# BRINGING LIFE TO OCEAN OBSERVATION

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## 1. Abstract

The Census of Marine Life (CoML)'s fourteen field projects have provided 20 million species/location references globally from the abyssal plains to the ocean surface. Some of the breakthrough technologies that make biodiversity monitoring possible now include DNA barcoding and microchips combined with standardized sampling techniques, upward looking and horizontal waveguide sonar techniques that view huge areas, use of animal-borne sensors to define oceanic habitats, and a combination of acoustic and satellite tracking techniques that allow us to reassemble species interactions in the open ocean to meet increasing demands for ecosystem based management of ocean resources. CoML's Ocean Biogeographic Information System (OBIS), which contains these records, has recently been accepted by the Intergovernmental Oceanographic Commission as a component of IODE, simplifying the process of linking biodiversity data with physical data on a global scale. OBIS contains records back a thousand years from the Oceans Past project and has been used to project scenarios forward in the Oceans Future project, so the feasibility of linking the physical and biological ocean is greatly enhanced. We focus on how best to implement these cross-over technologies.

## 2. Introduction

The over 2000 participants from over 80 countries involved in the Census of Marine Life (CoML) have invested some $750M during the first decade of the 21st century in compiling and distributing information about ocean biodiversity, identifying knowledge gaps and demonstrating new technologies for closing those gaps. This paper will attempt to summarize the achievements and conclusions from the last decade and will complement the Plenary Paper by John Gunn, which will focus on biological deliverables over the next decade. There are over a dozen Community White Papers that relate to this summary [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13] and many Additional Contributions that relate to higher trophic level biology that are only weakly represented among the Plenary Talks, so this whole paper could be filled with citations. What follows attempts to strike a balance between the scientific inputs and some societal benefits that have been to a large extent neglected in ocean observing to date. Routine observing of changing biological diversity in the global ocean is difficult, but not impossible, and is highly valued by society for both commercial and conservations reasons.

The CoML developed from the recognition that no country in the world had the capacity to meet its obligations under the Convention on Biological Diversity (CBD) to catalog marine species [14]. Recognizing that the CBD mandate would require continuing monitoring of diversity, CoML focused on the most economical, rapid and repeatable technologies for all of its Ocean Realm habitats and how best to include biodiversity measures in routine ocean observing systems. These same technologies have proved valuable for providing societal benefits in the GEO, GOOS context. CoML has shown by published examples the power of modern deep sea camera systems for identifying diversity [15], of tagging and tracking technologies for distribution [4,8] and of sonar systems for abundance. Advanced sonars can see shrimp 3km down [16] and wave-guide acoustics can count fish within a 100km circle [17]. Experimental concepts have become practical tools.

CoML brings its wealth of information on diversity, distribution and abundance of marine species to the Intergovernmental Oceanographic Commission (IOC) with the recent commitment for its Ocean Biogeographic Information System to become the diversity component of IODE. Many CoML projects already have ongoing commitments to provide regular ocean observations of biodiversity and habitat changes beyond the first census in 2010. The Nearshore projects have relatively simple, standardized protocols for repeated, rapid sampling of biodiversity using DNA barcodes and chip technology, for example, monitoring coral reef biodiversity using novel environmental gene sequencing for rapid enumeration. Coastal projects can monitor the movements of commercial and conservation species in near real time and link these to changing oceanographic conditions. These habitat data collected by sensors on animal platforms, particularly in the Ice Oceans are already being integrated into ocean models and providing ground truthing for satellite imagery by CoML and a suite of global projects using similar technology. Canada and a series of global partners are committed to support the Ocean Tracking Network spin-off project as a GOOS project through 2015. CoML's Open Ocean and Deep Sea projects have been and will continue to be major information contributors to policy development for seamount fisheries, mining, etc. under the FAO and Law of the Sea Convention. Society has difficulty recognizing the need for knowledge about these unseen places, but science does not. Techniques like high resolution upward-looking sonar have clear near real time monitoring potential even in the most difficult Mid-water Realm.

The plenary talk opened with these key questions:

1. What is an oceanic ecosystem?

2. How will global warming affect them?

3. Will biodiversity decline? Will production decline?

4. How much detail is needed to monitor biodiversity?

5. Can ecosystem based management differentiate climate effects from fishing effects?

## 3. Some Answers from Community White Papers

1. What is an oceanic ecosystem?

This question may seem naive because thousands of scientific articles have been written about ocean ecosystems, and the concept of Ecosystem-Based Management (EBM) of ocean resources is now widely accepted. However, CoML's gap analysis (Fig 1) of what we don't know about biodiversity in the ocean makes it clear that while some regions are well covered, others are sparse. The virtual absence of species records in the mid-waters between 1000 m depth and the benthos, means we really cannot claim to know the ecosystem of the largest volume of living space on the planet. Add to this the facts that new technologies are showing 100 times the diversity in microbial communities everywhere as anyone ever suggested before [18] and that the underestimation of the diversity

