ICES Journal of Marine Science

ICES Journal of Marine Science (2017), doi:10.1093/icesjms/fsx201

Quo Vadimus

Disciplinary diversity in marine sciences: the urgent case for an integration of research

Till Markus[1]*, Helmut Hillebrand[2,3], Anna-Katharina Hornidge[4,5], Gesche Krause[6], and Achim Schlüter[5,7]

[1]*Research Centre for European Environmental Law, University of Bremen, Universitätsallee GW 1, 28359 Bremen, Germany*
[2]*Carl-von-Ossietzky University Oldenburg, Institute for Chemistry and Biology of Marine Environments [ICBM], Schleusenstrasse 1, 26382 Wilhelmshaven, Germany*
[3]*Helmholtz-Institute for Functional Marine Biodiversity at the University of Oldenburg [HIFMB], Ammerländer Heerstrasse 231, 26129 Oldenburg, Germany*
[4]*Institute of Sociology, University of Bremen, Mary-Somerville-Str.9, 28359 Bremen, Germany*
[5]*Leibniz Center for Tropical Marine Research, Fahrenheitstr. 6, 28359 Bremen, Germany*
[6]*Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research (AWI), Earth System Knowledge Platform (ESKP), Bussestrasse 24, 27570 Bremerhaven, Germany*
[7]*Jacobs University Bremen, Campus Ring 1, 28759 Bremen, Germany*

**Corresponding author: tel: + 49 421 218 66103; fax: + 49 421 218 66099; email: tmarkus@uni-bremen.de.*

Markus, T., Hillebrand, H., Hornidge, Anna-K., Krause, G., and Schlüter, A. Disciplinary diversity in marine sciences: the urgent case for an integration of research. – ICES Journal of Marine Science, doi:10.1093/icesjms/fsx201.

Received 22 March 2017; revised 4 October 2017; accepted 4 October 2017.

Recent events and trends in international relations are making it necessary for scientists to design their projects in ways that can integrate disciplinary perspectives and learn how to communicate their results in governance processes. Some examples of settings in which such skills would be needed are the debates about the political and legal relevance of the "Anthropocene" as a concept, the establishment and implementation of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), the recent International Court of Justice's decision on what constitutes "scientific purpose" under the Whaling Convention, and the ongoing international efforts to regulate deep seabed mining activities. These events reveal an acceleration of growing environmental, distributional, and geostrategic conflicts over ocean resources which are changing the character of marine research. For some time now marine sciences have recognized the interdependence of social and ecological systems and the cumulative effects of multiple environmental pressures. In addition, we observe that the relationship between science and policy-making is rapidly changing in a process which we refer to here as the internationalization of knowledge, and that scientific research activities and results are progressively being internationally contested. Altogether these developments constitute extrinsic constraints that render transcending disciplinary boundaries a *conditio sine qua non* for future marine research. Better comprehension of these trends and their implications may help us to understand marine science's functioning in the near future, particularly the relationship between disciplines involved.

Keywords: cross-discipline interaction and communication, function of social sciences in marine research, globalization of knowledge, integrating disciplinary research, interdisciplinarity, international contestation of scientific research.

Introduction

Developments over the last five to six decades have substantially changed the amount, scope, and purpose of marine research, as well as the relative weight and role of disciplines involved. Marine research has come to a point where there are many diverse branches which are highly specialized, while at the same time there is a growing awareness of the interaction between social and ecological systems, as well as cumulating multiple pressures on ecological systems that create complex environmental problems. Two more significant and yet largely unexplored trends are the

internationalization of knowledge and growing international conflict over marine research activities and results, both of which are causing the various branches of marine research to undergo dramatic changes. We argue that these developments constitute strong extrinsic motivators for marine researchers to communicate and integrate their highly specialized disciplinary knowledge into different scientific, political, legal, or practical contexts. Though these trends were already set in during the late 20th century, they have become even more relevant in several recent political, legal and institutional actions such as the establishment of the IPBES, the inclusion of an explicitly ocean-focussed sustainable development goal into the UN 2030 Agenda, the International Court of Justice's decision on what constitutes "scientific purposes" under the Whaling Convention, the international regulation of ocean fertilization experiments, the establishment of the world's largest marine protected area in Antarctic waters, the United Nation's efforts to protect marine biodiversity in areas beyond national jurisdiction, the regulatory actions regarding deep seabed mining, and the adoption of several national and regional integrated ocean policies. Such actions indicate a growing urgency to develop tools and skills to communicate and integrate disciplinary knowledge. Better understanding these trends and their implications may help us to comprehend marine science's functioning in the near future, particularly the relationship between disciplines involved. Accordingly, this article traces the change in the functionality and disciplinary composition of marine research, explains why marine scientists increasingly have to be able to communicate disciplinary knowledge as well as integrate it into other disciplines, and finally outlines important mechanisms and strategies that foster coherence and the integration of research agendas, results, and expertise.

