The Role of a University in Developing Marine Science, Technology and Management in Support of Prosperous and Sustainable Human-Ocean Relations

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1. Introduction

The oceans are a precious resource, essential not only to humanity, but also to the function of our planet. We depend on the oceans for the food we eat, both from wild fisheries, which have leveled off globally since the late 1980s, and aquaculture, which now accounts for about one-fourth of the world's annual marine harvest and is steadily increasing.[i] The seas are essential for transportation, including a global shipping trade of more than 9 billion tons of goods loaded worldwide per year;[ii] and recreational, cultural and economic activity, including a substantial proportion of the global $1.1 trillion tourism industry.[iii] Marine-sourced fossil fuels, which are increasingly being extracted from operationally challenging environments such as the deep sea, support global economic development with attendant risks from extraction, transport and greenhouse gas emissions. Although it has no say in the matter, the ocean also serves civilization by receiving society's waste products, which are putting great pressure on coastal environments as the population of humans living within 150 km of the coast exceeds 3 billion, more people than inhabited the entire planet in 1950.[iv]

More broadly, the oceans, which occupy 71% of the earth's surface, are critically important to global climate and ecology. For example, marine phytoplankton convert the sun's energy to food for life in the sea and in the process produce half of all the oxygen generated by plant life on earth. In large part due to chemical reactions that lead to its acidification, the ocean has absorbed more than a fourth of the carbon dioxide generated by human activities over the past century, thereby mitigating the effects of anthropogenic climate change. Biological processes are also at play — they are responsible for enough of the carbon stored in the ocean to account for glacial/interglacial changes in atmospheric carbon dioxide.[v] And, changes in ocean circulation such as El Niño regulate regional and global climate in ways that can have profound influences on ecosystems, economies and societies.[vi]

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Considering also that many societies are culturally and in many cases physically anchored to the sea, and that the oceans are a true global commons, it is clear that the links between humanity and the oceans are truly inseverable.

With about 200,000 km of saltwater coastline — more than any other country in the world, bordering three oceans — and strong maritime links throughout its history tracing to the first inhabitants, Canada cherishes its longstanding, life-sustaining relationship with the oceans. As explained below, this relationship can be strengthened through new opportunities for responsible development, but only if significant local, regional and global challenges are addressed effectively. Using examples from Canada for context, here we describe the role of a university in developing marine science, technology and management in support of prosperous and sustainable human-ocean relations.

2. Marine technology: opportunities and challenges

As technology advances and societies develop, economic use of the ocean expands and diversifies. Opportunities come from technological advances that, if implemented in a framework of sustainability, can develop the nascent blue economy. For example, tides, waves and wind can provide green energy; aquaculture — possibly including new applications onshore and in open waters offshore — can potentially provide sustainably produced, high-quality food to supplement capture fisheries (which can in principle be sustained indefinitely); new technologies can be used to exploit previously inaccessible resources such as hydrocarbons and minerals in the deep sea and other extreme environments; and advances in shipping technology can greatly increase the efficiency and safety of marine transport while reducing emissions and pollution, including unwanted transport of invasive species in ballast water.

New opportunities for uses of the ocean come with challenges, especially if long-term sustainability is not factored in to the development and implementation of new technologies. In particular, it is imperative, but difficult, to minimize risks that are at the forefront today, such as depletion of resources and degradation of ecosystems through overfishing or destruction of habitat; pollution, including eutrophication, industrial wastes, endocrine disrupters and oil spills; invasive species that can compromise industrial cooling systems, overtake ecosystems or interfere with aquaculture through toxicity or reduction of yields; coastal erosion exacerbated by storm surge; and the hazards of wind, waves, currents and ice in the broad range of extreme environments where marine operations are conducted. Global change complicates risk management and environmental stewardship because economic use of marine resources is expanding rapidly while the ocean and its ecosystems are changing, subject to natural variability that is increasingly influenced by human activities at the local, regional and global scales.

