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Science and Societal Partnerships to Address Cumulative Impacts

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Funding and priorities for ocean research are not separate from the underlying sociological, economic, and political landscapes that determine values attributed to ecological systems. Here we present a variation on science prioritization exercises, focussing on inter-disciplinary research questions with the objective of shifting broad scale management practices to better address cumulative impacts and multiple users. Marine scientists in New Zealand from a broad range of scientific and social-scientific backgrounds ranked 48 statements of research priorities. At a follow up workshop, participants discussed five over-arching themes based on survey results. These themes were used to develop mechanisms to increase the relevance and efficiency of scientific research while acknowledging socio-economic and political drivers of research agendas in New Zealand's ocean ecosystems. Overarching messages included the need to: (1) determine the conditions under which "surprises" (sudden and substantive undesirable changes) are likely to occur and the socio-ecological implications of such changes; (2) develop methodologies to reveal the complex and cumulative effects of change in marine systems, and their implications for resource use, stewardship, and restoration; (3) assess potential solutions to management issues that balance long-term and short-term benefits and encompass societal engagement in decision-making; (4) establish effective and appropriately resourced institutional networks to foster collaborative, solution-focused marine science; and (5) establish cross-disciplinary dialogues to translate diverse scientific and social-scientific knowledge into innovative regulatory, social, and economic practice. In the face of multiple uses and cumulative stressors, ocean management frameworks must be adapted to build a collaborative framework across science, governance, and society that can help stakeholders navigate uncertainties and socio-ecological surprises.

Keywords: research priorities, oceans research, marine ecosystems, horizon scanning, transdisciplinary, governance, management, society

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INTRODUCTION

Ocean management is complex. High natural variability across spatial and temporal scales, regulatory uncertainties and blind-spots, and exploitative economic practices, all coincide with sectoral management that rarely incorporates interactions between different stressors and uses of the marine environment (Degnbol and McCay, 2007; Forst, 2009; Berkes, 2012; Long et al., 2015). Population growth, climate change, and increasing pressure from a diversification of both new and historical resource uses all result in increasing impacts on ocean ecosystems (Vitousek et al., 1997; Gibbs, 2009; Thrush and Dayton, 2010; Snelgrove et al., 2014). The identification of key research priorities through science prioritization exercises is one of many tools available to drive ocean and coastal research to address complex issues (e.g., Sutherland et al., 2014). These exercises are increasingly popular, aiming to identify new research topics, gaps in research, or key underpinning knowledge (usually biological or ecological) that can improve understanding of ecological systems, and their subsequent management (Rudd, 2014; Sutherland et al., 2014).

Horizon scanning exercises originated in commercial sectors as methods to bring together elements from the macro environment, as accurate forecasting of commercial direction is reliant on multiple external factors, including industries, markets, technological innovations, clients, and competitors (Amanatidou et al., 2012; Könnölä et al., 2012). Horizon scanning methodologies have more recently been applied to environmental and conservation sciences (Sutherland et al., 2006, 2009, 2014), including both national and global evaluations for ocean ecosystems (Rudd et al., 2011; Rudd and Lawton, 2013; Parsons et al., 2014). These exercises envision development of strategies that are pre-emptive rather than reactive, and that develop policy-relevant research to match the needs of managers and practitioners to facilitate evidence-based policy decisions in a timely fashion (Sutherland and Woodroof, 2009; Sutherland et al., 2009, 2011).

A challenge for these prioritization exercises is that science funding and priorities are not distinct from the underlying sociological, economic, and political landscapes that determine both priority setting, and values attributed to ecological systems (Lawton, 2007; Kato and Ahern, 2008; Bottrill and Pressey, 2012; Lawton and Rudd, 2014). Prioritization exercises also show systematic differences in priorities across different sectors and disciplines (Feary et al., 2013; Rudd and Lawton, 2013; Rudd, 2014). Marine systems are no exception, with research funding often biased toward enhancing economic drivers of use, particularly outside of coastal regions. As such, research priorities should be examined within an integrated, multi-sector management, and governance framework.

Here we use results from a science prioritization exercise to identify key research needs that underpin the ability to manage the diversity of stressors on New Zealand's marine ecosystems. Our goal was to identify research that could enable uptake of new scientific understandings into effective decision-making in the marine sector. Beginning with a vision of a future that includes a healthy and productive marine economy, marine environment, and communities, we ask what contributions marine science could make to secure this future.

The New Zealand Ocean Research Landscape

New Zealand is an ideal location to examine discrepancies between research funding priorities and policy and decision-making needs. The sheer vastness of the New Zealand Exclusive Economic Zone (EEZ) makes it a challenge for ocean management. New Zealand is responsible for the fourth largest EEZ, ranging from sub-tropical to sub-Antarctic waters, with an area of roughly 20 times its land mass. All major global marine industries are present in New Zealand, with significant potential to expand and diversify the economic benefits from the ocean's natural resources. Fisheries (both commercial and recreational) have a long history of exploitation, and are believed to be near capacity (Seafood New Zealand, 2014), while exploration of other natural (petroleum, minerals, renewable energy) or farmed resources suggests substantial potential for expansion (NZIER, 2010; PEPANZ, 2014). A range of other economic sectors also depend on the marine environment, including tourism, recreation, shipping, communication and aquaculture. New Zealand benefits from its "100% Pure" image, both for tourism (10% of GDP) and with environmental sustainability providing value-add in the export market for natural resources (New Zealand Treasury, 2011).