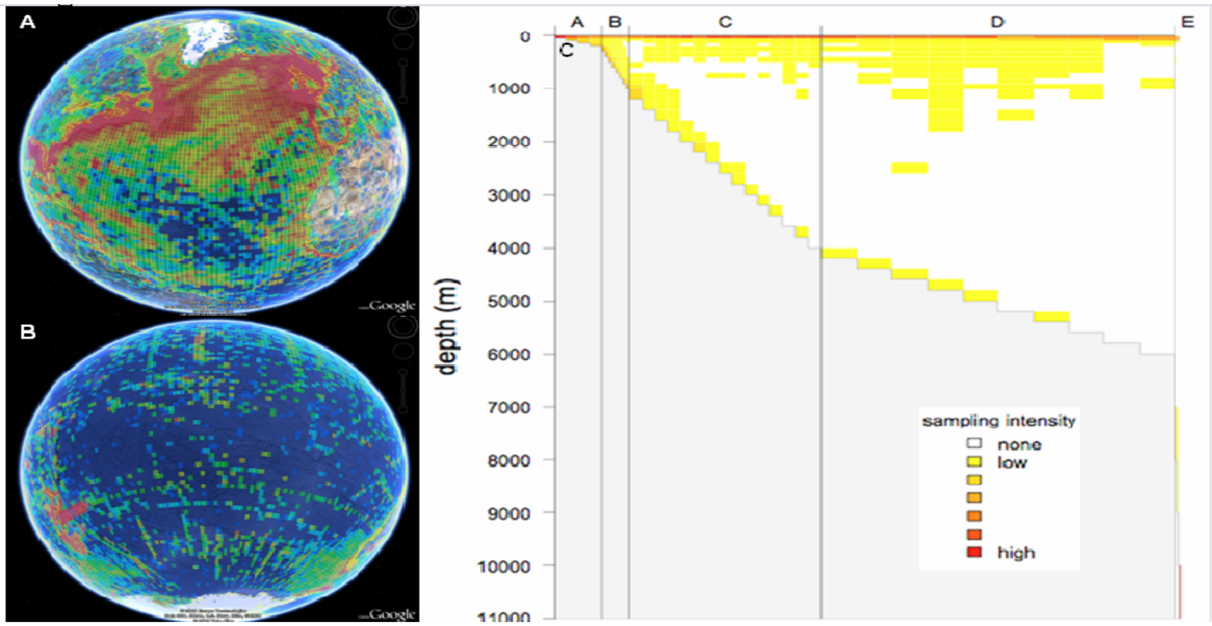


*Figure 1. Distribution of the 22,000,000 species records in the Ocean Biogeographic Information System. (A) North Atlantic biodiversity index by degree square – excellent coverage. (B) South Pacific – significant but sparse coverage. (C) Mid-water vertical coverage near zero between 1000m and the benthos. X-axis is proportional to the area at depth – A, 0-200m; B, 200-1000m; C, 1000-4000m; D, 4000-6000m; E, >6000m (T. Webb & E. Vanden Berge).*

of even something as common as marine snails is at least 10-fold [19], and we see the gaps widen. Beyond that, even large, well know things like mammals, birds, reptiles and fishes have amazed us with their mobility, with tagged individuals occupying whole ocean basins and even multiple basins [1,3,4,8,10]. This doesn't mean that we cannot talk meaningfully about regional shelf ecosystems, but it certainly makes it more complicated and requires that we keep both our minds and our ecosystems open. These mobile predators transfer energy between the known and the unknown habitats in complex four-dimensional matrices that will change with changing climate.

2. How will global warming affect them?

Continuous Plankton Recorder data indentified the northward translocation of warm water plankton communities in the North Atlantic for more than a decade ago [20] and recent studies [21] show clear impacts of this on chick survival in Svalbard where energy rich Arctic copepod species are being replaced by scrawny Boreal ones. Clearly, species matter. These are among the billion ($10^9$) tons of biomass that migrate vertically, daily in complex seasonally and temperature adjusted patterns throughout the oceans as illustrated in Fig 2. Predicting the combined effects of the interactions of species at five trophic levels, changing patterns and interacting in rapidly shifting vertical and horizontal planes would challenge several supercomputers, if we had the data to enter the initial conditions. We do not. Is this question in the realm of the unknowable? In part the answer is yes, but there are suggestions below for steps to move forward with a progression of approximations.

3. Will biodiversity decline? Will production decline?

Again, these are incredibly important but complex questions, and despite the consensus that they are linked, the causal links and specific mechanisms are unclear , including the direction of change. Part of the complexity relates to time course and part to geography. It may actually be easier to predict answers to these questions a hundred years out when the situation is hopefully stabilizing than ten years out when everything is still changing rapidly. As scientists we tend to think the answers in global terms, but most people are likely thinking of them in terms of their bay, their state or their nation.

The first guess would be that, overall, biodiversity will decline in the long term. We cannot predict the scale yet, but a major extinction event on the scale of those in the fossil record [22] cannot be ruled out. While many warm-water species can shift pole-ward, it is not clear where cold water species can go. Deeper is a possibility for some, but not for those that also need light. A huge factor will be the impact of acidification on the coral

