Note

On the Limits to Knowledge of Future Marine Biodiversity[1]

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Repetition has power, like the refrain of a song. Repetition emphasizes and makes things stick. US Congressman John Brademas liked to say when he presided over hearings in Washington DC, "Everything has been said, but not everyone has had a chance to say it." Nearly everyone has heard about the woes of the oceans in recent years. Many events and reports have lifted awareness of the challenges, for example, for conservation of life on seamounts. My premise is not repetition. Rather, I hope to improve our forecasts, their scope, detail, and likelihood or humility. Prediction is after all the true test of science.

One of the main strategies for winning improvements is by exploring the limits to our knowledge, that is, by asking what we know and why, what we could quite readily know, and what may be unknowable or very hard to learn.

We tend to fill conferences, magazines, and airwaves with what we know. We much less often explore and disclose the limits to our knowledge. Few experts like or bother to write *terra incognita* on their maps. Yet, disclosing the limits to our knowledge is often among the most useful of acts. Such disclosure helps people choose where to explore, and it helps people to hedge their bets. In this spirit, I will offer some generic comments and illustrations about the known, unknown, and unknowable and how they might bear on the disciplines and forms of expertise caring about marine biodiversity.

Scaling and simplification

Paramount challenges in ecology, oceanography, and meteorology involve scaling and simplification. System dynamics involve interactions among processes acting on diverse scales of space, time, and organizational complexity. To what extent in marine ecology do we have ways to scale from small to large and back? Can we represent the dynamics of aggregates, for example, in terms of the statistical dynamics of populations of individual agents or units? A famous expression questions how much knowing about a tree tells about the forest and vice versa. What about a fish and a school, or a small eddy and a large gyre? One might ask analogous questions about individuals, households, and larger human societies who consume seafood products. Does knowing the attitudes about the ocean in detail of a Malibu resident help predict the actions of California?

As analysts and modelers, we must hope that not every detail of interaction, space, and time matters to "know" important behavior. Otherwise, many behaviors, both macroscopic and microscopic, appear unknowable. At the microscopic scale, the multiplicity and complexity of interactions can make detailed knowledge impossible. What do we understand in marine biology about how to define, identify, and suppress irrelevant detail? Need we study life in every bay to understand life in every bay?

Indeed, how confident are we that we have selected the variables that determine behavior and outcomes in the marine realm? We love temperature in these days of global warming but dare we omit ocean acidity or ocean noise? Marine microbes, though they weigh 90% of ocean biomass, were rarely recognized until recently and may be perilously omitted from analyses.

Also, at all scales, unknowable or at least stochastic perturbations such as tsunamis hit systems. Can we characterize the relevant perturbations probabilistically? And what can we know about whether systems are sufficiently adaptive to absorb these influences and thus survive in roughly similar form?

At a more theoretical level, what we see or live with may reflect the capricious influence of historical events that cause bifurcations and thus represent but one realization of stochastic processes that admit many possibilities. A debated example is whether the genetic code is the only code possible in some broad sense. But are some regimes of marine life also ecosystems that just happened because of some bifurcation? If we believe such situations common, then are future ecosystems largely unknowable, especially as humans introduce more perturbations?

The antipode of simplicity is complexity, which may require modeling several sets of non-uniform interactions at once. To what extent could we be right about the whole even if unsure about some of the parts? Or if investment aims primarily at great detail about a few parts? A practical question concerns the implementation of a financially sustainable ocean observing system by, say 2020, that would usefully monitor marine biodiversity at several scales. Can we estimate how much a few expensive fixed sea floor observatories may contribute to broader synopses?

Data limitations

Models without data are empty balloons, and a related second, large set of urgent questions involve the volume of data and its limits. The single word technology establishes the most fundamental point. Humans need prosthetic devices to see, sniff, and feel the deep, the dark, the tiny, the swift, the shape-changing. Or to capture it. Our forecast of technology will determine much of what we might know as well as much of what might survive. Suppose we could, this year, instantaneously and continuously see from one or two ships the fish in the water over 100,000 square kilometers of continental shelf?

Snapshots of the ocean, even great synoptic gulps, hint at a different limit to knowledge. In some fields, including parts of biology and physics, data come from controlled experiments, allowing close matching between theory and experimental results. Experimental design is, of course, subject to a multitude of biases that may limit knowledge. At least as important is that in many fields, including oceanography, macroevolution and many social sciences, controlled experiments are impossible. Facts obtainable represent samples of what we would like to know in ways whose biases themselves may be hard to know.