Management of New Zealand's ocean environs is fragmented, with over 25 statutes, at least 14 agencies and institutions, and seven spatial jurisdictions addressing ocean management (Bremer and Glavovic, 2013; Brake and Peart, 2015). Over recent decades, New Zealand has trialed innovative ocean management and governance, with the first no-take marine reserve gazetted in New Zealand in 1975 (Ballantine, 2014), and a quota management system for fisheries implemented in the mid-1980s (Boyd and Dewees, 1992; Gibbs, 2007). Recent legislation [the EEZ and Continental Shelf (Environmental Effects) Act 2012 (EEZ Act)] provides guidance on environmental impacts of new and expanding economic sectors (aquaculture, petroleum, minerals), though this Act does not affect existing industries, nor does it have precedence over other sector-based legislation (e.g., Fisheries Act) (Brake and Peart, 2015).

Unique to New Zealand is the Māori (indigenous) connection with the ocean which permeates many aspects of Māori life (cultural, spiritual, practical, and economic), and Māori have specific rights as a Treaty of Waitangi partner. Explicit recognition of the potential for Māori knowledge, resources, and people to contribute to knowledge creation for the benefit of all New Zealanders is provided through the Vision Mātauranga policy framework (Ministry of Research Science Technology, 2007). This framework is a mechanism through which the New Zealand government endeavors to recognize and protect mātauranga or Māori knowledge and ways of knowing. The Vision Mātauranga framework identifies four themes designed to help researchers, research funders and research users consider the relevance of research to Māori: (1) Indigenous Innovation: Contributing to Economic Growth through Distinctive Research and Development; (2) *Taiao* (environment): Achieving

Environmental Sustainability through *Iwi* (tribe) and *Hapū* (sub-tribe) Relationships with Land and Sea; (3) *Hauora/Oranga* (health/wellbeing): Improving Health and Social Wellbeing; and (4) *Mātauranga* (knowledge): Exploring Indigenous Knowledge and Research, Science and Technology. For Māori, efforts to revitalize mātauranga are entwined with expressions of self-determination and autonomy and the advancement of Māori capabilities (Broughton and McBreen, 2015).

About 75% of all New Zealanders now live within 10 km of the coast, and there is growing conflict among the multiple economic, cultural, spiritual, and recreational uses of the marine environment. New Zealanders have a strong demand to know what science is doing, with very short links between government, science and citizens in a small country of <5 million. Research and development (R&D) funding is less than half of the OECD average, though a 70% increase has been calculated in research funding since 2007/2008 [Ministry of Business Innovation and Employment (MBIE), 2015]. One new ocean research initiative, the Sustainable Seas National Science Challenge (www.sustainableseaschallenge.co.nz), strives to integrate research across disciplines, and to develop management- and policy-relevant solutions-based research, though with high expectations relative to budget allocations.

METHODS

Horizon Scan of New Zealand Marine Science Issues

A multi-part exercise identified strategic gaps and research priorities required for successful ecosystem-based management for New Zealand's estuarine, coastal, and oceanic ecosystems (**Figure 1**). A horizon scanning exercise determined priorities for oceans research, based on a methodology used extensively in environmental and conservation science prioritization exercises (Sutherland et al., 2011). Peer-reviewed and gray literature was assessed, and a total of 17 reports or articles selected that identified priority research questions relevant to marine science (Supplementary Table 2). These publications included national and global priority setting exercises and policy documents, that were both specific to marine ecosystems, and those that were prioritizations across all ecosystem types, including some questions or statements specific to marine ecosystems (e.g., Sutherland et al., 2009; Rees et al., 2013; Rudd and Lawton, 2013; Sutherland et al., 2013; Parsons et al., 2014; Rudd, 2014). Priority statements/questions were compiled and summarized across topics, including questions of relevance to New Zealand's Exclusive Economic Zone and other regions (e.g., Ross Sea, Antarctica) where New Zealand has a significant input into research and management objectives. Statement/question content was modified to provide statements at a similar level of generality.

A subset of the New Zealand marine science community was invited to rank a set of research priority statements. Workshop participants were selected to encompass a range of expertise in marine science, and included research institutes, universities, regional and national government bodies, and funding agencies (**Table 1**). Participants were selected to cover both emerging and established research scientists from a diversity of marine research disciplines including social sciences, ecology, physics, chemistry, geology, economics, modeling, and marine management and policy (**Table 1**).

