The Census of Marine Life: review of lessons learned

Landcare Research
Manaaki Whenua

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The Census changed our views on how things could be done. We shared our problems and we shared our solutions.

Ian Poiner, Chair of the Scientific Steering Committee of the Census of Marine Life

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Summary

The Census

The Census of Marine Life was a decade-long $650 million program involving 2700 scientists from 80 nations and 640 institutions, who spent 9000 days at sea on more than 540 expeditions, plus countless days in labs and archives. One of the largest scientific collaborations ever conducted, the Census produced over 3100 scientific papers and many thousands of other information products. The global community now has a legacy of a baseline of data on life in many of the ocean's realms that will shape policies and management of the oceans for decades to come.

The Census pioneered a way to build scientific and community collaborations for the biological and ecological sciences. Unlike the physical sciences, biology and ecology have little heritage in undertaking global large-scale projects aimed at a challenging goal. The Census was created with a simple and visionary goal to understand the diversity, distribution and abundance of marine life to help answer the key questions:

- What did live in the oceans?
- What does live in the oceans?
- What will live in the oceans?

The Census leadership recognized that 'discovery' was a powerful message to mobilize scientists to build new knowledge in an under-studied part of our globe. But discovery is costly so a true census required global cooperation and significant funding over a long period. The combination of vision, need and opportunity was compelling and the support of the Alfred P. Sloan Foundation (hereafter 'the Foundation') in supporting the inception of the Census, the coordination of a global endeavor, and its delivery of a substantial body of new knowledge was a lynchpin in the success of the Census.

By any numerical measure the Census was an outstanding success. However, it is the stories behind such success that help us to understand what worked, why things happened and what did not work so well. Through an analysis of the Census and its comparison with other global initiatives, the lessons learned from the Census can be used to create other scientific collaborations.

The Project

The Foundation contracted an independent team from New Zealand to undertake a review of the impacts of the Census through interviews with people inside and external to the Census community and review of relevant documents. Over 60 people from around the world were interviewed and views were also gained from participation in, and observation of, a number of Census-related meetings. The review did not analyze the impact of the science – these impacts will continue to expand once the science moves into new projects, policy development and management of the oceans. Instead the review focused on issues such as governance, leadership, management, collaboration, globalization, data management, synthesis, education and outreach, and future legacies.

Findings

Governance: The Census evolved a governance structure that worked, but it lacked clarity in roles and responsibilities. A strong link with the Foundation as the key 'investor' ensured those interests were maintained and the Scientific Steering Committee (SSC) provided review and support for the various projects making up the Census. There was no governing board per se and the more latter development of an executive committee provided better support for the delivery of the Census. There was no successional plan or process for the SSC so the Census missed the opportunity to develop new leaders to take the Census forward beyond 2010.

Leadership: The Census began largely through the vision and drive of Dr Fred Grassle, Rutgers University, who saw the need, combined with the commitment and belief of Jesse Ausubel of the Foundation who provided some early investment to develop a new global collaboration. Leadership in any large program needs to evolve, and identifying and developing leadership for the different stages of the program (e.g. proof-of-concept, proof-of-performance, proof-of-implementation) should be part of leadership and governance initiatives. The Census did not take full advantage of the opportunity to develop a group of future leaders. Despite the clarity of the vision for the Census, the leadership (governors and managers) struggled to develop a dynamic strategy that would show participants how their ideas and projects would fit within the Census. It was not clear whose responsibility this was.

Management: Most international science programs are managed by a secretariat. These have various forms, responsibilities and budgets that need to be developed as part of the establishment phase. The Secretariat was based at the Consortium for Ocean Leadership in Washington, DC, and did an outstanding job of coordination across many dimensions. The Census could only achieve its goals through leveraging funding from national and international agencies for voyages and associated research, and technology development. This was a powerful approach but there were challenges in financial management. The Foundation provided funds to build proposals and to support the Secretariat and other cross-cutting initiatives such as Education and Outreach, and Synthesis, and the Secretariat had little oversight of overall finances of the Census. Management was also challenging with the strong influence of Jesse Ausubel of the Foundation across many dimensions. There was insufficient clarity on roles and responsibilities in the operations of the Secretariat. There was also belated attention to the risks to the program and it was only in 2007 that a more formal risk register was established. Managers and governors must address risks throughout the life of a program.

Collaboration: Without doubt the lasting impact of the Census will be the network of collaborating scientists and other participants who made the Census work. The availability of a willing investor (the Foundation) prepared to fund meetings of interested participants set the scene for success. Repeatedly, interviewees noted that the opportunity to meet, share ideas and data was critical in building the trust and relationships from which to develop targeted project proposals. Once that trusting culture was developed, the Foundation then supported the development of the project proposals and review. This was an innovative approach at variance with most directly contestable processes. The Foundation then funded secretariat-like functions for each project. New ways of working together were developed and the contest for ideas was in the development phase rather than with contestable processes. There were also very significant connections made between marine biologists (especially taxonomists) nearing the end of their career and new entrants to the science of marine biodiversity.

Globalization: The need for a global approach was a guiding principle from the inception of the Census. Only by leveraging global resources and experts could the goals be met. It is easy for program funders to work with a few countries or institutions but the global reach of the Census did challenge some of those more simple approaches. Participating countries and institutions had responsibilities to finance large parts of Census activities while the Foundation funding built the means to communicate and coordinate. Globalization was achieved through projects, but there were challenges from potential competing alliances and from varying capability and resourcing. The Projects and some allied initiatives were driven by scientific questions. The Census then did move to build a number of National and Regional Implementing Committees (NRICs) to ensure a wider global coverage. The significance of the NRICs was underestimated in the early phases of the Census and variable resourcing meant uneven participation and outputs. Comments were widespread that, despite significant resources, the US NRIC did not provide the expected leadership while other NRICs with minimal resources did make substantial impacts.

Education and Outreach: The excitement generated by discovery of new species, distributions and relationships provided fertile grounds to develop an effective Education and Outreach (E&O) component to the Census. The Census wisely contracted E&O professionals within a marine research environment (University of Rhode Island) who provided services and support for a wide range of activities. The E&O team reached out to other professionals to improve access to wider media outlets and the many thousands of press releases, web hits, use of images, video and film, etc. is clear evidence of their success. The strong interest of the Foundation in building a profile for the Census was critical as its funds supported E&O as an overarching theme and within the Census projects. This meant that researchers did not have to divert their national or institutional funding to these activities. The Census leadership was also very perceptive in supporting the use of Census outputs for film ('Oceans' – Galatee), maps (National Geographic), and other creative and artistic activities such as video, song and painting. There was widespread praise that the Census recognized the aesthetics of science as a noble activity and as a foil for a heavy reliance on economic outcomes.

Synthesis: The Census ultimately had 17 projects, 5 affiliated projects, 13 NRICs and 3 global coordination groups under its structure. Over two-thirds of the way through the program the leadership realized that some form of synthesis or overview of the outputs would be most useful. Developing the processes and structure for information flow to a new Synthesis group did cause concerns with a number of researchers. Finding the balance between 'discovery' and 'relevance' also challenged the Census. This tension remained throughout the Census and scientists will always be concerned about the use of their results especially where uncertainty or data gaps remain. The Census would have been wise to recognize this tension earlier in its development and encourage greater involvement with potential users of the information. As highlighted earlier, the NRICs could have played an earlier and more influential role in connecting Census results to potential policy or management regimes. Nevertheless, the range and quality of the products produced under the auspices of the Synthesis Group will be a significant legacy for many years.

Data management: Dr Grassle as a key founder of the Census was a passionate advocate of the requirement to share data on marine biodiversity. He created the framework for the Ocean Biogeographic Information System (OBIS) as the basis for data sharing for the Census. The Foundation provided substantial support to build the infrastructure for OBIS and it became the key repository for marine biodiversity data. There are now over 30 million records freely available, which is a very significant achievement. It was perceptive and innovative to build

the infrastructure early in the program and make data sharing a prime requirement for participation. Unlike the physical oceanographic community, marine biologists had no heritage of data sharing. Undoubtedly a major outcome of the Census has been to change the culture among biologists and provide the means to share data and information directly or via other global initiatives such as the Global Biodiversity Information Facility (GBIF) or the Encyclopedia of Life (EOL). However, the long-term prognosis for supporting OBIS is uncertain. There was insufficient attention by the OBIS governing group to developing a business case for ongoing support. This is an issue faced by many infrastructures that emerge from science programs and needs more global attention. OBIS, despite its move to the International Oceanographic Commission, will require more effort in building links to other data-sharing platforms and securing ongoing funding.

Future legacies: The Census has produced an enormous legacy of new knowledge that will continue to influence management of the oceans far into the future. The Census was a finite project concluding in 2010 and this focus limited the development of future plans and priorities for areas requiring further research. Nevertheless, the Census produced a considerable legacy well beyond the publications and other products:

- *Culture change:* The Census has shown biologists and ecologists that they can work together, and building personal relationships and trust is critical to that process. The Census built new collaborations that transcended disciplines, institutions and countries. There is now a legacy of a new global community of interest in marine biodiversity.
- *Technology:* The Census was not a technology development program but it did access and apply many new technologies. The Census coincided with significant molecular and IT progress so supporting the development of molecular barcoding of marine species, monitoring and tracking systems, and mapping and visualization tools. These and other technologies will revolutionize future research in the oceans.
- *Capability:* The Census did not specifically focus on building capability and capacity for marine science. However, it has left a lasting legacy in developing new disciplines such as environmental history and has created many new partnerships. It also reinvigorated some areas such as taxonomy. Many older scientists grasped the opportunity to work alongside emerging researchers, and through sharing data and ideas, new insights and publications have emerged. The new echelon of researchers will provide the leadership for taking the Census to its next phase.
- *Data management:* The Census showed that creating an infrastructure to share data, building trust so participants are willing to share data, and requiring that data must be made publically available are essential features of large-scale collaborative programs. OBIS, despite its challenges, will be a lasting legacy.

Conclusions

The Census pioneered global-scale and long-term biological research and we identified some key elements for its success and ‘lessons learned’ that might be applied to future programs. The Census succeeded in building a wide community of support and key elements that contributed to its success included:

- A simple but important message: participants could relate to the few clear goals of the Census

- Discovery was still important: the passion from undertaking missions of discovery should not be underestimated
- Globalization: the realization that only by expanding research into a global reach could real understanding of the Census goals be met
- Collaboration was better than competition: the Census built trust among scientists then delivered collaborative proposals for funds
- A culture of sharing data: the development of an infrastructure (Ocean Biogeographic Information System – OBIS) as a means to share data
- Leadership: Census participants were led by highly respected scientists and backed by powerful advocacy and Foundation support
- Effective management: by building on trust, bureaucracy was kept to a minimum
- Beyond science: the recognition that the aesthetics of science could be reflected in the involvement of the arts and entertainment sectors.
- Investing in ideas: the willingness of the Foundation to invest in the development and writing of proposals that would also leverage funding from other sources.

Areas for consideration in any future 'big science' global programs include:

- Clarity in the respective roles and responsibilities for governing bodies
- Building leadership through transparent successional processes and support for emerging researchers
- Coordination through an appropriately resourced secretariat with access to sufficient information to advise on appropriate action
- Understanding risks to the program and agreeing on mitigation strategies
- Ensuring a well-constructed and dynamic strategic plan translates vision into practice
- Building relationships with potential users of the science early in program development to ensure future relevance
- Requiring the governing body to address potential business models to ensure sustainability of key parts of the program
- Developing and supporting a strategy for globalization
- Supporting the development of a data management structure to enhance data sharing and research collaboration

The Census began from an idea within a small group, and the Foundation supported enlightened leadership and invested in bringing groups together. This built a new community of marine scientists committed to shared goals and ideals, operating in a collaborative culture, sharing data in an open portal and conducting much outstanding science. Collectively participants have shown that biologists can operate in a collaborative environment on 'big science' questions. The Census has changed cultures permanently for many and has built a baseline of knowledge that will increasingly influence policies on managing our oceans. It also raised the passion for discovery in still underexplored parts of our globe and reached a wide audience on the wonders of the marine environment. The legacies will live on.

1 Introduction

The Alfred P. Sloan Foundation (hereafter the 'Foundation') took the bold step in around 1998 to invest in scoping a potential decade-long (2000 to 2010) program to unlock existing knowledge and generate new knowledge about life in the oceans. The apparent lack of response in the US to the seminal publication 'Understanding Marine Biodiversity' (National Research Council 1995) calling for major action on gaining a better understanding of marine biodiversity led to the call for action from Dr Fred Grassle and others. The formative history of the development of what became the Census of Marine Life (hereafter 'CoML' or the 'Census') is well documented elsewhere (see Appendix 1 for a list of some key publications).

The key elements that coalesced around the inception of the Census included:

- An identifiable issue: The National Research Council (1995) report outlined how a national Marine Biodiversity Initiative might be conceived and what its goals might be
- A lack of response from traditional funding agencies in the US: Marine biodiversity appeared to have a lower priority from agencies such as the National Science Foundation (NSF) than oceanographic research
- A fragmented research community: Marine biodiversity researchers had few active coordinated national and international research programs and taxonomic research in particular was underfunded and scattered in disparate organizations
- No culture of collaboration and data sharing: Unlike the oceanographic community, marine biology was characterized by small research projects leading to publications but there was little experience or willingness to openly collaborate and share data
- No recognized open-access data portal for marine biodiversity data: Unlike the 'physical science' oceanographic community, there was no recognized data depository or common standards for sharing marine biodiversity data
- Increasing policy demands: The emergence of 'millennium development goals' with impacts on biodiversity and sustainable development meant policy agencies were requiring more information on which to base policy options
- Leadership: Dr Fred Grassle had the vision and commitment to raise the issues with potential funders and collaborators
- An investor: (the Foundation) willing to fund the development of ideas and the writing of proposals.

The Foundation has a long history of supporting basic science, especially in the physical sciences and astronomy. These communities have a deeper history and culture of collaboration and the sharing of data and infrastructure than has been the norm in the biological sciences. The Foundation saw the opportunity to build a more sharing and collaborative culture in marine biology that addressed some compelling societal issues and where many answers could only come from greater global cooperation.

Hence the Census commenced in 2000 as a program designed by scientists and supported by the Foundation to build partnerships and leverage funding to, by 2010, make a significant contribution to three key questions:

1. What did live in the oceans?
2. What does live in the oceans?
3. What will live in the oceans?

These questions were built around developing an understanding of diversity, distribution and abundance.

The Census was conceived as a science discovery program with an acknowledgement that the information will ultimately be of significant use to society at many levels, but with the compelling need to assemble existing information and fill substantial gaps in our knowledge. That the Census ultimately attracted over 2700 scientists from more than 80 nations into contributing to its goals is a testament to those needs being fulfilled.

The Census was conceived at a time when there were few large-scale global programs in biology, especially in areas where such large gaps in our knowledge were apparent. There were few models on which to base development of the Census. The Census was an idea where leadership, the means to build global collaboration and the technology to make significant advance coalesced into an endeavor that grew well beyond those initial expectations. There was an evolving structure and strategy that faced challenges by stepping into areas of scientific collaboration that traversed personal, institutional, scientific, national and international interests.

The Census concluded in 2010 so the Foundation sought an independent review of the program to develop some lessons that might be taken up by future collaborations in science. The review did not address the impact of the science but focused on aspects of governance, leadership, management, collaboration, globalization, data management, synthesis, education and outreach, and future legacies. A small independent team from New Zealand (see Appendix 2 for a summary of backgrounds) undertook the review over the period September 2010 to June 2011.