Sustainable development depends on careful management through policy and regulation. This is inherently difficult when it comes to managing the oceans because multiple stakeholders interact with the marine environment at local, regional, national and global scales; ecosystems do not respect jurisdictional boundaries; and the open seas are the common heritage of all. The challenges of marine management in a rapidly changing world are daunting, but the notion of a blue economy embraces them. Guided by evidence-based research, technology and marine management must advance together. Sustainable development and prosperity are thus possible in a new era of human-ocean relations. As demonstrated by the striking of this panel at the Beijing

Forum, there is a growing recognition that international cooperation is centrally important to the development of the blue economy.

3. The university as hub for ocean studies

It is critical that communities work together now — across sectors, regions and nations — to develop and implement strategies for sustainable relationships between humans and the oceans. The natural sciences and technology provide the foundations for responsible development and stewardship of the ocean and its resources; the social sciences, policy and law link evidence and inventions to responsible practice. Universities have a central role in this process. As long-established centers for teaching, learning, research and discovery, they are pivotal in society's efforts to build a sustainable and prosperous future for humankind in relation to the oceans.

Dalhousie University, established in 1818, has emerged as a national and international center of expertise in ocean studies, committed to active engagement in the development of marine science and technology in order to achieve sustainable development of the ocean. The story of ocean studies at Dalhousie is unique but nonetheless comparable to that of other universities. It provides context for exploring how the modern university can work with the public, industry and governments to support sustainable use of the oceans in an increasingly complicated world.

The history of ocean studies at Dalhousie – More than 50 years ago, Dalhousie identified ocean studies as an area of special expertise and established the first Department of Oceanography in the country. Its founder, Dr. Gordon A. Riley, is widely recognized as one of the most influential oceanographers of the 20th century, particularly noted for his development of marine ecosystem models that are centrally important to marine prediction and climate change research today.[vii] Subsequently, innovative programs of study in marine law and marine affairs were established[viii] and the university developed world-leading programs of research in marine biodiversity, conservation, and observation and prediction systems, among others, while the number of faculty in ocean-related teaching and research increased to more than a hundred, spanning the disciplines of agriculture, computer science, engineering, law, management, natural sciences and social sciences. Faculty members are among the world's top experts in ocean-related topics that span disciplines, socio-economic sectors and geography, and its graduates are making a long-term impact on marine science, policy and economic development worldwide.

Dalhousie's approach to law and policy research is rooted in anticipating and supporting the needs of state and non-state actors around the world. Researchers at the Schulich School of Law and their Marine & Environmental Law Institute (MELAW) have been involved in a broad range of ocean law and policy work for the past 40 years. Members of the faculty have been involved in international negotiations under regimes such as the UN Law of the Sea Convention, the Maritime Labour Convention, the International Maritime Organization, and the UN Climate Regime. MELAW has advised governments and non-state actors alike on a range of issues, including maritime boundary delimitation issues, arctic sovereignty, marine protected areas, the regulation of a range of ocean activities (including fisheries, aquaculture, shipping, resource extraction and energy production), a range of maritime law issues, environmental treaties, and the implementation of international commitments into domestic law. Faculty members also work domestically within Canada on a range of ocean-related law and policy issues.

The importance of partnerships – This development of Dalhousie's capabilities in marine studies has been systematically fostered through strong partnerships with government and non-governmental organizations, industry and academic institutions nationally and internationally. Recent examples include:

- The Marine Environmental Observation, Prediction and Response Network (MEOPAR), a cross-Canada team of researchers from universities and government labs working to help reduce Canada's vulnerability and exposure to hazards and to improve responses to marine emergencies. This is achieved through both new and existing partnerships with organizations including academia, all levels of government, the insurance industry, the oil and gas industry, marine technology firms, coastal communities and non-governmental organizations.
- The Ocean Tracking Network, sometimes called "the ocean's internet" — a global partnership to construct and sustain a scientific platform of advanced sensor arrays and tracking devices and the associated trained personnel to collect, store, share, analyze and use aquatic tracking and environmental data to support sustainable management of valued aquatic species.
- The Transatlantic Ocean System Science and Technology (TOSST) research school, linking two major centers of ocean research in Canada and northern Germany to train graduate students in technical and research skills in ocean science and advanced technologies and to promote the ability to manage deep-sea and open-ocean environments.
- The NSERC-Cooke Industrial Research Chair in Sustainable Aquaculture,[ix] a partnership between a leading aquaculture researcher and a major integrated aquaculture corporation to develop a validated modeling system for finfish farm planning and management in a quantitative approach to sustainability.
- Fish-WIKS (Fisheries – Western and Indigenous Knowledge Systems),[x] a research partnership including indigenous and non-indigenous scholars from universities and indigenous governance and research institutions, aimed at enhancing fisheries governance in Canada by identifying and using the best model or mix of models from western and indigenous knowledge systems to influence fisheries-related decision making within a regional context.

