The Ocean and Climate Change

Tools and Guidelines for Action

Dorothée Herr and Grantly R. Galland

IUCN U.S. Multilateral Office 2009

IUCN Global Marine Programme

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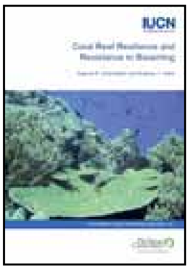
About the IUCN Work on Marine Climate Change Mitigation and Adaptation

The IUCN Global Marine Programme is committed to mobilizing action to build ecosystem resilience, reduce emissions and implement mechanisms that will help marine ecosystems, and the people that depend on them, adapt to the changing climate. IUCN has published a series of reports on management tools to promote resilience in marine ecosystems.



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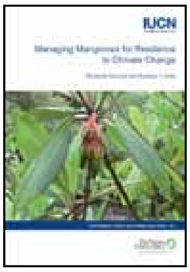

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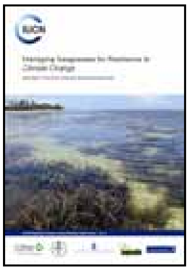

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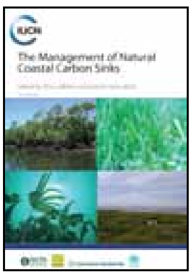
The Global Marine Programme is also exploring the role of marine ecosystems as natural carbon sinks and is providing guidance relative to climate change mitigation activities and their impact on the marine environment. For additional information, see
http://www.iucn.org/about/work/programmes/marine/marine_our_work/climate_change/



The Management of Natural Coastal Carbon Sink
Dan Laffoley and Gabriel D. Grimsditch (Eds.)
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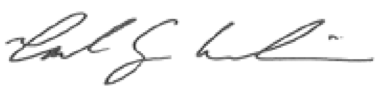
Foreword

The ocean plays a critical role in our climate system and is significantly impacted by climate change and ocean acidification. People around the globe are already observing key alterations to their environment with profound consequences: sea-level rise, increased intensity of storms, changes in ocean productivity and resource availability, disruption of seasonal weather patterns, loss of sea ice, altered freshwater supply and quality. These changes are happening at an unprecedented rate. Issues of food security and human health will affect local livelihoods as well as global economies.

Mitigation alone will not help us avoid the harmful effects of increasing temperatures and appropriate strategies have yet to be implemented at the required scale and pace. Some proposed mitigation actions such as ocean fertilization and carbon capture and storage need to be addressed with extreme caution.

Adaptation has become an indispensable part of any climate change strategies. Marine ecosystems provide millions of coastal residents with services such as storm protection and nursery grounds for fisheries. Unfortunately we have largely ignored the role that marine and coastal ecosystems play in livelihoods. Those with little margin to maintain a decent life for themselves often rely directly on provisions from local ecosystems. By maintaining, or restoring, biodiversity and ecosystem services, Ecosystem-based Adaptation (EbA) can help people adapt to the adverse effect of climate change and simultaneously support development objectives and reduce risk disaster. The actions we need now are not only about protecting ecosystems, but about protecting the earth's life support systems.

It is our intention that this publication will help inform the people responsible for policy and management decisions related to climate change, and all stakeholders, of the current state of knowledge of ocean and climate change issues and action opportunities.



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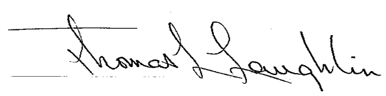

Thomas L. Laughlin
Deputy Head, IUCN Global Marine Programme

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Expert contributions

1. Introduction

The purpose of this report 'The Ocean and Climate Change – Tools and Guidelines for Action' is to engage, inform and guide decision makers with regard to the development and implementation of marine and coastal climate change strategies and programmes.

Despite its enormous importance in regulating global climate and its sensitivity to the impacts of climate change and ocean acidification, the ocean continues to get only peripheral attention in global climate research, climate change policy and implementation plans. For example, recent authoritative coverage of climate change in a Nature special issue made little reference to the ocean and no reference to marine biodiversity. This document on 'The Ocean and Climate Change – Tools and Guidelines for Action' serves to raise awareness and gives science-based action recommendations relevant to international and national climate change implementation processes.

The document provides an overview of the interactions between the ocean and climate and describes the impacts of climate change on the marine ecosystems and the goods and services they provide human society. Further, it outlines a set of recommendations for marine-related mitigation and adaptation policy and implementation actions. The potential and limits of the ocean in climate change mitigation strategies is highlighted by sections on marine renewable energy resources, natural marine carbon sequestration, carbon capture and storage and ocean fertilization. The publication further stresses Ecosystem-based Adaptation (EbA) as a means to improve social and ecosystem resilience to global ocean and climate change. Carefully designed marine protected areas and risk reduction management are included as means to reduce vulnerability of social and natural systems to future change.