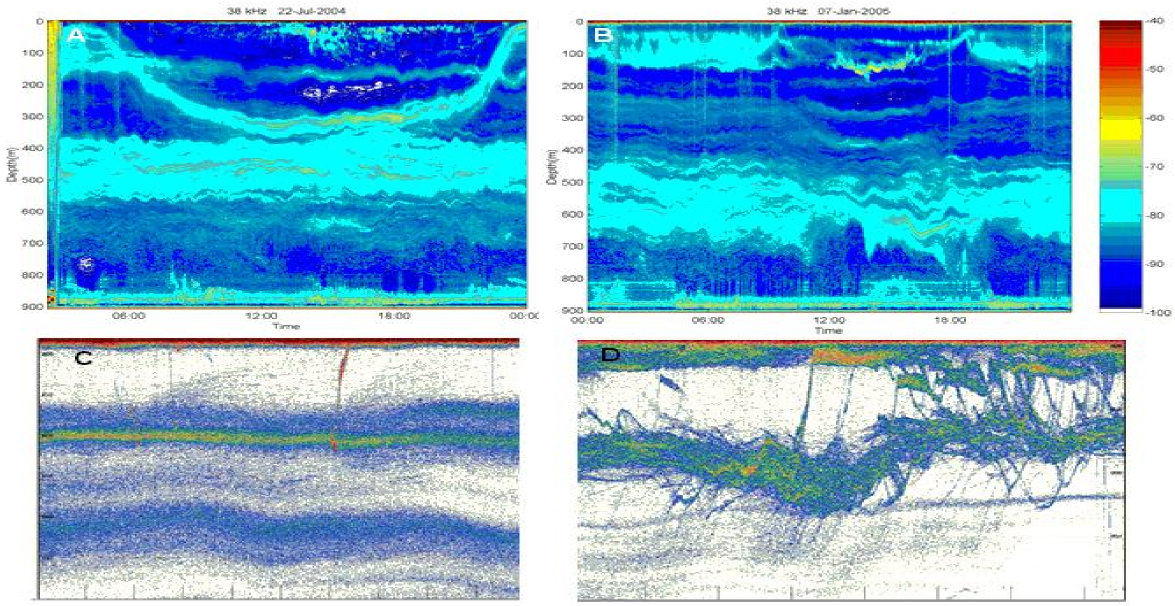


*Figure 2. Upward-looking Simrad sonar in the Charlie-Gibbs Fracture Zone on the Mid-Atlantic Ridge. (A) and (B): Dramatic reduction in diurnal plankton migration in winter versus summer. (C): 100m whale dives to feed, likely on squid, above an internal wave moving the whole plankton community. (D): Fish school breaking up at 50m and reforming near surface. Time bars 15 min., Data from CoML MAR-ECO project [36,37].*

reefs, which, like rain forests on land contain at least one third of the total diversity. We know that the synergistic effects of rising temperature and carbon dioxide levels will destroy many reefs globally, and there is no possibility that all of this biodiversity is duplicated or can be transferred naturally to other sites. Alex Rogers [12] recently proposed at the Copenhagen climate change meeting to stockpile frozen reef specimens and/or their DNA and relocate or restore these ecosystems later, but it is still too early to assume that this will be entirely successful. What is clear is that locally some mid-latitude regions will have increased biodiversity as tropical species invade while traditional species hang on.

The second guess would be that primary productivity might increase because of carbon dioxide available for photosynthesis, although the increased temperature over increased areas may have the opposite effect, decreasing productivity because of lowered solubility. Changes in the vertical mixing required to cycle other essential nutrients might make things worse. There is accumulating evidence for decreasing vertical mixing in the oceans, and it is clear from past episodes that stable, layered oceans are much less productive than mixed ones [22]. It remains hard to predict where this is going. It seems fairly clear that secondary productivity will decline at the highest trophic levels, i.e. the things we most like to eat, because increasing temperatures will increase energy consumption and biomass at this level depends on a long chain of events in time and space that allow little fish to grow into big fish by being in the right place at the right time. This could be thought of as an extension of the Cushing match-mismatch hypothesis [23]. Changes in productivity transfer through multiple trophic levels will be altered in both timing and location and these errors will accumulate at the highest level. Some intermediate trophic levels will likely increase production because they don't get eaten. At the moment jellyfish and cephalopods seem to be doing well, but that could change. Perhaps we need to develop recipe books for fishing down the food web [24]?

4. How much detail is needed to monitor biodiversity?

Ocean biodiversity involves over a quarter-million known eukaryote species globally and tens of thousands at most individual sites. Add to this tens of thousands of microbial "operational taxonomic units" per litre of sea water [18] and the complexity becomes quite unmanageable. We must use simplifying automated approaches and likely identify "sentinel" species or taxa that are representative of the full biodiversity. CoML has not yet done this in a comprehensive way, but several projects have taken great strides for particular

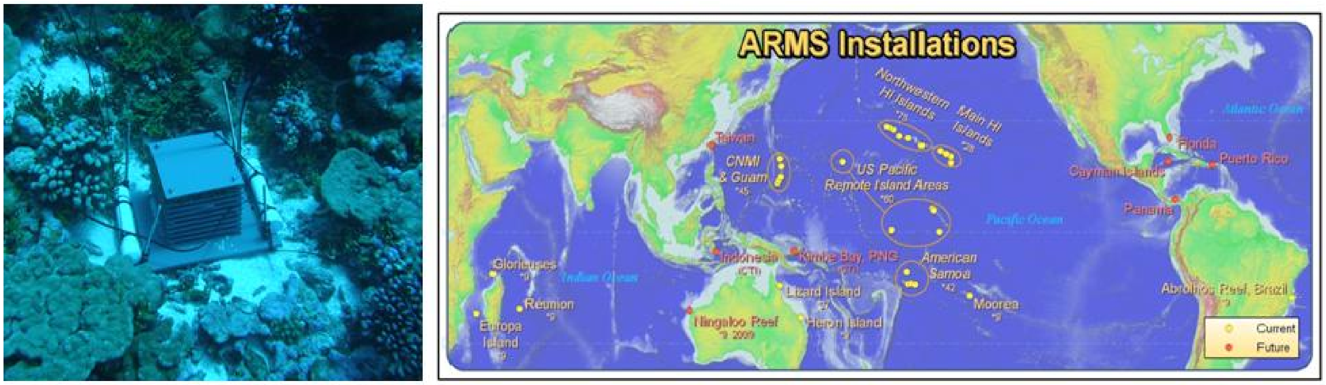

*Figure 3. Autonomous Reef Monitoring System (ARMS), being deployed in most coral seas, provide a common basis for comparing biodiversity and biodiversity changes among regions. Easily adapted to rapid molecular approaches like barcoding.*