2 Evaluation methodology

The Foundation sought an evaluation of the Census that would reveal some lessons for how future large-scale, global and collaborative programs might develop. The Census was among the very few initiatives that brought 'big science' into biology, especially linking a wide range of biological and ecological experts operating on a global scale. The review team established an approach that was largely based on qualitative methods to meet the overall aims of the evaluation, which were to:

1. Understand and describe how scientists work together in a global and transdisciplinary setting
2. Understand and describe factors that impeded or supported scientists working together
3. Derive 'lessons learned' from working collaboratively
4. Develop comparisons with other relevant global projects.

In effect, the evaluation sought to understand the perspectives and experiences of the participants and stakeholders of the Census. A qualitative, interpretive methodology was thus the most suitable for meeting the aims of the evaluation.

Qualitative methodology focuses on the subjective experiences of participants: their experiences, perspectives, understandings and interpretations of those experiences. It seeks to understand how participants made sense of their experiences. Where other approaches such as web-based surveys can achieve a superficial view of a larger number of participants, qualitative methodology requires an in-depth look at a fewer number of participant experiences.

Qualitative methodology does not aim to explore cause and effect or to consider representativeness. Rather, qualitative methodology allows the evaluator to examine questions of what, how and why; exploring both process and outcome. It also explores questions of 'so what?' or lessons learned.

2.1 Design

The evaluation used the three main methods of data collection in qualitative evaluation: interviews, participant observation and document analysis. Interviews were the primary tool for data collection.

As is typical in qualitative evaluation, the design is both *planned* (in the sense of tools to be used) and *emergent* (in the sense of the sequence of data collection). Casual conversations in the course of participant observations were written up as observation notes and, if needed, followed up with a formal interview. Interviews could lead to suggestions of meetings to attend, documents to be collected, or other interviewees. Analysis of documents generated topics to be explored in interviews or a second interview with some participants.

The data for this evaluation were collected over a period of 7 months, from August 2010 to February 2011. Data collection was considered complete when no new issues or themes emerged. This is known as *data saturation*.

There is no intent to generalize (in the sense of predictive validity) these findings to other groups. However, the findings should be able to be 'recognized' by, or resonate with, similar groups. Thus the sample used in the evaluation was *purposeful* rather than representative.

Interview participants were purposefully selected to include a range of roles and diverse experiences within the Census and in similar large-scale science initiatives. During the course of some interviews, participants would occasionally recommend another participant to interview for a more detailed understanding of a particular issue. This approach to gathering additional participants is the *snowball* approach.

Interviewees were selected to cover a range of functions and activities within the Census such as governance, investor (Foundation) interests, management (Secretariat), projects, data management (OBIS), and external advice. Some people had multiple roles. Views of parties external to the Census were obtained through interviews with leaders from:

- Natural History Museum, London
- Museum of Natural History, Smithsonian Institute, Washington, DC
- Consortium for the Barcode of Life
- Global Biodiversity Information Facility
- Lifewatch Consortium
- DIVERSITAS
- National Science Foundation
- Global Science Forum, OECD
- Swedish Research Council
- Oxford University
- Atlas of Living Australia
- CSIRO

Table 1 covers the distribution of interviewees having more direct interests across the Census. Given that some had multiple roles, over 60 individual or small-group (2–3 people) interviews were conducted. Each interview lasted between 45 and 90 minutes.

Table 1 The number of interviewees providing key insights into functions of the Census

Function	Number
Governance (SSC +)	8
Investor (the Foundation)	6
Management (Secretariat)	4
Projects	18
NRICs	3
Data management (OBIS)	2
External advice	6

2.2 Data collection

As stated, the study used the three main methods of data collection in qualitative evaluation: interviews, participant observation and document analysis.

2.3 Interviews

Qualitative semi-structured interviews were used to seek and understand participants' experiences and views of their participation in the Census. The topics for investigation were customized depending on the primary function of the interviewee(s) but had some key elements of:

- Drivers for becoming involved and key benefits
- Clarity of the objectives of the Census
- Advantages and disadvantages of being involved
- How the Census changed work practices during the project and likely changes in the future
- How collaboration was manifested – what were barriers and means to overcome them?
- How well did you understand the various functions, roles and responsibilities in the Census? What influence did these have?
  If you did it again what might you do the same, or differently?
- How did you utilise OBIS? What do you think might be the future for OBIS?

Interviews with leaders of external bodies focused more on governance and sustainability issues as well as gaining some insights on how the Census was viewed externally.

Participation was voluntary and permission was sought to record interviews. Participants were assured of confidentiality. The lead author alone holds all field notes and transcriptions of interviews.

2.4 Participant observation

Additional, observations were made of two meetings of the Scientific Steering Committee (SSC) and the lead author participated in the closing event for Census 2010 in London in October 2010. At this meeting numerous 'corridor' encounters provided many useful insights and the discussions around the formal presentations indicated fruitful pathways for enquiry. Participant observation is a form of unobtrusive observation, where the observer is also a participant in the activity or setting (relevant to the aims of the evaluation). Participant observation allows the evaluator to understand how the participants make sense of their work in interaction with other participants.

2.5 Document analysis

Documents can provide examples of how official and unofficial aims and understandings emerge and change over time. The lead author was given open access to meeting papers and minutes, and key planning documents. Issues raised by interviewees were checked against documents held by the Secretariat. In addition some key papers described the formation and history of the Census and its external relationships, and the books developed as part of the synthesis activities were valuable sources for a view on the overall outputs of the Census (see Appendix 1 for a list of key publications).

This review was not an evaluation of the scientific impact so there were no analyses of citation indices or other impact factors. The review team concluded that such an analysis was premature as there is still a large number of publications emanating from the Census that are yet to appear, let alone the time taken for scientific results to influence policy. Instead, the team is proposing that such a review take place 5 years after the conclusion of the Census (2015).

2.6 Data analysis

Data analysis in qualitative evaluation involves identifying themes that are grounded in, and emerge from, the multiple forms and sources of data collected. While the topics and issues to be evaluated are predetermined, the themes that might emerge are not so determined. Data analysis is inductive.

Identifying possible themes began with numerous readings of the data, looking for the ways participants made sense of the topics and issues. Comments were coalesced around some emerging issues. It was only after all interviews were assessed that a core structure for this report emerged around the core themes of:

- Governance
- Leadership
- Management
- Globalization
- Collaboration

- Data management
- Synthesis
- Education and Outreach
- Legacy and sustainability

Within each theme, lessons that might guide future projects were identified. Some illustrative observations and summaries of comments are provided in each thematic section.

Data analysis in qualitative evaluation is both ongoing and iterative. Initial ideas began with reading data collected in the beginning of the project and continued even as new data were being generated. As new themes and issues were identified, earlier data read previously were returned to and re-examined.

2.7 Credibility

Rigor and trustworthiness in qualitative evaluation are established through a transparent and systematic approach to data collection, data analysis and presentation of findings.

Multiple types of data and multiple sources of each type of data resulted in *triangulation* of data. Triangulation ensured many, and competing, perspectives were sought and brought to bear on the subsequent data analysis. The three members of the evaluation team read drafts of data analysis and both confirmed and challenged interpretations.

Early drafts and summaries of analysis were sent to up to five selected stakeholders and participants for *member checking.* Member checking provided opportunities to comment and elaborate on analysis and to challenge interpretations.

3 Governance

Governance of institutions and organizations has come under increasing scrutiny with demands for greater transparency in decision-making, performance expectations and delivering real benefits. Scientific endeavors have not been immune from such pressures and since the 1990s there has been an increasing focus on ensuring appropriate governance structures and systems are in place.

The Census developed over this period and a number of other large-scale collaborative research projects also emerged, all with different approaches to project governance. In this section we build on some core principles of governance, identify some core issues, show how governors might respond to these issues, and provide some comparative analysis of the Census with other science projects.

3.1 Why governance is needed

Governance is primarily focused on institutional objectives around strategy, performance, leadership and stakeholder relationships. Institutions have a core human and physical asset base and allocate resources to deliver to their core purpose. Lines of responsibility and accountability are usually clear and the governors through some form of board structure take responsibility for approving strategy, approving plans to deliver the strategy, allocating resources, assessing and managing risks, measuring performance, and appointing and assessing leadership. In Appendix 3 we provide some examples of the types of governance actions under the above functions.

Institutions usually have 'owners', be they public, private or mixed ownership models, and such owners set expectations in terms of delivering benefits, stakeholder relationships and financial performance. The role of governors is to ensure that ownership expectations are met, or if not, they take steps to rectify any deficiencies in performance. Science and education institutions are not immune from these demands so over the last 20–30 years there have been significant increases in expectations from governance.

Our review focuses on how governance might work in collaborative cross-agency, institution, discipline, and national and regional science projects. Each of the above will have their own governance structures and performance expectations and the challenge is how to link those to wider expectations for benefits from large-scale collaboration and what might be an effective model for governance. Such projects often have complexities from areas such as financial resources, differences in capability and capital assets, policies on IP and data sharing, political realities, and social and cultural differences.

Many governments have moved to try to bring science and education closer to their sector and stakeholder needs by reforming previous structures, creating new models for delivery and encouraging a wide range of partnerships. For example:

- In New Zealand science delivery was reformed in the early 1990s to construct sector-focused Crown Research Institutes (CRI) from a previous disciplinary and agency focus. These reforms gave a large measure of autonomy to these institutes under a company structure, so requiring boards to have the requisite skill base and

accountabilities. The CRIs have full capability and infrastructure responsibilities Cross-university initiatives have been supported through the establishment of Centres of Research Excellence

- In Australia, the Cooperative Research Centres (CRC) were designed to align resources from a range of institutions, government agencies and the private sector towards a clear benefit for a sector or societal issue. The CRCs are 'virtual' organizations and have limited numbers of directly employed staff but access human and capital resources from a range of providers who then maintain their responsibilities as employers
- The European Union (EU) has encouraged the development of scientific networks that lead to collaborative projects with funding to support networking and capacity building within Europe and with some non-European partners. Each network has its own governance and advisory structure (EDIT, IB4Life, etc,)
- International initiatives have been developed where there were clear benefits from large-scale collaboration. In the physical sciences there has been a long-standing tradition of collaboration to address big problems in physics (e.g. CERN) and astronomy and at the interface of chemistry and biology (e.g. GenBank). More recently the biological, ecological and information technology communities have developed collaborations such as the Global Biodiversity Information Facility (GBIF) and the Consortium on Scientific Collections (SciColl)
- Investments by philanthropic organizations have also seeded the establishment of a number of collaborations across countries and institutions. In the biological sciences examples include the Consortium for the Barcode of Life (CBOL), the Encyclopedia of Life (EOL), and the Census of Marine Life (CoML).

The above examples all have differing expectations for governance and accountability (see Appendix 3 for governance principles) and it is clear there is no single model that would meet the diversity of funding instruments, partnerships and stakeholder demands. In our view, there is no single 'right' model of governance – every set of governance arrangements contains compromises that reflect particular organizational circumstances, and often each compromise has to be balanced by another action to offset potential negative consequences. Thus, the design of effective governance needs to reflect a core set of governance principles rather than a rigid set of rules.

3.2 Governance principles and functions

Institution and project design can too readily draw up charts of structures and accountabilities. Instead we advocate an understanding of the key issues that might be faced by governors, how these might be mitigated and how responses might be manifested (see Appendix 4). These generic issues can be aligned with more specific objectives of the collaboration, and our analysis uses examples from collaborations on public-good issues with a more specific examination of the performance of the Census and lessons that can be derived.

Split incentives

Most organizations face the possibility of split incentives between the owner/investors and the managers – the so-called agency or principal-agent issue, where the agent (managers)

may have incentives to act in ways that are not in the best interests of the principal (owner/investor). Many collaborative projects have multiple funding sources and rarely do projects rely almost solely on a single 'investor'. Some, such as GBIF, are funded by national subscriptions and contributions based on Gross Domestic Product formulas and this can produce challenges where a dominant funder may seek to exert greater control. In establishing a governance model, it is important to understand and mitigate any risks from 'principal-agent' dominance and separate this from 'control' of directions of the project. A complex multiple-agency project may face conflicting objectives among several principals (e.g. the dominant-funder issue) and also conflicts among several agents, which can exacerbate the basic principal-agent problem.

CoML observations: The Census had the Alfred P. Sloan Foundation as the lead 'investor' to aid and facilitate the development of a multi-institutional and country collaboration. As the 'principal' for the development of the Census, the Foundation had a keen interest in ensuring that national and other funding was aligned to support the goals of the Census. This 'leverage' model for funding was highly effective in mobilizing resources to undertake relevant scientific endeavors. But each source of leverage funding was another principal; acting through a CoML project as one agent and through its own institution/s as another agent. Thus it was unclear how decisions on the investment from the facilitation funding from the Foundation were linked into decisions that leveraged resources that were usually taken at institutional or national levels.

Once the Trustees of the Foundation agreed to invest in the Census, there was significant autonomy given to the Program Director to set the parameters for their subsequent investment in Census-related activities. This gave admirable speed and flexibility in decision-making but carried the risk that others within the Census governance structure might be able to dominate the Program Director and leverage the Foundation's funds for purposes not consistent with Foundation objectives.

The governance of the Census appeared to evolve without a clear view of expected roles and responsibilities. With the delegation of 'ownership' responsibilities to the Program Director, he became the effective Executive Governor of the project. This meant that there was insufficient incentive to address any issues such as leadership that might impact on the Census and the need for any changes as the project progressed. There were risks to the project in that any complexities from the demands of other funders and research providers may not be adequately addressed. Concentration of both ownership interest and effective governance in a single individual exposed both the Foundation and CoML to the risk of losing that person and his knowledge (for a range of reasons). There was no evidence that this risk was effectively mitigated.

There was no 'Governing Board' as such. The Program Director drove the concept of the Census, through the Foundation and its Board of Trustees having been convinced of the need for a large-scale scientific endeavor and the role the Foundation could play in facilitating collaboration and funding. The history of the development of the Census in its initial phases has been documented in a number of publications (see Appendix 1) and in the internal documents of the Census. There appears to have been no explicit discussion on the most effective form of governance but this is understandable as there were few extant examples of effective project governance in the 1990s. However, some

more explicit guidance for governance from the Foundation's Trustees might have been helpful.

Governing boards should drive and approve the development of institutional (project in the case of the Census) strategies that align with the expectations of the 'owners'. The Census had its goals to elucidate the known, discover the unknown and explore the scope of the unknowable with respect to life in the oceans. These goals excited many in the marine science community and its success is well documented. This success came from the commitment of many researchers and their countries and institutions to address these goals. The diversity of views as to the incentives to become involved in the Census suggested a disjunct between the goals driven by a 'top down' vision and the desire of most scientists to enhance their own research through a 'bottom up' approach.

The Census built a mechanism for advice on directions through the establishment of a Scientific Steering Committee (SSC) with the Chair being the effective Research Leader for the project. The SSC seemed to expand without clear documentation on roles and responsibilities and how the relationship with the 'owner', through the governance role of the Program Director, would work. Should there have been issues of leadership (see Leadership section) or direction, there were no clear pathways for resolution or direct links from the SSC to the Foundation Board.