For marine questions our data are themselves very patchy. This fact turns into limits to vex analysts. For example, how do analysts avoid in-sample over-fitting? Split-sample analysis helps but is far from a universal solution. A variety of recent work in groups such as that of the late Ransom Myers has investigated these issues, incorporating bootstrap and other re-sampling methods, shrinkage estimation, and explicit consideration of the estimation efficiency loss from split-sample analyses.[2] How do we acquire information from unknown structures?

The emerging geographical information system for ocean life, the Ocean Biogeographical Information System (OBIS, *www.iobis.org*), offers a powerful instance of the bias of present observations. While a vertical distribution of an OBIS sample of about four million spatially referenced data of ocean life shows that most observations come from near the surface, most of the habitat lies down below. Ninety percent of observations come from the top 100 meters and 99% from the top 1000 meters, while the average depth of the oceans is 4000 meters. The diversity, distribution, and abundance of life below a few tens of meters remain largely unknown or extrapolated from very sparse observations. Tantalizingly, the spare observations suggest an abyss teeming with diversity.

One reason to initiate the microbes-to-mammals, bottom-to-top, pole-to-pole, shore-to-mid-ocean Census of Marine Life (CoML, *www.coml.org*) was the high fraction of data about marine life relating to the 200 or so commercially most important seafood species. Frustratingly, experts engage in bloody fights about numbers even for the most observed species such as salmon and tuna. Shockingly, in 2002 the US National Oceanic and Atmospheric Administration (NOAA) concluded that existing data and life history information are too meager to provide useful assessments for more than 60 percent of the 900 or so regulated fish populations in US waters. (NOAA 2002). In 2006 a CoML researcher reported that about 230,000 species of animals have been identified in the oceans (Bouchet 2006). If records abound for only a few hundred, Status Unknown or Status Little Known honestly describes a long list. And some experts believe a million or more species of marine animals remain to be identified.

Other kinds of bias matter. Systems may be simply too large or long-lived to observe. Understanding the life history of animals that live for two hundred or even for fifty years challenges researchers whose careers last only about 40 years and their grants only two or three years.

Rarity also makes difficulties, whether in ecological or financial systems. If a tsunami happens only once every two hundred years, how can we calibrate its impact when the life it affects will anyway have been transformed by fishing, coastal development, and other factors?

Bias of a more obvious nature must also be confronted. For example, knowledge of classical history depends substantially on one man, Herodotus, and we do not know how additional accounts would change understanding of Greece, Persia, Babylon, and Egypt. Strongly socially constructed observations, accidental experiments, and spare historical record often form much of the known.

With regard to marine life, we seem to know predominantly about what we eat and trade. Much work lies ahead to provide reliable information on the rest, for which we need clever tricks from statistics and modeling. Otherwise, practical limits of cost of sampling will keep us forever ignorant.

Culture also excludes information. Western science, in large part a product of Catholic monasteries, excluded women until very recently. In turn, scholarship largely excluded study of the history or even the health of women. Some argue that male domination of science accounts for greater emphasis on competition than cooperation in ecological and evolutionary sciences as well.

Academia in the USA and most other places now excludes almost everyone who has not taken identical political orders. I survive in US academia because I am a registered Democrat who often votes Green. A survey of decades of studies of the politics of American professors shows that liberals persistently outnumber conservatives by 4:1 or more (Gross and Simmons 2007). The Academy has mastered cloning well ahead of Medicine. Science should thus not be surprised that we often easily write consensus environmental reports, nor should we be surprised that much of the rest of America and the world rejects or ignores them given the genetic poverty of our tribe. Almost all researchers concerned with marine biodiversity think basically alike in a broad cultural sense. If the time were 600 years ago, our "international conference" would have been a gathering of Benedictine monks from dozens of different monasteries, impressed by our pseudo-diversity because some of the monasteries were in Spain, some in Transylvania, and some in Bavaria. How can we recognize our own profound and pervasive biases and access the knowledge of those whose cultures or frames of reference we reject?

Marine and ecological scientists must take care about rejecting the knowledge of those outside our monasteries and about ignoring uncomfortable facts. Karl Marx wrote about the plight of Silesian weavers but never talked to a weaver of any description nor visited Silesia. As far as we know, Marx never set foot in a mill, factory, or mine, nor talked to a peasant or landowner. Some of what he failed to understand was knowable, if only he made the effort to observe, but his belief system, like the codes of the biblical book of Leviticus, rejected all abominations, as academic ecologists reject Bjorn Lomborg. A look at the fertilizer industry gives a smelly shock that the information authors in *Nature* and *Science* repeat over and over about growth of nitrogen use is simply wrong (Frink, Waggoner and Ausubel1999). The usual, alarming nitrogen projections are about as exaggerated as were the Pentagon estimates of the size of the Soviet economy. Marine biodiversity will benefit from open talk about the data we do or do not have, could or could not have, and the information we reject and exclude.