habitats. In addition to the pyrosequencing approach already mentioned for microbes in water samples, the Zooplankton project is well advanced in creating DNA chips that will recognize all 10,000 or so holoplankter species collected in plankton nets and continuous plankton recorders globally from their DNA barcodes. The coral reef project has deployed Autonomous Reef Monitoring Structures (ARMS, Fig 3) in most of the world's coral seas and is developing DNA barcode catalogs for all of the juvenile species that settle on these structures, which should result in similar DNA chips for various reefs. It requires a major construction project to carve out cubic meters of the hard reef material in which the tens of thousands of adult species hide [18], but recolonization of reefs occurs largely from temporarily planktonic larvae and juvenile forms that settle on ARMS. A years worth of species can be scrapped off of settlement plates and analysed rapidly for DNA without involving months of taxonomist time looking down microscopes, once the links between traditional morphometric descriptions and DNA barcodes are established and recorded in online databases. The current state of the effort to barcode all marine species is shown in Fig 4.

5. Can ecosystem-based management differentiate climate effects from fishing effects?

After a number of high-profile failures to manage a range of marine living resources [25], most nations globally have recognized [26] that there are strong interactions among species and strong influences of physical and chemical parameters on the way ecosystems function. Most are in the process of adopting and testing either "ecosystem-based management" (EBM) or "ecosystem approaches to management" (EAM [27]) now. These terms are

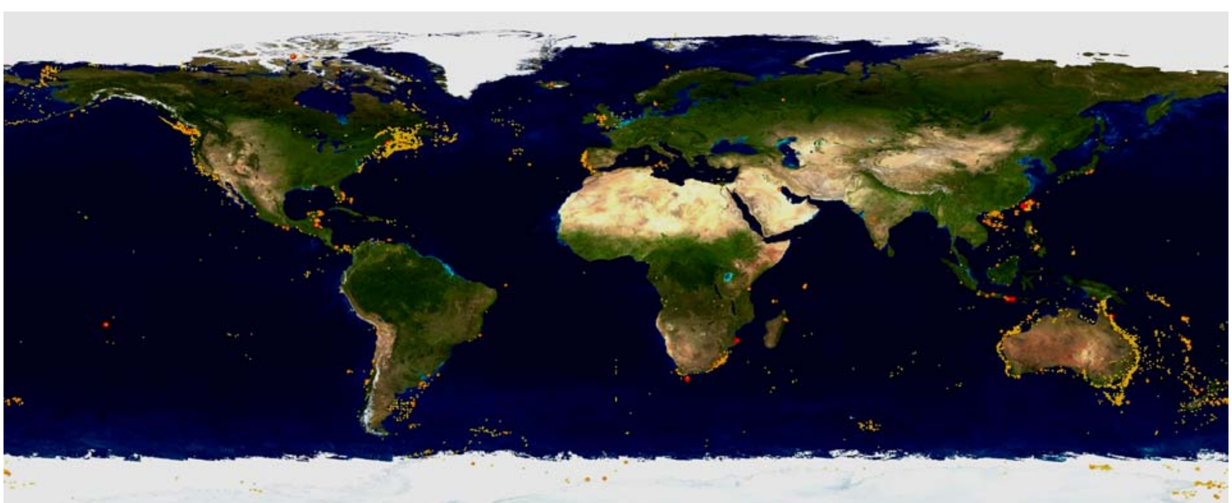
*Figure 4. Current global marine coverage from the Barcode of Life project.*

largely interchangeable, but there is really not a fully developed protocol for the process anywhere, although the oft quoted comment that "nobody knows what it means" is an overstatement. Everyone understands that there are major challenges in discovering and accounting for the many interactions that are only now emerging, but progress is being made and increasingly sophisticated models are being tested. Traditional single species management models have been around for decades, but they still yielded surprises when pushed beyond there limits.

The hardest part of question five is that most ocean ecosystems are now recognized as being out of balance in some way – too few top-down predators due to historical removals, too much bottom-up nutrient input from anthropogenic coastal sources, etc. Add to this the fact that changes in climate are rapidly being superimposed in the systems and you have a severe challenge for the modeling art. Even if we were able to monitor every physical, chemical and biological change in some system, how long would we have to continue monitoring to sort out whether a particular effect was being driven by rising temperature or was simply part of the recovery from an imbalanced starting point in the traditional system?

**4. Building on Success**

Based on a decade of observation and testing of technologies in preparation for the reports at the 4 October 2010 Symposium in London, the CoML has recommendations about the best ways to resolve the answers to the five questions above. These cannot all be detailed in this report, but we will try to provide a concise summary of what has been learned and what we think may be feasible, both technically and economically, to integrate biodiversity into the ocean observing system. Having the OBIS system available in IODE to record and display biodiversity data is an important step forward. Although earlier we used OBIS to illustrate what we don't know about mid-waters, it also records that there are some aspects of ocean biodiversity that we know reasonably well. Fig 1 displays the assembled 22 million records in OBIS as biodiversity indices in one degree squares on a global scale in a Google Earth context. Panel A focuses of the best known North Atlantic and Panel B contrasts the least known South Pacific.