The SSC took the role of translating the goals of the Census into a strategy for delivery. Participants from several parts of the Census commented that there was no effective strategy and alignment of resources in the early stages of the Census. People outside of the SSC were often unsure just how some subsequent project areas were chosen. The SSC became the developer of potential ideas for projects and other activities as well as acting as a reviewer for proposals prior to their submission to the Program Director. The SSC was not acting in a true governance sense as the key decisions were largely in the hands of the Program Director, who also 'controlled' significant funds. As the effective Executive Governor of the Census he would seek external advice to validate the SSC-mediated proposals as transmitted via the Secretariat (see Management section).

Findings: *A lack of clarity on expectations from the 'owner' (the Foundation) put an undue level of governance influence on the Program Director without the support of an effective governing board. There was also an undesirable 'single-person' risk concentration that was not effectively mitigated.*

Information asymmetry

Governors of enterprises and other initiatives expect to have access to sufficient information to question management on alignment to strategies. Complex endeavors such as with many science initiatives mean that governors face challenges in assessing proposals from management and leaders where there are high degrees of technical and intellectual risk. As geographic, disciplinary and cultural diversity expands, governance becomes increasingly complex. Strategies are needed that ensure governors do receive independent and competent advice before making key decisions.

CoML observations: For complex initiatives such as the Census, with its distributed global and leverage funding approach, there are risks that some projects within the Census umbrella could have undertaken work counter to agreed goals and strategies. There were views that the Census had effective and inspirational 'top down' goals and a strong emphasis on 'bottom up' project development and participation but lacked an effective strategic plan to ensure alignment of capability, resourcing and performance monitoring at least in its formative stages.

As outlined above, the SSC had a role in producing informed recommendations to the Program Director and ensuring proposals met the expectations of the owners' representative. Again the SSC was not really acting in a governance role but as an advisory board with the key decisions being made by the Program Director, who, in turn, often sought independent advice. In the latter years of the Census, decision-making processes were enhanced through having all staff of the Foundation review all funding proposals prior to their recommendation to the Trustees.

Findings: *The SSC acted largely as an advisory board with limited accountability for financial decisions. Governance functions were largely in the hands of the Program Director who sought advice independent of the SSC. Confusion of roles could have placed at risk achievement of the goals of the Census.*

Representative vs skills-based governance

Governance models are diverse and some initiatives have governance based on representation at national levels (GBIF) or institutions (EDIT) or a mixture of institutions and funders (EOL). Representative governance can provide strong knowledge of institutional contributions but may not have the breadth of disciplinary or other skills that enhance the information available to governors, and may lack enough independence to mitigate one or more principal-agent risks. An alternative approach is to have governors appointed who bring a balanced mix of specific skills to the Board such as relevant technical skills, business background, legal and financial knowledge. Some science projects do have a skills and experience requirement for governance (e.g. LifeWatch, Species2000).

CoML Observations: The Census did not have a formal governance structure so there was no evidence of discussion on governance models at its inception. However, the experience of the Census does support the need for early consideration of preferred approaches. The SSC built a membership that reflected geographic spread and brought together an impressive range of experiences in both research and key stakeholder communities. It appeared to be an ad hoc process and there were no expectations for any term-limitations or succession. This limited the development of new leadership that might take the Census community into future collaborations.

Finding: *Ad hoc processes for establishing and renewing governance of the Census limited the effective development of future leadership skills.*

Conflicts of Interest

It is important that any governance structure manage both perceived and real conflicts of interest. Processes to manage any conflicts should be robust and transparent. Representative governance provides some particular challenges and governors should not take part in any decisions impacting on their institutions.

CoML Observations: The SSC was not a formal governing board so it did not have well-documented procedures for managing any conflicts of interest. In its latter years the SSC developed better systems for recording any potential conflicts and promulgating decisions and monitoring progress. Ultimately, the SSC provided recommendations to the Program Director who acted as the effective Governor of the Census. Nevertheless, the SSC had a powerful influence on institutional and personal involvement in Census activities. Without a formal and open call for proposals, the SSC were active in developing concepts and themes and inviting proposals. This had the potential to open the SSC to charges of favoritism but there is little evidence that this was a major issue.

Finding: *The governance of the Census was not well documented in the beginning so issues of potential conflicts of interest, and measures to ensure avoiding the appearance or actuality of conflicts of interest, may not have been adequately addressed.*

Governance functions

Governing boards of any organization or other initiative should have well-documented procedures clarifying roles and responsibilities so ensuring that board and management functions are clear. Appendix 4 tabulates some of the key functions for governance.

CoML observations: As previously noted, the governance model for the Census was unclear and mixed functions across several layers of the organization. In considering expected governance functions we note the following:

- *Approve strategy*: There were clear goals set by the Foundation as 'owner' but a comprehensive strategy to achieve those goals and test progress and performance was slow to develop. It was only in later years that a more formalized process for strategic planning emerged through the SSC with links via the Project Director to the Foundation.
- *Approve plans*: The Secretariat was the effective 'manager' of the Census at least in terms of links from the Projects to the SSC then to the Program Director. Staff compiled workplans that were discussed in the SSC and progress and achievements were well documented. Their focus appeared to be towards supporting the SSC and Program Director with limited feedback to the Project participants.
- *Allocate resources*: The SSC and Secretariat did not have full governance and management responsibilities in that resourcing decisions and financial management were the responsibility of the Foundation as 'owner'. The Secretariat did not have the full suite of information to fully inform the SSC of

the need to allocate or redirect resources to achieve the workplans. The Program Director had a large degree of autonomy to influence funding, while the leveraged funding from institutions, etc. was independent and not able to be directly influenced by Census processes.

- *Assess and manage risks*: The Foundation took a significant risk in investing a substantial sum to bring together an extensive network of scientists and institutions to address some very challenging goals. The Trustees gave significant latitude to the Program Director and Census leadership but there is little evidence of formal risk assessment. Only more recently did the SSC undertake a risk assessment exercise that focused particularly on the targets to meet the 2010 completion of the Census.
- *Measure performance*: The Secretariat performed admirably in cajoling reports of progress on workplans, new and revised proposals, etc. and these reports were very useful to the SSC in gaining a picture of overall performance. However, this was not linked to financial monitoring and reporting. The Foundation conducted that function albeit with difficulties in gaining accurate financial information from the contracting institutions given the vagaries of different accounting processes. This is one of the challenges of operating a global program.
- *Appoint and assess leadership*: Leadership of the Census evolved (see Leadership section) and the decision of the Foundation to invest vested program direction to Jesse Ausubel and research leadership to Dr Fred Grassle. There was no formal process by any governance group to appoint the leaders nor is there evidence of any performance reviews. Such informality gave many advantages in the formative stage of the Census but hamstrung the SSC and the wider Census leadership in addressing issues as the Census expanded in size and complexity.

***Findings**: The Census achieved its goals with a governance mode that developed in an ad hoc fashion, did not have all of the review and assessment mechanisms that would be desirable, and failed to identify and mitigate some significant risks (which largely did not eventuate). There were significant risks to the Census in this approach but substantial benefits in giving flexibility and minimal bureaucracy to participants. Gaining an accurate picture of current financial performance was a challenge.*

3.3 Lessons learned

The Census developed at a time before there was more extensive discussion on expectations for effective governance. Systems, processes and leadership evolved into a structure that delivered a substantial body of new knowledge and built new collaborations and capability. In practice, the risks that were not well identified or effectively mitigated by the governance arrangements did not eventuate in a major way, so that any deficiencies in the governance structure had no major impact on either the program or on the Foundation.

In reviewing the experiences of governance of the Census in relation to other similar programs, we contend there is no one optimal model for designing governing structures, but we note the following issues:

- A ‘cornerstone’ investor (the Foundation) was critical and their willingness to commit a substantial sum for a decade underpinned the development of the Census community.
- The ‘cornerstone’ investor establishes goals and expectations and these should include preferred governance models and reporting processes.
- The substantial degree of autonomy and trust given to the Program Director by the Trustees of the Foundation enabled the Census to make rapid decisions about early investments.
- A clear strategic plan should be developed early in project planning to ensure the goals set by the ‘owner’ can be met. This plan should be regularly reviewed with input from all levels of the project.
- There needs to be clarity on the respective roles within governance groups including decisions on representative, skills-based or mixed memberships.
- Risk assessment and management is an important part of project direction and needs to be explicit.
- Leadership should be regularly assessed and reviewed to ensure new leaders are developed to support ongoing activities.

4 Management

The Census was a pioneer in the development of a large-scale collaborative project in the biological and ecological sciences. It was a unique assemblage of a family of projects and allied initiatives that evolved its management structures such that by the end of the decade it had a number of components and diverse memberships (Figure 1).

Figure 1 Components of the Census at its 2010 conclusion.

The Scientific Steering Committee (SSC) was the overarching body guiding directions, but, as has been discussed under Governance, it did not have full governance responsibilities. Instead it acted primarily as an advisory body developing and reviewing projects. Projects were the core of the Census. Areas for research were proposed and debated within the SSC and some pilot projects were supported in the formative stages of the program. There is evidence of considerable debate on directions and opportunities, with the ultimate deferral to Jesse Ausubel for approval to develop a full proposal to go through the Foundation's review process. Successful projects were funded for a finite term (up to 3 years) then a new proposal was submitted for continuation. These new proposals then reflected the changing emphasis of the Census. Each project had a structure that essentially mirrored the overall Census, with funds to support the PIs and a Project Coordinator, meetings of project participants, and additional Synthesis and Education and Outreach activities. As the scope of the Census expanded, so did the workloads on the PIs and Project Coordinators, with considerable stress towards the conclusion of the Census in 2010.

The Census evolved around key requirements that projects must address issues that benefit from sharing of ideas and data and be global in scope. National and Regional Committees (NRICs) developed during the life of the Census with a mandate to build more local partnerships to unlock data and resources. A Synthesis group emerged once the Census leaders recognized that assembling a number of outputs that cut across projects would maximize impacts from the Census. An Education and Outreach team also was formed and, as new technologies for mapping were developed, a team for Mapping and Visualization was assembled. A number of other areas became affiliated projects, and OBIS was the key data repository but had its own parallel governance and advisory structure.

The various components of this assemblage appeared to have few direct links to each other in terms of reporting, accountability and influence. The commitment of key people held the Census together but this was not without its risks. There was no clear documentation on roles and responsibilities and it was only in later years that the SSC developed a risk register. Interestingly the structure of the Census (www.coml.org) (Figure 2) does not have lines of accountability as would be common in most organizational structures and there is no pathway shown to the Foundation and other national and international funders.

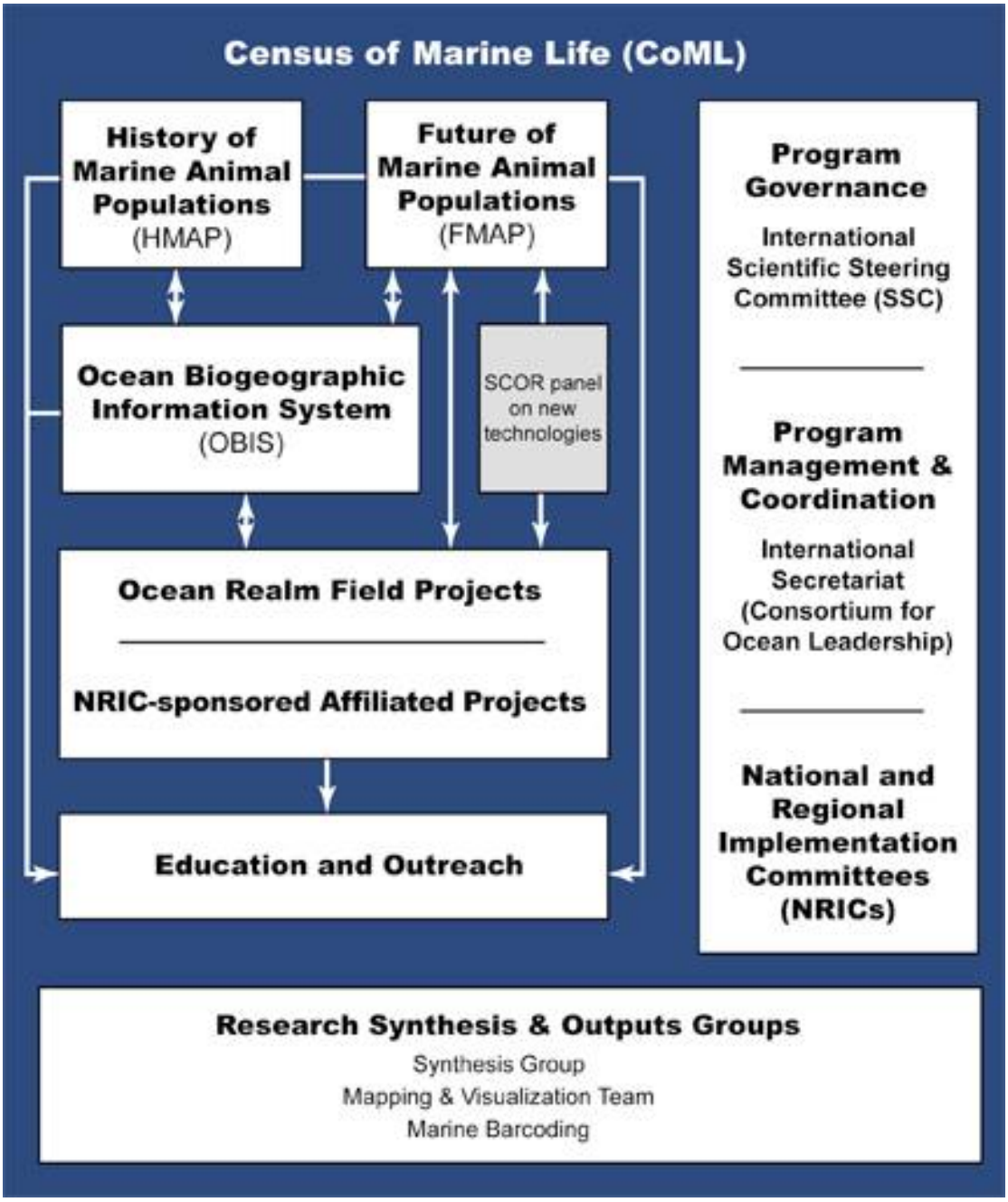

Figure 2 The organisational structure of the Census.

4.1 Coordination

Most collaborative international science initiatives are coordinated and managed by some form of secretariat whose roles and responsibilities vary. Secretariats generally service the needs of participants through supporting some form of governance and through providing communication with wider stakeholders. The last decade has seen the emergence of a number of initiatives in the biological sciences with variations in the way secretariats function (see examples following).

- GBIF has a secretariat that services the Governing Board, which, in turn, is made up of voting participants, associate country participants and associate international organization participants. The Secretariat has significant responsibilities in outreach, communication, support for informatics infrastructure, development of data-sharing processes and protocols, capacity building and financial management. It does contracts for services and research, and staff participate in many international science and policy meetings. The Secretariat is hosted within the University of Copenhagen in Denmark but is an entirely independent entity.
- DIVERSITAS is an entity under the umbrella of ICSU and has responsibility for promoting the sciences underpinning biodiversity research and management. It has a governance structure overseen by a scientific committee representative of biodiversity science but not of the financiers of DIVERSITAS. It has a small Secretariat with a coordinating role and organizes scientific conferences, with many activities delegated to national committees.
- CBOL (Consortium for the Barcode of Life) coordinates member countries and organizations involved in barcoding initiatives but does not undertake barcoding per se. It is directed by a small executive committee with oversight of outreach and communication in particular and of specialist working groups. It has a small secretariat providing administrative support.
- IBOL (International Barcode of Life) is a 25-nation project directed under a company structure and based in Canada. It has a board of directors representing funding agencies and with some independent experts and receives further advice from a science advisory board. It has a secretariat hosted by the University of Guelph that assists working groups with reporting and communications, manages overall finances and ensures adherence to policies and regulations.

