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Adapting to Climate Change in Marine and Coastal Areas: The International Legal Perspective

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Chapter 7

Adapting to Climate Change in Marine and Coastal Areas: The International Legal Perspective

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Key words

International law, climate change, marine environment, coastal areas, climate change adaptation.

Abstract

Human induced climate change is driving rapid biophysical changes throughout the oceans and seas that cover over two-thirds of the Earth's surface. The most widely discussed effect of climate change in the marine and coastal environment is sea level rise, and the transformation of coastal geography poses a profound climate adaptation challenge in the longer term. Accompanying sea level rise are other more immediate climate change impacts upon coastal and marine areas. These include rapid melting of sea ice (most notably in the Arctic Ocean, where the extent of summer sea ice reached a record low in 2012), saltwater intrusion into freshwater aquifers (affecting water supplies), rising water temperatures (affecting the productivity and distribution of fisheries, causing algal blooms, and damaging corals), storms and storm surges (which are exacerbating erosion), and ocean acidification (the changing chemistry of the oceans damaging many marine organisms). All of these impacts can be tempered, at least to some extent and within certain time scales, by general or tailored adaptive responses at national and international levels. This chapter surveys and assesses the emerging international legal framework for the adjustment of natural and human systems in coastal, inshore and offshore marine environments in response to climate change.

Introduction

Human induced climate change is driving rapid biophysical changes throughout the oceans and seas that cover 71 per cent of the Earth's surface, and which are the primary drivers of the global climate system. The oceans have been critically important in maintaining global climatic stability, absorbing around 40 per cent of carbon dioxide (CO_2) emissions from human activities and around 90 per cent of the heat added to the Earth system by climate change.[2] The most visible effect of climate change in the marine and coastal environment has been sea level rise and the transformation of coastal geography poses a profound climate adaptation challenge. Even if atmospheric concentrations of greenhouse gases are stabilised, sea level

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[2] S D Solomon et al, *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge University Press, 2007) 404 and 392.

levels will continue to rise for millennia,[3] making coastal adaptation an issue that will demand ongoing attention.[4]

Accompanying sea level rise are other climate change impacts upon coastal and marine areas. This include rapid melting of sea ice (most notably in the Arctic Ocean,[5] where the extent of summer sea ice reached a record low in 2012), saltwater intrusion into freshwater aquifers (affecting water supplies), rising water temperatures (affecting the productivity and distribution of fisheries, causing algal blooms, and damaging corals), storms and storm surges (which are exacerbating erosion) and ocean acidification (the changing chemistry of the oceans damaging many marine organisms). All of these impacts can be tempered to some extent by adaptive responses. The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as 'the adjustment of natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities'.[6] However there are limits to the capacity of natural and human systems to adjust to climate change impacts; for instance there is no way that many marine organisms and ecosystems will be able to acclimatise to ocean acidification beyond certain thresholds, and so it is only by mitigating emissions of CO_2 that the conditions for a healthy marine environment can be sustained.[7]

This chapter surveys the international legal framework relevant to the adjustment of natural and human systems in coastal, near shore and offshore marine environments in response to climate change. National and sub-national legal systems are developing adaptive responses to climate change in coastal and marine areas by adjusting coastal planning regimes, strengthening building codes, and through 'connectivity conservation' by establishing protected areas and wildlife corridors.[8] However developments on the international legal plane with respect to coastal and marine adaptation have been modest. The 1992 United Nations Framework Convention on Climate Change[9] (UNFCCC) addresses coastal adaptation to sea level rise, to a limited extent, but the international climate regime is largely silent on adaptation in the marine environment. The main framework for adaptive responses in the maritime domain is supplied by the law of the sea, in particular the 1982 United Nations Convention on the Law of the Sea[10] (LOSC), and there are a several complementary regimes of relevance to adaptation in specific sectors and at regional scales.

Climate Change Impacts on Coastal and Marine Environments

The impacts of climate change and connected phenomena on coastal and marine environments are manifold. The IPCC's *Fourth Assessment Report* summarised the observed physical and biological changes to the oceans to date, and made projections about likely impacts into the future under several emissions scenarios.

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[3] H Goelzer et al, 'Millennial Total Sea-Level Commitments Projected with the Earth System Model of Intermediate Complexity' (2012) 7 *Environmental Research Letters* 1.
[4] Ben Saul, Steven Sherwood, Jane McAdam, Tim Stephens and James Slezak, *Climate Change and Australia: Warming to the Global Challenge* (Federation Press 2012) 20.
[5] Peter Wadhams, 'Arctic Ice Cover, Ice Thickness and Tipping Points' (2012) 41 *AMBIO* 23.
[6] M L Parry et al, *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge University Press, 2007) 750.
[7] See Richard E Zeebe, 'History of Seawater Carbonate Chemistry, Atmospheric CO_2 and Ocean Acidification' (2012) 40 *Annual Review of Earth and Planetary Sciences* 141.
[8] See, eg, Craig R Groves, 'Incorporating Climate Change Into Systematic Conservation Planning' (2012) 21 *Biodiversity and Conservation* 1651.
[9] 1771 UNTS 107.
[10] 1760 UNTS 79.

IPCC Working Group I, which assesses the physical science basis of climate change, described significant observed changes in global scale temperature and salinity, regional changes in ocean circulation, marine biogeochemical changes, and sea level rise. It concluded that the heat content of the oceans had increased substantially since the beginning of the twentieth century, that thermal expansion of the oceans was the main driver of sea level rise, that cooler waters towards the poles were becoming fresher, while waters nearer the equator were becoming more saline, that ocean circulation is changing, and that the pH of the world's oceans is decreasing (i.e. becoming acidic).[11]

Working Group II, which assesses the impacts of climate change, adaptation options and vulnerability, considered the effects of climate change on marine and coastal ecosystems in its contribution to the *Fourth Assessment Report*. However, while a whole chapter of Working Group II's report is devoted to 'Coastal systems and low-lying areas', there is no dedicated analysis of climate change impacts on marine areas beyond the coastline. Where marine issues are dealt with they are considered in the context of specific regions (e.g. the polar regions), and there is next to no treatment of adaptation options for marine environmental management. This contrasts with Working Group II's extensive and influential analysis of coastal adaptation.[12]

Studies since the IPCC's Fourth Assessment Report in 2007 have documented more fully the impact on the biogeochemical and ecology of the open oceans as a result of greenhouse gases emitted from human activities.[13] In the discussion that follows the main climate change impacts upon coastal and marine areas requiring an adaptive response are highlighted.