Marine research in flux

Present social and ecological developments demand different scientific expertise concerning the seas and coasts than they did half a century ago. Traditionally, marine-related research was mainly carried out by biologists, chemists, geologists, and physicists (as well as non-scientific occupations such as naval officers, colonial seafarers, merchants and fishers) whose various goals included the documentation and better understanding of natural processes in the sea and of marine fauna and flora, as well as gaining an edge over competitors with improved navigation and military and commercial technologies (Deacon, 1997; Reed, 2009). Developments over the last five to six decades, however, have substantially changed marine research's overall character and functionality.

A growing world population, technological advances, and globalising markets' increasing demands for raw materials have led to what Hance Smith in 2000 called "the industrialization of the oceans" (Smith, 2000). Along these lines, competition over watercourses, fisheries, mineral and biological resources, and large marine areas have escalated and led to environmental, distributional, and geostrategic conflicts—a trend which is likely to continue in the future (WBGU, 2013). One example among many such conflicts over securing marine resources is the current political dispute between China and Vietnam with reference to several reefs and small islands in the South China Sea claimed by Beijing as Chinese territory (Roszko, 2015). In response to the growing number of such conflicts, national and international regulations, institutions, and juridical decisions of regional and global courts have proliferated (Harrison, 2011; Oxman, 2015).

Altogether, these developments have intensified existing research in the marine natural sciences and ignited new economic, sociological, anthropological, political, and legal investigations which analyse actors' interests and strategies, their behavioural patterns and negotiation practices, as well as the design, structure and functioning of political, and judicial institutions governing these issues (Hoagland and Ticco, 2010; Hallwood, 2014; Zacharias, 2014). In particular, marine management and conservation-related research activities have advanced significantly in both the natural and social sciences. As for the former, biological, ecological, physical, and chemical research increasingly analyses the quality and the extent of the effects of single and multiple pressures on the marine environment (Norse and Crowder, 2005; Halpern *et al.*, 2008; Levin *et al.*, 2009; Long *et al.*, 2015). As for the latter, sociology, political and legal sciences, and economics systematically evaluate social drivers behind exploitation and conservation, approaches to distribution, and the often contentious effects of depleting resources and deteriorating ecosystems on societies as well as possible mitigation strategies (Hornidge and Scholtes, 2011; Markus and Salomon, 2012; Schlüter *et al.*, 2013).

The urgent need for integrating research

The growing demands, competition, and conflicts regarding marine resources in addition to increasing environmental issues have not only intensified both natural and social science research but have also created the need for researchers to integrate their highly specialized disciplinary knowledge into different scientific, political, legal, or practical contexts. To be able to orient, communicate, justify, and legitimize research activities is at the core of these efforts. This holds particularly true where scientific research is supposed to directly support economic, governance, or judicial endeavours, and where its expenses and potential effects need to be justified to the satisfaction of funding agencies or the public.

The increasing recognition of interdependence of social and ecological systems

The imprint of human activities on the environment, including oceans, has become substantial. This is evident in the prominent discourses on the "limits to growth," "sustainability and precaution," "the planetary boundaries," "shifting baselines," and lately the "Anthropocene" epoch (Steffen *et al.*, 2011; Rockström and Klum, 2014). Besides the fundamental assumption that nature's capacity to provide for resources and recover from human interventions is limited, discussions around these concepts have made clear that social and natural processes are nowadays recognized as inextricably linked to one another and that neither of them can be fully appreciated without understanding the other (Berkes *et al.*, 2000; Berkes *et al.*, 2003; Ostrom, 2009). Scientists have become increasingly aware over the last decade that most ecosystems and resources are embedded in complex social–ecological systems and that effective research, governance and conservation activities urgently require the integration and communication of scientific knowledge between different actors, disciplines, and governance processes (Cash *et al.*, 2003; Schellnhuber *et al.*, 2004; Glaser *et al.*, 2012).