The Foundation, as the lead investor, has considerable experience in managing large scientific endeavors such as in astronomy. Early on in the development of the Census its leadership recognized the need for some form of secretariat to coordinate and manage this complex and challenging endeavor. If the Census was seen purely as a scientific program with limited societal objectives, a secretariat could have been hosted in a university alongside the key science leaders. Fortunately, the Foundation recognized the need to have close connections to political and policy leadership and invited the Consortium on Ocean Research and Education (CORE), as an organization with considerable experience in coordinating oceanographic research, to form and manage the Secretariat for the Census.

The Secretariat was established within the overall structure of CORE (later evolved to the Consortium for Ocean Leadership) and its functions expanded as the Census grew, with primary responsibility being to support the SSC and be the conduit for proposals and reports from PIs. As the breadth and complexity increased, the Census leadership recognized the need for some science advice to be embedded within the Secretariat so the role of Chief Science Advisor to the Census was funded as a staff position. This role was further expanded with an additional appointment with a special focus on the NRICs and some project areas.

The Secretariat played a critical role in being the link between the expectations of the Foundation (Jesse Ausubel in particular) and the PIs of the projects. This was no easy task and the interviewees contacted for this review all expressed considerable admiration for the way Secretariat staff handled this challenge. The Secretariat ably managed the process of early review of draft proposals and feedback as getting drafts of proposals accepted by

Ausubel before they were reviewed by the Foundation was often seen as the biggest hurdle for PIs – '*Once we got our ideas and proposals past Jesse we knew we had a good chance of being funded'.*

The Secretariat did not have complete oversight of the financing of the Census. It was supported by a grant from the Foundation to provide services to the Census community and, the apart from coordinating financial reports to the Foundation, all contracting with projects and PIs was through the Foundation. This prevented the Secretariat from being able to monitor expenditure versus Progress and recommend remedial action where necessary, and from being able to advise on, or support, additional investment in projects (notably, the SSC faced the same lack of information on financial matters).

Somewhat unusually, the Secretariat did not have direct responsibility for Education and Outreach (E&O). The need for greater activity in these areas was identified in SSC discussions in 2002 and a contract was established with the University of Rhode Island to develop an E&O project. E&O became a part of the Census with a more direct link to the Foundation rather than being coordinated via the Secretariat. Likewise the Mapping and Visualisation Team had a separate coordinating role.

By 2007, the SSC identified the need for a greater focus on synthesis activities and products and formed a Synthesis Committee. The Secretariat supported this committee and its reports to the Foundation. Also the need for greater oversight was identified in 2006 and a small Executive Committee (Ian Poiner (Chair), Jesse Ausubel, Kristen Yarnicik (Program Manager), and Ron O'Dor (Chief Science Advisor)) was established with monthly telephone meetings to ensure the Census stayed on track. The role and responsibilities of this committee are not documented.

As the deadline for the October 2010 presentations of results got closer, the Secretariat staff were under increasing pressure for delivery and, hence, significant increasing pressure was placed on Project and E&O staff and the other components. Without exception all interviewees were fulsome in their praise of the approach and competence of the Secretariat staff and the Program Manager in particular during this challenging period.

> ***Findings:*** *The Census developed a management structure that delivered some outstanding benefits to marine science and policy. Much of the success is due to the caliber of the people involved rather than any formal structure. This approach was not without its risks (to both CoML and the Foundation) given that roles and responsibilities of various elements of the structure were not clearly documented and that many responsibilities and much financial authority were concentrated in a single person.*
>
> - *This somewhat fluid and evolving structure allowed for considerable flexibility in directions and delivery but was frustrating to some participants, with a lack of consistency in demands and time frames for already busy people.*
> - *There is a fine balance between flexibility and adequate review and accountability and there is evidence that at times such fluidity did threaten delivery.*
> - *Workloads on key Secretariat staff and on Project leaders were excessive at some points in the Census and this was a risk to delivery.*

- *The Census was fortunate to have such dedicated and competent people in key positions of leadership and management.*
- *Having a Secretariat outside of a participating institution provided benefits from independence and an ability to exercise political influence.*
- *The Secretariat could have had a more explicit structure with individuals tasked with linking the key components of Projects, NRICs, E&O, Synthesis, Partners, and Affiliated Projects, etc.*
- *Neither the Secretariat nor the SSC received comprehensive financial information relative to the progress of projects. This prevented them from diagnosing any financial issues, proposing remedial actions, or supporting additional or alternative investment.*
- *Performance of the management structure could have been reviewed at a number of times in the life of the Census to embed support for the concluding phases and to clearly separate completion/exit responsibilities from the task of generating a compelling proposal for new investors.*

4.2 Lessons learned

Large-scale collaborative science projects often have very complex management issues to deal with. Stakeholders want systems that are low cost but which enable their voices to be heard. The challenge is to have the right degree of support for the higher levels of leadership but to ensure that issues raised by those who largely conduct the program can be heard. Issues for any future programs include:

- A secretariat is almost universal for large programs but its roles can vary from merely administrative to actually doing some of the work. Be very clear about what is expected from a secretariat, and ensure that they have all the information and tools needed to effectively carry out their administrative tasks.
- Workloads and stress are very real issues in such programs. There are competing demands and with global initiatives there are cultural, time-zone and financial issues to deal with.
- A strong executive secretary/director is needed who has a good working relationship with the governing leaders.
- An executive committee is desirable with the ability to act between board meetings. Clear roles and boundaries for decision-making are needed and must be formally documented.
- The secretariat should have an oversight of the whole program including the financial performance. It should be the part of the organizational structure that provides uniform and consistent information to the other elements such as an SSC, executive committee, and the funder/investor. This enables more complete recommendations on future investment and monitoring of performance.
- The secretariat has a key coordinating role in linking with other international organizations and promoting the initiative to a wide range of organizations.

- The secretariat must be responsive to the needs of its participants and communicate at all levels.
- Workplans and budgets should be developed by the secretariat and these should be linked to a strategic plan.
- The organizational structure should be reviewed at about three-yearly intervals to ensure that any new components can be designed and delivered in a timely fashion as the project passes though its natural life cycle. Ideally such reviews should be carried out in conjunction with reviews of possible changes in leadership, so that all such changes decided on are coordinated and complementary to each other.

5 Globalization

The Census was conceived as a project to improve our knowledge of life in the oceans. While countries had varying levels of information about marine resources within their coastal or continental-shelf regions, large areas of the oceans had no 'ownership'. Hence effective management would require a globally coordinated approach. UN-allied bodies such as the IOC would then take on a role in developing possible policy options for global implementation.

To the credit of the conceivers of the Census, Fred Grassle and Jesse Ausubel recognized that marine life knew few boundaries so any attempt at a Census would require global connections. While the Foundation has largely had a focus on North American programs, the Census had a global need and this challenged the Foundation into developing processes to support wide participation.

Globalization in the Census had two main dimensions:

- Projects: A few projects had a local or regional focus (e.g. Gulf of Maine) but the majority had research themes that required information from beyond national boundaries. Prior to the Census, a particular country may have funded open-ocean research with relatively little international cooperation. Results were held within that country with little data sharing. By bringing this research under the umbrella of the Census, the commitment to sharing data through OBIS and developing collaborative proposals to the Foundation did mean that global cooperation increased.
- National and Regional Implementation Committees (NRIC): These were developed later in the life of the Census as a means to mobilize support for Census activities at a more local level.

This section examines views on globalization of the Census from both project and NRIC perspectives.

5.1 Projects

Most projects developed global partnerships. While scientists may have interacted in the past at conferences and workshops, there were relatively few truly international projects in marine biodiversity. Unlike physical oceanographers, biologists had little heritage of large-scale cooperative science and data sharing. The SSC developed possible areas for projects and the Foundation provided the seed funding for workshops to bring interested people together. This was critical to the success in building collaboration (see Section 6: Collaboration). Once there was agreement that a project area was viable, the Foundation also funded the writing and review of proposals for project funding. Funding for pre-planning workshops and proposal preparation showed considerable foresight and was a key factor in the success of the Census.

The workshops enabled people to interact socially and professionally and the global expectations resulted in many new relationships. The Census leadership had the experience and seniority to access extensive networks in many areas. Not all key researchers committed

to the approach of the Census and there were some examples of European–US competition, but overall the Census developed global links across many areas of ocean science.

From the initial projects the Census grew rapidly, especially post-2005. By then the Census community had proven that the concept of global cooperation could work and there was a process to develop ideas for funding. The leverage funding model meant that partners developed their own funding for operations and, for many, this had a large focus on ship time and costs of cruises. The Foundation then funded Secretariat functions for each project to ensure delivery within a global framework.

The Census became a global 'brand' and many national funding agencies and institutions responded positively to proposals being coordinated via the projects. Census 2010 did show that biologists could work together on big-science projects and the challenge is now to build on the global connections and not revert to national and small projects.

Some of the comments supporting the role of projects in building global connections include:

- The importance of building bridges, trust and connections at all levels as project design proceeds: not just with scientists but with communities, governments, etc.
- Setting expectations too high can open projects to criticism, e.g. setting a global target but really only concentrating on one area. This has challenges in managing expectations.
- The Census had a laudable problem of rapid growth but not always having the systems in place to give a consistent message. The Census was different than normal funding systems where responses take longer and are more considered and competitive. Some scientists were uneasy in this new environment.
- Proposers must show that a single country cannot deliver what the collaborative project sets out to achieve and that there are clear advantages in sharing access to facilities and data.
- Building relationships takes time and it is important to recognize mutual interests and find mechanisms to share resources.
- Dealing within the Census environment without governmental constraints was often easier than through other inter-governmental initiatives.

Findings: *The requirement for projects to operate globally helped build the Census as a global brand and build new collaborations.* *Funding from the Foundation was critical in building relationships and sharing ideas before collaborative proposals were prepared.*

5.2 NRICs

The Census had early expectations to be global in approach but there was no real strategy other than a requirement that projects needed global perspectives and partnerships. The projects were largely driven by scientists, with few demands to link to relevant policy, political, and operational groups. As the debate on policy relevance developed, the Census community recognized the need to develop regional and national networks to develop the systems and capability to engage with regional science funders- and policymakers. The NRICs emerged as a 'network of networks'.

The importance of engaging with national and regional networks is often overlooked in global initiatives. The grand vision of global science is compelling but delivery does require significant national commitment. It is often easier to get commitment at the global level than releasing resources from science programs for implementing data sharing, infrastructure support etc. Institutional and personal jealousies may emerge at national levels especially where developments may appear to enter an area where some institution or group thought they had priority. This is particularly the case with some museum communities where building trust for data sharing often takes time.

An effective global project does need scientific collaboration but also needs regional or national gateways to both build support and act as information portals. OBIS (see Section 7: Data Management) was developed as a means to share data through regional or national nodes but there has been insufficient connection between OBIS nodes and NRICs in most cases to ensure the ongoing support of nodes and portals.

The Census did not have a well-thought-out strategy for how NRICs should operate and funding was very limited in most cases. Roles and responsibilities were unclear and there was no common approach. As the Census began to gain traction, at least within the US, a US national committee was formed with significant funding from the Foundation to develop science directions and allied funding from a range of sources. Views were widespread that this committee did not work particularly well*: 'People were more interested in what they wanted out of the Census rather than overall collaborative goals', 'People did not see the value in working together'*.

NRICs relied heavily on local leadership. A charismatic leader could drive the development of an NRIC, with widespread participation, and in some areas NRICs will continue to thrive post-2010. In others there is not the institutional or financial support to continue and this puts issues like collaborative research and data sharing through OBIS at risk. The Foundation supported NRICs for regional meetings but this was usually only to cover meeting and travel costs not personnel.

NRICs had no clear pathway into the Census leadership. There was no formal NRIC representation on the SSC but the Secretariat had some responsibilities for coordinating reporting. A more formalized structure for NRICs within the Census would have given more consistency and influence for this important group. Despite this, NRICs played an increasingly important role in synthesizing information: *'The summaries were among the best products for very little money – a great return on Sloan's investment'*.

Overall, the views were widespread that NRICs were the least successful of the Census activities. Some of the comments supporting these views include:

- The US national committee was not very effective. It came in after the initial project design so scientists saw a limited opportunity to influence directions. Were they 'in the club' or not?
- NRICs were not thought out strategically in advance. There was limited funding and roles were not clearly established yet NRICs are important for legacy and policy-relevance issues.
- It is important to have a project on which to hang some national and regional work but there was no real strategy on which NRICs could build – no common approach.

- NRICs had a role in outreach, but this was a challenge for some as the NRICs were initially a network of scientists. Some got more involved as they 'wanted to look good in front of the SSC'.
- NRICs were the least successful part of Census. They started too late and were under-resourced. They needed to have responsibility to act at national levels for additional funding and unlocking data but were generally unsuccessful.

Findings: *The importance of regional and national networks in building the basis for global cooperation in science is often overlooked. Such networks can be very important in building capacity to engage in global science and apply the results to improved policy. Clear roles and responsibilities for such networks are needed with close links to overall program leadership.*

5.3 Lessons learned

Many programs develop with expectations of having a global reach. Globalization has its challenges if it is to be truly embedded in the 'modus operandi' of a program. Global biological science projects are rare so any future such project should consider the following:

- Develop expectations for global collaboration and indicators for success.
- Require global science projects to have real links at national and regional levels.
- Develop a globalization strategy early in program development and be proactive in building connections with relevant international, regional and national organizations.
- Ensure regional and national networks are represented in overall program leadership.
- Ensure support at the secretariat and local levels for building links.

6 Collaboration

The Census was conceived as a means of bringing marine biodiversity scientists together to approach some big-science questions – not a common approach in biology and ecology. The physical oceanographic community has a long heritage of working together and sharing data, often in real time. Physical sciences, including astronomy, also often coalesce around some core infrastructure or large databases and derive new insights from examining data from a wide range of sources. The Foundation has supported such an astronomical program through the Sloan Skies initiative.

Biology has begun to coalesce around molecular biology with DNA being a unifying theme. Sequencing results are now submitted to GenBank and made publically available. However, whole-organism biology and ecology have not had a history and culture of working together and sharing data and ideas. Perhaps there are few unifying themes, people are used to working with relatively small and reductionist projects and it is a complex and chaotic environment.

The Census articulated some large goals for marine biology and the leadership required a new way of working together. A traditional small-project-based approach would not raise the profile and knowledge base of marine life to a level where it could become a core part of policy analysis. The Census did not specify a particular way of working, but, through the investment of the Foundation, brought diverse groups together to build trust to share ideas and data, develop new teams, and commence a more collaborative and global approach to 'big' biological science.

6.1 Collaboration in the Census

Building trust

Census participants who were interviewed were universal in their views that being involved in such a big program enabled them to work across disciplines, institutions and countries in ways that were not previously possible. They built new research teams and the funding available to support face-to-face meetings early in the formulation of ideas and the subsequent development of proposals was critical to working together. The groups built trust and an ability to articulate some big goals and build ownership of a strategy to achieve it:

> *Getting researchers to be able to articulate an 'outcome' is a big challenge – requires cultural change. Do this well then research gaps can be identified. Building a trusting culture is absolutely essential.*

These meetings demonstrated the value of sharing problems and ideas then developing some possible research directions, a shared vision and sense of purpose:

> *We developed a belief in what we were trying to do.*

The key was to bring people together where they came into the project as strangers and left as friends. We built relationships with each other, believed in the science and believed in the team.