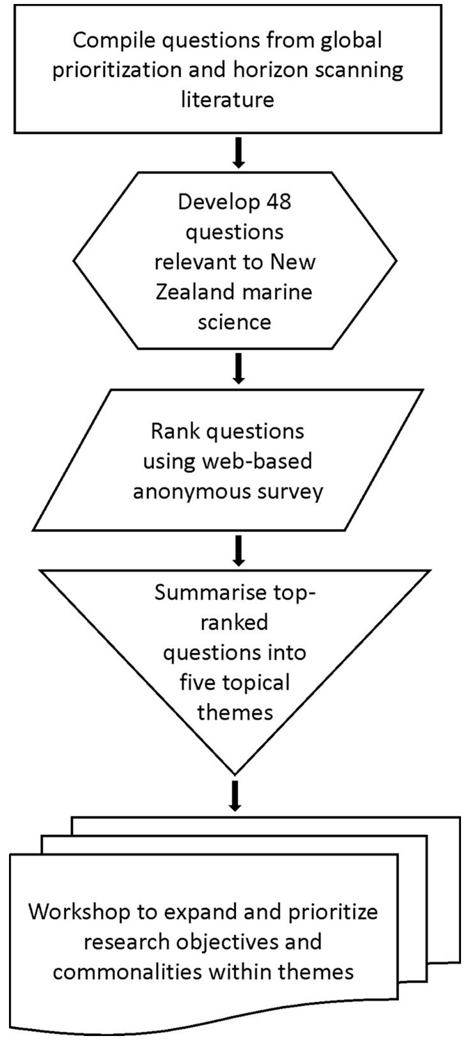

FIGURE 1 | Flowchart of New Zealand marine science prioritization exercise.

A total of 48 final statements (Supplementary Table 1) were provided to respondents in an anonymous web-based survey (Qualtrics). Prior to the workshop, attendees ($n = 42$) were invited to evaluate statements on a scale of 1–5 in order of their relative importance. Top ranked statements were chosen based on combined percentage of respondent allocations of top rankings (either rank 1 or rank 2).

Top ranked statements (top 16 of 48, ~33%) were allocated to a set of five key thematic topics by the project leaders, and these final themes were discussed in a workshop setting (**Figure 1**). Topical themes were selected to provide direct connections between basic biophysical or ecological research through to economic opportunities, social and cultural values.

TABLE 1 | Types of organizations and disciplines of participants involved in survey and workshop.

Type of organization	Institutions represented
Government (crown) research institutes	Landcare Research, National Institute of Water and Atmospheric Research (NIWA), GNS Science
Other research and environmental institutes	Callaghan Innovation, Cawthron Institute
New Zealand Academic Institutions	University of Auckland, University of Canterbury, University of Otago, University of Waikato, Massey University
Emerging researchers (Graduate students and postdoctoral research associates)	University of Auckland, University of Waikato, University of British Columbia (New Zealand-based student), University of Arizona (New Zealand-based student), NIWA
Indigenous research consultant	HH&R Mikaere Ltd.
Central and regional government	Ministry for the Environment, Ministry for Primary Industries, Department of Conservation, Waikato Regional Council
Disciplines	**Sub-disciplines**
Marine Ecology	Estuarine and soft sediment ecology, rocky reef ecology, environmental monitoring, fish ecology, ecosystem services and function, historical ecology, behavioral ecology
Biology and biodiversity	Taxonomy, biodiversity conservation
Social sciences and humanities	Governance, policy, human geography, economics
Fisheries	Fish and invertebrate commercial stock assessments, aquaculture, recreational fishing, benthic impacts, bycatch/species risk assessments
Indigenous issues	Governance and policy, indigenous relationships with science, cultural values, and valuation methods
Management	Fisheries, conservation, environmental management and decision-making, environmental monitoring
Physics, mathematics, chemistry	Physical oceanography, earth science, geochemistry, geology, paleontology, theoretical modeling, statistics
Gender	Female (51%), Male (49%)
Professional experience	Established researcher (77%), Emerging (<5 years post-degree) (23%)

We deliberately merged questions to create open, collaborative, transformative, and trans-disciplinary themes that have relevance to New Zealand as well as international ocean ecosystems and governance.

Workshop to Develop Strategic Priorities in New Zealand Marine Science

The workshop agenda was developed with the understanding that the political and funding landscape inevitably has an impact on research priorities. Recognizing this backdrop, we set up a series of interdisciplinary questions that put science into a futures framework, asking participants to deliberate about where science should be prioritized in order to promote action and decision-making, eventuating in a desired future state. Going beyond business as usual, we envisioned that the workshop participants would identify new science that could develop transformational win-win opportunities that could enhance the marine economy, build capacity in marine science, and promote environmental health.

The five topical themes, identified from the top-ranked survey statements, were used in round table discussions at a 1 day workshop attended by researchers from across New Zealand's marine science research community (**Table 1**). Unlike other workshops held recently in New Zealand marine science (e.g., Le Heron et al., in press), participants were free to represent their own academic and institutional interests. Rather, we aimed to determine over the course of the workshop whether the research community valued interdisciplinary research, and put a priority on bridging the science-policy gap.

Prior to the workshop, participants were provided with the overall prioritization of research statements and the five overarching themes based on top-ranked research statements to guide workshop discussion of key strategic gaps and research priorities, and develop strategic ocean research objectives for New Zealand. Each of the five topical themes was discussed at two separate round table discussions during the course of the workshop, with only the group leader (one of the project team) remaining with a particular theme. The participants were split into discussion groups designed to generate a broad range of perceptions at each round table, including at least one emerging researcher.

