for the Exploration of the Seas [ICES])

Our emphasis has been to encourage conversation and debate rather than the creation of documents. However, notes or reports are available from these meetings. The reports from both of the meetings assessing the overall value of a Census, the NRC and SOC/ICES meetings, which included scientists with notably diverse expertise and associations, endorsed it while considerably contributing to its definition.

The workhops and consultations have suggested that three questions encapsulate the Census. What *did* live in the oceans? What *does* live in the oceans? What *will* live in the oceans? A program to answer these questions would therefore have 3 components.

The first, paleo component would reconstruct as best possible the history of marine animal populations for, say, the past 500 years, since human predation became important. Addressing this question requires relatively inexpensive collection and integration of records as well as some new studies of marine sediments and other sources of traces of populations.

The second component, addressing what now lives in the oceans, would require an intense and costly observational program, likely to peak around the year 2004. The expensive part of the program would be new and greatly enhanced observations lasting 1-2 years, perhaps around 2004, to go out and look at what lives in the oceans. We would have voyages of discovery to the many parts of the oceans where the biology has hardly been glimpsed, for example, the open oceans and mid-waters, as well as strengthened efforts by national fisheries agencies that struggle with meager funds, personnel, and equipment to examine near shore areas for species of commercial importance. As a maximalist, I would hope to see beautiful integration and synchronization of technologies, platforms, and approaches.

Prediction requires modeling, so addressing what will live in the oceans will involve support of modeling of marine ecosystems that would use the new data collected as well as the historic data. A component to develop ecosystem and other models that would make use of the new data to explain and predict changes in populations and relations among them would probably cost little.

A major outcome of the program would be an on-line three-dimensional geographical information system which would enable researchers or resource managers anywhere to click on a volume of water and bring up data on living marine resources reported in that area. Importantly, the observational system put in place for scientific purposes could serve as the prototype for a continuing diagnostic system observing living marine resources, consistent with wishes for an operational Global Ocean Observing System. Obviously, the long run goal of the Census is not one snapshot but establishing cost-effective strategies for a periodic Census.

A proper worldwide Census might cost a total of $1 billion over ten years. Typically, US sources have paid about half the costs of international programs comparable to the Census. Because worldwide marine research now totals about $1 billion/year, the Census would lift resources for marine research by about 10% over the life of the program, if the expenditure is "new money."

Institutional developments

The Marine Census is necessarily international. We have held consultations with the key international organizations, both intergovernmental and nongovernmental. These include

--Fisheries Department of the UN Food & Agriculture Organization (FAO, Rome)
--Intergovernmental Oceanographic Commission (IOC, Paris) of the UN
--International Council for the Exploration of the Seas (ICES), which associates all the marine nations of the North Atlantic

--Scientific Committee on Oceanographic Research (SCOR) of the International Council of Science (ICSU, Paris)
--Diversitas, a joint intergovernmental-nongovernmental entity created to foster studies of biodiversity (Paris)
--World Wildlife Fund/International Union for the Conservation of Nature (Washington)
--Agencies for fisheries and for marine science of the European Union (Brussels)

The international reception has been good, although we have sought no commitments, other than from ICES, which has already formed a group to work with the Census and designated a leading scientist as liaison. Ultimately, international support stems from support by influential individuals and national institutions within their own countries. Scientists in several European nations, including Norway, UK, and Portugal, have taken an especially strong interest. A Norwegian newspaper featured a well-informed article about the Census.

Within the US, we naturally have sought an especially broad spectrum of views. These have included meetings and conversations with the US commercial fishing industry, organized by Ocean Trust, and with environmental activists and advocacy groups, organized by the Environmental Defense Fund. Both industry and environmental groups have proven friendly to the Census, although expressing symmetrical concerns. Fishers worry that more information will produce more regulation; environmentalists worry that discoveries of new fish stocks will bring overfishing before protective management regimes can be implemented. Environmentalists have also advised on ways the Census might conducted be so as to minimize disturbance to the animals and marine habitat. With the assistance of the National Fisheries Conservation Center, we have also surveyed the expressed priorities of the US regional Fisheries Management Councils, which represent diverse sectors of society and influence allocations of rights to fish in US waters.

We have also consulted with the other private US foundations most active in marine affairs, and several have verbally expressed willingness to join with Sloan in the Census. We have not yet sought their formal participation. We have also had some early discussions with corporations that make the types of equipment that a Census would require.

