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The Census of Marine Life—evolution of worldwide marine biodiversity research

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Abstract This paper discusses the origin and development of the 10-year Census of Marine Life, describing the way in which a visionary idea developed into a program involving over 80 nations. The time was ripe to engage in a large-scale marine biodiversity program incorporating the newest technology for exploration, along with the traditional approach of reviewing and synthesizing the known. We discuss the planning workshops, the development of the suite of projects as well as the management and support structures. The result was a international program with globally distributed responsibilities, but supported by a strong secretariat, national and regional organizations, an highly interactive outreach and education program, and the database, Ocean Biogeographic Information System. Scientific results are highlighted in 2,600+ publications, and the program, now completed, is expected to promote and influence biodiversity research and conservation for the long-term future.

Keywords Marine ecology · Biodiversity research · International program · Census

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The context

Towards the end of the 1990s, ocean science leaders were echoing a new mantra:

> "We know more about the backside of the moon than about our deep oceans."

It is hard to judge whether or not this is indeed so, although it is not inconceivable. The deep oceans had received woefully little attention, although ocean affairs were becoming increasingly visible. The United Nations declared 1998 as the International Year of the Oceans, and the participating nations and their ocean affairs agencies planned activities to honor the occasion. Much concern was expressed about the state of the oceans—for example, pollution, over-fishing, and the loss of species—and, as a result, these issues became evident to the public as well as to politicians. The role of humans in causing much of the stress also was recognized. In any event, it became clear that we had very little idea about the extent of life in the oceans. The fairly recent discovery of a totally new ecological system in the hydrothermal vent communities on the ocean bottom had illustrated what still could be found. Already in 1995, the case for—and difficulty in—implementing a comprehensive marine biodiversity program across all the environments and on appropriate time and space scales had been presented in the US National Research Council 1995 publication entitled "Understanding Marine Biodiversity."

The problem was enormous and challenging. Clearly, a very broad-based and flexible, responsive program had to be developed in order to tackle the vast volume of the oceans. Conventional approaches to planning and funding could not do the job. The Census of Marine Life was developed in this context, using new innovative approaches to create a worldwide program. The cross-cutting theme "what did live in the ocean, what does live in the ocean, and what will live in the ocean" provided the framework. Selection of projects, planning, and coordination were done in a way that departed from the normal procedures used in many countries, allowing the rapid development of a cadre of truly international projects, and providing the flexibility to allow the addition of more as the program developed. To be sure, initiatives such as President Clinton's Ocean Exploration Plan in 2000 had shown a willingness to look at different approaches, eschewing the focused hypotheses/process studies for a broader look into the marine environments.

The practical uses of biodiversity information are not easily understood. The 2007 Report Card on the implementation of the US Commission on Ocean Policy and the Pew Oceans Commission recommendations gave mediocre grades to Research, Science and Education, and to Fisheries Management. Yet, nowhere in the discussion was the need to know what lives in the ocean expressed explicitly, but only obliquely in the dialog on ecosystem-based management. The Census of Marine Life, in posing the comprehensive question, "What lives in the ocean?", addressed all marine life forms, regardless of their apparent relationship to commercial activities. Given that all components play an ecological role, this information is desperately needed before we can truly address the ecosystem in relation to fisheries, other services, or general health. There is this pragmatic imperative, apart from the need to find out what lives in the sea, in the race against extinction, and the Census of Marine Life has demonstrated an effective approach to exploring and studying the daunting vastness of the ocean.

In this essay, we will explore the evolution of the Census of Marine Life, its procedures, successes, and also its shortcomings.

Building the leadership and community support

The idea for a coordinated international effort to address the lack of information about marine biodiversity began in 1996 in a small office at Woods Hole Oceanographic Institution. Dr. Fred Grassle, a leader in the field of marine biology and ecology, the first Chair of the Census of Marine Life, approached Jesse Ausubel, a program director at the Alfred P. Sloan Foundation who had an interest in big science and experience organizing cooperative scientific programs (Marine Biological Laboratory 2009). Dr. Grassle had been one of 13 scientists who produced the National Research Council report on "Understanding marine biodiversity," providing a conceptual framework for a research program addressing the data gaps for marine biodiversity. That framework encompassed many ideas that would later become the Census—identifying patterns, understanding processes, retrospective analyses, modeling, new technologies, taxonomy and molecular genetics (National Research Council 1995). However, those recommendations sat on a shelf with no action taken by the US government or any others. Grassle and Ausubel decided to take action.

In 1997, the Sloan Foundation sponsored a series of workshops to examine the feasibility of a major international program to study marine life. The program was first labeled as a census of fishes, and by early 1998 the scientists at these workshops were clamoring to ensure an ambitious program to tackle "the much broader major goal, which unites all ecological research…to describe and understand the patterns of distribution and abundance of [all marine] organisms and to predict the impact of change on those patterns" (Alldredge 1998). More than 300 members of the scientific community participated in the scoping workshops from 1997–1999 and continued to shape the Census of Marine Life, as it now came to be known, and its grand challenge questions: "What did live in the oceans? What does live in the oceans? What will live in the oceans?" (Ausubel 1999).