Collaboration in the Census had no theoretical framework – instead it was pragmatic and involved people who were willing to be engaged in a new sharing culture to achieve some challenging goals. Nevertheless, the experiences of participants in the Census may provide insights from an analysis of the interviews and publications for wider studies of collaboration:

- Collaboration was not really defined by any participants, but key elements identified included:
    - data sharing (most often referred to), including getting feedback on quality of data
    - sharing resources (space, equipment, people)
    - shared IP and ideas (new ways of thinking about IP) and writing joint proposals
    - writing/publishing together (expanding the number of multi-author and multi-institution papers in a wider range of journals)
- Building new alliances across political, social and cultural boundaries
- Recognizing that '*a single country cannot deliver what the collaborative project sets out to achieve and there are clear advantages in sharing access to facilities and data.'*
- *'Building an interdisciplinary team is a powerful force to gain new insights but it is challenging for many as we move from an individual and hierarchical model of science to greater collective activity*.'

***Findings**: The Census had a clear and challenging goal and the 'seed' funding of the Foundation and the provision of resources to prepare proposals were critical to building the trust and relationships required to build a new collaborative way of working.*

Personal benefits

Collaboration within projects led to innovative science resulting in many publications in a wide range of journals. Questions were answered that were beyond a more disciplinary and small-project approach. However, there were many other personal benefits from building a collaborative environment:

- Early-career scientists gained enormously from the Census through building relationships with highly credible scientists and institutions. This has led to invitations to publish together, conduct joint research, etc.
- Late-career scientists had established their status and were delighted to be able to put their work into a wider context and find a way to share data and ideas. '*For the first time I was able to meet ecologists and begin to combine personal taxonomic interests with other scientists*'.

- Mid-career scientists were less beholden to the benefits of collaboration as they tend to 'follow the money' to build esteem and funding. At the conclusion of the Census many of these researchers moved on to other research.
- Many scientists had limited global perspectives and the Census widened international networks.

Findings: *Being involved in the Census changed the way many marine biodiversity scientists now work. Particular beneficiaries were early- and late-career scientists.*

Data sharing

Building the Census program committed participants to data sharing. This was a significant challenge for scientists who have operated in a more competitive and protective environment. The initial workshops were critical to developing a culture that shared data and ideas, and most Census-aligned scientists have undergone a significant change in their culture and views towards the benefits of data sharing. This has not been without its challenges such as institutional barriers towards IP and data ownership, concerns about misuse of data such as drawing unjustified conclusions, lack of recognition for data sharing, issues of data quality and coverage, etc. Building trust to share data does require a sound base in 'best practice'.

- *'International collaborations can be key to getting acceptance of data standards and interoperability: make sure data management is seen against best international practice.'*
- Being able to stress 'additionality' as a key benefit can bring people on board. *'If their current funding base is not threatened, you can "sell" the benefits from collaboration. Data sharing is a big issue with biodiversity scientists and there is still a long way to go to get full acceptance of data liberation. We should look to other data-intensive communities for examples. Meteorology has a long history of data collection and sharing where the real values come out of joining many databases together.'*
- Sharing ecological data on top of species-based data also faced challenges. Some scientists were reluctant to share data until they were able to publish and be certain of the quality of the data. *'Appropriate tools for data attribution are needed at the commencement of any new project.'*
- Change views of individuals that data is not 'owned' by individuals but that it is institutional with open access. *'Taxonomists began to recognize the need for a Census but the lack of a culture of data sharing limited the conceptual uptake. It took a few individuals to give up some data and show added value that slowly led to more positive views.'*

Findings: *Early agreement on data-sharing protocols is important as is showing early benefits from data sharing.*

Institutional barriers

Participants were willing to commit to the goals and approach of the Census despite their institutions. There is little evidence that many institutions, particularly universities, had any interest in the Census as a means to gain a wider profile. However, developing a wider

culture of data sharing and other collaborative activities presented some challenges for institutions in terms of staff and departmental reward systems: how to recognize and reward collective activity and data sharing?

- When building voluntary collaborations, leaders need to develop some mechanisms by which to exert authority such as for data sharing and IP attribution.
- Institutions have few rewards for sharing data and developing wider collaborations. There are barriers to data sharing such as attribution, promotion, prestige, etc. *'We need institutional reforms to incentivize data sharing and ensure that funding agencies have requirements to make data available.'*
- Cultural and social change requires proponents of collaboration and data sharing to show the benefits to staff and institutions of moving beyond self-interest. Some museums (and taxonomists in particular) had particularly conservative views on data sharing.
- We need to avoid unnecessary complexity in these collaborations. *'It is easier to establish relationships with multinational commercial companies than many national institutions. IP issues seem to limit collaboration in government-funded bodies.'*

Findings: *Institutional incentive and reward systems and data ownership and attribution policies can limit data sharing.*

Group dynamics

The Census was constructed around projects, interacting via the Secretariat, to the SSC and to the Foundation. Possible thematic or topic areas were identified either via the SSC (top-down) or researchers (bottom-up). If the SSC found merit in the idea, the Foundation provided funding to bring a group together to develop a potential proposal. The groups were largely self-forming but were generally international and consisted of researchers willing to enter into a collaborative project and to share data. Groups had to '*believe in the science and believe in the team'* and commit to real collaboration not just doing a sub-project. Some of the comments from the interviews may provide insights into how future groups might operate in other areas of science.

- The size of the group is important. The most effective groups appeared to meet best practice for group dynamics (about 8–12 participants). Where some projects went beyond that number, they sometimes struggled to get true collaboration.
- Each meeting must make commitments to deliverables and have everyone commit to bring something to each meeting. By building relationships people then share data.
- Recognize that collaboration is better than competition and that there are real and early benefits.
- Need for the use of collaborative tools to be thought through at the start of the project. Some uses can lead to closed teams, not shared systems.
- Collaboration needs to 30ecognizes the people-to-people issues as well as getting system-to-system designs in place. There is a wide diversity of opinions and approaches as there is a less unified disciplinary base in biology compared with the physical sciences. *'We showed the value of working together, which is rare in biology.'*

- Managing expectations can be very demanding. It is often hard to promote a unified voice until suspicions are eased and all buy in to the process.

Findings: *Group size and transparency are important in building the right environment to share data, issues, problems and ideas.*

Communities of practice

The Census created a large number of groups of scientists and others who were prepared to commit to a challenging vision and some stretch goals. They largely put aside their personal agendas and took the opportunity to work differently. This is a legacy that should be fostered by the marine science community and it is important that the emerging leaders in marine biology grasp this opportunity to build on the Census at least in some targeted areas. It will be too easy for scientists to step back into more traditional ways of working.

> *The Census was able to bring together marine biologists to work together, develop common standards, and share data. I have found this to be very difficult among scientists who typically practice 'small science'.*

A summary of some other relevant comments from interviewees follows:

- International collaborations can be key to getting acceptance of data standards and interoperability: make sure data management is seen against best international practice.
- Need to 31ecognizes that 'communities of interest' can be quite broad. However, bringing in groups such as NGOs can further exacerbate suspicions. NGOs often do not trust government agencies and may not buy in to data sharing as a 'modus operandi'.
- The more complex the project, the greater the risks. Many scientists do not manage risk particularly well. Need to break complex projects into meaningful bits and aim to build particular 'communities of interest'.
- Partnerships take a long time to nurture and there needs to be investment in time and money to develop these. International links need to be looked at in a very strategic way. Unlocking data from developing countries is an example where long-term engagement is needed.
- Good disciplines on metadata and requirements for projects to share data enabled people to work and publish together.
- Building collaborative endeavors must identify the key real-world/scientific question that can only be addressed through collaboration then ask 'what information do we need to address that question?' Then the 'why and how' questions can be articulated.

Findings: *The Census has demonstrated how biological and ecological scientists can build collaborative endeavors that share data and build links to other disciplines.*

Taxonomy

The taxonomic community, which is largely museum-based, was a major contributor to, and beneficiary from, the Census. Taxonomists have largely operated as individuals so it is salutary to observe how the practice of taxonomy has been challenged and changed through

the Census. It is a community that has a responsibility to name and describe the organisms found during the Census and expectations are high that this process will be done expeditiously. Biodiversity-related initiatives such as GBIF, EOL, Catalogue of Life, all rely on the sharing of data largely from museums. These have faced challenges in levels of digitization, metadata standards, interoperable systems as well as the social and cultural changes required. Some comments about collaboration provide insights into this community.

- *'The Census played a very important role in enabling me to interact with ecologists and articulate the value of taxonomy. For the first time I was able to meet ecologists and begin to combine personal taxonomic interests with other disciplines.'*
- Building trust with the museum community in particular was critical. Museums often feel underfunded and undervalued and saw the Census as a potential threat. *'Why has a research institute got the funding when we are the natural home of discovery?'*
- Taxonomists were often the main group experiencing unease. Basically a conservative group, they saw risks in diverting funding away from their work. They were not used to 'thinking big' and collectively. Taxonomists are often not used to data sharing so a culture change was required. The level of this effort might be underestimated.
- The Census was very successful in mobilizing resources and building trust. Taxonomists are not used to working in big projects with large funds. The Census changed the way taxonomists view themselves: *'Being able to take a long-term view of science was most important and really was the pinnacle of my career as a taxonomist. It was most valuable to be able to put taxonomy into a wider framework with ecologists, molecular biologists, oceanographers, etc. Taxonomy now fits within a system.'*

  Findings: *The Census has raised the status of taxonomy and the value of data sharing, and shown how taxonomy can fit into a wider collaborative endeavor.*

6.2 Lessons learned

Collaboration and transdisciplinarity are key features of large-scale science projects. A successful project should:

- Identify and understand potential barriers to collaboration and develop specific strategies and processes to 32inimizes these.
- Have a clear view of expectations of how each discipline can contribute and how such contributions are recognized. Be prepared for some lateral contributions such as from the arts.
- Have access to some specific funding to facilitate bringing people together. Building trust to work together is critical to future success.
- Provide funding to develop proposals.
- Develop some common communication and collaboration tools that can enhance full collaboration.
- Expect significant culture change in the way some science is conducted. Be prepared to support and reward positive change.

7 Data management

The Census was conceived at a time when biodiversity researchers were beginning to ask how value might be gained from the substantial biological collections that had been acquired, largely by the great natural history museums, through several centuries of exploration and discovery. Unlocking information about species, their taxonomy, relationships and functions would follow provided information could be digitized and delivered freely over the emerging Internet protocols. The protagonists thought this would reduce demands for repatriation of specimens and provide the means to aggregate data for more robust modeling and hence policy development.

GBIF and OBIS developed around the same time in the late 1990s with a few people asking how such information delivery could be done. Initiatives like GenBank developed in the digital age so data management protocols reflected that technology. Much biodiversity information pre-dated that era so there were few common standards and protocols for sharing data and developing interoperable systems. A few leaders identified the need and opportunity but there were significant questions on feasibility and funding.

GBIF took time to develop an organization based on governmental agreements operating under a non-binding memorandum of understanding with funding provided through a formula having some links to GDP. It was then able to create a secretariat and build the infrastructure and data-sharing tools for species and specimen information. GBIF is now seen as a core part of the digital information system with links into genetic data (GenBank) and many physical resource databases and observation systems.

OBIS was developed through the ideas of Fred Grassle at Rutgers University and had many parallels to the objectives of GBIF, albeit with a focus on marine biodiversity data. As the concept of the Census was being developed, OBIS became a central part of the data management system for the Census as a data repository for Census-generated data and as a unifying infrastructure. The Foundation recognized this opportunity and provided significant funding to develop the infrastructure for OBIS and encourage participants to share data: an investment in physical and software assets and in the social processes to encourage data sharing.

OBIS and GBIF had similar aspirations with the latter having a global reach while OBIS had a focus on marine biodiversity data. This synergy was recognized with OBIS becoming a key early participant in GBIF as the main provider of marine biodiversity data. As this awakening of digital data opportunities for biodiversity grew, several more initiatives emerged and became aligned with GBIF and OBIS. Much like the emergence of start-up companies, this often confusing spectrum of acronyms and interests may coalesce into a more sustainable data management system that takes biodiversity data into wider realms and uses.

This section concentrates on data management within the Census, prospects for OBIS and lessons learned for the long-term sustainability of data infrastructures.

7.1 The Census and data management

OBIS was the 'glue that held the Census together'. Undoubtedly the OBIS framework provided the means for the early sharing of data in the planning workshops and helped identify survey and research data gaps. The significant early investment in building a reasonably stable infrastructure was perceptive even if there were some questions on its relative significance. However, without such an infrastructure, projects would have developed their own databases with limitations to sharing and interoperability. Also the clear and powerful expectation from the Foundation was that data generated under the Census umbrella must be openly shared via OBIS.

Biodiversity scientists did not have a tradition of data sharing and the significant cultural change the Census required is a lasting legacy for marine biology (see Section 6; Collaboration). The early planning workshops brought together people who were willing to share data and ideas and OBIS was the means to compare data on a common platform. In a few cases people elected not to be part of that process and reserved the right to operate in a more competitive manner outside of the Census. However, this was very much a minority view.

The decade of the Census saw significant changes in data management. Hardware and software platforms proliferated and it was a challenge to keep providing processes and tools for data sharing and interoperability let alone invest enough in reaching out to researchers who had interesting datasets. This is one of the conundrums whereby requirements for metadata and data-sharing protocols can be imposed on new projects yet there may be substantial benefits in investing in opening old datasets to wider scrutiny. Interviewees did offer some comments that there was insufficient focus in some cases on identifying and releasing such datasets. The use of 'mini-grants' in some projects proved to be a very effective mechanism to get data into a form for sharing through OBIS.

Early investments in OBIS enabled systems' development, and the sharing of >30 million marine biodiversity data records through OBIS is a significant achievement. However, there are views that OBIS does not have sufficient resources to provide the full level of support needed to keep its premier position and some projects prefer to develop and use their own websites and servers for data management.

OBIS also had a parallel governance and advisory process that was challenged through personalities and an unclear link through the SSC to the Census as a whole. Risks inherent in this process could have been identified and mitigated earlier in the life of the Census. There were also challenges in OBIS's relationships with organizations such as GBIF. This appeared to be based around the issue of OBIS as 'the' node for marine biodiversity data or was it acting as one of several nodes? However, the Census did not cover all biodiversity-related research in the oceans nor did it have strong institutional commitments for data sharing, so, with OBIS being seen as a Census node, other researchers and institutions developed the means to share data with the likes of GBIF without going through the OBIS portal. This resulted in some tensions.

OBIS developed as a leading-edge data-sharing portal and proved that the marine community could share biodiversity data. Through the Census cultural change occurred and there were many demonstrable benefits from being able to build wider data into synthesis and modeling.

However, the move from 'proof-of-concept' to a more sustainable and central model with sufficient resources to keep at the leading edge of data management remains a challenge.