Sea Level Rise

Sea level rise remains of primary concern from a coastal adaptation perspective because of its capacity to cause large-scale damage to ecosystems and to human settlements and infrastructure.[14] Close to one quarter of the world's population lives within 100 km zone of the coast,[15] and the coastal population is projected to grow to up to 5.2 billion by the 2080s.[16]

The IPCC projects that sea levels will rise between 0.18 and 0.59 m this century as a result of thermal expansion of the oceans and the melting of ice sheets.[17] However this projection is conservative, and does not fully account for ice sheet dynamics. Given the recent melting of the largest-ever recorded area of the Greenland ice sheet,[18] it is possible that sea level rise could be several times the IPCC estimates.[19]

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[11] Solomon et al, *supra* n 2, 420-421.
[12] Parry et al, *supra* n 6, 340-344.
[13] See, among many others, P J Gleckler et al, 'Human-Induced Global Ocean Warming on Multidecadal Timescales' (2012) 2 *Nature Climate Change* 524; S C Dorney, 'The Growing Human Footprint on Coastal and Open-Ocean Biogeochemistry' (2010) 328 *Science* 152 and J B C Jackson, 'Ecological Extinction and Evolution in the Brave New Ocean' (2008) 105 *Proceedings of the National Academy of Sciences* 11458.
[14] Mark Stallworthy, 'Sustainability, Coastal Erosion and Climate Change: An Environmental Justice Analysis' (2006) 18 *Journal of Environmental Law* 357.
[15] Parry et al, *supra* n 6, 319.
[16] *Ibid*, 317
[17] *Ibid*, 45
[18] Suzanne Goldenberg, 'Greenland Ice Sheet Melted at Unprecedented Rate During July', *The Guardian* (London, 24 July 2012)

There is also significant regional variation in projected sea level rise, and hence some regions may be more seriously affected than others. Some areas, such as low lying regions, particularly deltas, are already highly vulnerable to changes in sea level and are already experiencing changes such as subsidence and flooding.

Warming Waters

Beyond sea level rise and coastal erosion and inundation, climate change will affect coastal and marine ecosystems in many other ways. One of the most obvious changes will be increasing water temperatures and changes in ocean currents. Rising water temperatures are damaging many coral habitats worldwide, by inducing bleaching (a stress reaction in which the symbiotic relationship between the corals and the algae living within them breaks down, and the algae is expelled). Most corals are sensitive to relatively small increases in temperature, and up to 90 per cent of corals worldwide may be lost if temperatures increase beyond 1.5°C.[20]

Increasing temperatures and changing patterns in oceanic circulation are also having a range of impacts upon fish species, affecting the productivity, distribution and yields of many fisheries.[21] One recent study examining the ecophysiology of marine water-breathing organisms has estimated that the average body weight of over 600 species of fish will decline by up to 24 per cent by 2050 under a high emission scenario,[22] posing major challenges for populations reliant on fish for primary animal protein. Warming waters not only affect fisheries, but can also exacerbate oceanic dead zones by promoting hypoxia (low oxygen levels),[23] the growth of parasites and other harmful pathogens,[24] and the transport, settlement and invasion of alien marine species.[25]

For marine wildlife, climate change is fundamentally a habitat issue, with rising temperatures and other ocean conditions making once stable environments unrecognisable to dependent species. The mobility of fish, cetaceans, and many other organisms in the marine environment may mean that they enjoy some level of adaptive resilience, in that they may shift their range in response to rising temperatures and other ocean changes. However, even for highly migratory species, such as whales and dolphins, their mobility may in fact be an illusive protection 'in view of known site fidelity for breeding, calving, nursing and feeding grounds.'[26]

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[19] Stefan Rahmstorf, 'A New View on Sea Level Rise' (2010) 4 *Nature Reports Climate Change* 44

[20] K Frieler, 'Limiting Global Warming to 2°C is Unlikely to Save Most Coral Reefs' (2012) *Nature Climate Change* (advance online publication doi:10.1038/nclimate1674).

[21] Parry et al, *supra* n 6, 333. See also U Rashid Sumaila et al, 'Climate Change Impacts on the Biphysics and Economics of World Fisheries' (2011) 1 *Nature Climate Change* 449.

[22] William W L Cheung et al, 'Shrinking of Fishes Exacerbates Impacts of Global Ocean Changes on Marine Ecosystems' (2012) *Nature Climate Change* (advance online publication doi:10.1038/nclimate1691).

[23] Cheryl Lyn Dybas, 'Dead Zones Spreading in World Oceans' (2005) 55 *BioScience* 552.

[24] C Drew Harvell, 'Climate Warming and Disease Risks for Terrestrial and Marine Biota' (2002) 296 *Science* 2158.

[25] Anna Occhipinti-Ambrogi, 'Global Change and Marine Communities: Alien Species and Climate Change' (2007) 55 *Marine Pollution Bulletin* 342.

[26] Erich Hoyt, *Marine Protected Areas for Whales, Dolphins and Porpoises* (Earthscan 2nd ed 2011) 80.

Ocean Acidification[27]

Another increasingly well-documented impact upon the world's oceans, occurring in tandem with climate change, is ocean acidification, which is damaging coral ecosystems and other pH sensitive organisms. Ocean acidification provides a clear example of an impact on the marine environment from greenhouse gas emissions for which there are few adaptation opportunities. Ocean acidification has major economic and food security implications given its potential to decimate commercially valuable fish stocks.[28]

The oceans act as a buffer for changes in atmospheric CO_2, absorbing large quantities of this greenhouse gas which has been emitted from human activities since the industrial revolution. When CO_2 dissolves in the oceans it reacts with H_2O to form carbonic acid. The oceans are naturally slightly basic, but oceanic pH is declining and the oceans are more acidic now than they have been for around 500,000 years, with flow on effects for marine organisms, especially those which form shells.

As CO_2 is absorbed in sea water and carbonic acid is formed, hydrogen ions are released which then combine with carbonate ions to form bicarbonate. This chemical process removes substantial volumes of carbonate ions from the water that are essential for many marine photosynthetic organisms and animals, such as molluscs, corals, echinoderms, foraminifera and calcareous algae. Oceanic pH has declined by around 0.1 pH units, and if it falls by as much as 0.4 pH units then levels of carbonate ions may slip below those required to sustain coral reef accretion, an outcome that may be reached as early as 2050.[29]

Coastal and Marine Adaptation: The Conceptual and Policy Framework

Coastal Adaptation

Given the significant impact that sea level rise will have on many coastlines, it is not surprising that there has been extensive analysis of the options for coastal adaptation.