The increasing recognition of cumulating environmental pressures

Another development necessitating the integration and communication of disciplinary knowledge is the pressing need to manage multiple activities and cumulating environmental pressures as a whole to maintain or restore good environmental status in marine environments (Underdahl, 1980; Halpern *et al.*, 2008; Markus *et al.*, 2011; Long *et al.*, 2015). Not least, this development has significantly changed the scientific underpinnings of nature conservation and ecosystem management, particularly concerning motives and purposes (see generally Mace, 2014; Abelson *et al.*, 2016). The focus has shifted from merely analysing and considering the effects of single damaging events on specific habitats or species in order to understand how to protect or maximize their use value, to instead acknowledging that there are multiple, sometimes cumulative or overlapping pressures, and that specific species and habitats form parts of more complex ecosystems. In response, various international conventions, programmes and scientific reports throughout the last decades have highlighted the need to consider the interplay between different exploitation and use activities and their effects on the marine environment. The recent establishment of the world's largest marine protected area in Antarctic waters as well as the UN's effort to develop an instrument to protect biodiversity in areas beyond national jurisdiction constitute two important examples in this regard (Ardron *et al.*, 2014; Freestone *et al.*, 2014; CCAMLR, 2016). In addition, governments have increasingly adopted national or regional programmes and instruments that acknowledge the importance of holistic policies that allow for a comprehensive and coordinated governance of the different activities and interests related to the seas. For example, in the 1990s, Brazil, the United States, Australia, and Canada began to develop comprehensive national maritime policies, in 2007 Japan introduced its Basic Act on Ocean Policy, and in 2008 the European Union adopted its Marine Strategy Framework Directive (Juda, 2003; Markus *et al.*, 2011). Such policies and instruments have included the adoption of measures aimed at sustainable use and conservation of marine biodiversity, in particular the establishment of marine spatial plans and marine protected areas. The underlying rationale of all of these initiatives is that use and conservation conflicts in the seas cannot be solved by measures addressing single activities, sectors or species.

The internationalization of marine knowledge

Another trend demanding the integration and communication of disciplinary knowledge is the changing relationship between research and policy-making. Research has always been guided and prioritized to some extent by policy-making and its resultant budgetary incentives (Longino, 1990, 2002). But scientific research and knowledge, in turn, has also influenced, catalysed, and framed political discourses and legal processes (Haas, 1992; Bocking, 2004; Pielke, 2007; Campbell Keller, 2009). It is argued here that this reciprocal relationship is presently changing in a process which we refer to here as the internationalization of knowledge. The process may best be described as one in which the identification, framing, assessment, and valuation of contemporary marine research results and demands is increasingly carried out in a partly scientific, partly political process at the international level. We argue that this process is particularly obvious in the area of marine research (see e.g. Haas, 1990; Walsh, 2004; Markus, 2013).

Given that marine ecosystem services and the effects of anthropogenic impacts on the marine environment often extend beyond national borders, the exploitation, management, and conservation of marine ecosystems and resources demand internationally coordinated approaches. To this end, different regional or global legal regimes and organizations are recognizing the importance of a shared scientific knowledge base for cooperation (see already Livingston, 1968). To inform political decision-making processes, some regimes require: (i) the ad-hoc analysis and assessment of specific issues, (ii) the identification of further research demands, (iii) the exchange of scientific information and data between states and other actors, (iv) the development of a common scientific understanding based on aligned scientific criteria and methodological standards, and (v) providing a continuous flow of the desired information. All of these activities require the establishment of some form of governance arrangement. The institutional design of such arrangements usually depends on their functions and tasks. Accordingly, the many existing arrangements vary quite substantially. The international organizations listed in Box 1 on the next page are examples of some of the major fora in which scientific expertise intersects with policy-making.

Most of these arrangements are not purely scientific. They are often composed of scientists as well as experts from national governments and their usual tasks are to prepare scientific information for political decision-making, identify needs for further political action, and make specific recommendations to governments for decision-taking. Accordingly, these governance arrangements can be understood as *fora* or social arenas in which scientific expertise intersects with policy-making. For example, the aforementioned Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) prepares regulatory options and decision-making for the CBD's Conference of the Parties (COPs). It has been estimated that ~90% of all its proposals are later adopted by the COP with only few minor modifications or none at all. The SBSTTA thus strongly influences decision-making-practices of the CBD-parties. Accordingly, political negotiations have largely shifted to the SBSTTA-meetings which also have been referred to as "pre-COP-exercises" (Johnston, 1997). But these kinds of governance arrangements do not only directly influence political decision-making. By analysing and assessing specific issues, identifying research demands, and aligning scientific criteria and methodological standards they shape the generation and use of scientific knowledge and thus contribute to the establishment of a standardized regional or even global understanding, perception, and valuation of specific topics and issues (Stokke and Coffey, 2004; Walsh, 2004; Gillespie, 2006; Markus, 2013; Hornidge, 2014). Where experts and scientists participate in deciding which type of knowledge is generated (particularly which research is being funded), which results matter, and which scientific insights and expertise will be considered in policies (and which are left out), they direct and influence the thoughts and actions of those actors engaging with the respective knowledge (Kitcher, 2011; Barker and Kitcher, 2014).

The increasing contestation of marine research activities

In recent years, marine research activities have more and more frequently been contested and have increasingly come into the focus of international politics and law (Gorina-Ysern, 2004; Stephens and Rothwell, 2015). The increased role of marine scientific research in international regulatory and judicial decisions is

Box 1: International governance arrangements shaping the generation and use of marine scientific knowledge

Relatively loosely integrated short and long-term working groups, networks, and programmes based on international agreements or created by international organisations

- Millennium Ecosystem Assessment (1998-2005).
- The Joint Underwater Noise Working Group of the Convention of Migratory Species (CMS), the Agreement on the Conservation of Cetaceans in the Black Sea Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS) and the Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS);
- The Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection [GESAMP].