Despite these issues OBIS was a key part of the Census and a summary of some of the many comments from interviewees on OBIS include:

- The mini grant system was very valuable to access data that might not otherwise be accessible. Sometimes people had a 'take not give' attitude so risks were there.
- The challenge of allowing each project to develop its own metrics. Despite expectation on consistency and standards, there was no real demand from the SSC to make this happen.
- *OBIS did not really deliver – it was OK for what lives where but not for meaningful comparisons*. OBIS was not really responsive to user/researcher demands so project-specific data management systems were developed for some projects – not always compatible with OBIS.
- Getting the data model right is important – inappropriate data formats and structures can constrain the ability to share data across a wide range of systems.
- Not enough staff to really interact as equal partners. Need to build more capability. Imbalance of budget and influence cf. GBIF. A critical mass of funding and capacity is needed to give confidence.
- In looking back probably there were too few nodes and as CoML funds are reduced, nodes are further under threat.
- Efforts to build systems but no money for content – a source of conflict.
- Some money eventually given for data rescue – 'taxonomists were expected to give them data for nothing.'
- Needs to be explicit at the start of the project. Data-sharing protocols and metadata recording are essential. Do not underestimate the need for culture change.

Findings: *Aligning a data management system (OBIS and an expectation to share data) within the Census was enlightened and provided the 'glue' that helped to build the Census community. There were complications around leadership and funding that limited the role of OBIS in the latter years of the Census.*

7.2 Future of OBIS

OBIS is now in transition from its role as part of a global research program to one where it provides core marine biodiversity data for a wide range of uses. It has proved it worked and produced some valuable products. Now the challenge is to keep the node system active and well supported and to keep the OBIS systems up to date. Like the Census as a whole, a key issue is to understand how to transition to a more sustainable and embedded future.

Since its inception OBIS has been strongly associated with Fred Grassle and Rutgers University and the research activities of the Census. During the research phase this was the correct location. However, with OBIS' attempts to have a wider role in ocean policy and education, as well as being a data portal, its relationships, governance and funding need to be

reassessed. The move of OBIS to come under the umbrella of the IOC through its International Oceanographic Data and Information Exchange Program (IODE) is timely and will enhance links to policy development. But there are risks that OBIS may no longer be the preferred portal for marine biodiversity data if its profile is lost within a wider oceanographic community.

The governance of OBIS and its relationships also need to be reviewed in light of its new 'ownership'. This report is not an in-depth analysis of OBIS but by applying some governance principles (see section 3: Governance) to any review, the marine community may be able to develop a model that meets both scientific needs and the demands of funders and users of the data. One immediate opportunity is to examine the relationship of OBIS with GBIF. Currently OBIS is an associate participant through being a data provider. With the move to the IOC, OBIS can be repositioned as a member of the Nodes Committee in the current GBIF structure with the IOC taking the current OBIS seat at the Governing Board of GBIF.

A reconstituted governing board for OBIS could also have a role in developing funding sources beyond what might come via the IOC and in developing links with data managers beyond the IODE. OBIS needs to have some form of identity and funding to keep it as the preferred data-sharing facility for marine biology. The alternative will see OBIS decline in importance as new data management systems emerge.

Any governance arrangement for OBIS also should examine its physical location. The review team has concerns that having such a core infrastructure within a university environment may not be the most secure. Universities provide excellent support for research projects that have finite durations but may not be the best location for a long-term infrastructure. Data centers are now emerging as a real alternative and they can provide the necessary hardware, software development and help-desk support that a small group of, albeit very dedicated and skilled people within OBIS, cannot provide on a long-term basis. A summary of some of the comments from interviewees include:

- Think of legacy issues early in project planning: data management (OBIS), building an effective legacy infrastructure and governance arrangements.
- OBIS is not the sole route for publishing marine biodiversity data: need to ensure close links with other data publishers.
- OBIS role – there were leadership issues, conflict of views on data ownership, and the strong role of Fred Grassle.
- There were uncertainties on Rutgers University's views on ownership and control.
- OBIS was well supported for infrastructure but not necessarily widely known outside the CoML community. Linkages to other initiatives not widely known.
- Focus has been on project delivery with little discussion on long-term directions. Not a strong strategic direction since 2006–07.
- OBIS was built by the enthusiasm of individuals without building enough institutional and country links. This may be fine for initial research applications but limits options for long-term sustainability.

- OBIS as legacy? Not quite living up to promise. Go beyond a university base (not the right place). IOC has some power but small size and limited budget but the value in the future will be its links to physical data

  Findings: *In common with many data-intensive initiatives there are challenges in moving to new long-term support. OBIS now has a new 'home' in IOC but questions remain on its long-term funding, governance and relationships with other initiatives. The IOC should become the Associate Participant in GBIF.*

7.3 Long-term sustainability of data infrastructures

Issues surrounding OBIS are a microcosm of wider issues facing the future of long-term environmental data often gathered as part of research projects. Research funding agencies will often fund data management systems as part of research projects but are reluctant to support the long-term infrastructure requirements. The conventional research process is to gather data and publish. Journals are increasingly requiring some form of data publishing but the institutions are not always well connected to metadata repositories or data aggregators.

Our ability to store and access vast datasets is now widespread so the issues are not necessarily technical. We need to consider new business models that support our capability to build relationships, development of capacity to make it easy and intuitive to share data, and working with end-users to develop new tools for their policy development. It is the social infrastructure that will be critical if we are to build a new approach – information technology and data storage can remain within institutions, as we are no longer aiming to build large centralized data storage.

Pioneering initiatives such as OBIS and GBIF showed that data could be shared while the individuals or institutions retain data ownership and storage responsibilities. As outlined earlier there has been a proliferation of initiatives in biodiversity each with different foci but facing some common issues of standards, software development, user support, etc. Increasingly there are joint meetings on these issues but most are still struggling to develop the business case for long-term financing.

The 'E-Biosphere' meeting in 2008 brought together leaders of a number of these initiatives but it is now time to move from problem identification to some potential solutions. Project-based funding will conclude for many in the next five years so leaders will need to consider options for embedding infrastructure in international institutions (e.g. OBIS into IOC), gaining key institutional support (e.g. in a major museum), linking with other international data-intensive initiatives (e.g. Global Earth Observation System of Systems – GEOSS), or archiving key metadata in data centers. An important lesson from the Census and the development of OBIS is that such consideration, at least at governance levels, should begin well before the end of the project or program.

The social and physical infrastructures for long-term data sharing must be robust and ideally funded beyond the short periods for research project funding. Developing the processes for funding will be challenging but a failure to provide support limits our ability to develop new insights and maximize the return on the investments in projects. Some of the insights from interviewees that support further thinking on future business models include:

- Recognize the need for information architecture at the commencement of the project. This must be more than an IT exercise and recognize the need for the development of cultures of data sharing.
- Observing systems and data infrastructures seem to be the next emerging area: need evidence to build the case for observing systems to ensure that the data can be readily converted into policy-ready recommendations.
- Metadata is a key factor – address how data can be stored, retrieved, accessed etc. Have data sharing as a requirement for funding and data validation should be a regulatory requirement.
- Look to other data-intensive communities for examples. Meteorology has a long history of data collection and sharing where the real values come out of joining many databases .
- How do you embed environmental data into a long-term infrastructure? Most projects are for a finite period and we should not expect too early delivery of benefits.
- Need vision then decide if an entity is needed and should it be time bound or become an ongoing entity? Can lead to conflicts with parent bodies. Find the right role for initiatives.
- Governments do not have good strategies around data management so they struggle to align resources to develop suitable platforms.
- Responsibility to lead on complex issues like data sharing, attribution – technology and culture.
- Developing infrastructure alone may not be enough – need to deliver to some of societies' pressing needs. Conundrum of being the vehicle to serve data to a wide range of users or focus on issues such as climate change or invasive species.
- Note the challenge of the Millennium Ecosystem Assessment (MEA) – raised a lot of profile but the data are in danger of being lost. A metadata depository is essential. By linking data from the MEA with initiatives such as CoML, synthesis activities become even more powerful.
- Any future projects need to have a clear data management policy at the beginning – difficult to impose after the project has begun. Need to have clear timeline for delivering data to the network.
- We need clarity on where data might be held and confidence that best practice is followed. Systems to ensure data quality are essential.

Findings: *Our technical ability to store and access vast amounts of data is growing rapidly. We have not adequately addressed the social and institutional infrastructures needed to maximize the benefits from wide access. Some more facilitation between key leaders of global initiatives may develop some more robust options for long-term support.*

7.4 Lessons learned

Large-scale long-term projects need early agreement on a core infrastructure to support data storage and subsequent data sharing (including audio, video, digital files) including support to

develop best-practice tools for data sharing, interoperability and review of data quality. Project governors need to address long-term sustainability of data storage and access at an early stage. Additional issues include:

- Have an explicit data-sharing policy at the outset of the program and include standard protocols for metadata, data quality, intellectual property, etc. that meet best international practice.
- Ensure that projects and individuals have specific expectations for data sharing and attribution, with appropriate sanctions.
- Consider having an advisory committee with specific responsibility for data management and ensure the infrastructure is supported within an appropriate organization.
- Ensure connections are made to other key initiatives.

8 Synthesis

The Census was conceived as a science discovery program. A key driver was to develop the baseline of information of life in the oceans that might then be used for future policy development and management of marine resources. Providing information in a format for relevance to policy and management was not an objective. As the Census progressed and grew in depth and breadth of coverage, the debate on potential relevance also grew. Most scientists were immersed in their projects and producing many scientific publications without expectations that their work would then be linked with other Census outputs.

By 2007 the SSC began to reassess directions and the looming end-point of 2010 began to focus attention on what sort of products might be produced to mark the conclusion of Census 2010. There appeared to be no real strategy behind the recognition of the need to bring together the findings of the Census into a range of products for diverse audiences. This caught some project participants by surprise and added some stresses to meeting their deadlines. Had the development of synthesis as a key theme been more clearly signaled and with clearer expectations, some of the angst that characterized the lead-up to the final reporting on the Census in London may have been lessened.

This was another example of the evolution of the objectives of the Census. The flexibility of the somewhat loose structure of Census management and the willingness of the Foundation to make rapid decisions on investments had advantages. But the lack of a guiding and dynamic strategic plan did mean that some participants were frustrated when sometimes inconsistent and contradictory messages emerged from the Secretariat. From the ‘surprise’ in 2007 that synthesis would now be a key product there was a long period before a consistent framework for reporting was produced. The Secretariat was merely reflecting the lack of clear direction from the Census leadership.

However, the Foundation did invest significant sums to bring together a team to focus on synthesis. This team did produce some substantial publications and other outputs (movies, maps, etc.) that will be lasting legacies. Getting to that point was undoubtedly stressful for many and it did divert some potential future leaders from giving consideration to where Census activities might continue. The focus on completion did come at some cost to the Census community.

As the products from synthesis of the activities of the Census began to emerge, the Census leadership saw the opportunity to become more engaged with organizations that might use information in developing future policies and management options. At its outset the Census appeared to have a somewhat agnostic view of the value of linking with international and intergovernmental organizations but this changed with the realization that some of the information could be of value. It is encouraging to note the emerging involvement of Census leadership in some of the debates on biodiversity under the UN umbrella agreements such as the CBD.

The Census leadership also recognized that policymakers required different products to those aimed at a science audience or the general public. The publication of ‘A Summary of the Census of Marine Life for Decision Makers’ (www.coml.org 2010) is important and mirrors similar publications produced by the Millennium Ecosystem Assessment and the

Intergovernmental Panel on Climate Change. Through such products and the significant body of data and conclusions behind them, we can expect the results from the Census to be very important in the future deliberations of the emerging Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES).

Building links where the science becomes 'relevant' to a stakeholder or end-user can be challenging to some scientists. Many participants in the Census were comfortable in doing the 'science we always wanted to do' but were more challenged where their results were being placed in a policy or management context. While the Census did develop significant baselines of information on marine species, there are still many gaps. Policymakers cannot wait for the definitive science but must use current information and balance this against other economic, environmental, social and cultural issues. The Foundation could look to providing assistance for Census scientists to better understand how the science–policy interface really works. This may help in reducing the concerns about the balance between a 'discovery' program and one focused on delivering outcomes.

Synthesis and relevance to achieving outcomes are linked. Some of the issues raised by Census participants include:

- Building bridges with key international agencies is the key to making an impact on policy – the Census should provide the evidence to show how knowledge of ocean life can help meet global commitments.
- Be clear on what relevance really means to your project – one can oversell relevance by raising expectations ahead of information. In many cases it is too early for a measurable impact on policy and there were not the right people in the Census to link with policy agencies. There has been a 'fear of relevance' in some quarters.
- Policy relevance requires a different language and understanding of pathways of uptake – has the Census helped to raise the ability of scientists to think about outcomes and societal benefits?
- Synthesis can demonstrate the value of data aggregation on many fronts – good examples abound where data from a range of sources give a more compelling case.

Findings: *There is a tension between doing great science in a discovery setting and converting results into language more relevant for policy development and management. The need for products that integrate and synthesize information should have been identified earlier in the Census alongside a consistent reporting framework.*

8.1 Lessons learned

A compelling and simple vision also needs to recognize that the information can be valuable beyond merely adding to the body of knowledge. In designing any future collaborative program, leaders and participants should consider:

- Results will be valuable beyond a scientific audience so pathways for converting findings into policy or management relevance should be identified early in development.

- People experienced in policy development should be brought in early to program leadership groups.
- Project proposals should identify potential relevance and societal benefits.
- A strategic plan should identify expectations for developing wider syntheses of results.

9 Education and Outreach

A simple message and the excitement of discovery meant that the Census had a compelling framework to reach a wide audience. The discovery of a new species, especially given the dramatic images of many of these species, excited media and the public about what might be living in our oceans. The Census could have been a science program with the focus on science outputs through the traditional publication routes. As such it would have been similar to programs funded through science funding agencies. Instead, the Foundation showed considerable foresight in requiring an Education and Outreach (E&O) component for each project and supporting an overarching organization through the University of Rhode Island.

Census 2010 became a 'brand' under which there were many activities related to marine biodiversity. By funding the preparatory workshops for projects, the Census was able to build a commitment to its objectives and expectations. It was clear that 10–20% of the Foundation funds were to be used for E&O and that each project would have a communication officer and the respective E&O activities were assessed in the proposal review processes. Communications are often added as an afterthought to projects and specialist staff see it as an added job with no resourcing, that leading to added pressure. The Census was perceptive in bringing communication into planning and resourcing early.

Census leadership recognized the need for overall coordination of the E&O activities within the program. While this could have been a function of the Secretariat, the leadership invited the University of Rhode Island to submit a proposal to be responsible for overall E&O of the Census. This was done in some haste and exposed the Census to some potential risks in that alternatives were not considered. Fortunately the performance and professionalism of the team and the close link with the Secretariat clearly reached wide audiences in many countries. The team was able to access external expertise to build networks and assist in writing for target audiences.

One of the challenges was to define what E&O means especially given the global scope of the Census. The E&O program was not technology transfer in that it was not working with users to ensure the research findings are embedded in their operations. Nor was it an education program in terms of specifically developing future capability, but there was a spillover benefit from the projects as a considerable number of graduate students and postdoctoral fellows were supported and these will be critical to any future program in research on life in the oceans.

The E&O program exposed many Census participants to new technologies and approaches for communication. Scientists are comfortable with publishing in scientific journals but less so in preparing materials for more widespread consumption including web pages and social media. The Census coincided with the rapid growth in communication tools and approaches and some projects were adept at using different media to communicate their results. Given how social media and collaborative tools have now become embedded in society, any future Census-like programs should agree on expectations for communication and the necessary infrastructure early in their formation.