Morning discussions focussed on: "What knowledge do we need in the short and long-term to address multi-use of marine environments?" Participants were asked to discuss why particular themes were identified as key research agendas, what the key gaps in our knowledge base are within each theme, and what kinds of research will fill these gaps.

Afternoon discussions focussed on: "What institutional and other arrangements will aid the generation of this knowledge and its application in management?" Within a institutional funding context, participants were asked to consider how research gaps could be addressed within the structural settings of New Zealand's science system [Ministry of Business Innovation and Employment (MBIE), 2015]. We envisioned attendees discussing whether existing funding and research institutions could provide adequate research to inform the environmental decisions that are coming to the forefront in New Zealand. This is particularly relevant to recent decisions by the Environmental Protection Authority within the context of the EEZ Act, such as those on sand mining and mineral extraction, where background information relevant to the understanding of ecosystem function was poor, and high levels of uncertainty were perceived to have a strong influence on decision-making (Straterra, 2015). To incorporate discussion of the influence of social and political agendas on science funding, participants were also asked to think about research projects that capture the imagination of not only scientists, but also the public, politicians, and policy makers.

Comprehensive notes were taken by an observer at each table and session, and key messages were summarized by each group at the conclusion of the workshop, and used to develop overarching messages to convey to the participants as a whole. The notes were then coded and subjected to qualitative thematic analysis. An inductive approach to thematic analysis was utilized to ensure that themes and patterns that emerged from the data were directed by the content of the data itself, rather than by pre-existing concepts or ideas. Thematic analysis is not tied to any particular epistemology or discipline, and is therefore a useful and appropriate tool given the interdisciplinary nature of this research.

This study was carried out in accordance with the recommendations of "Guiding Principles for Conducting Research with Human Participants" under the approval of the University of Auckland Human Participants Ethics Committee, with written informed consent from all participants.

RESULTS

Results from the prioritization exercise showed clear priorities across all workshop participants toward: managing for cumulative impacts and avoidance of undesirable change, integrated management, balancing of long and short term benefits, effective appropriately resourced networks, and translation of knowledge into practice (**Table 2**). Here, we deliberately were not attempting to horizon scan, and identify "blue skies" topics *sensu* economics or industry to predict new directions. Rather, our goal was to identify key research priorities and link them to over-arching themes of institutional frameworks, governance and decision-making, i.e., what does science need to contribute to the science-policy interface to enable economic use while maintaining environmental health. While anonymity prevented analysis by discipline or institution (a necessity due to the unequal distribution of marine scientists across institutions in New Zealand), consistencies were apparent with a combination of both biophysical and social science research topics being highly ranked by most respondents (**Table 2**).

The highest ranked statement (top ranked by 87% of respondents) was to identify policy, legal and institutional frameworks to enable integrated management of coastal environments. Similar to other ocean research prioritization exercises (e.g., Parsons et al., 2014; Rudd, 2014), statements about multiple stressors, cumulative impacts, tipping points and thresholds, and ecosystem function were highly ranked. Other highly ranked statements included a broad selection of transdisciplinary research, with management institutions, governance, societal and customary values, and other topics included in the highest ranked statements (**Table 2**). While our statements were deliberately broad, respondents gave lower rankings to statements about specific processes or impacts (e.g., bioinvasion) or ecosystems (e.g., deep sea biodiversity).

Workshop discussions had surprisingly similar conclusions across different breakout sessions for the five research themes (**Table 2**). A number of key messages and proposed solutions emerged from the break out discussions held at the workshop. Surprisingly, responses on gaps in science were mostly around gaps in organization, funding, and policy, and generally not about the knowledge itself or data to inform decision-making. All discussions noted challenges in optimizing research effectiveness given the structuring of research and funding priorities and practices by sector and discipline rather than by theme or problem. Participants confirmed the view that research projects tended to be set up in parallel rather than in partnership, limiting potential advances and cross-collaborations that could result in transformative research and innovation. Poor coordination across resource sectors, science funders, research institutions, academic disciplines and research programmes was held to limit understanding of interactions between multiple stressors, and the inability to predict short- and long-term responses of marine ecosystems to environmental change. This lack of coordination was also seen as limiting application of effective science for policy and management.

KEY MESSAGES

The workshop provided an opportunity for a diverse group of experts from a broad range of organizational affiliations and disciplinary backgrounds to engage in future-focused discussions about New Zealand's marine estate. By thinking through emerging research agendas as a collective exercise, participants were able to imagine new possibilities for how marine science might be done and the kinds of contributions that science, broadly interpreted, can make. From this exercise, the importance of developing new methodologies and working collaboratively to identify and address changing social values, to accommodate mātauranga Māori alongside marine science, and to better connect values and science to policy and regulatory practice was emphasized. This highlights the potential for interdisciplinary approaches to collectively generate new knowledge to shape marine science in New Zealand and globally (Castree et al., 2014; Victor, 2015).

Surprises and Tipping Points

Risk, uncertainty, and surprises were identified as a key area within which the marine science community could contribute knowledge, applications and new policy and governance structures to improve our ability to manage for change. Participants discussed the need to enhance knowledge about the conditions under which sudden, disruptive and substantive undesirable changes are likely to occur and the potential implications of such changes for New Zealand communities and marine environments. Surprises, thresholds and tipping points are increasingly documented in the ecological literature, as we push systems beyond the ecosystem's adaptive capacity (Scheffer

TABLE 2 | Statements ranked according to their combined percentage of ranks of either 1 and 2 from the survey emailed to workshop participants, organized by over-arching workshop themes.