In January 1999, an international Secretariat was established at the Consortium for Oceanographic Research and Education (later to become the Consortium for Ocean Leadership through a merger with the Joint Oceanographic Institutions.) The Sloan Foundation felt it important that the program be led by an organization competent in managing research programs which also has the support of the US research community. The Consortium fulfilled both of these needs (Cynthia Decker, personal communication). Fred Grassle, Director of the Institute of Marine and Coastal Sciences at Rutgers University, was a member representative on the Consortium, which included the major US oceanographic research institutions. As the new Census Secretariat, the organization's leading members in the field of marine biology were brought together with international colleagues to form the core of a Scientific Steering Committee (SSC). Early members included Vera Alexander of the University of Alaska Fairbanks (USA), Donald Boesch of the University of Maryland (USA), David Farmer then of the Institute of Ocean Sciences (Canada), Olav Rune Godø of the Institute of Marine Sciences (Norway), and Yoshihisa Shirayama of Kyoto University (Japan). The SSC ultimately grew to 16 members from 12 countries by the end of 2005. The initial task of the SSC was to integrate the most valuable and feasible ideas from the earlier workshops into a 10-year strategy encompassing about 2 years of planning and development, 2 years of demonstration projects, 3 years for a global major field phase, and 3 years for analyses, integration, and synthesis (Alldredge et al. 1999; Ausubel 2000a).

The first meeting of the SSC was held in June 1999 in Washington, DC. In the early meetings, the group discussed the development of an integrated data management infrastructure for all marine life, as well as a range of scientific questions that would later form the basis of Census projects: (1) the migration of Pacific salmon; (2) biodiversity at deep sea vents, (3) benthic biodiversity changes with depth, and (4) the state of marine ecosystems, as before intensive fishing. It was also at this meeting that the role of the SSC in reviewing, endorsing, and providing advice was solidified—they would have the ultimate say over what became a Census project.

A global Census would entail 10 years and a total of about US $1 billion (Ausubel 2000b). With this in mind, it was clear that the global Census would require, in addition to the participation of the international science community, the engagement and support of many groups outside of science and academia, such as government agencies, international governmental and non-governmental organizations, conservation groups, industries, and other stakeholders with interest in the oceans and the life within them (Ausubel 1997). Ausubel and the SSC spent the formative years of the Census engaging critical participation and endorsement, including the Partnership for Observation of the Global Oceans (POGO), the International Council for Exploration of the Sea (ICES), and the North Pacific Marine Science Organization (PICES), all of which participated with the Census in early joint scientific endeavors. In 2002, the Scientific Committee on Oceanic Research (SCOR) accepted the Census as an Affiliated Project. In 2005, the Census was officially endorsed by the Intergovernmental Oceanographic Commission (IOC) of the United Nations (Intergovernmental Oceanographic Commission 2005).

The science plan

Tackling an inventory of life in the oceans is a daunting task. The grand challenge questions placed the research components into three categories: past (a historical component), present (a field component), and future (a modeling and prediction component). Since scientists knew little about the diversity of organisms in the sea, discovery of new species was an important element in the program, but the Census research plan went beyond that to incorporate gathering information about species abundances and their geographic distributions (Yarincik and O'Dor 2005). It evolved into an articulated program goal, used throughout the life of the Census, to assess and explain the diversity, distribution, and abundance of life in the oceans—past, present, and future.

The idea forthe Ocean Biogeographic Information System (OBIS) was "sold" to the various regions during the KUU ("Known, Unknown, Unknowable") workshops as an entity that would compile all the museum catalogs worldwide, as well as all existing databases, and integrate them into one open access source. The idea of having the British Museum and Smithsonian catalogs online was irresistible, especially for the developing world. The OBIS database continued to grow as providers fed it with more data, as did the active Census projects. The US government supported the idea and OBIS became the first jointly funded project between the Sloan Foundation and other funding entities, namely the US Office of Naval Research and the National Science Foundation, through the National Oceanographic Partnership Program.

The Sloan Foundation's philosophy is to build partnerships and to work with various segments of the scientific community to bring timely scientific programs to fruition, and that is what they did with the Census (Ausubel 2000b). The initiation of OBIS is a good example, as were the partnerships with other funding sectors; however, the process by which Sloan generally approaches its science programs, as was the case with the overall Census, is not typical of funding processes within national science agencies to which scientists are accustomed. The SSC had the flexibility to select project topics and desired project leaders, usually top experts in an area of research, with strong collaborative skills. This approach enabled rapid start-ups, even though the project proposals and science plans were subject to rigorous review by the SSC and by external peer-reviewers prior to approval. The project leaders were expected to bring together international project teams—essentially building international expert communities—to both develop the project and perform the research. This not only ensured the best ideas and innovative approaches could be incorporated into the project methodologies but strengthened the Census—and its contributions to ocean science more generally—by broadening the base of additional financial support and partnerships. The Census recognized that financial support beyond the Sloan funding was necessary, but also acknowledged that costs for new research were high globally and that much could be accomplished by building on and expanding science and biodiversity assessments that were already being done (Decker and O'Dor 2003).