Fig 5 is the result of a request by the Tonga Minister of Fisheries at the FAO Committee on Fisheries meeting in 2008 for a map of what OBIS knows about diversity in his EEZ. This may not look too impressive to

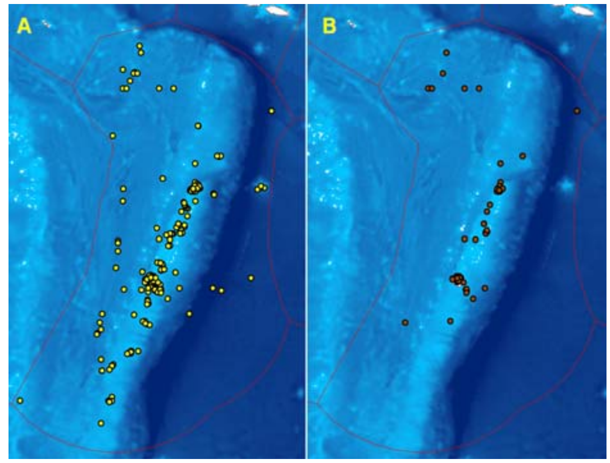


*Figure 5. What OBIS knew about biodiversity in the Tonga EEZ during the FAO Committee on Fisheries meeting in 2008. (A) 786 fish species records, (B) 276 non-fish species records.*

scientists, but such maps and the accompanying species lists are, for many countries, their best source of the information to catalog marine biodiversity as required by CBD. OBIS is now preparing a button on the website that can be pushed to automatically download such maps and lists to serve IOC member states. It is worth pointing out that CoML has never sent a project to Tonga to gather such information; it is simply the product of consolidating and searching over 700 databases from museums and agencies around the world that are learning the value of sharing data. The challenges of maintaining and updating such lists in the face of climate change are discussed in a section below.

**5. Observing the Mid-Waters in the Mid-Ocean**

The discussion of Question 5 above raises a major problem for such an integrated system. The vast majority of ocean observing capabilities, except for satellite-based systems, are coastal and associated with various nations' EEZs. These relatively near shore observations are exactly the ones most likely to be heavily influenced by anthropogenic activities and, therefore, the ones where it is most difficult to unravel the historical human influences on ecosystems from the coming climate influences. We argue then that all of the other questions become easier to answer if we explore systematic ways to document and understand the complexity of relatively isolated offshore habitats, and then move this understanding back into the disturbed regions.

Fortunately, we have learned from some of our charismatic megafauna how to find the crucial oceanic "hotspot" ecosystems. The megafauna can search whole ocean basins for the food or other conditions they require in a matter of weeks [28], so they essentially answer Question 1, for us. An oceanic ecosystem is the accumulation of everything they visit. They also answer Question 2. These animals migrate to find the conditions they need. The locations of these conditions vary with climate annually anyway, so the longer term effects of global warming will be reflected in cumulative changes in migration patterns, which have already been followed routinely with high precision in meso-scale physical features using satellite approaches (Fig 6). In other words, many of the ocean's large predators are valuable as sensitive indicators of changing conditions in the physical oceans as well as the lower trophic levels, and a detailed understanding of their behavior will pay dividends.

Unfortunately, while the satellite approach lets us track megafauna and may be extended to the second trophic level by technologies like Fully Integrated Tagging [8], it doesn't get us all the way to bacteria, which are important both in terms of biomass and function, and feed into the dynamic vertical mixing caused by plankton migrations. Satellites can tell us a lot about phytoplankton and primary productivity, but not the full story [11]. CoML Science Council 2020 has suggested the concept of an "Ecoscope" to looked at the nested scales of the ecosystem. Megafauna can define the largest scale, but it is unclear how many vessels or samplers it would take for the rest. CoML's Mid-Atlantic Ridge Ecosystem (MAR-ECO) project has shown us that an advanced research vessel like the *G.O Sars*, supported by an independent sampling vessel can define the ecosystem in a column of water from top to bottom and potentially from bacteria to whales [16]. Using advanced acoustic and video imaging systems on ROV and AUV samplers, combined with onboard DNA sequencing technology, perhaps a single vessel could define a piece of an ecosystem in near real-time and move on to define the next piece of the ecosystem the megafauna chose.

Clearly the local ecosystems don't disappear when the megafauna move on, so there should be equipment left behind to find out what happens in such locations over time. MAR-ECO has, in fact, left upward-looking Simrad sonars in place that record incredible details in a thousand meter water column (Fig. 2). It would also be valuable to identify crucial ecosystem components in areas that can be continuously monitored. Many of these have been identified by the OceanSITES program and would be prime potential partners. One of the most advanced observing systems on the planet is the MARS cable system in Monterey, CA, which, in fact, already has an upward-looking Simrad system connected to the cable and returning complex data in real-time (Fig 7, www.acoustics.washington.edu/DEIMOS). This is a high-production, nearshore site, visited by a host of megafauna, so it might be a good place to transition.