Theme/Statement	%
Theme 1: Enhancing knowledge about the conditions under which sudden, disruptive and substantive undesirable changes are likely to occur and the potential implications of such changes for New Zealand communities and marine environments, i.e., socio-ecological knowledge of tipping points and the development of our preparedness capability	
Identifying techniques to define tipping points and the consequences of alternative states	80
Identifying which aspects of climate change, e.g., storms, sediment transport, are most likely to affect marine ecosystems and coastal communities	63
Theme 2: Developing methodologies to reveal the complex and cumulative effects of change in marine systems, defining how and why these trajectories vary and their implications for resource use, stewardship and restoration in systems of different ecological health	
Developing techniques to quantify change and risk to ecosystem integrity associated with multiple stressors and cumulative impacts	80
Identifying the impacts and mitigation measures of marine and land based activities including emerging contaminants, new energy sources, and spills and accidents	73
Determining how exchanges of energy and matter connect habitats and ecosystems to maintain ecosystem function	60
Theme 3: Assessing potential solutions to management issues that balance long-term and short-term benefits and encompass sophisticated understandings of social and environmental change to define future trajectories based on societal engagement in decision-making	
Identifying the environmental and social impacts, benefits, and risks of human activities in oceans undergoing change due to extractive industries, fishing, tourism, navigation, and traditional uses	69
Formulating solutions which improve the wellbeing of communities and the environment simultaneously	70
Identifying the links between marine ecosystem function (including biodiversity and compositional structure components), ecosystem services and values	67
Finding appropriate and effective methods of valuing marine environments (including marine-based resources)	67
Understanding the unique challenges of high seas management and the best methods for ensuring effective and credible high seas governance and conservation outside national jurisdiction	60
Theme 4: Establishing effective and appropriately resourced institutional networks for monitoring marine environments and foster solution focused marine science encompassing local, regional, national and international scales	
Establishing and maintaining a network of institutions to identify and monitor environmental change and its impacts on biodiversity	77
Identifying the ensemble of indicators to assess the state of coasts and ocean	77
Theme 5: Establishing effective solutions-focused institutions for translating diverse scientific and social-scientific knowledge into innovative regulatory and social and economic practice that enhances the value society places on the marine environment in resource use and conservation	
Identifying the policy, legal, or institutional arrangements that are effective in integrating management for terrestrial watersheds and adjacent coastal environments	87
Establishing effective innovative governance systems which provide incentives to private and public sector leaders at all levels to engage and support healthy marine ecosystems and community wellbeing	73
Identifying the strategies which can be used to promote long-term integrated cross-disciplinary collaborations in ocean science and management	67
Establishing how uncertainty, risk, and precautions should be incorporated into effective ocean governance and policy-making	70

No. of survey respondents = 30 of 42 workshop participants.

and Carpenter, 2003; Folke et al., 2004; Levin and Lubchenco, 2008; Cote and Nightingale, 2012; Hughes et al., 2013). Surprises happen because there are limits to knowledge particularly of interdependencies in socio-ecological systems (Thrush et al. unpublished manuscript). Certainty, both in predictive models, and the data available to parameterize and validate them, and the use of averages rather than extremes to develop predictions, also can lead to unexpected consequences. Surprises can be ecological, physical, or social, with new industries and foreign investment being common causes of surprises. Navigating surprises is an ongoing challenge for marine industry, environmental resource managers, and marine resource policy makers. The focus of marine resource management is often on resource use or impact control within limits, however it is becoming imperative to consider how marine science might build capacity to manage tipping points, thresholds and surprises.

Key challenges in managing for surprises were considered to be a limited understanding of ecological resilience and of the subtle shift in processes that lead to changes and tipping points in both social and ecological systems (Thrush et al., 2009). In ecological systems, these tipping points often demonstrate that there is an environmental limit to certain kinds of economic growth, but if the socio-economic system is adaptive and resourceful, new opportunities may occur. Managing by limits requires cognizance that ecosystems are dynamic and limits can change (Craig and Ruhl, 2010). Cumulative effects, for example, through additional new marine industries, climate change and other stressors that reduce environmental capacity, push on limit setting processes and increase the risk of limit failure and environmental, economic, or social collapse (Scheffer and Carpenter, 2003; Hughes et al., 2013). The challenge is how to support the management of ecosystems in a different way, and develop tools that translate complex socio-ecological processes into dynamic reactive and adaptive management strategies. Providing buffers and ecological and environmental insurance against surprise is critical for creating certainty for industry, communities and the environment. Ways forward are through the acknowledgment of uncertainties and clear communication of gaps in knowledge including limiting drivers of change. Better management will also involve learning from history by examining systems with strong interactions and how they respond to change to develop mitigation or buffer strategies to reduce surprises and avoid exceeding tipping points.