Recognizing that new studies must take into an account the historical abundance and distribution of species, the first research project to be funded under the Census, in 2000, was the History of Marine Animal Populations; this had the goal of extending the baseline of information back 500 years or more. This project brought together multiple disciplines in the natural and social sciences to create a unique field of study in marine environmental history, a primary legacy of the Census.

Six pilot field projects, based on ideas brought to or generated by the SSC, were put into planning between 2001 and 2003. These included the application of new tagging technologies for open ocean predators (TOPP) and along continental shelves (POST). One took on biological inventories along with ecological, physical, and geochemical studies in one regional ecosystem (GoMA) to learn what information would be necessary for effective ecosystem-based management. Another looked at the life above and around the Mid-Atlantic Ridge (MAR-ECO). The first truly global field projects on nearshore seagrasses and macroalgae (NaGISA), and vent and seep ecosystems (ChEss) emerged as well (see http://www.coml.org).

These early projects were worthy endeavors, but more prioritizing was needed to narrow the scope among the many possible projects. Part of this was achieved through the identification of priority scientific gaps that the Census would address (e.g., criteria for projects) and the compartmentalizing of the ocean into manageable realms and zones (or habitat-based classifications) (O'Dor 2003). The SSC finalized the project criteria at its February 2002 meeting; these included priorities such as: identifies patterns of diversity, distribution, and abundance; offers opportunities to discovery new taxa; demonstrates and exploits novel technologies or applications; tests technologies with immediate operational potential; quantifies multiple species indicative of biodiversity; is at least regional in scope; has potential for application to larger areas; and so forth. They also identified a lack of species information in key habitats, such as extreme environments (vents and seeps, gas hydrates, etc.), the deep ocean, the open ocean water column, seafloor sediments, global coral reefs, and large scale microbial studies.

Still more thought was needed to ensure efforts were focused efficiently and on research that would ensure the biggest returns. Tackling the question of "what lives in the ocean" required not only intense exploration but also a thorough review of what had already been discovered in order to avoid redundancy and questions to which an answer was unlikely to be uncovered. The Sloan Foundation, due to then President Ralph Gomory, had a philosophy of breaking science down into the "Known, Unknown and Unknowable." As each project was identified and initiated, the emerging leaders were asked to bring together the experts in the specific field of study to gather all information already known and to identify critical unknowns (gaps in knowledge) that could become known with current research capacity, including new and innovative technologies. The project teams also identified unknowns that should not be included in their current scope of work (unknowables). All of this led to the development of strong science plans for each of the field projects, the History of Marine Animal Populations, and, later, a modeling component called the Future of Marine Animal Populations.

From 2003 to 2005, the six pilot field projects were fully underway and, having successfully demonstrated their feasibility, were being encouraged to become global in scope. This worked well in most cases, with one notable exception, GoMA, which was conceived as a thorough, multi-disciplinary study of all aspects of an ecosystem which, practically speaking, could not have been expanded globally within the 10-year timeframe. During its synthesis phase, though, the demonstrated approach for the Gulf of Maine was compared with other semi-enclosed ecosystems, such as the Gulf of Mexico and the Baltic Sea, to see how well it could be applied elsewhere.

Eight more ocean realm field projects were initiated at a full-scale global level, based on lessons learned and experiences from the pilot projects: coral reefs (CReefs), continental margins (COMARGE), abyssal plains (CeDAMar), seamounts (CenSeam), the Arctic (ArcOD), the Antarctic (CAML), zooplankton (CMarZ), and marine microbes (ICoMM). This provided a suite of 14 field projects, deemed a manageable number given the manpower resources available through the Secretariat staff and the SSC membership. The 14 also encompassed most of the major ocean habitats, and would accomplish a fairly comprehensive survey of life in the oceans (Fig. 1). Some environments, such as deep ocean trenches, were omitted due to the lack of the technical ability and scientific capacity. With a 10-year timeframe set by the Sloan Foundation, the Census had to focus on endeavors that would yield significant results by 2010, and the limited technology and high costs associated with surveying trenches rendered science unlikely to produce much data or meaningful results from this realm during the first Census program.

Other omissions were phytoplankton and mangroves. The CMarZ project focused solely on animal plankton because that in and of itself was a major task. No taxonomically comprehensive, global assessment of marine zooplankton biodiversity had been undertaken, and only about 6800 species were known. Using traditional collection methods such as nets, pumps, and bottles that would not have worked for phytoplankton. Addressing nearshore environments, NaGISA chose to focus primarily on soft-bottom seagrass and rocky macroalgae habitats because of their global geographic distribution, which was needed for a grand-scale study of this kind. Mangroves are generally restricted to the tropics and subtropics.