More integrated committees and bodies institutionalised under issue-specific treaties:

- The Technical and the Legal Expert Committees on Ocean Fertilization (London Convention/Protocol on Dumping);
- The Legal and Technical Commission of the International Seabed Authority;
- The scientific committees of the many different Regional Fisheries Management Organisations [RFMOs], such as the International Commission for the Conservation of Atlantic Tunas (ICCAT); the Western Central Pacific Fisheries Commission (WCPFC), or the North East Atlantic Fisheries Commission (NEAFC)
- Subsidiary Body on Scientific, Technical and Technological Advice ary Body of the Convention on Biological Diversity (SBSTTA)
- Scientific and Technical Review Panel of the Ramsar Conventionon Wetlands (STRP)
- Scientific Committee Antarctic Research of the Antarctic Treaty
- Scientific Committee under the International Whaling Convention
- International for Conservation of Nature's Global Marine and Polar Programme (IUCN-GMPP).

Long-standing and relatively independent international or intergovernmental research organisations, with or without legal personality under international law:

- The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES);
- The Intergovernmental Oceanographic Commission (IOC);
- International Council for the Exploration of the Seas (ICES).

evidence that scientists are more often required to communicate, justify, and legitimize their research to the public, to funding agencies, to political institutions, and even to courts.

Two recent events illustrate the necessity of several states to take political and legal action in order to define and defend legitimate scientific research. In the first case, the fear of unilaterally authorized commercial ocean fertilization as well as adverse and irreversible environmental impacts of scientific fertilization experiments compelled the international community under the London Convention and Protocol on Dumping to regulate the issue during the years between 2007 and 2012. To ban fertilizing for commercial purposes and yet allow environmentally sound research, states had to establish criteria and procedures which: (i) distinguished between what has been termed "legitimate scientific research" and "commercial activities" and (ii) ensured that experiments would not negatively affect the marine environment. In essence, they created an assessment framework which requires a scientific quality check to ensure that experiments have "proper scientific attributes" and an environmental impact assessment (Markus and Ginzky, 2011). The second example concerns Japan's practice of catching whales "for scientific purposes." The meaning of what actually constitutes scientific research was disputed between Australia and Japan before the International Court of Justice between 2010 and 2015. Basically, Australia argued that Japan's practice of hunting whales neither constituted "science" nor was it carried out "for scientific purposes" as understood under the International Convention for the Regulation of Whaling. In abstaining from giving a general definition as to what constitutes scientific research, the Court decided that Japan's whaling programme was not reasonable in relation to its officially claimed scientific objectives and therefore was not carried out "for the purpose of scientific research" (International Court of Justice, 2014).

In addition, it has been pointed out that marine scientific research activities are increasingly met with scepticism for their environmental effects and trade-offs (e.g. Verlaan, 2007; Hubert, 2015). Though marine environmental threats posed by scientific activities are generally deemed low compared with industrial ones, some research experiments—including seismic surveying, ocean fertilization, the introduction of genetically modified organisms into marine waters, and the killing and study of large animals such as whales or tunas, as well as all other kinds of invasive research in sensitive areas (e.g. seabed areas in which hydrothermal vents exist)—have been subject to public criticism.

Accordingly, marine scientific research activities often have to be justified against public concerns and criticism and are increasingly subjected to national and international environmental regulation (Hubert, 2015).

Strategies and techniques for marine researchers under new conditions

Against the background of these drivers and trends that are changing marine research we argue that it would be in the interest of scientists involved in marine research to develop the necessary skills to be able to solve complex ecological problems, and to communicate, justify, and legitimize research activities to scientists from other disciplines, policy makers, funding agencies, and the public.

A concrete example highlighting the importance of integrating disciplines and communicating between them, and also between science and governance, is the concept of "ecological stability." Natural scientists have developed multiple loosely defined measures of stability to capture the ability of ecosystems to absorb or withstand environmental change, making stability a cornerstone of ecological research, especially in a global change context (Pimm, 1984; Ives and Carpenter, 2007; Timpane-Padgham *et al.*, 2017). Donohue *et al.* (2016) conducted a systematic literature review and detected a tendency within ecology towards reductionist approaches where each study focused on a single driver of change and a single aspect of stability in isolation. Even more striking, however, is that the different stability aspects used in ecology were not at all congruent with the stability concepts used in major environmental policy documents addressing conservation, ecosystem management, and services. Thus, because the different scientific communities have not yet been able to develop a complex and generalizable approach to measure stability, the scientific and regulatory communities are not guided by a common analytical framework.

