Draft 20 January 1997

The Census of the Fishes: Initial Thoughts

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Purpose:
To explore the value, timeliness, and feasibility of stimulating, designing, and organizing a period of intense, comprehensive oceanic observation whose purpose would be to assess and explain the global distribution and abundance of marine life.

Sea life holds great interest for the public in the USA and around the world. Aquariums and exhibitions on marine life in natural history museums draw many millions of visitors. Shark shows are the most highly rated science and nature programs on American television. Along with clean coastal waters and beaches, life is the main reason for popular interest in the oceans. The fascination with the travels of Chessie the manatee along the East Coast of the United States during the summer of '95 and the growing numbers of whale-watchers affirm this truth. The oceans, like the heavens, offer a preferred route to increasing public understanding of the world in which we live, and of science.

Fish also provide humans about 25 million tons of protein annually, about the same as beef or half the protein we raise in rice or corn.

Remarkably, in 1997 we do not know how many fish are in the sea.

Fundamentally, the reason that knowledge of marine life remains crude is the impermeability of water. But, at a reasonable cost, new technologies may now offer a chance for substantial improvement. For example, increased bandwidth in acoustical signal processing greatly increases the potential for understanding the structure, shape, motion, and distribution of fish.

One may of course ask, do we need a reliable answer to the question of the number of fish in the sea? I believe the answer is yes. The lack of a good answer neatly summarizes major gaps in marine knowledge. Among the gaps in understanding are the interplay among nutrients, fishing, and species; the magnitude and nature of fisheries beyond the edge of the continental shelves; and the the diversity of ocean life. We also face big gaps in understanding of the power and mechanics of the ocean's "biological pump," which transfers carbon from the atmosphere into the deep ocean, lowering atmospheric concentrations of the main greenhouse gas, carbon dioxide. Knowledge of the abundance and distribution of fishes, or more formally, the higher trophic levels[1] of marine animals, would greatly help to balance the accounts of the materials and energy that flow through oceanic food webs.

Recent observational surprises further confirm the potential value of an extensive Census. For example, reports from the Arabian Sea now unexpectedly suggest annual production of fish at middle depths of several million tons, associated with offshore extensions of upwelling regions, and in the mid-Pacific, unexpectedly large volumes of jellyfish have been observed.

Urgency attaches to the Census because of fears of the widespread destruction of fish populations. Based on a very few, very general assumptions, Ryther (1969) calculated the total annual world fish production. He took estimates of primary production of biomass for the different major sectors of the oceans and multiplied these by the "ecological efficiency" of conversion for the number of trophic levels in each sector and combined the results to obtain an annual bottom line of 240 million tons. Ryther said humans must share this total with marine mammals and sea birds and so estimated a maximum fisheries yield of about 100 millions tons per year, close to the present world take.

So, the value of the knowledge—for its inherent interest, for wiser regulation, and for understanding and scientific testing of hypotheses to come--that would culminate in a sound sum motivates consideration of a serious Census of the Fishes. Analogously, the value of the decennial census undertaken in the US and many other nations does not reside so much in learning the total population as in understanding its components and their distribution, and in creating a database useful for many detailed analyses, anticipated or not.

In the late 1960s and early 1970s the Food and Agriculture Organization (FAO) of the UN did seek to inventory the "fish resources of the oceans." Then and now, serious problems mar fisheries statistics. Fishers tend to underreport catches, and commercial activity addresses fished stocks, rather than fish stocks. "By-catch" data are used to fill in estimates of some other species. Governments in most countries have weak means to verify or adjust the numbers they receive.

Only a few governments regularly send out research vessels to make direct scientific measurements for assessments of stocks. The ships basically trawl nets in a few locations and count what they catch. The agencies that carry out such surveys, such as the US National Oceanic and Atmospheric Administration, have little funding for these purposes. They sample a tiny fraction of the sea, mostly near shore and at a very limited selection of depths. Mesh size matters greatly, as do statistical sampling strategies.

[1] A trophic level is one of the hierarchical strata of a food web characterized by organisms which are the same number of steps removed from primary producers. It is generally believed that open oceans have 5 trophic levels, coastal areas 3, and upwelling areas 1.5.

In turn, little is known about the validity of the mathematical models used to turn the available data into widespread assessments of stocks. Moreover, the goal of the assessments of fish stocks in many cases is to construct an index of abundance, rather than an absolute Census.

So, the fact is that no serious inventory of marine life has ever been made. Piecemeal, examinations have been made in a few regions, such as the North Sea and the California Current. In total, biological surveys have scanned perhaps 5 percent (and maybe much less) of the world's oceans. The major scientific discoveries of the past two decades about animals in the deep ocean and in the ocean bottom come from only a dozen or so sites. Little effort has been directed at the open oceans. Data even on the seasonal cycle for ocean biomass are lacking.