The results of the early findings from the KUU workshops along with some overarching synthesis from the fields of systematics and biodiversity were summarized in the 2003 Baseline Report from the Census. This report also clearly, for the first time, articulated the strategy of the Census "to clarify and make much more accessible what we know, to identify what we do not know and why we do not know it, to learn much more of what is knowable, and also to identify what we may never know or at least not learn for a very long time, well beyond the life of the research program… [The Census] humbly recognizes the formidable

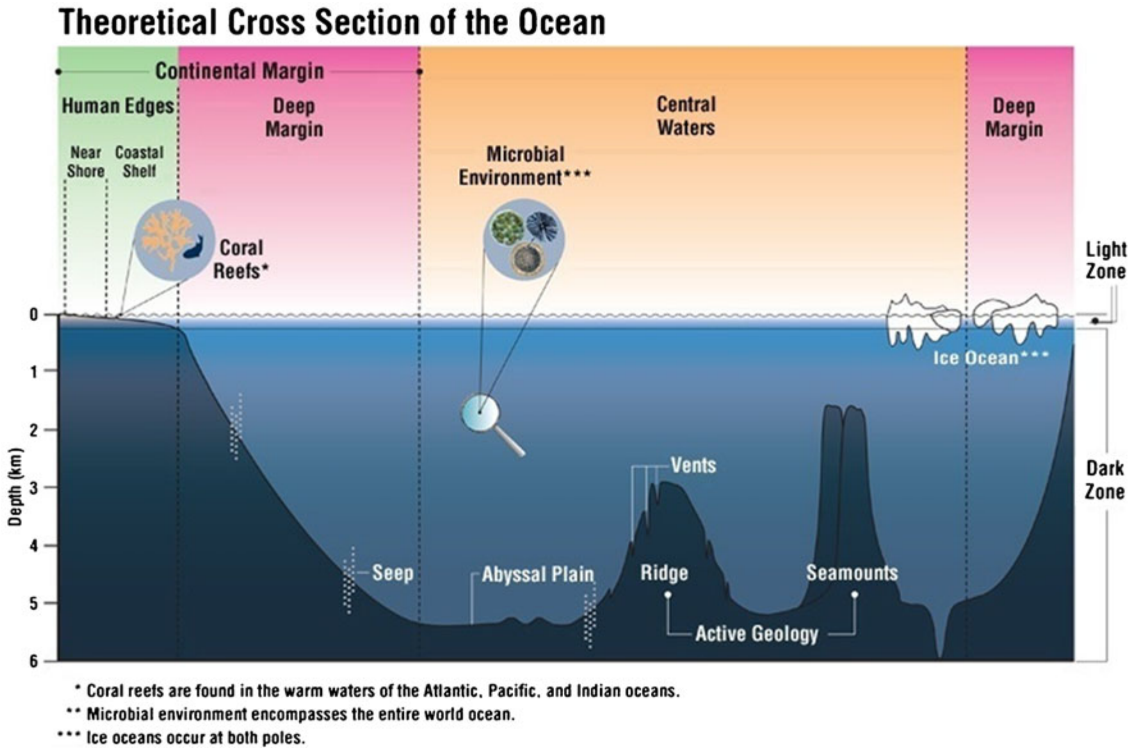

Fig. 1 Cartoon cross section of the oceans, showing the realms

limits to knowledge" (O'Dor 2003). In 2005, with the full suite of projects identified and at least well into their planning phases, the Census science plan was formally published (see Yarincik and O'Dor 2005; O'Dor and Gallardo 2005).

Early in the Census, as the field projects were beginning to explore the various ocean realms, with many new discoveries and encouragement to expand their global coverage, another strategy to realize a truly global program was implemented. Few Census projects were able to participate at a global level, mainly due to limitations in capacity (oceanographic or research ships), resources, and logistics. The SSC began to reach out to the global community to organize more regionally or nationally focused KUU workshops to review the status of knowledge of marine biodiversity in particular regions, as well as to identify the gaps in this knowledge. One outcome of these workshops was the publication of very valuable regional volumes that compiled a review on the status of knowledge of marine biodiversity. Another outcome was the formation of national and regional committees (NRICs) that took responsibility for coordinating efforts in marine biodiversity research under the common vision of the Census. From 2002 to 2007, the Census reached out and raised awareness about the importance of studying marine biodiversity to 237 institutions in 65 countries, certainly an unprecedented accomplishment. Details about the NRICs can be found in O'Dor et al. 2010.

The NRICS contributed to the global science plan through national or regional involvement in Census projects and by bringing in a "local flavor" of national or regional activities not related to the projects but to other marine diversity activities within their geographic areas. After the first Census (or beyond 2010), it is more likely that the national committees will continue their activities, while the regional ones will probably break up into national organizations. If this is indeed the case, the truly international flavor of the Census cannot continue.