Several steps may be undertaken to promote the objective of communicating between and integrating disciplines. First, scientists may consider formulating research questions and designing experiments in ways that allow and encourage collaboration with different disciplines. Different disciplinary perspectives should be able to work together to provide integrated 'answers' to larger umbrella questions. Second, researchers may strive toward gaining a basic understanding of governance processes and developing techniques to connect their results to these processes (Boesch, 1999; Cash, 2003; Ostrom, 2009). For both, a basic understanding about other disciplines, their epistemological perspectives, and problem foci constitutes a substantial asset for all involved researchers. On a basic level, this requires a continuous and institutionally supported interdisciplinary exchange, the clarification of terminologies, research practices and methods, and the various disciplines' concrete contributions to the joint research question, as well as jointly developed models (Kohler, 2002; Cash, 2003 here speak of conscious and systematic "boundary work" for crossing disciplinary gaps). This can best be achieved if researchers have been socialized into a community where they have the opportunity to develop the required interdisciplinary language, conceptual, and methodological skills, and thus can interact in a mutually respectful and productive manner. Building such a community includes measures reaching from educational programmes to establishing institutions that continuously engage in knowledge integration and interdisciplinary work (Lentsch and Weingart, 2011). It also requires education in the theory of science, introduction to rudiments and basic ideas, terms, and concepts of other disciplines related to one's own research field, and the teaching of analytical and methodological approaches for integrating research results from different disciplines (Lang *et al.*, 2012; Neßhöver *et al.*, 2013; Ciannelli *et al.*, 2014; Pohl *et al.*, 2017).

On a scientific level, disciplinary knowledge integration demands an analytical or classificatory framework that allows the organization of research results from different disciplines (Ostrom, 2009). Future marine research and conservation efforts may thus gradually be designed in a transdisciplinary and synthesising way, acknowledging the causal links between societies and ecosystems as well as the complexity of ecosystems and the different types of cumulative and overlapping pressures from different sea-, air-, and land-based sources (Levin *et al.*, 2009; Tallis *et al.*, 2010; Long *et al.*, 2015). With respect to marine conservation, this suggests in practical terms the development of ecological, economic, and social indicators and environmental scientific criteria based on current marine environmental and socio-economic statuses, and an ideal status and management strategy (ibid). It also argues in favour of identifying and quantifying ecosystem services, evaluating social demands and interests of different actors from different sectors, and identifying and evaluating trade-offs among management options (ibid). In this regard, bridging different spatial, ecosystem, and administrative scales and sectors is often necessary (Krause, 2014; Schwerdtner Máñez *et al.*, 2014). It is important to stress in this context that interdisciplinary work must not in any way reduce the quality of specific disciplinary research results but must instead find ways to link and accumulate it.

Scientists must become more aware that their work is necessary to solve the problems of our time, that it is a pertinent part of complex political and economic processes, that it may have substantial impacts on the marine environment, and that it may influence future scientific knowledge generation and use. These aspects make scientific research more than ever subject to contestation, both in national and international public, political, and even legal contexts. Scientists should prepare to communicate and legitimize their work in these contexts and in light of these kinds of demands and concerns. The following is a general list of strategies that may help scientists to communicate and justify research activities within public, political, regulatory or even judicial processes:

(i) making the purpose of scientific endeavours transparent to allow a clear distinction between scientific ends and commercial interests (who benefits?);

(ii) clearly articulating the potential environmental, socio-economic, and socio-cultural effects of the research; and

(iii) participating constructively in the regulation of scientific endeavours where negative effects on the environment or society cannot be ruled out.

(iv) outlining the underlying rationale and the data used in decision making processes, and disclosing value judgments and uncertainties;

(v) including distinguished and independent experts to guarantee that research results and arguments are based on well-founded expertise;

(vi) including representatives from different cultures and scientific backgrounds;

(vii) consider making research methods and results publicly available (if commercial interests in carrying out experiments should be ruled out);

(viii) granting permission to those affected by the research projects to voice their interests.

Conclusion

Changing research demands have redefined contemporary marine research. Natural scientific research has become more specialized and is increasingly complemented by research in the social sciences and the humanities. Greater recognition of the interdependence of social and ecological systems, rising demands for enhancing marine environmental conservation, the internationalization of knowledge, and the growing conflicts over marine scientific research are making it essential for marine scientists to design their research questions in such a way that they may be integrated with other disciplinary perspectives in order to achieve a more holistic understanding of the interdependences between the ocean and the social, economic, and political world.