Encouraged by the interest and support from the various expert and stakeholder groups, during 1998 we increased our consultations with the US government. We visited with officials at a range of levels in the key federal agencies concerned with marine science and fisheries, especially the Navy (and its Office of Naval Research), National Oceanic and Atmospheric Administration (NOAA, in the Department of Commerce), and the National Science Foundation. We also visited some of the government laboratories most deeply involved in the relevant science.

The Navy, NOAA, and NSF and other "ocean agencies" of the Federal Government (Department of Energy, Coast Guard, Defense Advanced Research Projects Agency, National Aeronautics and Space Administration, Environmental Protection

Agency, Geological Survey, Minerals Management Service, Office of Science and Technology Policy, and Office of Management and Budget) cooperate through the legislated National Ocean Partnership Program (NOPP). One of the goals of NOPP is to strengthen oceanographic efforts by identifying and carrying out partnerships among federal agencies, academia, industry, and others in the ocean science community. We have met with NOPP to share what we have learned and to gain their perspectives.

The secretariat for NOPP is provided by the Consortium for Oceanographic Research & Education (CORE). Fifty-three U.S. oceanographic research institutions, universities, laboratories, and aquaria representing the nucleus of U.S. research and education in the ocean belong to CORE, whose offices are in Washington DC. CORE seeks to facilitate the formulation of goals, policies, and objectives and provide advice and management for educational and research programs and facilities in oceanography and related fields. We have met with the officers of CORE, and CORE has reported to its members about the Sloan feasibility studies.

Next steps

1) Preparation of a brief (20-30 page) written document outlining the Census. Such a document will draw heavily on the ideas and documents already generated (such as the Alldredge report from the NRC Monterey meeting) and should be completed in the spring of 1999. We also want to make readily available, perhaps through a website, the workshop reports and other documents connected to the feasibility studies. These and other relevant literature would contribute significantly toward a much more detailed proposal of goals and plan for the Census, which the scientific community might prepare during the next year or so.

2) Extending involvement in the discussions to experts and regions which may have been underrepresented so far. While scientists from, for example, Japan and Australia have participated in meetings, we need to stimulate more discussion with experts from these countries and more generally with experts in Pacific and developing nations. We will seek to do this in 1999.

3) Exploring and building international arrangements. The question of which international mechanisms for cooperation might work most effectively looms large in 1999. Mechanisms will be needed to coordinate the potential funders (national governmental agencies for science and for the oceans, the EU, perhaps the World Bank), the performers of the Census (oceanographic research institutions and others), and its overall planning (probably by an international scientific advisory committee). Programs including the International Geosphere-Biosphere Program and the Deep Sea Drilling Program offer precedents. Success usually requires high-level political support, for example, through the science advisors to heads of government. We will begin to explore the form international arrangements might take and how best to achieve them.

4) Exploring and building US arrangements. Once again mechanisms will be needed to coordinate both funders and performers. Priority attaches to direct, formal cooperation

with US government agencies and other entities that would ultimately need to bear the major costs of the Census in the gradual process of the detailed design and specification of the program. NOPP might provide a crucial US mechanism through which to advance the funding of the Census. We are exploring with NOPP whether it might consider inviting Sloan and other partners interested in funding the Census to join NOPP in 1999 to coordinate decisions in this regard. In this scenario, NOPP (including Sloan) might issue requests for proposals addressing key needs of the Census. We also look forward to exploring with the US community whether CORE or another organization might appropriately host a scientific steering committee and a small professional secretariat to advance the Census generally.

5) Substantive development. Some research to make the Census possible need not await plans. Areas might include alternative sampling and observational strategies; instrument development; data management frameworks; ecosystem modeling to refine hypotheses; historical reference studies; and pilot or demonstration projects.

6) Outreach. During the past two years we maintained a generally low profile for the Census feasibility studies. A higher profile might be beneficial in 1999, to gain public and political views and support. Outreach might involve projects with the media (video, radio, internet, print) as well as Congressional (or parliamentary) hearings.

In December of 1998 the Sloan Foundation's Board endorsed that we move from assessing the feasibility of a Census to trying to make a Census happen. During 1999 the Foundation expects to make grants along the lines outlined to help create the most favorable chances for the Census or address particular early needs or questions in a timely fashion.

Conclusion

The adventures of discovery of Cook, Darwin, and the explorers of Linnaeus' century are open to our generation. The urgency to cope with changes in abundance of fish amplifies the adventure of discovery. In any case, anecdotes, affection for nature, and the plight of fishers on the beach will impel nations to spend and prohibit. The first ever proper worldwide Census of the Fishes can first guide and then strengthen the actions so they will produce the hoped for conservation and restoration unalloyed by disillusionment or failure.