Use of new/innovative tools

The baseline report of the Census of Marine Life (O'Dor 2003) presented a framework for exploration of marine life and reported essential elements of knowledge and its limits. Sampling in the ocean requires technology, which has improved significantly in the last decade, boosting our capacity and reducing the gap between the known and the unknown. Technologies used by the Census include techniques for accessing archives and visualizing the past as well as sophisticated sensors and tagging devices installed in marine animals, satellites, underwater cameras, submersibles and remotely operated vehicles, and all the benefits from the high speed information age (Snelgrove 2010). Stone et al. (1999) stated that electronic marine animal tagging would open a new frontier in ocean science that would allow studying patterns of marine life. Since

1999, tags (sonic, satellite, or archival and “pop-ups”) have improved in terms of how they are attached to the animals, and have become smaller with a better geo-reference system and software. For taxonomists, who have the heavy responsibility of identifying and describing the specimens collected by these exploration campaigns, internet tools, electronic communication, and online information represent a tremendous advantage. Perhaps the outstanding example of an online electronic tool is the Encyclopedia of Life, a web-based initiative, permanently growing, that will contain an electronic page for each species on Earth, providing information and links to either published and unpublished material. In addition to the Encyclopedia, the World Register of Marine Species is another online resource that provides an authoritative and comprehensive list of names of marine organisms, including information on synonymy, which is controlled by taxonomic experts. Another important tool for taxonomists has been the use of molecular techniques to identify and/or separate species. In this area, Census taxonomists engaged with the Barcode of Life project. The Barcode of Life was proposed in 2003 as a way to identify animal species in a relatively cheap and fast way by using a very short genetic sequence from a standard part of the genome (the mitochondrial cytochrome c oxidase I gene or COI). By the end of 2009, the Barcode of Life Database (hyperlink: http://www.barcodinglife.org) reported COI sequences from over 620,000 specimens from over 58,000 animal species (Ausubel 2009); with more than 19,000 marine species barcoded (Dirk Steinke, personal communication).

Visualization is a challenge when dealing with such huge amounts of data. The Census established a Mapping and Visualization Team, as well as a key partnership with Google Earth through the advisory council of Google Ocean. Google Ocean is a powerful visualization tool for marine data launched in 2009; it allows the viewer to virtually dive in the world’s ocean while providing scientifically accurate information (as layers) contributed by well recognized organizations working in the oceans.

Building the real global picture: synthesis and cross-project cooperation (2008–2010)

As the information produced by Census research increased, and scientific articles and books were published, the SSC began to think about a way to synthesize the efforts and plan for the final products. A group named the Framework Committee started to work in May 2006 on ways for the Census to organize key findings for specific target audiences. From this group and their recommendations, the Synthesis Group evolved, starting in May 2008. The Synthesis Group integrated and synthesized the vast body of information gathered by the Census projects, the NRICs, and other research activities into common themes and overarching messages to ensure comprehensive content and communication to all audiences in 2010. The synthesis products were envisioned at three levels: within projects, across projects, and within the full Census. Most of the products within and across projects were scientific papers or entire collections published as special volumes that dealt with specific scientific questions. As for the products of the overall Census, three major contributions were planned: (1) a book targeted to a general audience, narrating a summarized version of the different activities of the Census, (2) a scientific book including one chapter from each project, synthesizing their major findings and relevance, and (3) a collection of regional articles prepared by the NRICs reviewing and analyzing the state of knowledge of their local and regional diversity and how research carried out by the program in the region in the 2000–2010 decade reduced the ‘unknowns” as identified in the early national and regional workshops. These products—and many more addressing different audiences and a number of topics and crosscuts of the Census—were to be published and available before the culmination of the program and announcement of findings in October 2010.

Local, regional and global support to a new marine biodiversity initiative

Why was the international scientific community so receptive to the idea of engaging in this program? Leading up to the Census, there were several local and regional ocean and biodiversity initiatives developing around the world; these paved the way for an international, collaborative, and multidisciplinary enterprise. One such initiative was the DIVERSITAS Program, established in 1991 with the goal of inventorying and monitoring biodiversity that would be useful for both the scientific community, by providing a better understanding of ecosystem function, and to policy makers concerned, for example, in the implementation of the Convention on Biological Diversity. In 1993, the International Network for DIVERSITAS in the Western Pacific and Asia was created by scientists of the Asian region, and, in 2001–2002, an International Biodiversity Observation Year took place. A manual on biodiversity research methods was published for this purpose (Nakashizuka and Stork 2002). The manual contained a new protocol for monitoring biodiversity in coastal macrophyte communities (Shirayama et al. 2002), which became the basis for the globally distributed Census project, NaGISA.

