Pressures on the Ocean: Scientific Perspectives

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INTRODUCTION

A key aspect of the ocean is its fluid motion and connectivity which means that cause and effect (e.g. sources/ causes and damages/ impacts) are usually separated geographically. The legal and courtroom implications and consequences of this connectivity have commonalities, conceptually, with those encountered in areas such as long-range air pollution, water resources, and groundwater use/contamination. Dealing with such issues can be complex and often slow, in part because of jurisdictional issues but also because of the scientific difficulty of attribution (i.e. linking cause with effect). Given that legal remedies to conflicts and damages associated with the marine environment are complex and slow to establish, it is worth peering into the future and looking back on the recent past in order to identify trends in order to anticipate issues that could impact future development, application or interpretation of legislation. This type of trend analysis or projection is undertaken generally by the scientific community in isolation, sometimes with the subsequent production of “Summaries for Policymakers” or other guidance for non-scientists. In this paper, I follow this approach and present an overview of ongoing and future changes of the marine environment at large scales, which I believe are increasingly the causes or drivers (forcing) for damage and conflicts at local and regional scales which end up being litigated in the courtroom.

Despite having taken the conventional, “isolated” approach for this paper, I believe it is becoming necessary to connect legal, enforcement and scientific communities more effectively and regularly in a joint process of envisioning the ocean’s future. Ideally, this would lead to policies and legal approaches better suited to altered situations of the future ocean. However such cooperative visioning would also recognise that policy and regulation of human activities plays an increasingly important role in determining the the future state of the marine environment.

THE NATURE OF OCEAN CHANGE

Pressures on the ocean environment are strongly mediated by two main classes of forcing: 1) “direct” human forcing linked to societal change and specific human actions, including technology development, population growth and growing demands for living and non-living resources; and 2) “indirect” forcing associated with human activity, especially energy-use and agriculture which, with present technologies, impact climate and ecosystems on a global scale.

Direct Human Forcing: Human population is projected to rise to between 9.6 and 12.3 billion by the end of this century with the bulk of the growth occurring in Africa[1]. The Low Elevation Coastal Zone (LECZ; elevation < 10m), was home to 625 million people (c. 10% of the global population) in 2000 despite representing only 2.3% of global land area[2]. Projections under various scenarios suggest that the population of the LECZ will increase to between 1 and 1.4 billion by 2060, representing c. 12% of global population. Whereas the bulk of the coastal population is located in Asia, the most dramatic growth will be in Africa, especially West Africa.

[1] Gerland P, Raftery AE, Ševčíková H, Li N, Gu D, Spoorenberg T, et al. World population stabilization unlikely this century. Science 2014; 346: 234–237. doi: 10.1126/science.1257469 PMID: 25301627

[2] Neumann B, Vafeidis AT, Zimmermann J, Nicholls RJ (2015) Future Coastal Population Growth and Exposure to Sea-Level Rise and Coastal Flooding - A Global Assessment. PLoS ONE 10(3):e0118571. doi:10.1371/journal.pone.0118571

(In contrast, Canada's coastal population is projected to rise moderately from its 2000 value of 1.2 million to about 1.6 million in 2060).

A recent landmark review on "marine defaunation"[3] noted the widening range of direct human pressures on the marine environment. The authors suggested that the ocean is starting to experience human alternation of habitat analogous to the habitat degradation on land that was set in motion by the industrial revolution. Their list of recent developments includes the growth and expansion of coastal cities, land reclamation, advancements in seafloor mining, dredging, oil and gas extraction, tidal/wave energy generation, growth of marine transport and the development of ocean farming in addition to the growth of industrial fishing and bottom trawling that has been underway for some time.

Indirect Forcing: Energy-use and resulting future emissions of CO_2 are the subject of "Representative Concentration Pathways" (RCPs)[4] which are projections of future pathways of greenhouse gas concentrations and radiative forcing up to 2100 based on scenarios of socio-economic and technological change. The four RCPs (2.6, 4.5, 6 and 8.5) project atmospheric CO_2 levels of c. 400, 500, 600 and 950 ppm respectively by the end of this century. These are, in turn, associated with projected warming, sea-level rise, changes to ice-cover and other phenomena (see below for more detail) that are projected using climate models[5].