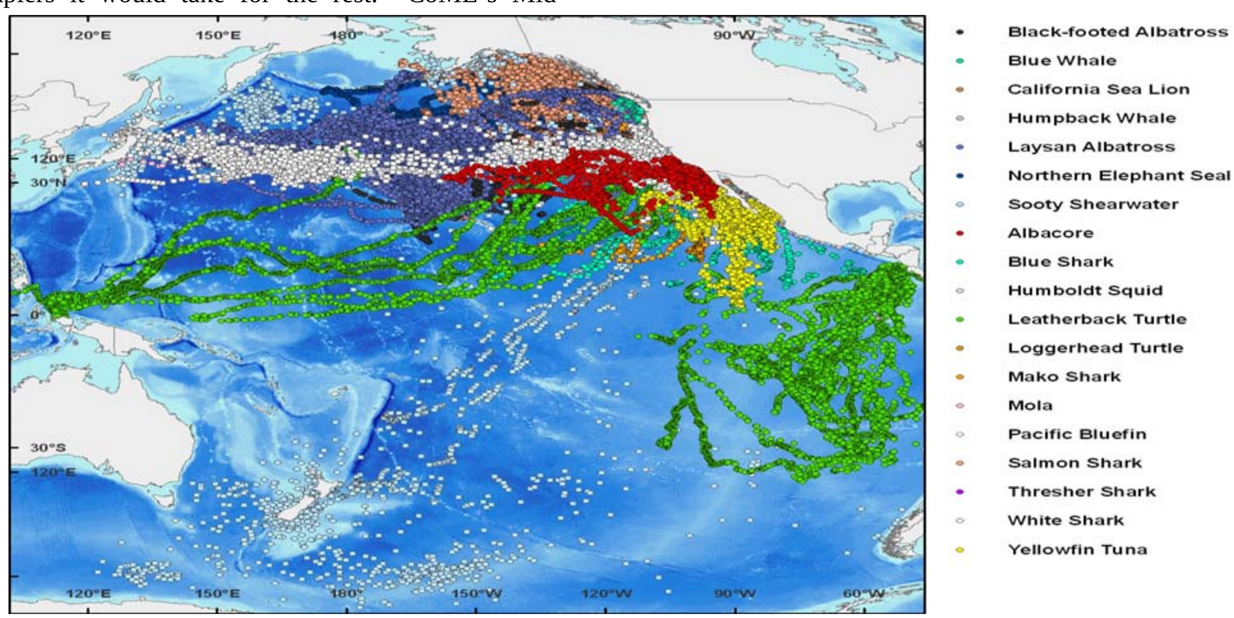


*Figure 6. Tracks of 19 species of marine vertebrates tracked as part of the TOPP program. The tracks show areas of overlap and common habitat utilization. These data are being examined with respect to the underlying oceanographic features that may be responsible for these patterns (see www.topp.org).*

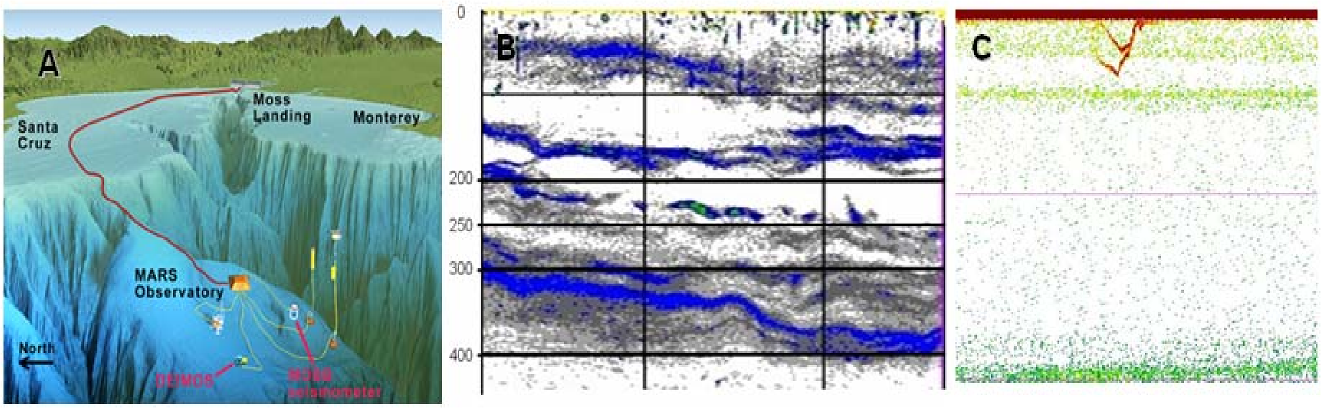


*Figure 7. (A) DEIMOS, the upward looking sonar on the MARS observatory in Monterey Bay, California. (B) Classes of organisms in the various layers observed during an ROV dive 6 May 2009. 200-250m - chaetognaths, euphausiids, polychaetes, isopods, and a few myctophids, 300-400m - chaetognaths, tunicates, jellyfish, siphonophores, polychaetes, salps, and a few myctophids and squid (Bruce Robison). (C) Two animals diving to about 30m in the view of DEIMOS - probably seals.*

**6. Reconstructing Nearshore Biodiversity Patterns**

Conceptually at least, as observations of isolated open ocean ecosystems build our confidence that we can model and understand "end to end ecosystems" and tease out the interacting effects of ecosystem disturbance and global warming, we should be able to transfer this knowledge back to the highly disturbed, but better observed and documented coastal zones. CoML's Oceans Past project has shown that reasonably detailed observational records of higher trophic level biodiversity can be reconstructed from unlikely literature sources [29]. Such long time-series going back a thousand years before direct scientific observational data began being collected have allowed the CoML Oceans Future project to project trends and conclude that even areas where biodiversity has been devastated over centuries show significant signs of recovery when protected for years to decades [30]. This perhaps suggests a new strategy for the ocean observing community, to add biodiversity time-series reconstruction to their mandate. Certainly the community recognizes the value of temperature and oxygen time-series, for example, for understanding current events, but may not be aware of this potential for biodiversity. Before the oceanographic community says, "Great, one more thing to pay for!", I should add an anonymous quote, "Historians work for even less than biologists."