Much of this knowledge is consolidated in the contribution of Working Group II to the IPCC's Fourth Assessment Report,[30] which devotes a chapter to 'Coastal Systems and Low-Lying Areas'. As the IPCC observes, 'reactive and standalone efforts to reduce climate-related risks to coastal systems are less effective than responses which are part of integrated coastal zone management (ICZM), including long-term

[27] This section draws from Rachel Baird, Meredith Simons and Tim Stephens, 'Ocean Acidification: A Litmus Test for International Law" (2009) 4 *Carbon and Climate Law Review* 459.
[28] See further R Allan and A Bergin, 'Ocean Acidification: An emerging Australian Environmental Security Challenge' (2009) 1 *Australian Journal of Maritime and Ocean Affairs* 49. See also Cooley, S.R. and S.C. Doney, 'Anticipating ocean acidification's economic consequences for commercial fisheries' (2009) 4 *Environmental Research Letters* 024007
[29] Ove Hoegh-Guldberg et al., "Coral Reefs Under Rapid Climate Change and Ocean Acidification", (2007) 318 *Science* 1737.
[30] Parry et al, *supra* n 6.

national and community planning.'[31] This reinforces the importance of integrated coastal and ocean management generally.[32]

While there is a need for ongoing research into the coastal impacts of climate change, especially at localised coastal scales, there is now good agreement on the types of adaptation interventions that are effective in the coastal zone.[33] The IPCC has provided a conceptual framework for coastal adaptation practices, categorising adaptation measures by reference to the goals of protection, accommodation and/or retreat (see Figure 7.1, below).

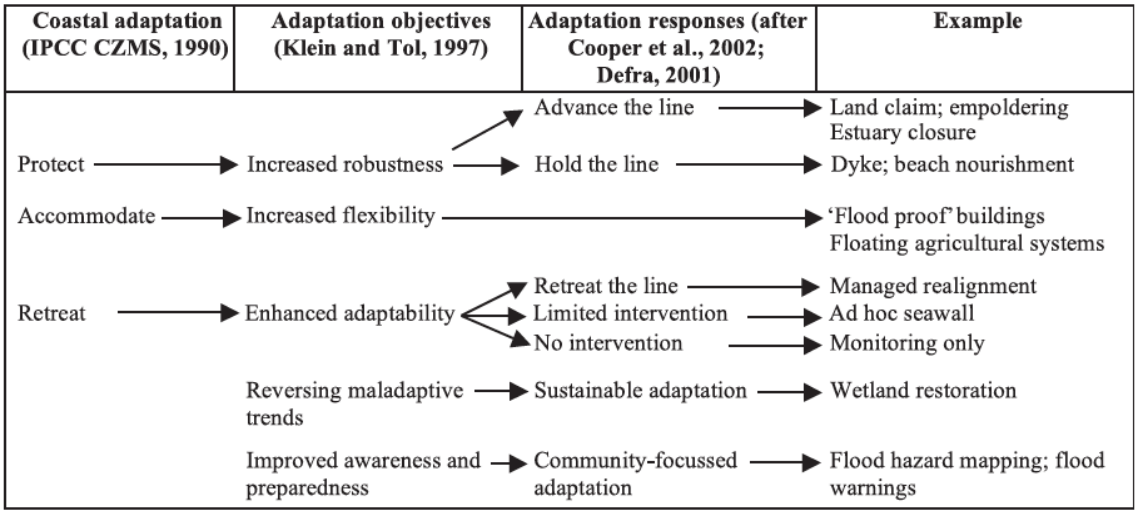

Figure 7.1. Evolution of planned coastal adaptation practices. Source: IPCC AR4, WG II, 342.

The central coastal adaptation challenge is therefore less one of knowledge and more one of translating the adaptation imperative into an effective legal and policy framework within a timeframe that will avert the most serious environmental and socio-economic risks. There are various impediments in developing and implementing an appropriate regulatory framework, including institutional complexity and weaknesses, the lengthy functional life of most coastal settlements and infrastructure, and also societal opposition to anticipatory adaptation measures. For instance the construction of seawalls and other hard defences may cause significant controversy. There may be opposition from some sections of the community because of their impact upon natural ecosystems and the visual environment, yet others may prefer to 'stay and defend', rather than allow coastal geography to shift as the seas rise.[34]

There are several tensions at play in the development of coastal adaptation regimes. These include the need to anticipate change but not overestimate the likely harm,

[31] *Ibid,* 340.
[32] See generally Donald R Rothwell, 'Environmental Integration and Coastal and Marine Law' in Rachel Baird and Donald R Rothwell (eds), *Australian Coastal and Marine Law* (Federation Press 2011) 348.
[33] Richard Klein et al, 'Coastal Adaptation to Climate Change: Can the IPCC Technical Guidelines be Applied?' 4 *Mitigation and Adaptation Strategies for Global Change* 239, 239-252.
[34] See further Jonathan Verschuuren and Jan McDonald, 'Towards a Legal Framework for Coastal Adaptation: Assessing the First Steps in Europe and Australia' (2012) *Transnational Environmental Law* (advance online publication doi:10.1017/S204710251200009X).

and thereby incur opportunity costs by ruling out necessary development.[35] This is the tension between certainty and uncertainty, and is essentially a temporal problem, as laws and policies need to be developed now in respect of impacts that have not yet fully materialised. It can be addressed by ongoing research and coastal assessment, and by iterative systems of adaptive coastal management. Another tension is between global, regional, national and local planning. This is the spatial challenge of coastal adaptation. An overarching approach is needed to ensure consistency in the adaptation framework, but if an umbrella regime is too prescriptive it can prevent authorities from responding to climate change impacts at the local scale. A further tension is between private rights and public goods. This is the societal challenge of coastal adaptation, recognising the interests of private property owners so far as possible without governments becoming insurers of last resort for poor coastal planning. The effective management of these tensions is the central objective of a policy framework for coastal adaptation.

Marine Adaptation

While coastal adaptation policy has been the subject of extensive analysis, marine adaptation has not attracted the same level of scrutiny, despite the threat that climate change poses to key economic sectors including fisheries, aquaculture, and tourism.