This indirect forcing is global in scope, so that regional and local changes, pressures and impacts on the marine environment and individual communities are, increasingly, the result of activities that are initiated and ongoing far away in both space and time. An obvious example of this is the rapidly changing transportation and hunting environment of Canada's northern peoples which results from climate change and the reduction of Arctic sea ice extent. Similarly, property damage due to sea-level rise cannot be attributed to specific individuals, organisations or even countries: the cause is of global extent and involves the actions of most of humankind.

Such climate-related changes to the ocean include physical changes such as ocean warming, sea-level rise, changes in sea-ice extent and iceberg distributions and, potentially, changes in the frequency and intensity of storms and the large-scale ocean circulation. These physical changes impact, in turn, the chemical and biological processes which alter marine ecosystems. However in addition to such changes resulting, ultimately, from changes in radiative forcing there is additional global-scale forcing of change associated with changing chemical composition of the atmosphere. In particular, there is considerable concern that the ocean's uptake of anthropogenic CO_2, and the associated decrease in seawater pH, is adversely affecting certain marine species and/or life-stages of aquatic organisms. This process of "ocean acidification"[6] has potential implications for corals and other carbonate-shell forming organisms, including commercially-valuable species such as oyster, and related marine food chains. Global changes to the nitrogen cycle, especially the long-range transport of fixed, bio-available nitrogen from land to remote, nutrient-deficient ocean "deserts" via atmospheric transport, is now also recognised to have the

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[3] McCauley DJ, Pinsky ML, Palumbi SR, Estes JA, Joyce FH, Warner RR Marine defaunation: Animal loss in the global ocean. Science 2015; 347: doi: 10.1126/science.1255641

[4] vanVuren et al

[5] Intergovernmental Panel on Climate Change; https://www.ipcc.ch/report/ar5/

[6] IGBP, IOC, SCOR (2013). Ocean Acidification Summary for Policymakers – Third Symposium on the Ocean in a High-CO2 World. International Geosphere-Biosphere Programme, Stockholm, Sweden.

potential to impact marine ecosystems on large scales[7] in addition to the more acute, local impacts of coastal eutrophication.

THE CONFLUENCE OF SIMULTANEOUS CHANGE AND MARINE RISK

Both classes of forcing (direct and indirect) are operating simultaneously and globally so that the overall human relationship with the ocean, and the human exposure to marine-related risk, is impacted by both and their confluence.

On the one hand, technological developments and rapid population and economic growth in the coastal zone, are altering the ways in which humans make use of, and interact with the marine environment. These changing uses can be causes of conflict, especially where new uses are introduced in the vicinity of traditional or historical uses. Examples are numerous and varied and include the development of aquaculture, growth in the use of ocean spaces for tourism or renewable energy generation, the ever deeper and global development of offshore oil and gas resources, growth of coastal megacities, the development of larger ships and associated ports, etc.. In addition to these new uses and developments, existing and longer-established use-patterns are also changing. For example, the over-exploitation of capture fisheries in waters adjacent to developed countries, together with technology development, has led to a massive, global shift of fishing pressure towards waters surrounding less-developed nations, for example in Africa[8]. Whereas impacts and conflicts resulting from these changing human use of the ocean are usually national, regional or local, the trends and patterns of change are now global. This implies a need for exchanging views on how to minimise conflicts or damage and manage the response to change on a global scale.

On the other hand, primarily as a consequence of fossil-energy use but also as a result of other global-scale industries such as agriculture, the planetary environment itself is changing, including increasingly rapid changes within and around the ocean. Here the issue is frequently related to climate change and its knock-on consequences such as sea-level rise or the dramatic reductions of sea-ice cover in the Arctic. The changing human use of the ocean is taking place in the context of these rapid and large-scale change of the environment. Examples of these ongoing and projected changes are listed below with most information referenced to the IPCC[9].