Another important initiative was the MarBEF (Marine Biodiversity and Ecosystem Functioning) network of excellence in Europe, officially launched in early 2004. MarBEF integrated the research efforts of over 700 scientists around Europe from a variety of disciplines in marine science, creating a virtual European institute to address the scientific challenges of topical marine biodiversity questions and to provide new insights and answers at an unparalleled research scale. This program consisted of three research themes: (1) examining patterns of species diversity, (2) identifying what structures species diversity, and (3) the socio-economic consequences of biodiversity change (Heip et al. 2009). Several of the researchers involved in MarBEF were also part of the Census, either through research projects or through their involvement in the NRICs or in the SSC. At a global level, the role of POGO was significant in engaging regions such as Japan, the Indian Ocean, and South America in the Census program. POGO was initiated in 1999 with the goal of promoting global oceanography, particularly the implementation of an international and integrated global ocean observing system, and developed into a partnership of institutions involved in oceanographic observations, scientific research, operational services, education and training. Shortly after its establishment, POGO's directors thought of the importance of enhancing oceanographic biological observations to benefit its goals of long-term monitoring, as well as to help address scientific issues. In this way, POGO provided background and support for early Census workshops and related activities at the regional level and became a crucial partner for promoting ocean and marine biodiversity observations to the intergovernmental Group on Earth Observations as well as to the Global Environment Facility (GEF) coral reef project, linked to CReefs.

Governments and global funding agencies also played an important role in providing support and the opportunity for local and regional marine biodiversity research. In the Arafura and Timor Seas region, for instance, in 2006 the governments of Australia, East Timor and Indonesia submitted a funding proposal to the GEF to undertake a Transboundary Diagnostic Analysis and develop a Strategic Action Program for the Arafura and Timor Seas region. The full-scale project proposal was called the Arafura and Timor Seas Ecosystem Action program and was launched in October 2009. Another example of government support was provided by the National Natural Science Foundation of China, which had deep understanding of the local system, its mechanisms, and the academic capacity, both human and institutional, and had a long experience in international collaboration. It partnered with the Sloan Foundation in sponsoring the early Chinese workshop for the Census.

The IOC also played an important role in the establishment of the program in some regions, where the Census program overlapped with IOC regional committees or regional sub-commissions. In this way, the IOC was present in the early KUU workshops of the Indian Ocean, the Arabian Sea and Gulf of Oman, the Caribbean, Japan, and South East Asia regions. The interest of the IOC in the Census program was mostly in the potential of its education and capacity building components.

The organizational structure

The Census program was able to accelerate quickly because of the Sloan Foundation's approach to funding and research. A mere 2 years after the first community workshop was held to assess feasibility and priorities for a science program in marine biodiversity, the first funding for the program infrastructure and research began to flow. The planning process was rapid but thoughtful, with a strategy that allowed for flexibility throughout the development and implementation of a program. This enabled the SSC to take advantage of opportunities and developments in science and technology and partnerships as they presented themselves, because they were not held to a rigid framework. On the other hand, this opportunistic approach sometimes rendered the science strategy non-transparent.

While the projects did not begin through a competitive process, their selection was not random. The SSC identified leaders in the areas of science they wished to facilitate and those leaders were charged with building international collaboration to design and perform their research. The Sloan Foundation provided the seed funding to support the international teams and to facilitate the creation of ambitious, global projects. While additional support was needed to do the scientific research, the administrative and staff support from a single foundation meant that priorities in workload and scientific goals were clear.

The infrastructure support from the Sloan Foundation offered the opportunity to build core international teams for planning at all levels of the program, from the Secretariat and SSC to the leadership of the individual projects. The funding for meetings and administrative support for project development created strong science plans and proposals and facilitated the international collaboration that made the Census so successful.

The management of the program was both top down and bottom up. The SSC was responsible for determining the goals of the Census and which projects would ultimately fall within its scope. The Secretariat supported the SSC in this capacity and collected information, through annual reports, milestone and management plans, that helped the SSC assess progress toward goals, outcomes, and legacies. Each of the projects and the NRICs had its own core management team as well, all projects and some NRICS with financial support from the Sloan Foundation. The Census program itself was large and distributed, and each of the research projects was just as complex in its partnerships and participation, so the administrative support was essential for efficient coordination and tracking of progress, maintaining momentum, and communication and centralization of information throughout the program (Fig. 2). This would not have been possible if the SSC had not been able to recruit some of the best scientific talent in the world.

The SSC and Secretariat recognized that the program structure worked because of the flexibility and relative lack of bureaucracy, but yet could cause frustration as plans evolved, so they maintained an "open door" policy from the beginning, always welcoming concerns and input from the project leaders. Every 2 years, the Secretariat organized an "All Program" meeting for representatives from each project, NRIC, and other components of the program to discuss current scientific findings, as well as the directions for the coming years and ultimately the final Census synthesis. These community meetings facilitated congeniality throughout the program and helped build the sense that everyone's voice was important.