Undoubtedly the use of images and other visual cues such as maps makes for compelling media releases. What is widely seen as a 'masterstroke' was the involvement of the arts in its various forms in profiling the discoveries of the Census:

> *The 'aesthetics of science' should not be underestimated: do not get totally hooked into economic justifications – art and science are compelling interfaces to transform discovery for different audiences.*

The link with National Geographic and Google also had significant impacts for the Census. For example, the map produced by National Geographic is a significant educational resource and the development of Google Oceans provides an interactive platform on which to deliver data such as from OBIS.

The Census was a very diverse program and there was a diversity of responses to E&O. The skill mix of the designated communicators within projects varied, as did the material available from which to launch a media profile. Content had to be provided via the scientists but we must not underestimate the importance of getting the right language for wide media uptake. To this end the contracted services ability of Terry Collins to create press releases and use his networks to gain access to the media was critical to the Census.

The E&O team played a key role in the penultimate London event that profiled the Census to wide media interests. Undoubtedly this was a very stressful period with many changes and revisions. The close relationship between the Secretariat and the E&O team was critical to the success of the event. However, scientists were challenged in that the event was tightly controlled and beyond the normal expectations of many researchers. Perhaps the expectations and processes were not developed soon enough to get a clear commitment and understanding from the scientists?

Overall the E&O team made a very significant contribution to the Census and the support of its activities in building the Census 'brand' should not be underestimated. Some comments supporting the E&O program include:

- Speed and decisiveness can be beneficial but must recognize the risks: be prepared to protect the 'brand' and have clear responsibilities for handling media and other comments.
- New discoveries are seen as a 'politically safe environment' especially when aligned with visual messages.
- Learning from the experiences around communication of climate change science might be valuable – scientists need to be aware that the way they work and publish can be misconstrued.
- Outreach was challenged by the need to find a balance between the 'wow' factor and the need to demonstrate some policy relevance. There was also the balance between species ('wow') and ecosystems (relevance for management).
- The early decision to make E&O a key element of CoML was critical and underestimated in terms of significance early in the life of CoML. It made the research accessible to a wide audience

Findings: *E&O was a very effective and influential part of the Census. The Census had a high global profile and the media statistics show a wide diversity of outputs. The*

Foundation was able to invest in coordinating an E&O program but some of the scope and expectations for E&O could have been developed earlier. The investment in connecting science to the arts in the Census was a 'masterstroke'.

9.1 Lessons learned

Science programs cannot operate in isolation from their wider communities of interest. Successful programs will have specific E&O expectations that are relevant to their stakeholders:

- Understand the target audiences and access the appropriate skills to focus activities.
- Develop a few performance measures on which to assess impacts with target audiences.
- Utilise current social media to build widespread collaboration, support and awareness.
- Have specific responsibilities within a secretariat to coordinate E&O activities.
- Be sure that allied projects understand their expectations for E&O and resource them appropriately.
- Make sure the 'brand' for the program is appropriately protected to ensure the quality of science, communications and impact is maintained.
- Remember to use the arts and creative sectors in combination with science to enhance aesthetic/discovery/ethical dimensions of the results.

10 Legacies and sustainability

The Census was a defined program that ceased in 2010. Very few science initiatives have such a lengthy commitment by a 'cornerstone' investor and this enabled Census participants to plan challenging and long-term projects and to spend time building collaborative teams. Such long-term commitment is rare in international and national funding. The Census developed some infrastructure such as OBIS but it was largely a program that 'did science'. It developed projects that reached into many realms and regions and produced substantial baselines of new knowledge. It had a simple message and built a 'brand' based on discovery combined with technologies and knowledge sharing. It also created new teams of researchers who worked in a collaborative environment.

The challenge now is the success of the Census raised expectations that it would continue in some form. While the Census leadership was aware of the 2010 target and in later years supported a strong focus on completing deliverables, there was insufficient attention given to developing future leadership, business models and relationships for future funding. The Foundation has given additional resources to support Secretariat functions for about 6 months to ensure the information from the Census is secure and enable some people to come together to plan a way forward.

The Census has given the science community a legacy of experience in establishing and running complex global projects in biology and ecology. There are many participants wishing to be part of continuing endeavors but there are concerns that momentum may be lost unless some structures are put in place to ensure some continuity of the networks developed in Census 2010.

The SSC did not develop robust discussions on potential business models for some ongoing activities. It appears that this was not actively encouraged as it may have diverted attention from completion in 2010. Following the London meeting in October 2010, the SSC, Project leaders and NRIC representatives did meet to plan a potential way forward. The timing was probably not the most propitious as many participants were suffering from 'completion fatigue', so there were no clear views on a potential way forward. Since that meeting, some emerging leaders have developed a potential model to keep some areas of the science together towards fostering a 'Census 2020' program. This will be progressed further at the World Conference on Marine Biodiversity in September 2011.

In developing a 'Census 2020', participants need to be mindful of how Census 2010 evolved and built infrastructure and approaches to marine biodiversity science. Interviewees were asked about the legacy of the Census and what might happen next. Some of the key issues from discussions with interviewees on the future included the following.

10.1 Clarity of the issues

The Census had a simple message with clear goals. It was understood by funding agencies, institutions and researchers and by stressing 'baselines, baselines and baselines' the basis for developing future policy and management options became possible. Some comments on this focus include:

- 'Baselines, Baselines, Baselines' is a compelling concept if a potential use can be identified. What are the needed baselines for effective policy?
- Very important to understand the core purpose of the initiative – sometimes messages were confusing. From the core purpose, the need for resources becomes more transparent – must ensure that resources support that core with other resources then adding value.
- CoML is a 'discovery' program and having been able to complete a baseline census of some major parts of the ocean, the question now is 'where to from here'?
- Cannot resell the same projects beyond 2010. What is the new paradigm and format? How might we develop better links to policy?

10.2 The Census as a 'brand'

Many existing researchers coalesced around the Census. It can be argued that research in marine biodiversity would have continued without the Census but with a less global and collaborative process. The Census provided 'additionality' by bringing multiple funding sources together. It was held together by the innovative funding from the Foundation that supported the development of trust and collaboration, built a culture of data sharing and the infrastructure to support, and built a public profile and 'brand' by a very active Education and Outreach project.

The Census 'brand' is a powerful construct and those involved in past and future activities should ensure the science conducted under the Census maintains a high profile and that any future science that claims to be part of a Census does meet characteristics of data sharing, collaboration, quality publication, etc.

- Ongoing and any new projects that build on Census 2010 need a framework for any use of the 'brand'.
- Need for the use of collaborative tools to be thought through at the start of the project. Some uses can lead to closed teams, not shared systems.
- Being able to stress 'additionality' as a key benefit can bring people on board. If their current funding base is not threatened, you can 'sell' the benefits from collaboration.
- Build on the momentum of the Census to sustain a new marine biodiversity community. We do not need a Census again but we need to build some new communities such as to reinvigorate taxonomy.
- Need to have a duty of responsibility to finish the process of description and vouchering. A lasting legacy is a community of scientists that can be mobilized to coalesce around funding opportunities.
- New message, new leadership, build on the 'brand'. 'Ocean Health'? Future programs must show societal benefits.

10.3 Building leadership

Governance of any future program needs to build on the capability developed within the Census, especially from the emerging scientists who were active in leadership roles in projects and other key components of the Census. Any new program will need to build a model for governance that sets roles and expectations for various functions and should develop a specific leadership development process. We do not advocate an excessively bureaucratic process but experience from the Census suggests some more structure would reduce risks to delivery. Some of the key elements include:

- Need to build consideration of long-term support into governance and strategy at an early stage. Too many projects delay this phase. Having a goal of independence may be important.
- Leadership needs to evolve over the course of a project. This is not often done explicitly. The model of the entrepreneur/scientist might be one to explore further. At what point in a collaborative project that may have had its genesis in 1 or 2 people do you have to move leadership on?
- Leadership is critical. Encourage convergences – set the goal and build alliances with potential funders.
- Think of legacy issues early in project planning: data management (OBIS), building an effective legacy infrastructure and governance arrangements.
- Governance models need to be enduring and 'fit for purpose': regular review of governance performance, roles and responsibilities is needed.
- Funding may come and go but a sound governance structure should endure.
- Governing groups/ boards need a good process for renewal of skills: have in place a succession and development process.
- Revisiting priorities and strategic drivers are essential governance functions during the course of a project: need robust and transparent processes for establishing priorities.

10.4 Management

Most global science initiatives are managed by some form of secretariat. Sizes, budgets, roles and responsibilities all vary but are generally established in response to the needs for coordination and building links to key stakeholders. Census participants all recognized the major contribution made by the Secretariat and consider some such body would be necessary while considering some of the following issues:

- Design a program management structure that has clear roles and responsibilities. Enable contributions from those that want to commit.
- Need for the use of collaborative tools to be thought through at the start of the project. Some uses can lead to closed teams, not shared systems.
- The more complex the project, the greater the risks. Many scientists do not manage risk particularly well. Need to break complex projects into meaningful bits and aim to build particular 'communities of interest'.

- Need to build an exit strategy to keep the global community together. Risk we may drift apart unless some secretariat functions can be sustained.
- Managing risks is a key role of governance: needs to be transparent and have clear accountabilities through the Executive Director or equivalent.

10.5 Data management

A key legacy of the Census is the creation of the means to share data for wider benefits (OBIS) and the development of a culture among Census participants where data sharing is a new way of working in marine biology. It is important than any future collaborative initiatives build on these infrastructural and cultural advances while recognizing that significant changes are needed in terms of developing long-term support and reforms to institutional incentive and reward systems. Specific policies on IP and data sharing need to be developed for any future program. Comments relating to the future of data management include:

- Culture change leads to greater collaboration. Can we move marine biology into the data-sharing culture of physical oceanographers and astronomers?
- OBIS is a critical legacy that must be supported in a more robust structure.
- Data sharing is a big issue with biodiversity scientists and there is still a long way to go to get full acceptance of data liberation. Issues such as a lack of trust on data use, data quality, attribution, etc. are all important.
- IP can be a sensitive issue especially in discovery projects in developing countries: need a clear IP and data ownership policy that reflects best practice.
- Look to other data-intensive communities for examples. Meteorology has a long history of data collection and sharing where the real values come out of joining many databases together. Meteorological data have parallels to biodiversity data in that the data are collected locally then scaled up to regional, national and global scales.
- Observing systems and data infrastructures seem to be the next emerging area: need evidence to build the case for observing systems to ensure that the data can be readily converted into policy-ready recommendations.

10.6 Discovery to relevance

The Census was a science discovery program first and foremost. It had a clear goal to add knowledge of marine biota especially in realms where data were limited. Undoubtedly it has provided key baselines from which future options for policy and management can be developed. It is often too easy to overpromise relevance or economic advantages before there are sufficient information or technologies available. However, now it is possible to begin to show actual and potential relevance so any future program should have clear expectations that certain outcomes would be achieved should the science and links to key stakeholders be successful. Any future program should have some stakeholder (end-user) involvement in governance and advisory functions. In moving to a greater relevance, a program would need to re-evaluate outreach with an increased focus on technology transfer instead of profile-raising and ‘brand’ development. Some comments from interviewees include:

- There has been a 'fear of relevance' in some quarters. Given the large number of new species discovered, the taxonomic community will have to become even more involved and be prepared to move the process of naming and description along using new technologies.
- Be clear on what relevance really means to your project: can oversell relevance by raising expectations ahead of information.
- Be prepared for the unexpected: role of barcoding in food and border protection.

10.7 Capability and capacity building

The Census was aimed at increasing knowledge baselines and did not have a specific focus on developing capability in terms of student and postdoctoral support. In the event there were large numbers involved in the Census and a number of project coordinators gained substantial experience in doing global science. These people will be of great value to any future program. The Census did not have a specific aim to increase the capacity of developing nations in particular to participate in the research and the attempts to build more regional and national links through the NRICs were uneven at best. Any future program will need clarity on its role in capacity building and be prepared to support regional initiatives that might expand data access and policy relevance. Such initiatives might be very significant in operating OBIS nodes and some commitment to education might help to build regional capability.

10.8 Business models

The Census evolved its structures from a clear science vision. It did not construct governance and advisory systems with a view on a long-term future; instead it had a focus on completion by 2010. This imposed some strong disciplines on participants to deliver results but at the expense of enough thinking on future options. Any new program should have access to skills at governance levels to assess future directions and assist in the development of a range of models for ongoing funding. An effective program will have the ability to evaluate progress, reprioritize resources and search for funding. The Census did operate a 'leverage'-funding model that was highly successful in most areas but there is a need for some more transparency in how such funding is accounted for.

Many areas of 'public good' science do not have robust business-case disciplines and structures to assess progress and the need for future investment or disinvestment. In this report we contend that such an approach in the Census may have resulted in some greater levels of resource reallocation and identification of opportunities for ongoing funding. In many ways public good science as epitomized in the Census has many elements in common with more technological or entrepreneurial science. Such science is partly linear but also opportunistic but with some strong business-case disciplines to assess investment. The 'Valley of Death' has long been a well-recognized limiting factor to taking ideas from the laboratory into the marketplace and some investors now provide funding to help cover that gap. In more-public-good science the gap is often at the intersection of research results and policy development and finding funding to bridge that gap remains an ongoing challenge.

Any future program that builds on the Census will need a governance and management model that can assess progress and consider potential long-term funding and investment models. In many areas of science we face challenges in moving beyond project-based funding to embedding key results and data into core infrastructures or 'spinning out' science and technologies into some alternative business models.

10.9 Lessons learned

The Census focused on completing an ambitious workplan by 2010 and the delivery of new knowledge. However, this was at the expense of more substantive discussions on supporting future research initiatives that could build on the success of the Census. Any future program should:

- Consider a governance structure that supports some long-term planning for future legacies and potential funding at an early stage in the life cycle of the program
- Identify a business model that will best facilitate program delivery and ongoing support
- Have a specific leadership development program and successional processes
- Have a globalization strategy that builds early links and capability with key countries and institutions
- Seek support for an independent secretariat to coordinate the program
- Have clear expectations for data sharing and storage
- Build early links with potential end users of the research
- Identify and support specific capability needs

11 Lessons learned

A key aim of this review was to understand the operations, successes and possible failures of the Census so that any individuals or groups contemplating the development of a global collaborative science program might have some understanding of potential pitfalls. Each section of the review has built a story around particular components of the Census, attempted to reach some conclusions (or Findings), and developed some lessons learned. These lessons are compiled below.

11.1 Governance

The Census developed at a time before there was more extensive discussion on expectations for effective governance. Systems, processes and leadership evolved into a structure that delivered a substantial body of new knowledge and built new collaborations and capability. In practice, the risks that were not well identified or effectively mitigated by the governance arrangements did not eventuate in a major way, so that any deficiencies in the governance structure had no major impact on either the program or on the Foundation.

In reviewing the experiences of governance of the Census in relation to other similar programs, we contend there is no one optimal model for designing governing structures, but we note the following issues:

- A 'cornerstone' investor (the Foundation) was critical and their willingness to commit a substantial sum for a decade underpinned the development of the Census community.
- The 'cornerstone' investor establishes goals and expectations and these should include preferred governance models and reporting processes.
- The substantial degree of autonomy and trust given to the Program Director by the Trustees of the Foundation enabled the Census to make rapid decisions about early investments.
- A clear strategic plan should be developed early in project planning to ensure the goals set by the 'owner' can be met. This plan should be regularly reviewed with input from all levels of the project.
- There needs to be clarity on the respective roles within governance groups including decisions on representative, skills-based or mixed memberships.
- Risk assessment and management is an important part of project direction and needs to be explicit.
- Leadership should be regularly assessed and reviewed to ensure new leaders are developed to support ongoing activities.