These examples only partially describe the breadth and pervasiveness of partnerships in ocean research and education at Dalhousie and many other universities. Clearly, the university does not stand in isolation as a center for ocean studies; partnerships provide complementary perspectives, expertise and relevance (not to mention resources) to the university's mission of teaching, learning, research and discovery.

However, focusing only on partnerships aimed at economic returns and specific objectives of immediate relevance to industry or economies — so-called targeted or applied research — runs the risk of sapping the university of its lifeblood, discovery.[xi] To maintain its capabilities to support environmental stewardship and economic development, the university must continue to recognize and nurture its unique role as the reservoir of knowledge, incubator for the development of new ideas and training ground for the next generation of experts. Successes to date show that a healthy balance can be maintained.

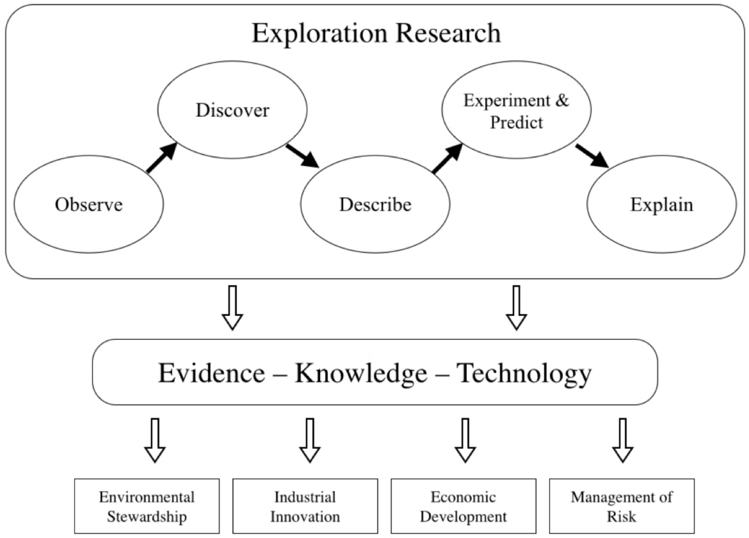

Figure 1. Relationships between scientific exploration and societal needs.

4. Scientific foundations for sustainable development

Knowledge of how the oceans work is fundamentally important to advances in marine technology, sustainable economic development of marine resources, and protection of coastal and offshore environments. Our base of knowledge must be continually expanded if we are to address the challenges of sustainable development outlined above. By definition, knowledge is increased by observation, discovery and explanation — that is, exploration research, also called basic research (Figure 1). In the process, evidence accumulates (for example, documentation of change associated with climate and human activities), knowledge (including technical know-how) increases and technology advances. These products of research are fundamentally important to environmental stewardship, industrial innovation, economic development and management of risk. Exploration research is driven by curiosity in its most positive sense. Targeted research can follow a similar path, yielding valuable results of immediate importance. But by definition, exploration of the unknown creates new knowledge, the fuel of innovation. Exploration research is by no means the exclusive domain of universities, but as reservoirs of knowledge for education and research, universities have a special role that must be nurtured.

Three of many possible examples illustrate how fundamental research has expanded knowledge of the oceans and earth systems, with important implications for sustainable development. They do not fit neatly into categories such as basic or applied research, but they do show the value of nurturing the university's role in developing marine science, technology and management. These three examples, discussed below, are ozone depletion, fisheries conservation and the global decline of phytoplankton.