Cumulative Impacts

Developing methodologies to reveal the complex and cumulative effects of change in marine systems will enhance management of resource use, stewardship, and restoration. Workshop participants discussed the levels of organization and interactions within and between scales in marine systems, and how cumulative impacts could be seen as moving a system along a gradation from pristine to degraded. Complex interactions and context-dependent effects change the risk of return, or chance of successful restoration, along this gradient. Discussions pointed to a need to understand how cumulative impacts set up trajectories in natural system dynamics that have their analogs in investment decision making and economic transformation. An example that was provided was that of economic geography using ecological metaphors to understand path dependency in economic and social transformation (Mackinnon et al., 2009).

Adopting strategic management approaches that consider cumulative impacts will be required to avoid problems associated with immediate, discrete decision making processes that tend to give priority to "first-come" applications. With both environmental and economic management working within such parameters, cumulative impacts and dynamic implications are not prioritized in research funding or decision making. They require a different knowledge platform and different research and management methodologies. They also require on-going renegotiation of mandates for research and resource use. Significantly, reference to cumulative impacts in the workshop directed attention to thresholds and tipping points, and that management to pre-empt thresholds necessitated analysis of cumulative impacts (Thrush et al., 2009; Thrush et al. unpublished manuscript). Discussion also shifted backwards and forwards between the social and the ecological, in terms of the generation of cumulative impacts and considering their implications. In this context participants saw the disconnection between the different kinds of agencies in science, science funding, and management as most troubling, and indeed represented the pivotal challenge for managing cumulative impacts as institutional.

Much of this discussion would appear to be routine to scholars concerned with cumulative impacts. Its novelty, rather, is in the trans-disciplinary and collaborative character of the thinking. Within the workshop participants demonstrated an ability to consider questions addressing what society expected of its marine environments leaving aside their own institutional thinking. This was facilitated by considering trade-offs among values, aims, and targets for restoring system balances and provision of services. Most workshop participants accepted the challenge of thinking about cumulative impacts in the social as well as ecological worlds. That is, they could be convinced to look past static conceptions of socio-cultural values and economic settings to accept the social as at least as dynamic as marine ecologies and therefore much more complex than ordinarily allowed for in such debates. As well as requiring long-term scientific programmes at appropriate spatial and temporal scales to adequately assess natural variability, impacts, and restoration trajectories within in marine management, we also require much more sophisticated understandings of social and economic processes. Participants advocated strongly for taking a step back in the prioritization of science agendas to identify guiding principles for understanding cumulative impacts of multiple stressors. The challenge is to use the present as a starting place for implementing change in making and applying knowledge for future socio-ecologies.

Balancing Short- and Long-Term Benefits

Workshop participants identified the need to develop solutions to management issues that balance long- and short-term benefits and trade-offs in economic and ecological values. Making trade-offs requires sophisticated understanding of social and environmental change to define future trajectories, plus more diverse or strategic societal engagement in decision-making. Most participants expressed the perception that economy and short-term gains tend to overwhelm long-term environmental gains. A central focus of discussion was mismatches in both temporal and spatial scale due to mismatches between political cycles and ecological processes, and the power of vested interests (both political and communities) to suppress changes in decision-making. Regular changes in institutions, governance, and infrastructure, make it difficult to fill in gaps in science and do not facilitate strategic thinking. At the same time, marine science typically proceeds independently of social, economic and political needs, and without evaluating political and governance structures and the outcomes of management decisions. Marine management lacks both baseline and monitoring of decision-making “experiments” to see how they are working.

A key challenge determined for incorporating trade-off thinking into decision-making was the mismatch in ideology and values between different stakeholders (Chapin et al., 2009). Currently, stakeholders have different levels of knowledge and power (Bremer and Glavovic, 2013), and those with economic interests often drive decision-making, resulting in inequitable compromises. Stakeholders (including environmental scientists) often lack shared long-term aspirational goals, compromising the ability to weigh short term decisions against long-term outcomes. Participants stressed the need to understand the values and aspirations of all community members, and recommended an ecosystem based management project that incorporates all stakeholder goals, as well as consideration of all uses and impacts on the marine environment including land-based activities.

The transformation toward participatory decision-making was seen as the way forward in developing shared visions for long-term sustainable management that balance short- and long-term gain. Participatory processes based around environmental future scenarios, incorporating industry, public, and indigenous viewpoints and values, can be used to inform decision-making, and highlighted limitations of sector-based management to maintain a trajectory toward future states (Le Heron et al., in press). To build on current management tools and move to a more ecosystem-based approach the presentation of options and bottom-lines around marine spatial planning needs to be more focused, maintaining ecosystem services and the adaptive capacity of ecosystems (Blau and Green, 2015).

Creating Collaborative Institutional Networks and Data Sharing Culture

Enabling marine science research to feed into policy and decision-making requires communication between institutional networks and frameworks, and the establishment of effective and appropriately resourced institutional networks for collecting long-term datasets that allow for monitoring marine environments. Time series data is essential for detecting change and predicting surprises and tipping points, and to evaluate the success of management strategies. Without monitoring decision makers become increasingly reliant on models that are often unvalidated.