Bringing to bear the state of the art in physics, engineering, statistics, and other relevant fields, a program to Census the Fishes might greatly expand the space and time windows for monitoring the biology of the oceans. The needs are completeness, continuity, and comparability.

The Census might proceed along the following lines:

Beginning at the beginning, interested parties—scientific, governmental, commercial—should phrase several questions the Census should answer. Then, proceeding to hypothesis, scientific groups might be invited, based on current theories, to predict the distribution and abundance of marine life in all marine regions. These estimates would form testable hypotheses for the program. Importantly, each estimate would make explicit the present ideas about food webs, trophic levels, the roles of environmental factors, human predation, and other factors explaining population sizes and distributions.

Based on the predictions, a few regions might then be selected for an intensive, prototype observational program. One might argue for a region, such as the North Atlantic, relatively well-studied and surrounded by nations with marine scientific resources. Alternatively, it might be attractive to observe a region more likely to elicit surprises and new information. In either case, the question would be to match prediction and observation. If the observations affirm the reliability of our present theory and knowledge, the Census might be terminated. If the results differ, then the logic strengthens to proceed, and to complete the effort globally, with appropriately revised hypotheses. This may be a parsimonious way to achieve a global effort, without ever fully implementing a massive global observational system all operational at the same time.

Still, at an early time the question might be asked, "Given infinite resources, what observational system for marine life should be implemented?" One reason to undertake the program in the near future is the progress achieved in acoustic and optical technologies that can observe marine animals. Every fish is basically a submarine, with a distinctive shape and acoustic signature. With the end of the Cold War, technologies developed for looking for mechanical submarines are now becoming available for other purposes, at lessening cost. The trawling of nets could never achieve the coverage that new computerized techniques might. (Although computers cannot count what comes up in a net, but they can be trained to count acoustic signatures.)

Although surely not practical to descend far in trophic levels, the ultimate goal for science (or natural history) would be an *all taxa marine biological inventory*, including not only fish, but marine mammals, cephalopods (squid), euphausids (krill), molluscs and crustaceans, and selected plankton. Discoveries in all these areas might be exciting. For example, experts conjecture that one quintillian copapods (10^{18}) live in the seas, making them the second most abundant species after round worms. According to current estimates perhaps 90 percent of marine biomass resides in zooplankton and phytoplankton. Sound assessments of the fishes will clearly require increased understanding of non-fish marine life as well as information on temperature, salinity, light, and other environmental factors.

Although censusing a small number of relatively large objects rather than a large number of very small ones seems appealing, the challenges for the sampling program will still be hard. Problems persist, for example, in acoustic surveys of mid-water fishes because of dense acoustic layers that fluctuate diurnally. Moreover, acoustic signal strength is species as well as size dependent. And the higher trophic levels are unevenly (patchily) distributed: a ton of whale is much more concentrated and localized than a ton of plankton. Interannual variability could be high. The question of the technical feasibility of the Census must be faced early.

Precedents exist for large-scale observational programs in physical oceanography (WOCE, addressing world ocean circulation; TOPEX, addressing the surface topography of the oceans). The "GEOSECS" program greatly extended measurements of the chemistry of the oceans. The global ocean ecosystem dynamics (GLOBEC) program is currently addressing some fish and zooplankton biomass issues in the context of global climate change, while the Joint Global Ocean Flux Study (JGOFS) is considering carbon cycling in the oceans. Proposals exist for a Global Ocean Observing Systems (GOOS) which would include attention to living resources. Lessons might also come from the Global Atmospheric Research Program (GARP) of the 1970s, which culminated in a Global Weather Experiment. GARP for the first time sustained a comprehensive observational system of Earth's atmosphere. The GARP data sets continued to be fruitfully analyzed for many years, and demonstrated the feasibility of improved weather forecasting in the 3-10 day range.

The Census would require support and participation of many groups inside and outside of science, including navies (concerned about opacity), government agencies concerned with fisheries and with research, commercial and recreational fishers (who might fear increased regulation), environmental groups (who might fear that newly discovered stocks would be destroyed), and international organizations, both non-governmental and intergovernmental (such as ICSU/SCOR, ICES, PICES, UNESCO/IOC, and FAO).

Conclusion

Overall, the time appears ripe to consider a much better mapping of the biogeography of the oceans, including species composition and time history, in short, a Census of the Fishes. Such a Census might yield not only greatly increased public and scientific understanding of the oceans but also information useful for management of fisheries, marine pollution, and other ecological concerns.

To proceed, the numerous concerned parties must evaluate a) the possible purposes of a Census of the Fishes, including its scientific and societal benefits; b) how the Census might be conducted, and its general strategies; c) the costs and level of effort entailed; d) and whether the wish and will exist to do it.

Comments on all aspects are welcome.

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