Ozone depletion – As society continues to struggle with the implications of continued greenhouse gas emissions — for example, as articulated by the Intergovernmental Panel on Climate Change (IPCC) — it is instructive to review briefly a scientific success story, the

Montreal Protocol.[xii] The major issues surrounding ozone depletion have been resolved and the global community has acted decisively, so the role of science in environmental stewardship, management of risk and economic prosperity can be evaluated in retrospect. Simply, scientific guidance refined over many years through peer-reviewed research was right,[xiii] and the critics, whose arguments against ozone science[xiv] ring familiar today, were wrong. It is now firmly established that substances released to the atmosphere by humans are responsible for stratospheric ozone depletion and that the resulting increases in ultraviolet-B radiation have significant effects, especially on biological systems. Society responded, industry developed economically-viable substitutes for ozone-depleting substances, and both the ozone layer and economies weathered the crisis.[xv]

The resolve of the international community to do something about ozone depletion was buttressed by scientific research that was targeted on specific questions about the process of ozone depletion and its environmental effects, but which had no direct economic return. Clearly, society recognized the value of this research: Publications about ozone depletion increased from about ten per year in the mid-1980s to more than 200 per year since 1994,[xvi] representing large investments in the study of how earth systems work. The expanding base of knowledge and expertise supported the discovery of previously unexpected interactions between climate change and ozone depletion in the Antarctic that should be included in future climate projections.[xvii] The rapid acceleration of ozone research in the early 1990s did not come from de novo training of specialists; rather, environmental scientists who understood the basics turned their attention to questions of topical importance. Investments in exploration research paid off in environmental stewardship and management of risk. Were it not for a deep reservoir of knowledge and expertise, much of it housed in institutions of fundamental research such as universities, when the tap was turned on in the 1980s it would have yielded only a trickle.

Fisheries conservation biology – The story of fisheries scientist and marine conservation biologist Ransom A. (Ram) Myers and his research on the decline of fisheries is a shining example of rigorous scientific research communicated effectively to decision makers and to society, resulting in improved human-ocean relations.[xviii] It also illustrates the special role that universities can play in the application of marine science to management and sustainable development. A mathematically gifted and passionate scientist, Myers began his professional career working for Canada's Department of Fisheries and Oceans (DFO), studying life history evolution, oceanography and population modelling while grounding his research in the fundamentals of ecology, evolutionary biology and quantitative genetics. His deep commitment to conservation biology developed during the 1990s, when the collapse of the once-massive northern cod fishery inflicted profound economic, sociological and emotional impacts on the people of Newfoundland, where he lived and worked. Myers and his co-authors felt morally obliged to communicate to the media their scientifically-grounded conclusions about the link between excessive fishing and the decline of the cod, but they were hampered by bureaucratic control of the flow of information from DFO to the public. Some time after receiving an official reprimand from his superiors for communicating to the media conclusions that were consistent with the peer-reviewed literature but not with views presented by department spokespersons, Myers moved to Dalhousie in 1997 as its first Killam Chair in Ocean Studies, attaining the right of freedom of expression.[xix] During the following decade, he, his students and his colleagues had an enormous impact on the study of fisheries and biodiversity, helping to found the field of fisheries conservation biology.[xx] Consistent with his appointment in a university with a longstanding commitment to academic freedom and an emphasis on peer-reviewed research, Myers communicated regularly to the general public and policy makers with passion, succinctness and authority, attaining international renown and influence for his clear descriptions of fisheries issues. In no small part due to his leadership, fisheries conservation has attained widespread public recognition[xxi] and considerable traction in emerging management strategies.[xxii] The success of Ransom Myers, tragically cut short (he died of inoperable brain cancer in the prime of his career), shows how science explained effectively to society can help humanity to live in harmony with the ocean during the new era of the blue economy. Universities have an important role in preserving the freedom to explore and explain.

Global decline of phytoplankton over the past century – The ozone hole and the collapse of the northern cod were dramatic developments that generated widespread concern and focused attention. But what of fundamental changes in the ocean that have been underway for centuries as fisheries have transformed food webs,[xxiii] coasts have been influenced by eutrophication, and climate has been changing due to natural variability influenced by human emissions of greenhouse gases?[xxiv] The questions are immensely complicated and the perspectives needed to address them are multifaceted; research targeted on describing and explaining change in the ocean comes close to encompassing ocean science in its entirety.