11.2 Management

Large-scale collaborative science projects often have very complex management issues to deal with. Stakeholders want systems that are low cost but that enable their voices to be

heard. The challenge is to have the right degree of support for the higher levels of leadership but ensure that issues raised by those who largely conduct the program can be heard. Issues for any future programs include:

- A secretariat is almost universal for large programs but its roles can vary from merely administrative to actually doing some of the work. Be very clear about what is expected from a secretariat, and ensure its staff have all the information and tools needed to effectively carry out their administrative tasks.
- Workloads and stress are very real issues in such programs. There are competing demands and with global initiatives there are cultural, time-zone and financial issues to deal with.
- A strong executive secretary/director is needed who has a good working relationship with the governing leaders.
- An executive committee is desirable with the ability to act between board meetings. Clear roles and boundaries for decision-making are needed and must be formally documented.
- The secretariat should have an oversight of the whole program including the financial performance. It should be the part of the organizational structure that provides uniform and consistent information to the other elements such as an SSC, executive committee, and the funder/investor. This enables more complete recommendations on future investment and monitoring of performance.
- The secretariat has a key coordinating role in linking with other international organizations and promoting the initiative to a wide range of organizations.
- The secretariat must be responsive to the needs of its participants and communicate at all levels.
- Workplans and budgets should be developed by the secretariat and these should be linked to a strategic plan.
- The organizational structure should be reviewed at about three-yearly intervals to ensure that any new components can be designed and delivered in a timely fashion as the project passes though its natural life cycle. Ideally such reviews should be carried out in conjunction with reviews of possible changes in leadership, so that all such changes decided on are coordinated and complementary to each other.

11.3 Globalization

Many programs develop with expectations of having a global reach. Globalization has its challenges if it is to be truly embedded in the ‘modus operandi’ of a program. Global biological science projects are rare so any future such project should consider the following:

- Develop expectations for global collaboration and indicators for success.
- Require global science projects to have real links at national and regional levels.
- Develop a globalization strategy early in program development and be proactive in building connections with relevant international, regional and national organizations.
- Ensure regional and national networks are represented in overall program leadership.

- Ensure support at the secretariat and local levels for building links.

11.4 Collaboration

Collaboration and transdisciplinarity are key features of large-scale science projects. A successful project should:

- Identify and understand potential barriers to collaboration and develop specific strategies and processes to minimize these.
- Have a clear view of expectations how each discipline can contribute and how such contributions are recognized. Be prepared for some lateral contributions such as from the arts.
- Have access to some specific funding to facilitate bringing people together. Building trust to work together is critical to future success.
- Provide funding to develop proposals.
- Develop some common communication and collaboration tools that can enhance full collaboration.
- Expect significant culture change in the way some science is conducted. Be prepared to support and reward positive change.

11.5 Data management

Large-scale long-term projects need early agreement on a core infrastructure to support data storage and subsequent data sharing (including audio, video, digital, etc. files) including support to develop best-practice tools for data sharing, interoperability and review of data quality. Project governors need to address long-term sustainability of data storage and access at an early stage. Additional issues include:

- Have an explicit data-sharing policy at the outset of the program and include standard protocols for metadata, data quality, intellectual property, etc. that meet best international practice.
- Ensure that projects and individuals have specific expectations for data sharing and attribution with appropriate sanctions.
- Consider having an advisory committee with specific responsibility for data management and ensure the infrastructure is supported within an appropriate organization.
- Ensure connections are made to other key initiatives.

11.6 Synthesis

A compelling and simple vision also needs to recognize that the information can be valuable beyond merely adding to the body of knowledge. In designing any future collaborative program, leaders and participants should consider:

- Results will be valuable beyond a scientific audience so pathways for converting findings into policy or management relevance should be identified early in development.
- People experienced in policy development should be brought in early to program leadership groups.
- Project proposals should identify potential relevance and societal benefits.
- A strategic plan should identify expectations for developing wider syntheses of results.

11.7 Education and Outreach

Science programs cannot operate in isolation from their wider communities of interest. Successful programs will have specific E&O expectations that are relevant to their stakeholders:

- Understand the target audiences and access the appropriate skills to focus activities.
- Develop a few performance measures on which to assess impacts with target audiences.
- Utilize current social media to build widespread collaboration, support and awareness
- Have specific responsibilities within a ecretariat to coordinate E&O activities.
- Be sure that allied projects understand their expectations for E&O and resource them appropriately.
- Make sure the 'brand' for the program is appropriately protected to ensure the quality of science, communications and impact is maintained.
- Remember to use the arts and creative sectors in combination with science to enhance aesthetic/discovery/ethical dimensions of the results.

11.8 Legacies and sustainability

The Census focused on completing an ambitious workplan by 2010 and the delivery of new knowledge, but this was at the expense of more substantive discussions on supporting future research initiatives that could build on the success of the Census. Any future program should:

- Consider a governance structure that supports some long-term planning for future legacies and potential funding at an early stage in the life cycle of the program
- Identify a business model that will best facilitate program delivery and ongoing support
- Have a specific leadership development program and successional processes
- Have a globalization strategy that builds early links and capability with key countries and institutions
- Seek support for an independent secretariat to coordinate the program
- Have clear expectations for data sharing and storage
- Build early links with potential end-users of the research
- Identify and support specific capability needs.

12 Conclusions

The Census, by any statistical measure, was a great success. The large number of scientific papers published and still to be published by Census participants, alone, would be sufficient. Instead the Census has achieved truly global science in biology. It did not profess to provide a complete Census of life in the ocean in 2010 but it did substantially increase the baselines of knowledge in often underexplored ocean realms. From this knowledge base future research and surveys will add more data that can be shared through web-based services such as OBIS. From this we may be able to derive estimates of population diversity, distribution and abundance for selected groups of organisms or regions and a future compilation of such data will show how far our knowledge has moved from 2010.

The Foundation can, therefore, be justifiably proud of the achievements of the Census. From an idea within a small group, supporting enlightened leadership and investing in bringing groups together, the Foundation built a new community of marine scientists committed to shared goals and ideals, to operate in a collaborative culture, to share data in an open portal and conduct some outstanding science. Collectively participants showed that biologists could operate in a collaborative environment on big-science questions. The Census changed cultures permanently for many and built a baseline of knowledge that will increasingly influence policies on managing our oceans. It also raised the passion for discovery in still underexplored parts of our globe and reached a wide audience on the wonders of the marine environment and reinvigorated some areas of science such as the taxonomy of marine organisms and the use of new tools such as barcoding and metagenomics.

The Census also capitalized on some technologies that were used in oceanographic research, such as acoustics, and it used telemetry to add significant information on distribution and behavior. Some new technologies were developed that will transform the future study of marine biology.

From developing collaborative and global science to building infrastructures and engaging the public through outreach in many forms, the Census has demonstrated that such ambition is possible for complex global issues. The Census evolved at a time when there were few models for effective governance and management for such public-good science initiatives. It developed systems and practices that worked to a large degree but there were challenges and risks.

This review, with its focus on lessons learned, identified a number of issues across several aspects of the Census that will be of value to any future initiatives. Our conclusions support the need for early development of clear roles and responsibilities across all levels from governance to project delivery and the need for effective coordination through a secretariat. Leadership development should be a specific component and an open data management system should be a cornerstone to building collaboration.

The Census also showed how science funding could move from a contest of individuals and institutions to a more collaborative process where ideas are discussed and the potential for a project agreed with advice. The innovative funding from the Foundation that brought interested people together to build trusting relationships and share data fostered such a contest of ideas. Further funding to develop proposals reduced individual and institutional

stress and the funding of coordinating and outreach functions also reduced demands on operating funds.

Undoubtedly much research on marine biodiversity would have been carried out over the last decade without the Census. But it would have lacked the global reach and the access to data and technologies that made the Census unique. The resources of the Foundation also demonstrated that science and aesthetics such as via the arts were intertwined. The legacies of the Census will live on in forms yet to be determined but the base in knowledge, experience and management should be capitalized on before people move to other areas of research.

13 Acknowledgements

Such a review would not have been possible without the willingness of many people within the Census community and those interested external observers who shared their experiences in such an open and honest manner. Statistical comparisons and document reviews do not show the true richness of ideas and cultures that emerged from such discussions.

The Secretariat of the Census through the Consortium for Ocean Leadership was an invaluable source of documents and Kristen Yarincik (Program Manager) was of particular value in unraveling the challenges and intricacies of managing such a complex program. Some lengthy discussions with Ian Poiner, Chair of the Scientific Steering Committee, greatly helped understanding the evolution of governance and management of the Census.

The Alfred P. Sloan Foundation through Jesse Ausubel had the foresight and the resources to support this innovative review of the lessons learned from the Census. Support for the open publication of this review should also assist others contemplating the challenges of global collaborative science.

Our thanks also go to Aaron McGlinchy, Landcare Research, for his effective project management and Christine Bezar for editorial review.

Appendix 1 – Key publications from the Census of Marine Life

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Appendix 2 – Backgrounds of the Review Team

Professor David Penman (Principal Investigator) led the project, developed the draft framework, conducted the key interviews, and led preparation of papers and reports. David brought to this project his extensive experience in the governance and management of collaborative biodiversity-related projects at national (New Zealand) and international levels. He is an entomologist by professional training and the past Chair of the Governing Board of the Global Biodiversity Information Facility.

Dr Andrew Pearce is a former CEO of Landcare Research, an environmental research institute in New Zealand, and has extensive governance and management experience in scientific organizations, national and international collaborative research projects, science funding, governmental organizations, and in commercial companies. Andrew provided advice on possible governance and management structures for collaborative science projects.

Dr Missy Morton is a qualitative social science and educational researcher and provided advice on the structure of interviews and conclusions drawn. Missy is a Senior Lecturer in the College of Education at the University of Canterbury in New Zealand and has extensive research experience in delivering educational outcomes.

Appendix 3 – Purpose and principles of governance

The issue	How it may be manifested	How it can be mitigated
Split incentives The 'agency' or 'principal-agent' issue, where 'ownership or investment' and 'control' are separated, and their incentives may differ. A key purpose of governance is to mitigate the risk that those in control will act in their own interest rather than the interests of the owner/investor/funder.	Agents (managers, project leaders, institutions) may subvert the purpose of the principal (owner or funder) by undertaking activities that are suited to their own interests and ends. In a complex organization or project, there can be many layers of principal-agent issues. Governors need to assess which of them are important (material) enough to be addressed. The leadership of the organization may not be performing well, or may no longer be able to provide the skills and capabilities most appropriate for the changing needs of the organization.	Governors ensure that strategy and operational plans align with owner's purpose and strategy. Governors ensure that manager's proposals (and at successive lower levels as required) are aligned with approved strategy & plans. Governors ensure that performance and achievements are regularly assessed, and that resources are (re-) allocated to reflect results. Governors seek independent external assurance to validate management proposals & representations. Governors appoint top leadership, evaluate performance, and regularly assess whether a change of leadership is needed.
Information asymmetry Managers are better informed than their governors about the details of activities and results. Key principles for governors are that: they minimize information asymmetry in order to make well-informed decisions; they seek independent external advice on technical matters to avoid their sole reliance on technical advice from managers; and they seek independent external assurance on the completeness and accuracy of information reported to them.	Governors may not have enough knowledge and information to assess the merits of strategies & plans, nor to assess progress and performance. In complex organizations and projects with high technical content and multiple activities, the managers/project leaders at every level of the organization are better-informed and more knowledgeable than higher levels of management and governance.	Ensure that some governors have high levels of skills and knowledge about the organization's activities. Governors seek external expert advice on project proposals, selection, resource allocation, evaluation & decisions on continuance/termination. Governors seek independent external advice and assurance, at multiple organization levels if required, to validate and test that reported information is 'true and fair'.

Representative vs skills-based governors		
In organizations with multiple 'participants' it is important that participants' knowledge and skills can be used and reflected in governance decisions, but in a manner that ensures the purpose and objectives of the owner/funder remain paramount.	Governors who are representative of institutions/participants may have incentives not aligned with those of the owner/funder (potentially worsens the split-incentives issue).	At the highest governance level, owners ensure that there are several governors, potentially a majority, who are independent of any of the participants.
	Representative governors are more knowledgeable about their own institution/participant than other governors (increases the differential among governors of information asymmetry between governors and managers).	At the highest governance level, preference is given to appointing a chairman who is independent of any of the participants.
	In complex technical projects/organizations with multiple parties, it may be essential to have some governors who are affiliated with a party in order to have enough technical knowledge among governors to minimize information asymmetry.	Owners and governors establish an agreed set of skills, capabilities and knowledge that, collectively, the governors must have.
		Chairman and governors ensure that the governors recommended to owner/funder, collectively, meet and continue to meet these requirements.
Conflicts of interest		
A particularly important example of the split-incentives issue is that governors and managers should not be able to influence or take part in making decisions that would have an effect on their own interests, or those of a party they may represent or be affiliated with.	There are many situations, especially in complex and multi-party organizations, where conflicted governors and/or managers could either influence or make decisions on (for example) project selection, resource allocation, project termination/continuance, or the appointment of personnel, that would be of benefit to their personal interests, or those of their employing organization, or those of an organization that they represent.	Governors establish clear policies and practices on disclosure, avoidance and management of interests that are consistently applied at all organizational levels.
		Governors and managers ensure that whenever possible, conflicts of interest are avoided, and if avoidance is not possible, that conflicts are appropriately managed. For example, conflicted parties must not take part in the discussion of, or decisions on, matters which may have an effect on their personal interests or the interests of any party they may represent or be affiliated with.
		Governors seek external expert advice and assurance that all conflicts of interest are disclosed and that best practice is being consistently adhered to in conflict disclosure, avoidance and management.

Appendix 4 – Key functions of governance

Approve strategy	Approve plans	Allocate resources	Assess & manage risks	Measure performance	Appoint and assess leadership
Ensure organization has a clear strategy with well-documented objectives, which is consistent with the purpose and goals of owner/funder. Regularly test whether the current strategy and objectives are the best way of achieving the purpose and goals of owner/funder.	Regularly assess and approve an operational ('business') plan that is judged most likely to effectively achieve the goals and objectives of the organization's strategy. Ensure that clear measures of performance, progress or achievement are documented for all major objectives.	Approve the allocation of resources to goals, objectives, and major projects of the strategy and in successive operational plans. Re-allocate resources, as appropriate, on the basis of regular appraisals of progress, feasibility & achievement of objectives, to best achieve the organization's strategy. Seek independent assurance on progress & feasibility.	Ensure all significant risks are identified and that effective mitigation is in place: • Ethics • Intellectual property • Indigenous peoples rights • Other cultural risks • Legal • Political • Financial • Environmental • Corruption • Data integrity & storage • Reputation Seek independent assurance to validate management's assessments & representations.	Ensure progress and achievement are regularly measured, & that corrective action is taken, where required. Ensure that reporting systems provide timely, complete & accurate information. Seek independent assurance that appropriate action is taken to correct adverse results. Ensure strategic goals & objectives are reviewed, & revised if necessary, based on progress and feasibility.	Appoint leader & approve appointment of all directly-reporting subordinates. Regularly appraise whether leadership style & skills continue to match organization's needs. Change leadership when required to match changes in state and needs of organization. Provide assurance to higher levels of authority that leadership is appropriate & performing well.