One of the additional benefits—and insights—of the Sloan Foundation was the establishment of core teams for program-wide support in the areas of education and outreach, mapping and visualization, and integration and synthesis. The Education and Outreach Team was funded in 2003 at the University of Rhode Island's Office of Marine Programs. This team served to communicate the findings

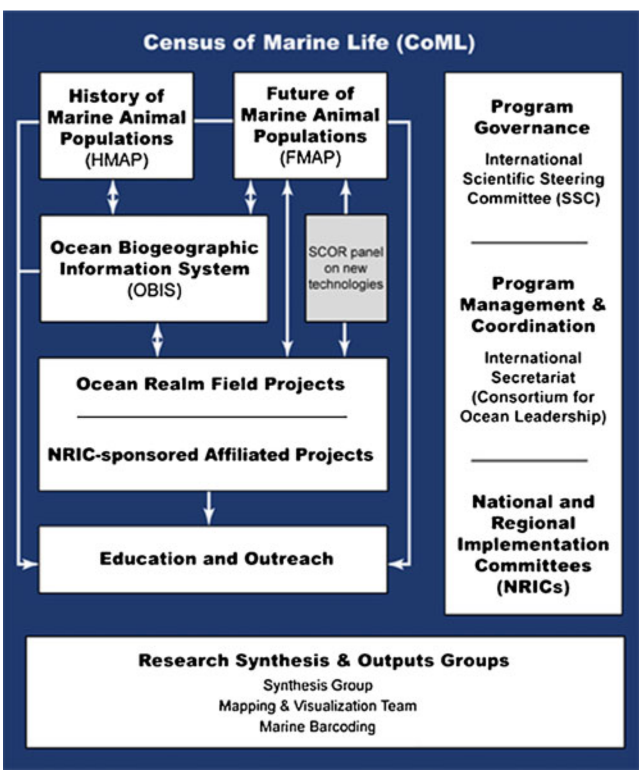

Fig. 2 The Census of Marine Life management structure

and news from the Census to a broad public audience through regular press releases and input to book and film projects, as well as to support the Census projects and NRICs in their own education and outreach, which they were required to undertake by their support from Sloan. Education and outreach needed to reach several vastly differing audiences, and the press releases (three per year) were fundamental to communicating Census results to the general public. Many of the projects were ambitious and very successful in their outreach and education activities, which included artist collaboration and art competitions, programs with school groups, and clever naming of research subjects, such as the tagged elephant seal Stelephant Colbert that ensured a feature on the popular US Colbert Report television program.

The Synthesis Group at Memorial University and the Mapping and Visualization Team at Duke University were funded in 2007 with comparable missions to integrate the findings of the Census in formats that could be digested by scientists and a wide variety of other audiences and stakeholder groups. The Census projects and NRICs had responsibility to design much of how they would report their findings. The Synthesis Group outlined the suite of products that would encompass the reporting of results throughout the Census at the level of the overall program. The Mapping and Visualization Team supported the projects, NRICs, and Synthesis Group in their reporting. They also generated key partnerships, in collaboration with the Education and Outreach Team, to take advantage of innovative outlets such as Google Oceans and National Geographic maps and programs, for visually communicating Census results.

Partnerships like these were essential to the success of the Census. The strategy from the beginning was to leverage expertise and support to ensure the most efficient use of available resources for the biggest returns. The Census collaborated with the Barcode of Life and Encyclopedia of Life, both also Sloan-supported initiatives, to increase the productivity of all three programs. The Census contributed specimens to the Marine Barcode of Life; likewise that project continually enhanced the genetic information bank against which Census collections could be analyzed. The Encyclopedia of Life is building a highly visible Internet outlet for information about all of the species on Earth, which increases public interest in the Census, and the projects contributed information toward the development of the species pages for the Encyclopedia. Partnerships were fruitful outside of the realm of science as well. The Census collaborated with the French production house, Galatée, as scientific advisors for its Oceans film. While the Census helped to bring scientific accuracy to a beautiful and moving film about the life in the oceans, the film, released in 2010, is bringing greater public support to issues of ocean science and biodiversity in a critical year for the announcement of the Census results and for planning for a second Census.

Legacies and the broader impact

The Census is a novel program, with little of the conventional scientific structure used throughout the world for supporting scientific programs. Because of the mode, it has provided a fertile setting for exploration and experimentation. The facet that has made this possible is its structure as a conglomeration of projects, each independent in execution, yet held together by excellent centralized communications, management, and coordination, with "seed" financial support for each project from the Sloan Foundation, dedicated professional support for education and outreach, and the opportunity to hold periodic meetings with representatives from all components of the program, as well as, more recently, for synthesis of the results. While on the face of it all this would appear ponderous, in fact it has not been so. The Census has produced a worldwide federation of projects and a network of collaborators involving, over the course of the program, more than 2,700 people in more than 80 nations, with complete freedom for scientists to innovate and lead exciting scientific activities while contributing to global goals and receiving all the necessary centralized support. The downside is that the projects by and large had to raise most of their research funds from their usual funding sources, albeit made easier by the seed money available for planning and development. The Sloan investment was near US $75 million, and the total funding for the program was US $650 million. The Foundation investment thus made a huge impact in leveraging funds leading to this worldwide effort.