Recent incidents indicate an acceleration of these trends and issues as well as a growing urgency to be able to communicate and integrate disciplinary knowledge. These trends require mechanisms that foster coherence and integration of research agendas, results and expertise. Such mechanisms may be either of a more procedural type or more of a methodological type. Interdisciplinary integration and boundary crossing, however, must not in any way reduce the quality of specific disciplinary research results but instead must find ways to link and systematically synthesize. This can only be achieved if there is a community of researchers which has been socialized into and developed the required skills for interdisciplinary work, and thus can meaningfully interact accordingly. Building that community requires educational programmes and institutions that continuously engage in interdisciplinary work; it furthermore encourages scientists to become more aware of the theory of science, to become more literate in the rudiments and basic ideas, terms, and concepts of other disciplines related to one's own research field, and to acquire an analytical and classificatory framework for integrating research results from different disciplines. The benefits of a basic integration of increasingly specialized research activities are hard to estimate, though it is possible that inconsistencies and inefficiencies may for the most part be avoided while synergetic and mutual benefits may be reaped. Interdisciplinary research has for a long time been carried out by intrinsically motivated scientists and it has been seen as a necessary *addendum*, adding some "extra flavour" to disciplinarily designed projects in order to systematically diminish the blind spots created by the disciplinary boundaries guiding our thoughts. We have entered a new era of interdisciplinarity, where extrinsic constraints make transcending disciplinary boundaries a *conditio sine qua non* for future marine research.

Acknowledgements

Authors have been funded by the University of Bremen, the University of Oldenburg, the Helmholtz-Institute for Functional Marine Biodiversity at the University Oldenburg (HIFMB), the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, and the Leibniz Centre for Tropical Marine Research. This article has also been inspired by the discussions taking place under the Oceans Past Platform (OPP) COST Action network (IS1403) as well as the Ocean Governance for Sustainability (OceanGov) COST Action network (CA 15217), both of which have been supported by COST (European Cooperation in Science and Technology). It also draws inspiration from work and courses carried out at the Bremen International Graduate School for Marine Sciences - GLOMAR, MARUM - Center for Marine Environmental Sciences, University of Bremen, as well as in the context of The International Research Training Group INTERCOAST – Integrated Coastal Zone and Shelf-Sea Research. We would like to thank three anonymous reviewers as well as Michael Flitner (University of Bremen), Victor Smetazceck (Alfred Wegener Institute), Simon Lohse (University of Hanover), and Ellen Sabo for their valuable ideas and comments on early drafts of this article. All limitations, errors or obscurities remain entirely the responsibility of the authors.

References

Abelson, A., Halpern, B. S., Reed, D. C., Orth, R. J., Kendrick, G. A., Beck, M. W., Belmaker, J. *et al.,* 2016. Upgrading marine ecosystem restoration using ecological-social concepts. BioScience, 66: 156–163.

Ardron, J. A., Rayfuse, R., Gjerde, K., and Warner, R. 2014. The sustainable use and conservation of biodiversity in ABNJ: What can be achieved using existing international agreements? Marine Policy, 49: 98–108.

Barker, G., and Kitcher, P. 2014. Philosophy of Science. Oxford University Press, Oxford.

Berkes, F., Colding, J., Folke, C. (Eds.) 2000. Linking social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience. Cambridge University Press, Cambridge.

Berkes, F., Colding, J., Folke, C. (Eds.) 2003. Navigating Social-Ecological Systems – Building Resilience for Complexity and Change. Cambridge University Press, Cambridge.

Bocking, S. 2004. Nature's Experts – Science, Politics, and the Environment. Rutgers University Press, New Brunswick.

Boesch, D. F. 1999. The role of science in ocean governance. Ecological Economic, 31: 189–198.

Campbell Keller, A. 2009. Science in Environmental Policy - The Politics of Objective Advice. MIT Press, Cambridge.

Cash, D. W., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., Guston, D. H., Jager, J. *et al.,* 2003. Knowledge systems for sustainable development. Proceedings of the National Academy of Sciences of the United States of America, 100: 8086–8091.

CCAMLR 2016. Conservation Measure 91-05, Ross Sea region marine protected area. https://www.ccamlr.org/en/measure-91-05-2016 (last accesse 2 August 2017; 17: 39).

Ciannelli, L., Hunsicker, M., Beaudreau, A., Bailey, K., Crowder, L. B., Finley, C., Webb, C., Reynolds, J., Sagmiller, K., Anderies, J. M. *et al.,* 2014. Transdisciplinary graduate education in marine resource science and management. ICES Journal of Marine Science, 71: 1047–1051.

Deacon, M. 1997. Scientists and the Sea, 1650-1900: A Study of Marine Science. Ashgate Publishing Limited, Farnham.

Donohue, I., Hillebrand, H., Montoya, J. M., Petchey, O. L., Pimm, S. L., Fowler, M. S. *et al.,* 2016. Navigating the complexity of ecological stability. Ecology Letters, 19: 1172–1185.

Freestone, D., Johnson, D., Ardron, J., Morrison, K. K., and Unger, S. 2014. Can existing institutions protect biodiversity in areas beyond national jurisdiction? Marine Policy, 49: 167–175.