Explanations for this policy blind spot at national and international levels include the dynamic character of the marine environment, the natural variability in oceanic conditions, and that impacts upon the marine environment are less visible and tangible than coastal climate change impacts, such as coastal erosion from sea level rise. However some climate impacts upon the marine environment are increasingly apparent, such as the bleaching of coral reefs and large-scale algae blooms in enclosed and semi-enclosed seas. These very visible changes have served to highlight the need for adaptive responses to improve the resilience of marine ecosystems in the face of environmental change. The impact of climate change upon fisheries is also increasingly visible because of the flow on economic impacts to the fishing industry and fishing dependent communities. Around 520 million people globally are supported by fishing activities.[36]

We have seen that the main goals of coastal adaptive policy have been identified by the IPCC as protection, accommodation and, where necessary, retreat. This conceptual framework can also be applied, with some modifications, to marine adaptation.[37]

Protective adaptive policies in the marine domain include measures to conserve marine ecosystems, including through the establishment of marine protected areas. However, there is a significant lead-time (several years or even decades) in devising and implementing marine protected areas, meaning that they are seldom sufficiently responsive responses to rapid environmental change. Other management tools such as reduced fishery quotas, or limits on gear and fishing effort can normally be implemented more rapidly as there exist well-established regimes for fisheries

[35] Andrew Macintosh, 'Coastal Climate Hazards and Urban Planning: How Planning Responses Can Lead to Maladaptation' (2012) *Mitigation and Adaptation Strategies for Global Change* (forthcoming).
[36] Sumaila *supra* n 21, 449.
[37] See, eg, Elizabeth M P Madin et al, 'Socio-Economic and Management Implications of Range-Shifting Species in Marine Systems' (2012) 22 *Global Environmental Change* 137, 142-143.

regulation, and these can often be adjusted by administrative decision rather than requiring legislative action.[38]

In terms of accommodation approaches to adaptation in the marine environment, these may include adjustments to fisheries management areas to reflect the shifting range of a particular fishery, or managing fishing pressure by setting more conservative total allowable catches where the productivity of a fishery is declining. Where protection and accommodation are not sufficient to safeguard marine ecosystems and the services and resources they supply, retreat from existing marine uses and activities may be the only adaptive option.[39] In the fisheries context this could entail the complete closure of fishing access, and the shift of fishing effort to other fisheries.

It is the extent and rate of change that determines the emphasis that will need to be placed upon these three adaptive strategies; if change occurs slowly then marine ecosystems may be cushioned against changing ocean conditions, however a warming of several degrees within a century (as we are on track to experience) will leave many organisms and ecosystems unable to cope, and as a consequence the permanent retreat from current marine uses will be inevitable.

There are therefore limits to the extent that adaptation is a feasible response to climate change in the marine environment. Where those limits lie are not fully known, and it should not be expected that climatic changes or the ecological responses to them will be linear. As Barnosky et al report in a recent review of ecosystem responses to climate change, localised ecosystems may shift quickly from one state to another when they are pushed beyond certain critical thresholds, or tipping points.[40] In the marine realm the example given is the phenomenon of vast 'dead zones' in several ocean regions, most notably Chesapeake Bay and the Gulf of Mexico in North America. Barnosky et al note that there are risks that the global ecosystem as a whole, encompassing both terrestrial and marine systems, may be overwhelmed by human influence, leading to a state shift in Earth's biosphere.[41] Given the risks of such a state change, a key adaptive strategy is improving early warning systems of impending transformations, so that human systems are able to respond in advance of the worst impacts being felt.

Policies of protection, accommodation and retreat in marine adaptive management are likely to involve significant flow-on socio-economic impacts; subsidence fishers may not have viable alternative fisheries to turn to generate income, food security may be threatened if other nutrition sources are not available, and conflict may be generated from competition over dwindling fish stocks and the displacement of fishers to new fisheries. This underscores the need for adaptation strategies for fisheries to include not only traditional and contemporary tools of fisheries management (the setting of total allowable catches, quotas, season windows, vessel and gear limits, and marine reserves) but also for livelihood diversification options.[42]

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[38] Ibid, 143-143.
[39] Alistair McIlgorm et al, 'How will Climate Change Alter Fishery Governance? Insights from Seven International Cases Studies' (2010) 34 *Marine Policy* 170, 175.
[40] Athony D Barnosky et al, 'Approaching a State Shift in Earth's Biosphere' (2012) 486 *Nature* 52.
[41] *Ibid.*
[42] Sumaila et al, *supra* n 21, 6. Food and Agriculture Organization, *The State of World Fisheries and Aquaculture: 2012* (FAO, 2012) 119.

The immediate priority in developing marine adaptation options is improved monitoring and assessment of the marine environment. Once these knowledge gaps are filled then the availability of appropriate adaptation strategies can be determined. Central questions that need to be addressed include: how the distribution and productivity of marine species and communities are changing and will change, whether certain species can be used as indicators for climate change impacts and whether reducing other environmental stressors (such as pollution) will enhance ecosystem robustness.[43]

Improved knowledge of impacts, the constraints in adaptive responses, and the potential for rapid and irreversible change in the marine environment, ought also to shift attention back to the primary importance of mitigation policy.

Coastal Adaptation: The International Legal Framework

Physical Adaptation

There is an expanding body of international law of relevance to adaptation to climate change, although, as Freestone notes, 'adaptation is widely regarded as the poor relation of the international climate change treaty regime' in comparison with the mitigation imperative.[44] The UNFCCC is premised on the capacity of human and natural systems to adapt to some level of gradual climate change. Article 2 of the UNFCCC states that the ultimate objective of the international climate change regime is to achieve the stabilisation of greenhouse gases in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system, and this level is to be achieved 'within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.' This recognises the natural capacity of ecosystems to respond to environmental change, so long as the pace of that change does not exceed certain tolerances.

The UNFCCC specifically addresses coastal adaptation. Article 4(1)(e) requires states to '[c]ooperate in preparing for adaptation to the impacts of climate change' and 'develop and elaborate appropriate and integrated plans for coastal zone management'. Parties are also required by Article 4(8) to focus on the specific needs and concerns of developing states vulnerable to coastal impacts, including small island countries with low-lying coastal areas. To advance this objective, Decision 5/CP.7,[45] adopted at Marrakesh in 2001, founded the Least Developed Countries Fund and required it to assist in the development of national adaptation programmes of action (NAPAs). After a hiatus in the development of further adaptation responses under the climate regime, at the 2010 Cancun COP the parties adopted the Cancun Adaptation Framework, which for the first time identified adaptation as a priority of equal importance to mitigation.[46] Moreover, the Framework makes specific reference to the importance of parties adopting national adaptation plans that address 'marine ecosystems' and 'coastal zones'. The Least Developed Countries Fund, which is managed by the Global Environment Facility, is dispersing funds for the development