How does the research community address the pressing need to understand global change? Again the themes of exploration (Figure 1) and communication to the public emerge. Recent research on global change in the concentrations of marine phytoplankton is exemplary. Four years ago in the journal *Nature*, Dalhousie's Daniel Boyce, Marlon Lewis and Boris Worm reported a global decline in the concentrations of marine phytoplankton over the past century.[xxv] Their estimate of a rate of decline of 1% of the global median per year was startling, as reflected by headlines such as "Phytoplankton loss could spell disaster for marine ecosystems"[xxvi]and "The dead sea: Global warming blamed for 40 per cent decline in the ocean's phytoplankton."[xxvii] These summaries for the general public exaggerated the authors' carefully measured conclusions, but they left a mark. Subsequently, scientific research proceeded as it should: Aspects of the study were challenged and responded to in the peer-reviewed literature,[xxviii] data were made freely available[xxix] and an analysis with more data and new techniques yielded refined estimates of change that confirmed long-term declines in global phytoplankton but revealed complicated patterns, including regional increases and multi-decadal variability, that defy simple encapsulation in flashy headlines. If history serves as a guide, this line of research will have a significant influence on future studies of marine ecosystem structure, geochemical cycling and fishery yields, and its conclusions will be incorporated into global assessments of climate change such as IPCC reports. But it is likely that the tension between the need for catchy headlines and sound science will remain.[xxx] A commitment to improving the communication of scientific results through the media is surely part of the strategy for environmental stewardship; toward that end, marine conservation biologist Boris Worm serves as the Canadian Broadcasting Corporation's "Oceans Guy", regularly explaining complex issues to the public.[xxxi]

5. Targeted research

Through research targeted on specific themes or applications of direct societal importance, the base of fundamental knowledge and technological capabilities is exploited and expanded to support pressing needs such as industrial innovation, economic development and management of risk, including environmental threats. As the example of stratospheric ozone research demonstrates, research targeted on a specific issue need not be tightly constrained nor inimical to discovery — the opposite can be true. But there is widespread concern in the scientific community that too much focus on targeted research can threaten the foundations of scientific discovery and innovation. Recent examples of large multidisciplinary research networks headquartered at Dalhousie illustrate how targeted research can foster discovery while promoting the development of enabling technologies and management tools of immediate value for sustainable use of the ocean:

- The Ocean Tracking Network[xxxii] is a global research and technology development platform that has been deploying Canadian state-of-the-art acoustic receivers and oceanographic monitoring equipment in key ocean locations around the world to track commercially, culturally and ecologically important marine animals that have been tagged with acoustic transmitters, with the goal of documenting how their movements and survival are influenced by oceanographic conditions. The network includes more than 20 industrial partners and more than 400 international researchers from 20 countries, along with many more trainees, graduate students and postdoctoral fellows. Social scientists are working with natural scientists to pursue OTN's well-defined mission: to collect, store, share, analyze and use aquatic tracking and environmental data to support sustainable management of valued aquatic species. The mission is targeted, but the research questions — focused on the interacting influences of environmental variability, ecological processes and human activities on animal habitat use and movements — are fundamental, and broad in their potential applications.
- The Marine Environmental Observation, Prediction and Response Network (MEOPAR)[xxxiii] has a clear focus on a topic of immediate societal relevance: marine hazards, arising from weather and climate change, including storms and coastal erosion due to waves; tsunamis; chemical and biological change, for example ocean acidification; and direct human impacts, such as oil spills and ship accidents. MEOPAR's goal is to better understand and predict the impact of marine hazards on human activities and ecosystems — and to improve response. These are pressing needs as development of the ocean expands while climate change influences marine systems that are already subject to natural variability and human activities. Like OTN, MEOPAR is large and multidisciplinary, with many partners across sectors, including government and industry. Also like OTN, its central focus is well defined. Yet their approach is broad: MEOPAR's projects involve fundamental research on how to observe and predict marine dynamics on scales from hours to seasons and seasons to decades; and collaboration with social scientists provides context and guidance for the development of responses, including policy. Notably, the Scientific Director of MEOPAR, chemical oceanographer Douglas Wallace, holds the Canada Excellence Research Chair in Ocean Science and Technology

through which he leads a diversified program of fundamental and applied research to develop new approaches to observe the changing ocean and study ocean processes.