In addition to the coral reef project mentioned earlier, CoML has Nearshore projects that have already initiated a global time-series using low cost protocols for sampling seagrass and rocky shore habitats (Fig 8). These have been adopted by local communities, citizen scientists, university and even high school classes, so they can be conducted by volunteers and create local interest, awareness and involvement [31]. The only hard part of this process is identifying the biodiversity collected, but like Reefs and Zooplankton this project is moving quickly toward DNA barcode approaches that can provide near real-time results about changing patterns and invasive species in the places people care about most. This will be a powerful new tool for linking local physical and chemical observations to changing biodiversity.

In a similar vein, the discussants at the CoML Biodiversity Forum recognized unanimously that the Continuous Plankton Recorder (CPR) data provided by the Sir Alister Hardy Foundation for Ocean Science (SAHFOS) for more than 60 year is the single most

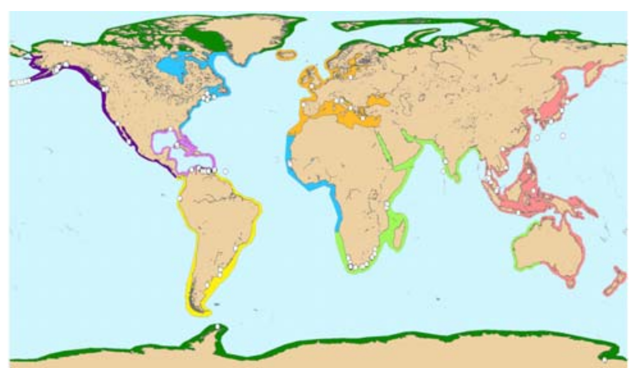

*Figure 8. The current global coverage of sites where the NaGISA Protocols [32] have been conducted. Some of these sites are committed to repeated sampling for up to 50 years*


*Figure 9. International cooperative tracking of endangered Atlantic salmon using Ocean Tracking Network data management system (www.oceantrack.org), suggests a track like this. It looks like they are headed for lines in Greenland next (Background image from Google Earth).*

important biodiversity time series available and it is crucial to maintain as an observational tool [9]. It, too, is data collected largely by volunteers, in this case commercial vessels, and is a great bargain. SAHFOS is working rapidly to replace direct morphological taxonomy with rapid molecular techniques to accelerate data accession processes and reduce costs. The Forum recommended that the development of this technology and new, perhaps near real-time, analytical tools be developed for updated CPR platforms that could include physical and chemical sensors as well as biological ones, for greater data integration. The observing community was also urged to work to expand CPR routes to more places, particularly in developing countries, which will be most heavily impacted by global warming and have the greatest need to expand the information base about their biodiversity and how it is changing.

The Ocean Tracking Network (OTN) [8], a GOOS pilot project, is another valuable tool for reconstructing large-scale relationships among commercial and conservation species in the coastal regions. It incorporates elements of the CoML TOPP project [4] to provide long-term data on animals moving between acoustic receiver curtains over large distances, but is primarily built around a global collaboration of small-scale tagging and tracking projects that share their data to learn surprising facts about where animals go when they leave "home". The discovery of endangered green sturgeon from California rivers in British Columbia and Alaska by OTN collaborators in the CoML POST project [32] is a now classic example, but similar surprises are now turning up in the Atlantic as the system expands. Fig 9 illustrates the principles of OTN well. By sharing data on Atlantic salmon smolts tagged by the National Oceanic and Atmospheric Administration in a local study of migrations in the Penobscot River in 2009, one fish has already been detected crossing the OTN Halifax Line and then again by a Fisheries and Oceans Canada equipment array in Newfoundland. The total distance travel by this tiny fish already rivals that of the giant sturgeon. Because much of the equipment currently in place has to be recovered to collect data, we expect many more detections as data is assembled.

One of the strengths of the OTN is the addition of permanent lines like the one in Halifax that can download data via acoustic modems without retrieval, which moves OTN toward a routine observing system within GOOS. OTN is already testing real-time communications between its receivers and the cabled VENUS system in Victoria, BC. Fig 10 illustrates further recent progress as collaborators in Spain and Morocco have completed high resolution swath mapping of the area in the Strait of Gibraltar where a permanent OTN line will be added in 2010. We should note that these lines collect unique synchronous time-series data from physical and chemical sensors co-located with the animal detecting receivers. This will, of course, be shared with the oceanographic community. Understanding flow fields in the Strait will be key to understanding behaviors of both the local and long-range species that cross the line.