[43] CSIRO, *Marine Climate Impacts and Adaptation,* <http://www.csiro.au/en/Organisation-Structure/Flagships/Climate-Adaptation-Flagship/Marine-Climate-Adaptation.aspx> accessed 13 September 2012.
[44] David Freestone, 'The International Legal Framework for Adaptation' in Michael B Gerrard and Katrina Fischer Kuh (eds), *The Law of Adaptation to Climate Change: United States and International Perspectives* (ABA, 2012) 601, 601.
[45] Doc FCCC/CP/2001/13/Add.1.
[46] Freestone, *supra* n 44, 608.

and implementation of NAPAs, many of which are directed at protecting coastal regions.[47]

The LOSC provides the global legal framework for all mitigation and adaptation measures that impact upon ocean space. The LOSC was concluded in 1982, well before there was widespread international understanding of the threat of climate change (which coalesced much later, in 1990, with the adoption of the IPCC's First Assessment Report). None the less, by virtue of its broad definition of 'pollution of the marine environment', which includes the introduction of 'substances or energy into the marine environment, including estuaries',[48] and its extensive provisions seeking to control pollution, the LOSC clearly has relevance to the mitigation of climate change in order to protect the ocean environment. The LOSC, which now has 162 parties, seeks to prevent marine pollution, requiring all states to take, individually or jointly as appropriate, all measures necessary to prevent, reduce and control pollution of the marine environment from any source.[49]

The LOSC also sets limits on the extent to which coastal states may take physical adaptive steps in responding to climate change in the coastal zone.[50] Coastal states are for instance not permitted to implement large scale coastal engineering works unless there is an assessment of their potential marine environmental effects,[51] and they must adopt laws and regulations to 'prevent, reduce and control pollution of the marine environment from land-based sources',[52] which would include coastal works such as sea walls or land reclamation works. In *Land Reclamation by Singapore in and Around the Straits of Johor*[53] the International Tribunal for the Law of the Sea (ITLOS) invoked several provisions of the LOSC relevant to land reclamation works,[54] and the Tribunal's decision has some relevance to coastal works for climate adaptation purposes.

Implicitly referencing the precautionary principle, ITLOS held that 'prudence and caution' required that Malaysia and Singapore cooperate in assessing and limiting the impact of the land reclamation activities in the strait in order to protect the marine environment. In a more recent decision, ITLOS in its Advisory Opinion in *Responsibilities and Obligations of States Sponsoring Persons and Entities with Respect to Activities in the Area*, specifically recognised that there was a 'trend towards making this approach part of customary international law'.[55] This indicates that international law requires coastal states to exercise a high degree of caution when planning coastal adaptation works, and suggests that in the first instance states should investigate adaption options that do not involve substantial physical alteration of the coastal environment.

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[47] Ibid, 610-612.
[48] LOSC, art 1(1)(4).
[49] LOSC, art 194(1).
[50] See further David Freestone, 'International Law and Sea Level Rise' in Robin Churchill and David Freestone (eds), *International Law and Global Climate Change* (Graham and Trotman 1991).
[51] LOSC, art 206
[52] *Ibid*, art 207(1)
[53] *Land Reclamation by Singapore in and Around the Straits of Johor (Malaysia v Singapore) (Provisional measures)* (ITLOS) Case No 12, 8 October 2003).
[54] See generally Tommy Koh and Jolene Lin, 'The Land Reclamation Case: Thoughts and Reflections' (2006) 10 *Singapore Yearbook of International Law* 1.
[55] (2011) 50 ILM 455, [135]. See further Duncan French, 'From the Depths: Rich Pickings of Principles of Sustainable Development and General International Law on the Ocean Floor—the Seabed Disputes Chamber's 2011 Advisory Opinion' (2011) 26 *International Journal of Marine and Coastal Law* 525.

Beyond the general provisions of the LOSC regarding marine environmental protection, there is no agreed international framework addressing the coastal protective measures that states can or should take in response to climate change. It is beyond the scope of this chapter to offer an assessment of the many domestic legal frameworks that are being developed by coastal states worldwide to facilitate coastal adaptive governance. There is a considerable variability in the types of national and sub-national legal responses that are being pursued, and these are reflective of a range of social, economic, cultural and political differences in these jurisdictions.[56]

Hence as a matter of international law states enjoy considerable discretion in determining whether and what measures they will implement in response to coastal threats from rising seas and associated risks. In some regions an effort is being made to fill this gap in providing some general guidance to coastal states. This has tended to emphasis the need for integrated, 'ecosystem' or 'nature' based adaptive responses. For instance the OSPAR Commission, established by the 1992 Convention for the Protection of the Marine Environment of the North-East Atlantic[57] (OSPAR Convention), has urged states in that region to integrate adaptation measures into Integrated Coastal Zone Management and marine spatial planning.[58] In relation to the Seas of East Asia, in 2009 ministers from Cambodia, China, Korea, Indonesia, Japan, Laos, Philippines, North Korea, Singapore, Timor-Leste and Vietnam signed the 2009 Manila Declaration on Strengthening the Implementation of Integrated Coastal Management for Sustainable Development and Climate Change Adaptation in the Seas of East Asia Region which recognises the importance of coastal and marine adaptation policies in order to protect water resources, food security and livelihoods, and to safeguard biological diversity.[59]

The parties to the 1971 Convention on Wetlands of International Importance[60] (Ramsar Convention) have also been addressing adaptation issues in relation to coastal wetlands such as mangroves, tidal flats and saltmarshes that are important ecosystems and also provide important natural barriers to storm and tidal surges. At COP11 in 2012, the Ramsar parties adopted Resolution XI.14[61] updating and consolidating previous resolutions on climate change and wetlands. Resolution X.14 urged parties:

> to maintain or improve the ecological character of wetlands, including their ecosystem services, to enhance the resilience of wetlands as far as possible in the face of climate-driven ecological changes including, where necessary, to promote the restoration of degraded wetlands, and further to promote the ability of wetlands to contribute to nature-based climate change adaptation, particularly the roles of wetlands in regulating water, including reducing risks from water-related disasters, and to sequester and store carbon as important responses for climate change mitigation through the maintenance and enhancement of their ecological functions, and to reduce or halt the release of stored carbon that can result from the degradation and loss of wetlands

[56] See Verschuuren and McDonald, *supra* n 34.
[57] (1992) 32 ILM 1069.
[58] OSPAR Commission, *Assessment of Climate Change Mitigation and Adaptation* (2009) <http://www.ospar.org> accessed 27 August 2012.
[59] <http://pemsea.org/eascongress/section-support-files/manila_declaration.pdf > accessed 1 October 2012.
[60] 996 UNTS 245.
[61] <http://www.ramsar.org/pdf/cop11/res/cop11-res14-e.pdf> accessed 3 October 2012.