Behavior

Let me briefly mention a final area that limits knowledge and also responds to the limits, namely behavior. One of the hardest limits to knowledge is knowing what is in the mind of another. Probably nothing is more powerful than being inside the mind of the enemy. While nations, companies, and faculty engage in spying of various kinds, we outlaw torture and drugging.

Even if we could enter others' minds, we probably could not predict financial markets, which are the outcome of behaviors that may be fundamentally unknowable. Financial markets exemplify most obviously the difficulty of anticipating behavioral responses. Major tax reforms rarely have the expected outcomes. In the USA the well-intended Clean Air Act of 1970 and its concept of New Source Review perversely caused scores of filthy coal-burning power plants to operate to this day.

We need to recognize that humans are not infrequently perverse and criminal, that cheating students, plagiarizing professors, crooked corporations, and corrupt UN bureaucrats skimming money from oil-for-food programs are natural. Human nature includes a snake brain, and individually and collectively we are rarely rational. The limits to knowledge of economic and political institutions and the danger of the fallacies of rational expectations or rational behavior more broadly weigh heavily on marine biodiversity.

For example, no demographer has produced a model that successfully predicts fertility, so we do not know how many human mouths will seek food in 50 or even 30 years. Human health and disease of course also depend substantially on behavior. Trailer parks cause tornadoes, explained engineer Norman Augustine (1997). Petting zoos kill children by transmitting infections. Sushi kills, too, but only those who eat raw seafood (and even then only a tiny proportion). A profound summary of the famine and other suffering from the Sahel droughts of the early 1970s stated "Nature pleads not guilty" (Garcia

1981; but cf. Hellden 1991). Not only do humans not know how numerous we will be in future, nor do we know what diet we will follow or how we will expose ourselves to the oceans. Maybe, as for orthodox Jews, shellfish will be taboo for all people. Maybe, as in much of Europe during the 19th century, women will be forbidden to disrobe at the beach and lack the opportunity to swim in public.

We also should not count on the woes of the ocean earning consistent or top public attention. The 2005 release of the Millennium Ecosystem Assessment was almost entirely drowned by news of the sex life of Michael Jackson, a Papal funeral at which the Roman Emperor Constantine would have felt entirely comfortable, and the London wedding of Prince Charles and Camilla. Marine biodiversity needs to thrive within real limits of human interests.

Insurance

Many sectors in fact thrive in the face of irrational behavior and an unknowable future. Maybe fields like environmental management could learn strategy from fields like entertainment. If film producers understood behavior, every film would be a hit, while in practice most flop. The entertainment industry understands it needs to make a large portfolio of films, precisely because 90% fail.

Similarly, the insurance industry copes with limits to knowledge through understanding probability. The insurance industry even deals with so-called incomplete contracts. In some cases, a fixed sum is payable if an unknowable event happens, for example, for loss of valuables such as paintings where verifying value of destroyed items is hard. A more recent variation on the theme ties insurance payout to some objective index correlated with the dollar value of the loss. In so-called catastrophe bonds the index may be a parametric description of the event, such as the Richter-scale reading of an earthquake, or some economic index, such as insurance industry losses triggered by the event.

How well might fixed-sum or indexed contracts cover unknowable events in the marine realm? A key point is whether parties can find contract language to trigger a fixed-sum payment when the triggering event was unknowable *ex ante*. Maybe communities should begin seeking coverage for collapse of marine ecosystems. The point is insurance can cover both known and unknowable events. Obviously we want to lower the chance of collapse, but if we accept, like Jared Diamond (2005), that collapses happen, buying insurance makes sense, too.

Conclusion

I hope these comments about limits to knowledge with respect to scaling and simplification, data, and behavior, and possible insurance against the limits, stimulate some new thinking about marine biodiversity. Because the expert community concerned with marine life is quite homogeneous, the temptation simply to please each other with popular tunes is high. While our community may enjoy its social solidarity, our solidarity has protected few tuna so far. By defining candidly the limits to knowledge about future marine biodiversity, diverse actors may find more powerful ways to better the chances for marine biodiversity to flourish.

Notes

1. The essay was first drafted as the opening plenary talk for a Scripps Institution of Oceanography conference on the Future of Marine Biodiversity: the Known, Unknown, and Unknowable. 22 April 2005. http://www.coml.org/history/Limits%20of%20Knowledge%202005.pdf
2. Ransom A. Myers' work is available at *http://as01.ucis.dal.ca/ramweb/content.php?lang=en&i=4&sub=0*. See also Shao, J. 1995. *Mathematical Statistics.* New York: Springer.

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