Warming: The globally averaged surface temperature has warmed by 0.85°C since 1850. This has not been spatially uniform and a few oceanic regions (including the NW Atlantic) experienced no significant long-term warming. The warming extends into the deep ocean

[7] Kim I-N, Lee K, Gruber N, Karl DM, Bullister JL, Yang S, Kim T-W. Increasing anthropogenic nitrogen in the North Pacific Ocean. Science 2014. 346: 1102-1106. DOI: 10.1126/science.1258396

[8] Worm B, Hilborn R, Baum JK, Branch TA, Collie JS, Costello C, Fogarty MJ, Fulton EA, Hutchings JA, Jennings S, Jensen OP, Lotze HK, Mace PM, McClanahan TR, Minto C, Palumbi SR, Parma AM, Ricard D, Rosenberg AA, Watson R, Zeller D. 2009. Rebuilding Global Fisheries. Science Vol. 325, Issue 5940, pp. 578-585 DOI: 10.1126/science.1173146

[9] IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

(<2000m). By the end of this century, models project global surface temperatures to be at least 1.5°C higher relative to 1850 for all RCPs except RCP2.6 and >2°C for RCP6.0 and RCP8.5.

Sea-level rise: Over the past century, global sea level rose by 0.19 m and faster than over the previous 2000 years. Thermal expansion, melting of glacial ice and large ice-sheets have contributed roughly equally to this increase. Projections of future rise are dependent on the RCP and remain controversial. The rate and even sign of sea-level rise is non-uniform, and is particularly variable around Canada due to differences in response to loss of land-ice since the last ice age. Global estimates of relative sea-level rise are 0.42 m and 0.85 m for RCP4.5 and RCP8.5 respectively[10] with projections for the Canadian coastline ranging from <0 to 0.7 m (RCP 4.5) depending on location.

Ice-cover changes: The annual mean Arctic sea ice extent decreased dramatically between 1979 and 2012 at a rate of 3.5 to 4.1% per decade. Summer extent decreased at 9.4 to 13.6% per decade. Projected summertime reductions by the end of this century range from 43% (RCP2.6) to 94% (RCP8.5) and from 8% to 34% for RCP8.5 in winter. Hence an ice-free summertime Arctic Ocean is projected for only the most extreme-case climate-change scenario.

Ocean acidification: Projected changes in surface ocean pH by the end of this century depend strongly on the amount of CO_2 emitted and range from 0.06 (RCP2.6) to c. 0.31 for RCP8.5.

OCEAN VALUE AND CHANGING MARINE RISK

The intersection or confluence of these two classes of forcing means that the nature and amplitude of marine-related risks is changing. These risks are to human life and quality of life, marine ecosystems as well as to property and economic activity in and around the oceans.

The ocean-related activities, industries and ecosystem services have considerable economic value. The global GDP of the “ocean economy” has been estimated at US$2.5 trillion per year, equivalent to that of the 7th largest national economy[11]. This did not include the GDP associated with offshore fossil-energy and other uses of the sub-seafloor.

In some cases, marine risk is altered by fundamentally new hazards that did not exist previously. The Fukushima radiological disaster[12] was the consequence of a hazard that did not exist several decades earlier. The Deepwater Horizon disaster[13] is another such example. More commonly, it is the frequency or amplitude of long-existing hazards which is altered such as sea-level rise or coastal flooding. Changing vulnerability to hazards, for example due to changing use of the coastal zone, contributes significantly to altered risk.

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[10] Carson M, Köhl A, Stammer D, Slangen ABA, Katsman CA, van de Wal RSW, Church J, and White N. 2016. Coastal sea level changes: Observed and projected during the 20th and 21st century. Climatic Change, 134:269–281 (2016): DOI 10.1007/s10584-015-1520-1

[11] Hoegh-Guldberg, O. et al. 2015. Reviving the Ocean Economy: the case for action - 2015. WWF International, Gland, Switzerland., Geneva, 60 pp.