Legal Adaptation

International law, and specifically the international law of the sea, is relevant not only to physical adaptation measures but also to legal responses to climate change. Foremost among these is the continued assertion of territorial sea baselines in the face of rising seas that are altering coastal geographies. A related (but more straightforward) issue is whether maritime boundaries agreed between opposite or adjacent coastal states need to be altered if coastlines shift. It is a less complicated question, in that boundary agreements are generally understood to be permanent and dispositive, and not susceptible to termination or withdrawal (except on mutually agreed terms), even if there is a fundamental change of circumstances.[62]

Under the LOSC, the normal baseline which sets the boundary between internal waters and the territorial sea, and from which coastal maritime zones are projected, is the low water mark.[63] Low-tide elevations (or 'drying rocks'), if they are within the 12 nm territorial sea may be used to generate their own territorial sea.[64] Where the coastline is deeply indented, or where there is a fringe of islands, states may draw straight baselines, including from low-tide elevations, even those beyond 12 nm, having lighthouses or other similar installations upon them.[65] States may only assert an EEZ and continental shelf from islands that are above water at high tide and which can sustain human habitation or economic life.[66]

The central international legal question posed by sea level rise is whether states may continue to insist upon their existing baselines and basepoints, along their coastline, on low-tide elevations and reefs, and from islands, or whether instead these lines and points are ambulatory, automatically receding landwards as territory is inundated. Schofield has observed that 'measures to physically protect the coast from sea-level rise are generally unrealistic, save in exceptional circumstances for critical basepoints, in light of the sheer scale of the challenge' and he notes that '[a]lternative legal options may therefore be pursued.'[67] With the exception of deltas and highly unstable coasts,[68] the LOSC does not expressly countenance the fixing of baselines or basepoints. But likewise it does not provide that baselines move automatically, or must be adjusted by states in response to accretion or avulsion.

It is unlikely that states will simply allow maritime space to be lost without a legal response, and Schofield observes coastal states may decide to declare unilaterally the continued applicability of their baselines to preserve the extent of maritime estate under coastal state sovereignty and jurisdiction. In doing so, Purcell argues, coastal states will be on firm legal foundations.[69] Following an exhaustive study of the history of the baseline provisions of the LOSC, she rejects the 'ambulatory baseline thesis' and argues that states may if they wish adopt the ambulatory approach (as the

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[62] Vienna Convention on the Law of Treaties, 1155 UNTS 332, art 62(2)(a).
[63] LOSC, art 5.
[64] LOSC, art 13.
[65] LOSC, art 7.
[66] LOSC, art 121(3).
[67] Clive Schofield, 'Sea Level Rise and Options to Secure Maritime Jurisdictional Claims' (2009) 4 *Carbon and Climate Law Review* 405, 406. See also David Caron, 'When Law Makes Climate Change Worse: Rethinking the Law of Baselines in Light of a Rising Sea Level' (1990) 17 *Ecology Law Quarterly* 621.
[68] *LOSC,* art 7(2)
[69] Kate Purcell, 'Maritime Jurisdiction in a Changing Climate' in Michael B Gerrard and Katrina Fischer Kuh (eds), *The Law of Adaptation to Climate Change: United States and International Perspectives* (ABA, 2012) 731.

United States appears to do), or continue to rely on their existing baselines. Purcell contends that '[a]daptation measures aimed at the retention of existing rights to maritime space in their present local and full extent…are largely unnecessary', and that '[t]he current legal regime provides for the establishment of maritime baselines and zonal limits that take geographical circumstances into account but are not in the thrall to the variable coastal and marine environment.'[70]

Marine Adaptation: The International Legal Framework

The UNFCCC makes limited reference to the marine environment beyond the coastal zone. The threat of sea level rise to coastlines is clearly recognised, with Article 4(8) requiring parties to give full consideration to the effects of climate change on small island countries and countries with low-lying coastal areas. Yet only passing mention is made of marine ecosystems, and only in connection with the environmental services they provide as carbon sinks rather than the importance of protecting the marine environment *per se*. The Preamble to the UNFCCC acknowledges the importance of marine ecosystems as sinks and reservoirs of greenhouse gases, and Article 1(d) requires parties to promote sustainable management, conservation and enhancement of reservoirs of greenhouse gases including those found in marine ecosystems. It is possible to read into Article 4(1)(e), under which parties are required 'develop and implement integrated plans for coastal zone management' in adapting to the impacts of climate change, an obligation to develop adaptation plans in near-shore environments to address the effects of climate change. However, the UNFCCC does not expressly extend any such obligation to offshore environments.

In addressing adaptation, the UNFCCC has an almost exclusive terrestrial and coastal focus, and the Kyoto Protocol[71] does not alter this. Moreover the UNFCCC and the Kyoto Protocol deal only with 'climate change', defined in Article 1(2) of the UNFCCC as the change of climate attributed to human activity that alters the composition of the global atmosphere. This does not encompass ocean acidification, which is a separate process from climate change, even though it is caused by a greenhouse gas, CO_2, emissions of which are primarily responsible for rising global temperatures. The upshot is that Article 3 of the UNFCCC, which requires states to protect the climate system from adverse effects of climate change does not include any requirement to prevent ocean acidification. Hence neither mitigation of, nor adaptation to, ocean acidification is recognised as an objective of the international climate regime.

It is necessary therefore to turn to the body of international norms directed specifically to the marine environment to gauge the responsiveness of public international law to the marine adaptation challenge. As noted above, the central regime of relevance is the LOSC, which provides an extensive, globally applicable, regulatory framework for all uses of ocean space. The LOSC recognises coastal state sovereignty and jurisdiction over a wide range of maritime zones extending from internal waters, through the territorial sea, the exclusive economic zone (EEZ) and the continental shelf. Of particular importance is Part V which concerns the EEZ, and Part XII of the LOSC which relates to the protection of the marine environment. These provide coastal states with extensive capacity to protect coastal and marine environments.[72]

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[70] Ibid, 737.
[71] (1998) 37 ILM 22.
[72] See further Donald R Rothwell and Tim Stephens, *The International Law of the Sea* (Hart Publishing 2010) 461ff.