The International Secretariat for the Census provided in-house capability for handling financial matters and travel support for the international program management. The Secretariat handled communications, meeting organization, and liaison with the University of Rhode Island Education and Outreach activities. The program was very well balanced globally, although the location of the Secretariat might have produced the impression that the Census was controlled by the US or was very US-centric. There was a conscious effort to organize many, if not most, of the meetings and major activities outside the US, and most of the projects were truly international with coordinating offices in multiple countries. The NaGISA, ICoMM, ChEss, CReefs and CMarZ projects are particular examples with numerous sites and nations involved. There was a definite advantage in having the Secretariat relatively close to the Sloan Foundation offices in New York City as well as to many international organizations important for partnerships and/or funding with offices in Washington DC or New York, again making meetings with them very easy.

A criticism that has been raised is the lack of openness—for example, no opportunity for all comers to participate in the program through an "Announcement of Opportunity" or a "Call for Proposals." The fact that the projects were added sequentially in an opportunistic way supports this concern. While allowing rapid start-up and implementation, the issue of fairness is perhaps a valid consideration. Observing the development of the program from the SSC perspective, we have noted the efficient use of scientists' time, with no need to prepare multiple competitive proposals with possible multiple rejections. Quality control by SSC members, external reviewers, and the Sloan Foundation Board seems to have been adequate, and ultimately the various national funding entities also conducted their normal reviews before providing support. In ecological terms, we are truly looking at a top down (SSC, Sloan Foundation), bottom up (scientists, projects), functional entity—one unique in the conduct of large, coordinated research programs.

The Census has brought attention to the field of systematics, and demonstrated the extent of the work that remains to be done. In the past, funding for systematics was limited, due to the perception that it is descriptive and not state-of-the-art scientific research. If, indeed, the Census has revitalized the field and demonstrated its continuing value, that will be a fine long-term legacy. Time will tell, however, as it is difficult to assess this as yet. We can point to the amazing discoveries of new distribution records and of new species in every environment visited. One of the major legacies of the Census that does not derive from the projects is the review of the state of knowledge in marine biodiversity in regions around the globe. Many of these had a lot of information in gray literature and totally inaccessible. The Census encouraged the organization of KUU workshops, as well as the final NRIC collection that summarized and analyzed the state of knowledge of marine biodiversity in 26 regions around the world (see: http://dx.doi.org/10.1371/issue.pcol.v02.i09) and making it available to everyone. The picture of what is known is much clearer in the regions than it was 10 years ago, even in the absence of new information. The results are spectacular, but clearly much yet remains to be discovered. That this information is preserved in OBIS is itself a long-term legacy, and the links with the Encyclopedia of Life and the Barcode of Life programs also strengthen the legacy of the Census. The Census encouraged the use and development of new technology, as well as the formation of alliances with other programs. In spite of all these advantages, the program has not, however, produced much quantitative information on abundance, but it has established a significant and strong baseline of information that will be invaluable for further study.

Conclusion

The important question now is whether there will be an effective follow-up to the Census, what is to be its nature, what will be the financial support base, and how will it build on the momentum and results of the present program. If, indeed, the role of the seed funds and central support and coordination are essential ingredients, the way these elements are addressed could greatly influence the success of a new program.

Perhaps more important than these practical considerations, the philosophical leadership was a major factor in the success of the Census. Two visionary leaders—Fred Grassle and Jesse Ausubel—set the stage and provided guidance through the development. These leaders recognized the need for a program on marine biodiversity and went about organizing it. Subsequently, the evolution of the "Known, Unknown, Unknowable" approach and the establishment of several entities to guide and support the program served to strengthen and give direction to the overall effort. Most recently, the NRICs have developed, and, in some cases, are playing an important role; perhaps a structure involving these could develop. Whatever mechanism does arise will require the nurturing attention that was inherent in the Census, encouraging scientists to conduct their work freely, openly and effectively.

It is appropriate that the United Nations has declared 2010 the International Year of Biodiversity. Continuity of momentum is important. A workshop held in 2006, sponsored by the US National Committee for the Census, concluded that the evidence shows that biodiversity does matter, and conservation of natural biodiversity could substantially improve the way people approach ecosystem-based management (Palumbi et al. 2009). We might add that this is the only way to truly invoke ecosystem-based management and to address the pressing issues facing our ocean habitats and marine life. With the information gained to date, we can now move forward in this direction.

As the 10-year program is ending, we recognize that the work is not complete. This was the first Census, and more will need to follow—the age of discovery is far from over.

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