A major challenge is ensuring the funding infrastructure to coordinate both data sharing and monitoring and data collection. Participants in all breakout sessions emphasized the need to develop strategies for integrating research and data collection, analysis, and informing of management and policy across research programmes and management sectors. However, acquiring funding to support long-term dataset collection is challenging, and funding for monitoring is often difficult to obtain. While recognizing the value of long-term datasets, participants commented that limited funding availability inevitably means that funding toward long-term monitoring takes away from other science funding. Other countries have programmes such as the LTER and NERR (U.S.A.) where long-term datasets allow breakthroughs in understanding of complex ecological processes (Knapp et al., 2012). However, New Zealand’s current system is disjunct, with datasets reliant on individuals and institutions, poor long-term sustainability and accessibility, and limited coordination and standardization for collection methods, storage and compatibility of data (Parliamentary Commissioner for the Environment, 2007). All of these require coordination, and in New Zealand, initiatives have begun across the natural resource sector to consolidate and coordinate data collection and monitoring across research and funding institutions, as well as individual researchers [e.g., Hewitt et al., 2014 and the Regional Councils Special Interest Group Coastal (CSIG) who are developing standardized sampling methodologies and data bases for coastal and estuarine monitoring].

While strategic monitoring of agents of change that test assumptions of predictive models can assist in predicting and avoiding tipping points and threshold behaviors, institutional networks should also foster solution-focused experimental marine science encompassing local, regional, national, and international scales. Strategic monitoring and hierarchical scales can be adapted to connect regional, national and global scales (Overton et al., 2015). Communications between marine scientists and managers should occur to discuss practicalities of what variables should be monitored, and appropriate spatial and temporal scales of monitoring to ensure monitoring data is able to answer questions of relevance for management.

Novel methods of data collection can assist when funding is insufficient. Development of citizen science projects such as the Marine Metre Squared (www.mm2.net.nz) project and community shellfish monitoring, were seen as having the added benefit of tying in to what people value, and establishing hubs for citizen science led by research organizations and marine scientists. The implementation of New Zealand’s National Science Challenges suggests society is looking to engage in particular kinds of work and are willing to pay for it. Part of that is the “wow” factor that draws people in, which is something that politicians can use in promoting funding for research through recognition of societal values and including targeted funding toward projects that engage society in the monitoring, management, and enhancement of these values.

Enabling Science-Policy Dialogue

Workshop participants discussed the need for establishing effective solutions-focused institutions for translating diverse scientific and social-scientific knowledge into innovative regulatory and social and economic practice that enhances the value society places on the marine environment in resource use and conservation. The discussion focused on problems that have arisen as a consequence of institutional and jurisdictional fragmentation, which leads to a siloed approach. This can also affect how different organizations set their priorities. Participants discussed the challenges associated with doing research and reconciling this with implementation, particularly for those organizations who have a dual role, i.e., research and implementation.

At present, resource decisions in the marine environment may be stymied by lack of knowledge of specific processes and changes associated with resource use. Such lack of knowledge is presently dealt with by adopting the precautionary principle. However, the role of science in the definition of what constitutes sufficient knowledge has been taken over by court procedures and is now a public issue, rather than a strictly scientific one (e.g., Straterra, 2015). In this context, although scientists may produce credible information, contrary information and public or political pressure may result in decisions (both for and against the environment) not based on science. Thus, a large challenge is to overcome cynical views of science held by society and often by politicians. Contributing to this is the difficulty that surprises and potential threshold effects pose for adaptive management of resources.

Participants also identified and discussed the various opportunities and constraints that exist as a result of how research and management are structured; that is, how universities, government agencies and research institutes function and interact. In discussing what has happened in New Zealand, examples from overseas were drawn upon to demonstrate alternative approaches that have resolved some of the problems associated with fragmentation. An example raised was the case of an oceans policy, which used an ecosystem framework and brought changes to how decision making was approached (Blau and Green, 2015). Institutional deficiencies were identified at all levels of management and across levels of management (i.e., poor or poorly developed communication pathways). There was consensus that more effective institutional arrangements that enhance science-policy dialogue were needed, and a range of possibilities (as well as challenges) were identified.

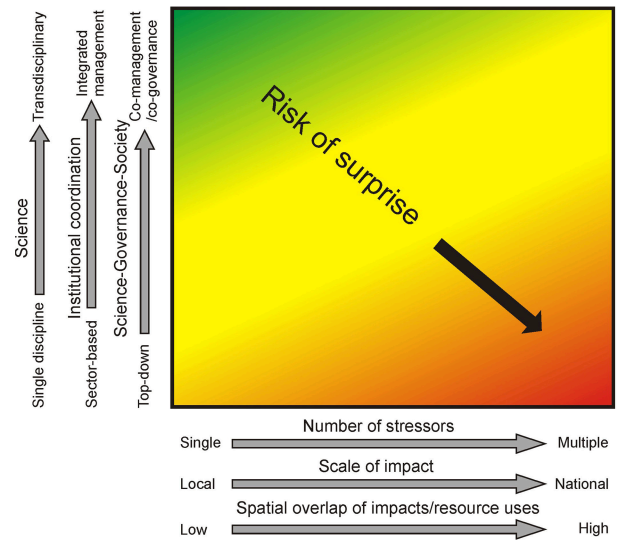

FIGURE 2 | Inter-connections between science, governance, and society that drive our ability to manage for socio-ecological surprises.