[12] International Atomic Energy Agency. 2015. The Fukushima Daiichi Accident. 1st ed. Vienna, Austria: International Atomic Energy Agency, 2015. STI/PUB/1710; (ISBN:978-92-0-107015-9); 1254 pp.; 311 figures.

[13] National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling. Deep Water: The Gulf Oil Disaster and the Future of Offshore Drilling. Report to the President. January 2011

This global phenomenon of ongoing major change is the context for legal disputes which arise in connection with ocean activities and associated risk and damages.

EMERGING ISSUES FACING THE OCEAN

A number of fundamentally new, emerging issues are worth mentioning specifically. Each has the potential to radically change the way in which we use the ocean.

Geoengineering: intentional large-scale manipulation of planetary processes is discussed increasingly as a possible approach for mitigation of dangerous climate change. Two main approaches are considered[14]: reducing levels of greenhouse gases in the atmosphere, and altering radiative forcing. Schemes have been proposed for use on land, the atmosphere, space and the ocean. The ocean-based schemes[15] are focussed on CO_2 removal and include ocean fertilization; ocean alkalinity modification and deliberate manipulation of upwelling and downwelling circulation. Their effectiveness has been questioned[16] and even with optimistic estimates of carbon sequestration efficiency, the potential for CO_2 uptake via ocean fertilization is small relative to future emissions. Nevertheless, interest in the idea of adding small amounts of "limiting" nutrients (e.g. iron) in areas where other essential nutrients are in excess, in order to initiate phytoplankton uptake of CO_2 continues. Some of the interest likely lies with the closely associated potential for manipulating plankton blooms in order to increase fish stocks. For example a controversial iron fertilization effort was conducted by the Haida Salmon Restoration Corporation, 200 nautical miles west of Haida Gwaii in 2012, partly for CO_2 sequestration but mainly to investigate a hypothesis which linked "natural" iron deposition from volcanic ash and recruitment of Pacific salmon. The fertilization with over 100 tonnes of iron sulphate and iron oxide was conducted (without prior approval) and has been investigated by Environment Canada.

In addition to issues of legality and effectiveness, fertilization approaches have the potential for unintended consequences: for example, they can involve risk of growth of toxic algae. Addition of a limiting nutrient in one location may prevent subsequent utilization of other, excess nutrients "downstream", thereby "robbing" downstream ecosystems.

Deep-sea mining. There has been a recent upsurge of interest in deep ocean mining, with granting of 27 contracts for deep ocean mineral exploration of ferromanganese nodules, crusts and massive sulphide deposits by the International Seabed Authority[17]. Two national governments have granted mining licenses for massive sulphides within their economic zones. On the other hand, shallow-water mining has been restricted as a result of environmental concerns. Nevertheless, the increased interest suggests that as technological barriers to deep

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[14] Shepherd JG. Geoengineering the climate: an overview and update. Phil. Trans. R. Soc. A (2012) 370, 4166–4175 doi:10.1098/rsta.2012.0186

[15] Zhang Z, Moore JC, Huisingh D, Zhao Y. 2015. Review of geoengineering approaches to mitigating climate change, J. Cleaner Production. 108: 893-907. DOI: 10.1016/j.jclepro.2014.09.076

[16] Wallace, DWR, Law, CS, Boyd, PW, Collos, Y, Croot, P, Denman, K, Lam, PJ, Riebesell, U, Takeda, S, Williamson, P, 2010. Ocean Fertilization: a Scientific Summary for Policy Makers. IOC/UNESCO, Paris (IOC/BRO/2010/2), 18 pp.

[17] Petersen S, Krätschell A, Hannington MD. 2016. The Current State of Global Activities Related to Deep-sea Mineral Exploration and Mining. FR TG 08. EAGE/DGG Workshop on Deep Mineral Exploration, 18 March 2016, Münster, Germany

ocean mining are overcome and if commodity prices become attractive, the potential exists for rapid growth of marine mining in the deep ocean.