German Advisory Council on Global Change (WBGU). 2013. World in Transition: Governing the Marine Heritage. http://www.wbgu.de/en/flagship-reports/fr-2013-oceans/ (last accessed 2 August 2017; 16: 18).

Gillespie, A. 2006. Establishing reliable foundations for the international scientific investigation of noise pollution in the oceans. Review of European, Comparative and International Environmental Law, 15: 211–226.

Glaser, M., Krause, G., Ratter, B., and Welp, M. (Eds.) 2012. Human-Nature Interactions in the Anthropocene: Potentials of Social-Ecological Systems Analysis. Routledge, New York.

Gorina-Ysern, M. 2004. An International Regime for Marine Scientific Research. Brill Nijhoff, Leiden.

Haas, P. M. 1990. Saving the Mediterranean. Columbia University Press, New York.

Haas, P. M. 1992. Knowledge, Power, and International Policy Coordination. International Organization, 46: 1–35.

Halpern, B. S., Walbridge, S., Selkoe, K. A., Kappel, C. V., Micheli, F., D'Agrosa, C., Bruno, J. F. *et al.,* 2008. A global map of human impact on marine ecosystems. Science, 319: 948–952.

Hallwood, P. (Ed.) 2014. Economics of the Oceans: Rights, Rents, and Resources. Routledge, New York.

Harrison, J. (Ed.) 2011. Making the Law of the Sea. Cambridge University Press, New York.

Hoagland, P., and Ticco, P.-H. 2010. Marine policy overview. *In* Marine Policy and Economics: A Derivative of the Encyclopedia of Ocean Sciences, pp. 3–10. Ed. by J. Steele, S. Thorpe, and K. Turekian. Elsevier, London. 618 pp.

Hornidge, A. K., and Scholtes, F. 2011. Climate Change and Everyday Life in Toineke Village, West Timor – Uncertainties, Knowledge and Adaptation. Sociologus - Journal of Empirical Social Anthropology, 61: 151–175.

Hornidge, A. K. 2014. Wissensdiskurse: Normativ, Faktisch, Hegemonial. Soziale Welt, 65: 7–24.

Hubert, A. M. 2015. Marine scientific research and the protection of the seas and oceans. In Research Handbook on International Marine Environmental Law, pp. 313–337. Ed. by R. Rayfuse. Edward Elgar Publishing Limited, Cheltenham. 512 pp.

International Court of Justice, Judgment of 31 March 2014 - Whaling in the Antarctic (Australia v. Japan: New Zealand intervening).

Ives, A. R., and Carpenter, S. R. 2007. Stability and diversity of ecosystems. Science, 317: 58–62.

Johnston, S. 1997. The convention on biological diversity: the next phase. Review of European, Comparative and International Environmental Law, 6: 219–230.

Juda, L. 2003. Changing national approaches to ocean governance: the United States, Canada, and Australia. Ocean Development and International Law, 34: 161–187.

Kitcher, P. 2011. Science in a Democratic Society. Prometheus Books, Amherst New York.

Kohler, R. 2002. Landscapes and Labscapes. Exploring the Lab-Field Border in Biology. The University of Chicago Press, Chicago.

Krause, G. 2014. The scientific challenge of bridging the gap from the local to the earth system level: lessons from the study of mangroves and people in North Brazil. Regional Environmental Change, 14: 2089–2103.

Lang, D. J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M. *et al.* 2012. Transdisciplinary research in sustainability science: practice, principle, and challenges. Sustainability Science, 7: 25–43.

Lentsch, J., and Weingart, P. 2011. Quality control in the advisory process: towards and institutional design for robust scientific advice. *In* The Politics of Scientific Advice, pp. 453–374. Ed. by J. Lentsch and P. Weingart. Cambridge University Press, Cambridge. 381 pp.

Levin, P. S., Fogarty, M. J., Murawski, S. A., and Fluharty, D. 2009. Integrated ecosystem assessments: developing the scientific basis for ecosystem-based management of the ocean. PLoS Biology, 7: e1000014.

Livingston, D. 1968. An International Law of Science: Orders on Man's Expanding Frontiers. Bulletin of the Atomic Scientist, 24: 6–10.

Long, R. D., Charles, A., and Stephenson, R. L. 2015. Key principles of marine ecosystem-based management. Marine Policy, 57: 53–69.

Longino, H. 1990. Science as Social Knowledge. Princeton University Press, Princeton.

Longino, H. 2002. The Fate of Knowledge. Princeton University Press, Princeton.

Mace, G. 2014. Whose conservation? Changes in the perception and goals of nature conservation require a solid scientific basis. Science, 345: 1558–1560.

Markus, T., and Ginzky, H. 2011. Regulating climate engineering: paradigmatic aspects of the regulation of ocean fertilization. Carbon and Climate Law Review, 477: 477–490.