DISCUSSION

A step change in how we manage the oceans is required, toward cumulative multi-user management and policy, in order to achieve improved marine futures. The increasing diversity and cumulative nature of current stressors to marine ecosystems present challenges for management, and increase the risk of surprises, and the potential for ecological, social, or economic collapse (**Figure 2**). The impacts to marine environments are broader and far more overlapping than can be assessed and managed through a suite of single sector approaches to both research funding and management (**Figure 2**). Rather, we need to do science differently, and modify the organization of institutional frameworks and research funding in a way that emphasizes the need for better coordination across research and management to ensure that ecosystems retain their ability to adapt to change (**Figure 2**).

An important step toward improved marine futures is the need for a radical change in information exchange between policy and decision-makers and scientists to better prioritize and coordinate research agendas. Research funding should be identified and targeted strategically to provide information to support integrated ecosystem based management, and allow us to cope with "wicked problems" (Davies et al., 2015). Chartering an agreed national strategy would allow more transparency, informing the public of the priorities and strategic science questions as the system changes. Furthermore, engaging the public can enable the public to become involved and have an invested interest in the future of New Zealand, and what is at stake if we continue at the status quo. Recognizing the need for trade-offs in resource uses and social, cultural, spiritual, economic, or environmental values can identify and mitigate against challenges and conflicts between different user groups.

In spite of the growing awareness of the importance of ecosystems and biodiversity to human welfare large scale losses of biodiversity and degradation of ecosystems still continue and these trends are likely to increase with population growth and climate change (De Groot et al., 2010). Fundamental changes are therefore needed in the way biodiversity, ecosystems and their services are valued by the business community, society, and policy makers. Various types of failure have contributed to such large-scale and persistent degradation of the natural environment. These failures include problems of management and governance of ecosystems including institutional failures, the fact that many services are public goods with insufficient incentives to maintain ecosystems for continuing provision of services and in some cases a lack of information about the direct contributions of ecosystem processes and biodiversity to human welfare (De Groot et al., 2010). The landmark publication that focused on the economic valuation of global ecosystem services (Costanza et al., 1997) and the release of the Millennium Ecosystem Assessment (MA) (2005) have helped to foster the use of the concept of ecosystem services by policy makers and the business community. Similar frameworks have been adopted by IPBES (the International Science-Policy Platform for Biodiversity and Ecosystem Services), which aims to systematically link the functioning of ecosystems with human well-being using concepts such as natural capital which represent the limited stocks of physical and biological resources (Díaz et al., 2015). A critical research direction will be to integrate not only economic or monetary values, but to also understand and give due attention to the underlying changes in ecological (e.g., ecosystem integrity and support functions) as well as socio-cultural values. This will require a broader range of approaches including: complex systems approaches to valuation, biophysical quantification approaches to ecosystem services including the mapping and spatial prediction of ecosystem services, ecological (rather than economic) perspectives, adequate inclusion of socio-cultural values, and the use of non-anthropocentric applications to the concept.

Science needs to do work. Science contributes in many forms to the richness of our knowledge and our society, and can be used to resolve future problems. But increasingly society is demanding more from scientists in terms of addressing major issues of environmental change. Our responsibility here is to both generate the data, ideas and capacity to inform choices and responses, but also to be able to offer a vision of options based on rigorous and credible science. We require different platforms for making and knowing science and need to develop "principles of pertinence" for prioritizing strategic research questions. The shift in research agendas from individual and institutional environmental politics, to making a trans-disciplinary contribution, is a challenge. Developing the conditions under which that contribution emerges (creating research relevance) needs to be part of standard practice.

These findings underscore the need for exploring new ways to engage marine scientists across disciplines in co-design, co-production, and co-implementation of research with partners in government and civil society, including indigenous and local knowledge holders. Co-production of knowledge requires high levels of engagement, and challenges traditional thinking about how science is framed and carried out. Making this transformation will therefore require innovation on the part of all involved in marine science and management, from scientists to funders, marine resource users and communities. Making a constructive contribution and acknowledging the importance of multiple perspectives and approaches is at the heart of inter- and transdisciplinary science. In this exercise, we attempted to define and navigate the landscape for New Zealand marine science to offer a new alternative to the current piecemeal approach. The hope is to develop capacity and capability in funders for strategic research to attempt such transformative actions, resulting in marine science that both produces knowledge and supports it. Furthermore, this transformation needs to permeate the rooms of decision makers to shape and deliver change.

AUTHOR CONTRIBUTIONS

CL, ST, RL, KF, JH, NL, JE, DS formed the Marine Futures programme team that jointly designed the concept for the New Zealand marine horizon scanning survey and the subsequent workshop. KC and TB performed the literature search to develop summary questions used in the NZ survey, and analyzed the NZ survey data. All authors contributed to refining questions for inclusion in the survey, and participated in workshop development. AG contributed to workshop development, and facilitated the workshop. CL drafted the main text of the manuscript, with writing contributions from all authors. All other authors revised the manuscript critically for intellectual context, and approved the final version for publication. All authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://journal.frontiersin.org/article/10.3389/fmars.2016.00002

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