Both the Ocean Tracking Network and MEOPAR could be classified as targeted research, possibly representing a drain on discovery, but we feel that the implied dichotomy between basic and applied research does not apply — because they are broad in scope and approach, and dependent on the generation of new knowledge, these projects will also increase our ability to explore and explain the unknown.

Independent of large programs, applied research and close cooperation with industry and governments are integral to the university's mission. For ocean studies at Dalhousie, this takes the form of contract research, government-sponsored partnerships with industry such as the Industrial Research Chair in Sustainable Aquaculture and service of faculty on important reviews like the Doelle-Lahey Independent Aquaculture Regulatory Review for Nova Scotia.[xxxiv] Results of research are also provided to the public or governments, with direct economic benefits: For example, Dalhousie contributed significantly to Nova Scotia's Play Fairway Analysis, a project that identified diverse rich hydrocarbon potential in the offshore with an in-place resource of 121 trillion cubic feet of gas and 8 billion barrels of oil, resulting in $2.05 billion CAD in work commitment bidding.[xxxv]

The preceding examples show that investments in targeted research can also support the exploration and the generation of new knowledge that is needed for discovery and innovation. Still, there is a risk: Many avenues of scientific exploration are too fundamental to be linked directly to economic or social benefit, yet the results of those explorations regularly fuel unexpected innovation and improved understanding of the relationships between humans and the ocean.

Universities can and should pursue targeted areas of applied research; but to truly thrive they *must* remain as centers for pure, curiosity-driven research, growing the reservoir of knowledge from which mankind can draw in the decades and centuries ahead.

6. The source of new ideas to address emerging issues

There are many examples of life-changing inventions that were based on curiosity-driven research. Here we describe how a broad, deep and expanding base of fundamental knowledge and technical know-how is needed for society to respond to emerging issues.

A technical and scientific challenge of immediate commercial and environmental importance, ballast water treatment, illustrates the dependence of problem solving and innovation on the reservoir of knowledge that accumulates through exploration research. Widespread recognition of the threat of invasive species transported by ships has led to global response and the adoption of an international convention that will require all ships to implement a ballast water management plan consistent with International Maritime Organization guidelines.[xxxvi] In turn, vessels sailing in United States waters will be required to meet ballast water discharge standards developed by the U.S. Coast Guard (USCG), which have similar objectives but different criteria for validating the effectiveness of treatment: The IMO sets standards for maximum numbers of "viable" cells discharged by ships whereas the USCG sets standards for "living" organisms.[xxxvii] This seemingly subtle distinction has profound implications, though: Treatment with ultraviolet radiation (UV), a proven technology for wastewater sterilization, is demonstrably effective for disinfecting ballast water of microscopic plankton. However, UV renders these organisms harmless by damaging DNA so they are incapable of reproduction — they are not viable and can't invade ecosystems, but they retain some signs of life and can appear to be "living" in USCG assays.

The "living" vs. "viable" issue presented a challenge to ballast water treatment industries using UV, including Canada's leader in UV treatment, Trojan Technologies. Working with Trojan in a research partnership supported by government,[xxxviii] Dalhousie researchers Hugh MacIntyre and John Cullen are addressing the esoteric but critically important distinction between living and viable phytoplankton in a comprehensive program of highly targeted research, the results of which are providing scientific evidence that can pave the way to improved regulations for the protection of coastal ecosystems and the commercial success of UV-ballast water treatment technology. Importantly, the scientific and technical foundations of this program of applied research came from diverse studies that had little or nothing to do with the intentional killing of plant life or any other commercial venture, including research on the effects of ozone depletion on marine photosynthesis; studies of the optical properties of phytoplankton as applied to remote sensing from space; examinations of the responses of microalgae to long periods of darkness, as occurs during burial in sediments; and a multitude of studies of how microalgae grow and the extent to which their physiological condition can be diagnosed with optical measurements such as those now applied in ocean observing systems.[xxxix] Exploration research over decades provided the knowledge to respond to an immediate need; solutions for tomorrow's problems will surely depend on continued investigation of the unknown.