Markus, T., Schlacke, S., and Maier, N. 2011. The Implementation of Integrated Ocean Policies: The EU's Marine Strategy Framework Directive. The International Journal of Marine and Coastal Law, 26: 59–90.

Markus, T., and Salomon, M. 2012. The law and policy behind the upcoming reform of the Common Fisheries Policy. Journal for European Environmental and Planning Law, 9: 257–284.

Markus, T. 2013. Changing the base: leal implication of scientific criteria and methodological standards on what constitutes good marine environmental status. Transnational Environmental Law, 2: 1–21.

Neßhöver, C., Timaeus, J., Wittmer, H., Krieg, A., Geamana, N., van den Hove, S., Young, J. *et al.,* 2013. Improving the Science-Policy Interface of Biodiversity Research Projects. GAIA - Ecological Perspectives for Science and Society, 22: 99–103.

Norse, E.-A., and Crowder, L.-B. 2005. Why marine conservation biology? In Marine Conservation Biology: The Science of Maintaining the Sea's Biodiversity, pp. 1–18. Ed. by E. Norse, and L. Crowde. Island Press, Washington. 575 pp.

Ostrom, E.-A. 2009. General framework for analyzing sustainability of social-ecological systems. Science, 325: 419–422.

Oxman, B.-H. 2015. Courts and Tribunals: The ICJ, ITLOS, and Arbitral Tribunals. In The Oxford Handbook of the Law of the Sea, pp. 394–415. Ed. by D. Rothwell, A. Oude Elferink, K. Scott, and T. Stephens. Oxford University Press, Oxford. 1072 pp.

Pielke, R. A. 2007, The Honest Broker – Making Sense of Science in Policy and Politics. Cambridge University Press, Cambridge.

Pimm, S. L. 1984. The complexity and stability of ecosystems. Nature, 307: 321–326.

Pohl, C., Krütli, P., and Stauffacher, M. 2017. Ten reflective steps for rendering research societally relevant. GAIA - Ecological Perspectives for Science and Society, 26: 43–51.

Reed, C. 2009. Marine Science: Decade by Decade. Infobase Publishing, New York.

Rockström, J., and Klum, M. 2014. Big World, Small Planet: Abundance Within Planetary Boundaries. Yale University Press, New Haven.

Roszko, E. 2015. Maritime Territorialisation as performance of sovereignty and nationhood in the South China Sea. Nations and Nationalism, 21: 230–249.

Schellnhuber, H. J., Crutzen, P. J., Clark, W. C., Claussen, M., and Held, H. (Eds.) 2004. Earth System Analysis for Sustainability. MIT Press, Cambridge.

Schlüter, A., Wise, S., Schwerdtner Mánez, K., de Morais, G., and Glaser, M. 2013. Institutional change, sustainability and the sea. Sustainability, 5: 5373–5390.

Schwerdtner Máñez, K., Krause, G., Ring, I., and Glaser, M. 2014. The Gordian knot of mangrove conservation: Disentangling the role of scale, services and benefits. Global Environmental Change, 28: 120–128.

Smith, H.-D. 2000. The Industrialization of the World Ocean. Ocean & Coastal Management, 43: 11–28.

Steffen, W., Grinevald, J., Crutzen, P., and McNeill, J. 2011. The Anthropocene: conceptual and historical perspectives. Philisophical Transactions of the Royal Society, 369: 842–867.

Stephens, T., and Rothwell, D. R. 2015. Marine scientific research. *In* Oxford Handbook on the Law of the Sea, pp. 559–581. Ed. by D. R. Rothwell, A. G. Oude Elferink, K. N. Scott, and T. Stepehns. Oxford University Press, Oxford. 1072 pp.

Stokke, O. S., and Coffey, C. 2004. Precaution, ICES and the common fisheries policy: a study of regime interplay. Marine Policy, 28: 117–126.

Tallis, H., Levin, P. S., Ruckelshaus, M., Lester, S. E., McLeod, K. L., Fluharty, D. L., and Halpern, B. S. 2010. The many faces of ecosystem-based management: Making the process work today in real places. Marine Policy, 34: 340–348.

Timpane-Padgham, B. L., Beechie, T., and Klinger, T. 2017. A systematic review of ecological attributes that confer resilience to climate change in environmental restoration. PLoS ONE, 12: e0173812.

Underdahl, A. 1980. Integrated marine policy: what? Why? How? Marine Policy, 4: 159–169.

Verlaan, P. A. 2007. Experimental activities that intentionally perturb the marine environment: implications for the marine environmental protection and marine scientific research provisions of the 1982 United Nations Convention on the Law of the Sea. Marine Policy, 31: 210–216.

Walsh, V. M. 2004. Global Institutions and Social Knowledge. The MIT Press, Cambridge.

Zacharias, M. (Ed.) 2014. Marine Policy: An Introduction to Governance and International Law of the Oceans. Routledge, New York.

Handling editor: Howard Browman