Offshore Aquaculture: aquatic systems (ocean and freshwater) presently supply c. 2% of global food supply, despite biological productivity of the oceans and land being roughly equivalent[18]. On the other hand, aquatic systems already supply almost 1/3 of the animal meat consumed by humans and c. 12% of total animal protein. Aquaculture is already similar in magnitude to production from capture fisheries and there is a widespread view that feeding of the Earth's future population will require massive expansion of ocean aquaculture[19]. This is likely to exacerbate conflicts with other ocean uses through competition for space and due to environmental impacts. The potential of moving aquaculture of plants, molluscs and fish further offshore is viewed as a likely development due to space availability and the increased potential for diffusion of wastes[20]. Both technological and regulatory factors are limiting this expansion presently, and the potential of offshore aquaculture to contribute significantly to global food production is questioned, however as technology improves, growth can be expected to develop rapidly.

SUMMARY AND SOME IMPLICATIONS FOR THE FUTURE

At the turn of the century, the renowned marine ecologist Jeremy Jackson published a seminal article[21] which chronicled the history of human disturbance (i.e. pressures) on marine ecosystems. It is instructive to revisit this article c. 15 years later. At that time, the history of disturbances was dominated by fishing, which was also the first major human pressure on the ocean dating back to the beginning of the Holocene. This has been followed, more or less sequentially, by pressures arising from coastal pollution, mechanical habitat destruction associated with coastal structures, invasive species introductions associated with marine transportation and, most recently, climate change. Based on the situation today, a number of emerging and potential threats can be added to Jackson's list including coastal aquaculture, deepwater resource extraction, faster and larger ships, ocean acidification and global changes in nutrient supply, as well as the potential for offshore aquaculture and even direct interventions into the planetary-scale processes in the form of geoengineering

As discussed above, a key characteristic of our times is that these pressures to our oceans are multi-faceted (involving simultaneous societal and environmental change), changing rapidly (and accelerating), and global in scale. The nature of the change presents enormous challenges to scientists, policymakers, and those responsible for regulating use of the marine environment. In particular, due to the rapidity and potential magnitude of the consequences of change, policy

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[18] Olsen Y. 2015. How can mariculture better help feed humanity? Front. Mar. Sci. 2:46.doi: 10.3389/fmars.2015.00046

[19] Duarte CM, Holmer M, Olsen Y, Soto D, Marbà N, Guiu J, Black K, Karakassis I. 2009. Will the Oceans Help Feed Humanity? BioScience 59 (11): 967-976. DOI: https://doi.org/10.1525/bio.2009.59.11.8

[20] Edwards P. 2015. Aquaculture environment interactions: Past, present and likely future trends. Aquaculture. 447, 2–14

[21] Jackson JB1, Kirby MX, Berger WH, Bjorndal KA, Botsford LW, Bourque BJ, Bradbury RH, Cooke R, Erlandson J, Estes JA, Hughes TP, Kidwell S, Lange CB, Lenihan HS, Pandolfi JM, Peterson CH, Steneck RS, Tegner MJ, Warner RR. 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science.293(5530):629-37.

must increasingly be based on projections of how the oceans are likely to look and behave in the future.

These projections represent a major scientific challenge which must, ultimately, rely on models that take into account the complex and non-linear interactions, thresholds and even tipping-points that exist in the Earth System and the oceans. These interactions include those of humans and their technologies and policies. Hence the models must represent changing processes and the behaviour of an entire planet and its human population (which is, obviously, unreplicated), and include representation of processes that are operating on global scales and forcings, which often with no historical counterparts. Hence the development of science-based projections of future ocean state is a "grand challenge" to the scientific method. Duarte[22] has analyzed this challenge and discussed possible approaches to addressing this grand challenge and, especially, "validating" or testing projections of future ocean state. However he also noted the importance of scientists, policymakers and managers working closely together to develop the capacity to manage ocean problems adaptively "where uncertainties and unknowns are addressed through a learning-by-doing approach".

[22] Duarte CM. 2014. Global change and the future ocean: a grand challenge for marine sciences. Frontiers in Marine Science. Volume 1, Article 63.4015–4036. doi:10.3389/fmars.2014.0006