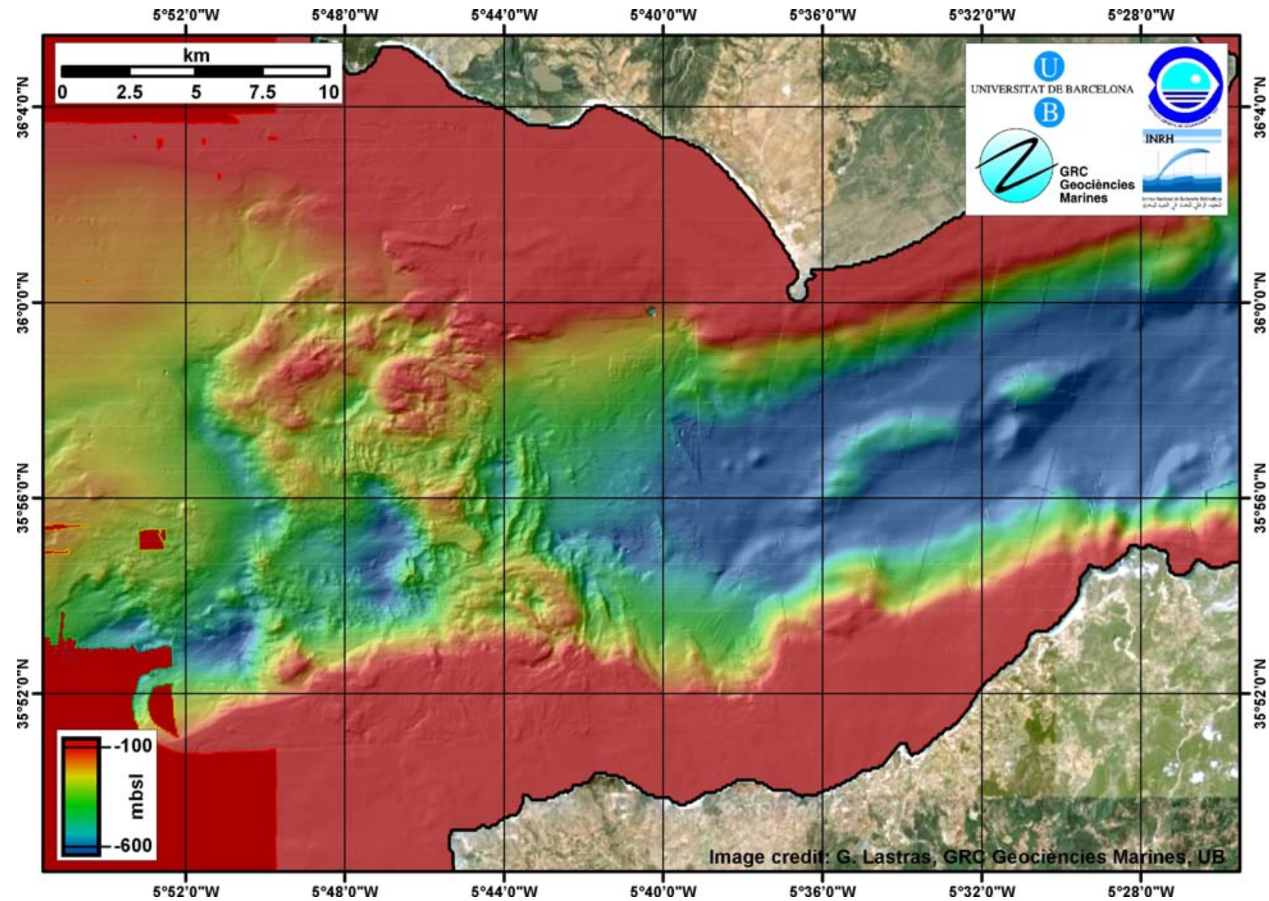


*Figure 10. Recently updated high-resolution bathymetry from Spain to Moroccan to facilitate construction of the OTN Gibraltar Line by placing equipment on a longer but shallower line to improve tracking sensitivity (Courtesy of Universitat de Barcelona and Instituto Español de Oceanografía.)*

## 7. Animal Oceanographers

Another crossover area between traditional observing and biological observing that was a focus of many CWPs [1,3,4,10] was the use of animals as platforms for collecting near real-time physical and chemical data. Although the paramount reason for tagging animals is to understand where they go and identify their critical habitats [33], as discussed earlier, animals are returning high quality oceanographic data at higher rates and from places like frontal zones and under ice that are inaccessible to the highly successful Argo Float program. Data from animal platforms is rapidly making its way into oceanographic data centers and models and recent data is timely and indistinguishable in quality from Argo data [34]. Outfitting animals with equivalent sensor arrays and collecting their data is no more costly than Argo Floats, and most animals require zero ship time to launch! There is no suggestion that animal oceanographers can replace Argo Floats, permanent moorings, drifters or traditional oceanographic cruises, but more careful coordination between the biological and oceanographic communities could produce better coverage and reduce costs for ocean observing.

## 8. Conclusions

Canadian Geographic [35] recently referred to CoML as The Transparent Oceans Project, which we think is apt because CoML has done much to make the oceans less dark and mysterious. As pointed out above, this doesn't mean that there is nothing left to learn, but that the necessary technologies for observing all parts of the ocean now exist and need only be applied systematically to monitor the many changes that will occur over the coming decades. A recent prelude [15] to the Census 2010 reports puts this transparency in spectacular view with over 250 images. The goal of this plenary presentation and paper is to make it clear that the CoML community does not view 2010 as an end, but a beginning. This large global team of marine scientists keenly recognizes that the true value of a census is not the baseline it lays down, but the ability to measure changes against that baseline over time.

We are extremely grateful for the many opportunities the ocean observing community made available to us at OceanObs'09 to present the case that biodiversity is not only important, but observable, and for the patience shown for the "new kids in town". We recognize that long-term observing in these vast ocean regions is a demanding and expensive proposition. We hope that we have shown the community some tools that will help make continuing observations of biodiversity affordable. We hope here to have laid out some approaches that will allow the move toward biodiversity observing to be staged and orderly, moving from that we can do immediately to that we must do before crises grow. We realize that funding for enduring activities is a tremendous challenge at the best of times, but we believe that the value society places on biodiversity and the recognition it brings to science will help build stable funding for the broader observing community as we go forward.

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