Also of relevance is the 1992 Convention on Biological Diversity[73] (CBD), which has engaged with the linkages between biodiversity conservation and marine and coastal adaptation measures. In 2008 the Conference of Parties to the CBD adopted a decision on marine and coastal biodiversity that set out scientific criteria for identifying areas that require protection.[74] And in 2010, the CBD parties adopted a comprehensive decision on 'Marine and Coastal Biodiversity' that catalogued the impacts that climate change is having on marine and coastal biodiversity and acknowledged the importance of maintaining this biodiversity in adapting to climate change.[75]

Areas Within National Jurisdiction

An assessment of the international legal framework for marine adaptation needs to make reference to the maritime zones in which adaptation measures are proposed. Within the territorial sea, which extends to a limit of 12 nm from the territorial sea baselines, a coastal state has broad ranging capacity to implement rigorous marine environmental protection provisions consistent with its sovereignty over the zone. Hence coastal states may limit fishing or close fisheries, establish marine protected areas and parks, and impose special protective measures for areas such as reefs. However there are some limits placed upon coastal states by the innocent passage regime under which foreign flagged vessels are entitled to navigate freely through the territorial sea. Under Article 21 of the LOSC coastal states may adopt laws and regulations relating to innocent passage, including navigational safety and the regulation of maritime traffic, conservation of living resources and preservation of the marine environment including the prevention of pollution. Such laws and regulations may clearly be directed not only to the protection of the marine environment *per se* but also to the objective of climate change adaptation which may be advanced by, *inter alia,* reducing marine pollution.

Beyond 12 nm, and out to a maximum distance of 200 nm, coastal states may claim an EEZ, a zone in which coastal states enjoy exclusive sovereign rights in the living and non-living resources of the water column and seabed. This entails that coastal states may implement adaptive measures in relation to resources with little, if any, consideration of the interests of other states. The coastal state is given sole discretion in setting allowable catches for fisheries, taking into account the best scientific evidence, and the responsibility to conserve and manage fisheries so that they are not endangered by over-exploitation.[76] In principle a coastal state is required to give access to other states to its EEZ living resources if it has insufficient capacity to harvest the allowable catch it has set, with particular regard to landlocked, geographically disadvantaged and least developed states.[77] But in practice this right of access to the surplus accorded to foreign states is unenforceable, because coastal state decisions determining the allowable catch, the extent of harvesting capacity, and the allocation of surpluses, fall within one of the few exceptions to the compulsory dispute settlement system set out in Part XV of the LOSC.[78] Coastal states therefore have largely unfettered rights and jurisdiction in EEZ fisheries and can therefore take those adaptive measures are considered appropriate for fisheries located within this zone. Indeed this capacity is implicit in the reference in Article 61(2) to the requirement that coastal states take into account 'the best scientific

[73] 1760 UNTS 79.
[74] Decision IX/20, UN Doc UNEP/CBD/COP/DEC/IX/20 (2008).
[75] Decision X/29, UN Doc UNEP/CBD/COP/DEC/X/29 (2010).
[76] LOSC, Art 61.
[77] LOSC, Art 62.
[78] LOSC, Art 297(3).

evidence' available to it that fisheries management authorities should take a precautionary approach so as to enable fisheries to adapt to changing conditions.

In relation to non-living resources, coastal states have a clearly unencumbered right to decide whether and under what circumstances mineral resources are exploited within their continental shelf and claimed EEZ areas. Article 56(3) of the LOSC provides the rights of coastal states with respect to the seabed and subsoil in the EEZ are made coterminous with those under the provisions of the convention addressing the continental shelf, in Part VI. In essence it is for the coastal state alone to determine whether to explore or exploit the natural resources of the continental shelf, and no other state may undertake such activities without the express consent of the coastal state.[79] As a consequence coastal states are fully within their rights to include climate change adaptation considerations in the planning, assessment and approvals processes for proposed oil and gas development of the EEZ. Consistent with a policy of protection or retreat they may adopt moratoria or permanent prohibitions on offshore oil and gas development.

Whereas, in relation to the fisheries and mineral resources of the 200 nm EEZ and continental shelf, coastal states have wide if not completely unconstrained discretion in taking adaptive measures, the same cannot be said for measures targeting other elements of the marine environment. In relation to marine pollution from vessels, and the risks posed by vessel movements through sensitive marine environments, which remain key concerns for marine environmental protection, coastal states must normally adhere to those international standards adopted under the auspices of the International Maritime Organization (the IMO), which are incorporated by reference in the LOSC. However, the IMO regime does allow the designation of certain ecologically vulnerable marine areas as Particularly Sensitive Sea Areas (PSSAs), which in turn allows for the adoption of 'associated protective measures' to prevent, reduce or eliminate the threat posed by international shipping. The Great Barrier Reef in Australia was the first PSSA to be designated by the IMO, in 1990.

PSSAs are normally, but need not always be, included within marine protected areas (MPAs). MPAs are emerging as a critically important area-based tool for marine conservation in the era of climate change. While there are around 120,000 protected areas on land worldwide, covering around 12 per cent of the Earth's land surface,[80] MPAs cover only around one per cent of ocean space beyond the territorial sea. There is increasing recognition of the value of MPAs in enhancing the resilience of marine areas in order to adapt to climate change. The 2009 Manado Ocean Declaration, adopted in Indonesia during the World Ocean Conference, emphasised the importance of MPAs, with states resolving 'to further establish and effectively manage marine protected areas, including representative resilient networks, in accordance with international law, as reflected in [the LOSC], and on the basis of the best available science, recognizing the importance of their contribution to ecosystem goods and services, and to contribute to the effort to conserve biodiversity, sustainable livelihoods and to adapt to climate change.'[81] Several governments have taken this objective seriously, including Australia which in 2012 announced the establishment of the world's largest network of marine reserves.[82] This reserve

[79] LOSC, Art 77.
[80] L Coad et al, *State of the World's Protected Areas 2007: An Annual Review of Global Conservation Progress* (Cambridge, UNEP-WCMC, 2008) 17.
[81] 2009 Manado Ocean Declaration, [15].
[82] <http://www.environment.gov.au/coasts/mbp/reserves/index.html> accessed 27 August 2012. See also Lorne Kriwoken, Julie Davidson and Michael Lockwood, 'Marine Protected Areas and Transboundary Governance' in Robin Warner and Simon Marsden (eds),

system is in part designed to sustain the health and resilience of the marine environment threatened by climate change.[83]

Shared maritime domains and areas beyond national jurisdiction

A key arena in which adaptation to climate change in the marine environment is being addressed is in relation to fisheries that are shared across multiple coastal state EEZs, that straddle EEZ areas and high seas, or are found exclusively on the high seas. Many such fisheries are subject to management by Regional Fisheries Management Organisations (RFMOs), several of which are beginning to consider adaptive responses.[84] Most wild capture fisheries are already under significant pressure, with the Food and Agriculture Organization estimating that 90 per cent of fisheries are being harvested are or beyond their sustainable limits.[85]