7. Conclusions

Universities embrace their centuries-old identity as centers of teaching and learning, but the days of the ivory tower are long gone. Like leading universities worldwide, Dalhousie is committed to promoting service and engagement with broader society, locally, nationally and internationally. The scope of engagement is broad, fostered through strong partnerships with government and non-governmental organizations, industry and academic institutions nationally and internationally. Synergy is the hallmark of these partnerships, and for ocean studies, new technologies, knowledge and management strategies are a result, leading to an improved framework for prosperous and sustainable relationships of humans with the ocean.

As institutions committed to excellence in teaching, learning, research and innovation, universities have a unique role in partnerships for a sustainable future. They must continue to serve as the reservoirs of knowledge that may or may not have immediate application, and also as the fonts of new discoveries that will be required to sustain innovation and environmental solutions in the future. A thriving, globally competitive university absolutely needs to take a balanced approach, pursuing both targeted research and pure curiosity-based research. Without the former we risk our engagement and direct connection with broader society; without the latter we would lose our ability to illuminate, investigate and address the unknown. Society critically needs both.

[i] The State of World Fisheries and Aquaculture 2014, FAO, Rome.
[ii] UNCTAD/RMT/13.
[iii] Annual receipts, UNWTO World Tourism Highlights 2014.
[iv] UN Atlas of the Oceans http://www.oceansatlas.org/servlet/CDSServlet?status=ND0xODc3JjY9ZW4mMzM9KiYzNz1rb3M~
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[vii] Mills, E. L. 2012. Biological oceanography: An early history, 1870-1960. University of Toronto Press.
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[ix] Funded jointly by the Natural Sciences and Engineering Research Council of Canada and industry, with contributions from the host university.
[x] http://fishwiks.ca
[xi] Casassus, B. Put focus back on basic research, say science unions. Nature News (03 September 2014) | doi:10.1038/nature.2014.15817.
[xii] http://ozone.unep.org/en/montreal_protocol.php
[xiii] Periodically reviewed, e.g., WMO (World Meteorological Organization), Scientific Assessment of Ozone Depletion: 2010, Global Ozone Research and Monitoring Project-Report No. 52, 516 pp., Geneva, Switzerland, 2011.
[xiv] Taubes, G. 1993. The ozone backlash. Science 260: 1580-1583.
[xv] Rapid international response through the Montreal Protocol and the ensuing Vienna Convention for the Protection of the Ozone Layer has done much to limit the depletion of stratospheric ozone, but recovery of the Antarctic ozone hole is just beginning and will require decades.
[xvi] Web of Science, topic = "ozone depletion".
[xvii] Eyring, V., J. Arblaster, I. Cionni, J. Sedláček, J. Perlwitz, P. Young, S. Bekki, D. Bergmann, P. Cameron-Smith, and W. J. Collins. 2013. Long-term ozone changes and associated climate impacts in CMIP5 simulations. Journal of Geophysical Research: Atmospheres 118: 5029-5060.
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[xxx] A problem discussed in an interview: http://occamstypewriter.org/stuffysour/2009/09/16/catchy_headlines_vs_sound_science_interview_with_john_cullen/

[xxxi] http://wormlab.biology.dal.ca/media/media-radio/; also, Dalhousie oceanographer Robert Fournier has presented the "Science Corner" on CBC radio for more than 20 years.

[xxxii] http://oceantrackingnetwork.org

[xxxiii] meopar.ca

[xxxiv] http://www.aquaculturereview.ca

[xxxv] http://energy.novascotia.ca/oil-and-gas/offshore/play-fairway-analysis

[xxxvi] http://www.imo.org/OurWork/Environment/BallastWaterManagement/Pages/Default.aspx

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