It was noted earlier in this chapter that well developed tools of fisheries management may be deployed to control access to fisheries in response to the effects that climate change is having upon their productivity. Where a fishery falls wholly within a coastal state's maritime jurisdiction there is greater likelihood that the fishery management system will be anticipatory of potential change, and responsive to observed climatic impacts. This is because nationally-managed fisheries are less susceptible to the 'tragedy of the commons' problem besetting multi-jurisdictional and high seas, fisheries. The performance of RFMOs varies significantly depending upon their membership and institutional dynamics, and given the failure of many RFMOs to manage the stocks under their jurisdiction in a sustainable manner there are reasons to doubt they will respond effectively to climate change. A case in point is the Commission for the Conservation of Southern Bluefin Tuna, established by the 1993 Convention for the Conservation of Southern Bluefin Tuna,[86] which has not halted the progressive decline in the abundance of this species because of an insistence by key members, most notably Japan, that the Commission adopt an unsustainable Total Allowable Catch.[87]

Climate change is affecting not only the productivity of fisheries but also their distribution, which calls for a reconsideration of management approaches and in some RFMOs for a reassessment of an even more fundamental question, namely the legal boundaries of fisheries management set by RFMO constituent instruments. An example is the 1980 Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR). CCAMLR, is part of the Antarctic Treaty System of which the 1959 Antarctic Treaty[88] is the linchpin. CCAMLR operates within the 'CCAMLR boundary', which is a saw-toothed circumpolar line that roughly approximates the

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Transboundary Environmental Governance: Inland, Coastal and Marine Perspectives (Ashgate, 2012) 85.

[83] See, eg, Director of National Parks, *Draft South-East Commonwealth Marine Reseves Network Management Plan 2012-22* (2012) 14. See further Lorne Kriwoken, 'Australian Marine Protected Areas: Charting a Course Towards a Representative System' in Warwick Gullett, Clive Schofield and Joanna Vince (eds), *Marine Resources Management* (LexisNexis, 2011) 171. For an assessment of the impact of climate change upon Australia's maritime estate see E S Poloczanska, A J Hobday and A J Richardson (eds), *A Marine Climate Change Impacts and Adaptation Report Card for Australia 2009* (NCCARF Publication, 2009).

[84] Mark Axelrod, 'Climate Change and Global Fisheries Management: Linking Issues to Protect Ecosystems or to Save Political Interests?' (2011) 11 *Global Environmental Politics* 64.

[85] FAO, *supra* n 42, 56.

[86] 1819 UNTS 359.

[87] 1329 UNTS 48.

[88] 402 UNTS 71.

polar front (often called the 'Antarctic convergence'), the oceanic boundary where colder Antarctic waters meet warmer northern waters.[89] All marine ecosystems in the Antarctic are vulnerable to climate change, and key food chain species such as krill are declining as a result of warming waters.[90] Moreover there is evidence of a southward shift in the polar ocean front, and Haward and Jabour have noted that if this continues or accelerates then from a management perspective the 30 year old CCAMLR boundary will no longer embrace all relevant Southern Ocean conservation and fisheries interests.[91]

Conclusion

The international legal framework for climate change adaptation in coastal and marine environments is in an early stage of development, by comparison with national and sub-national legal responses. In the coastal and in-shore zones the focus nationally and internationally has been on adaptive policies that can allow communities and ecosystems to adjust to rising sea levels. The imperative for coastal adaptation to climate change is a long-standing one, and has been considered since the early 1990s, and is supported by several clear references in the texts underpinning the international climate change regime.

There is also growing understanding of the relevance of the law of the sea to physical and legal measures taken by coastal states to protect their entitlements in littoral areas, whether this be by coastal defence measures and land reclamation, or through technical legal responses to fix baselines despite the shifting sands and rising seas that climate change is bringing to many coastal zones. In relation to physical responses, coastal states may only take those measures that do not further worsen the marine environment, in order to meet the obligations under the LOSC to protect and conserve the totality of the marine environment, and in conformity with the precautionary principle which has been recognised by ITLOS as an emergent rule of customary international law. This clearly suggests that coastal states should given priority to soft protection measures, which build the resilience of ecosystems and habitats such as mangroves and reefs that offer protection against climate change impacts such as storm surges. In relation to legal responses, whether these be proactive decisions to reaffirm existing baselines, or through studied inactivity by declining to reopen existing lines in the sea, the LOSC offers a more resilient system than often thought, with jurisdiction determined primarily by objective physical factors at the time of claim and delineation.[92] This will of course often only a marginal level of comfort to small island states the very existence of which is threatened, and in relation to which serious consideration needs to be given to legal mechanisms for preserving existing entitlements to offshore marine resources.[93]

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[89] CCAMLR, art 1(4).

[90] P N Trathan and D Agnew, 'Climate Change and the Antarctic Marine Ecosystem: An Essay on Management Implications' (2010) 22 *Antarctic Science* 387, 387.

[91] Marcus Haward and Julia Jabour, 'Environmental Change and Governance Challenges in the Southern Ocean' in Tim Stephens and David VanderZwaag (eds), *Polar Oceans Governance in an Era of Environmental Change* (Edward Elgar, forthcoming 2013).

[92] Purcell, *supra* n 69, 760.

[93] See Rosemary Rayfuse and Emily Crawford, 'Climate Change, Sovreignty and Statehood' in Rosemary Rayfuse and Shirely Scott (eds), *International Law in the Era of Climate Change* (forthcoming 2012); L Yamamoto and M Esteban, 'Vanishing Island States and sovereignty', (2010) 53 *Ocean and Coastal Management* 1 and Emily Follett, 'Sinking Islands, Shrinking Maritime Entitlements: Is a New Rule of International Law Needed to Protect and Promote Offshore Minerals Exploration and Mining?' (2012) 29 *Environmental and Planning Law Journal* 75.

It is in areas beyond the coastal zone, in the offshore marine environment, where there is an urgent need for greater attention to climate change adaptation issues. With the exception of some fisheries, there are next to no steps being taken to safeguard large marine ecosystems that are directly threatened by climate change impacts. This is seen most clearly in relation to ocean acidification, which is a climate change related impact just as serious as global warming of the atmosphere, yet has not merited specific mention in any legally binding international agreement. As in the littoral zone, the first step towards an effective legal and policy framework is understanding of the extent of the changes requiring adaptive responses, and for most marine areas while there is improving scientific knowledge, there has been little analysis of the flow-on social and economic effects to which human civilisation will need to adapt if it is to weather the coming climate storm.