2. People, the Ocean and Climate Change

People, the ocean and the climate are inextricably linked: the circulation patterns of ocean currents make our planet inhabitable; about half of the oxygen in the atmosphere is derived from oceanic sources; and large sectors of the global economy depend on ocean-related commerce, including fisheries, tourism and shipping. People all over the world rely on the ocean for their basic caloric needs, and some coastal peoples obtain 100% of their animal protein from its waters. Regardless of where we reside, however, we depend on healthy ocean ecosystems and the services that they provide. The ocean is the life support system for our planet.

The ocean covers more than 70% of the planet's surface and is so immensely deep that it contains over 90% of the inhabitable space for life on Earth. All parts of this space are filled with magnificent biodiversity, ranging from relatively simple, but extraordinarily abundant microbes to some of the most social and intelligent animals on Earth: whales. In fact, approximately 90% of the planet's biomass lives in the ocean.

Unfortunately, the vast size, productivity, and diversity of life in the ocean have given us false comfort. For millennia, humans have worked to harvest ocean resources and used the ocean to communicate with neighbors and distant lands. In recent decades, technological and industrial changes have greatly accelerated humanity's ability to extract resources and modify ocean and coastal environments – through pollution (from hydrocarbons, chemical and organic pollutants, nutrients, plastics, and sediment), habitat destruction and invasive alien species, never imagining that we could alter such systems. As a result, fisheries have collapsed, ecosystems have suffered, and once abundant species have become threatened with extinction. Now, the ocean is facing new and substantial threats, as a result of climate change, which compound existing pressures from growing human activity in the ocean. The scale and rate of environmental change, driven by increases in concentration of greenhouse gases in the atmosphere, is unprecedented in human history (IPCC 2007). These changes will negatively affect the ocean's ability to continue to support ecosystems, human populations, and cultures.

The ocean and the atmosphere are so completely intertwined that negotiations surrounding future climate change mitigation and adaptation actions cannot be complete without consideration of both. The coupling of these two global systems not only regulates the earth's climate but also provides all species, including humans, a favorable environment, in which to grow and reproduce.

In the following sections, the relationships between People, the Ocean and Climate Change are discussed further, in order to provide an overarching picture of the issues involved.

The role of the ocean in climate

Earth's climate is a result of the physical, chemical, and oceanographic properties of its components. Both regional and global climate patterns depend on long-term interactions between the ocean and the atmosphere (Stewart 2005).

The ocean plays a complex role in our climate system. It stores most of the sun's energy that reaches the Earth and acts as the Earth's most significant global heat buffer. In fact, at least one quarter of Earth's anthropogenic surface warming has been absorbed by the ocean (Ramanathan and Feng 2009), thereby postponing the consequences of our actions, delaying more severe climate change impacts, and buying us time to develop mitigation and adaptation strategies. The ocean also acts as a giant heat distribution unit, pumping massive amounts of warm water and air toward the poles and cold water and air back to the tropics (Talley et al. 2009). These patterns heat places like Europe and New Zealand and cool places like southern California and coastal Peru. The consistency of ocean currents keeps these regions from experiencing large climatic and seasonal swings that they might otherwise experience. Instabilities in the ocean currents caused by climate change could lead to major shifts in regional climate and weather patterns and associated human migrations in the future.

Furthermore, the ocean plays a major role in wind and precipitation patterns. Cloud formation (evaporation), cloud movement (wind), and rain/snow (condensation) are all linked to the ocean (Talley et al. 2009). Weather systems, such as the monsoon in South Asia, are a direct result of the interaction between the ocean and continental masses. Water vapor that evaporates over the ocean moves over land and falls as precipitation because of ocean circulation patterns and the differential absorption of heat by the ocean and by land or air (Talley et al. 2009).

Sea ice also affects climate. When sunlight hits ice most of its energy is reflected away from the Earth (Curry et al. 1995). When sea ice melts, the ocean absorbs the sun's energy. As the Arctic warms, sea ice cover shrinks and darker open water replaces the sea ice, thus creating a feedback loop that amplifies warming and increases ice melting (Curry et al. 1995; Anisimov et al. 2007).

Finally, the enormous volume of the ocean allows it to act as a giant reservoir for carbon, soaking up carbon dioxide (CO_2) from the atmosphere. The ocean acts as a buffer for Earth's climate. The oceanic uptake of CO_2 has somewhat mitigated the effect of global warming by reducing its concentration in the atmosphere. However, this continual absorption of CO_2 changes the ocean in ways that have potentially dangerous consequences for humans and for marine biodiversity.

The ocean plays an integral part in influencing our climate and is intrinsically linked to the atmosphere through:

- **heat storage**
- **transportation of heat around the globe**
- **evaporation**
- **freezing and thawing in polar regions**
- **gas storage and exchange (including CO_2)**

Climate change and ocean acidification

The ocean has a natural ability to buffer the atmosphere and the ocean surface is in a state of equilibrium with the atmosphere with respect to CO_2 and heat. As concentrations of either increase in the atmosphere, they increase in the ocean as well. These increases change the physical and chemical properties of the ocean and affect several oceanic processes.

- **Ocean warming**

Ocean warming has several consequences. A well-known example is sea-level rise. As water warms, it expands, and the ocean surface rises. Currently, most of the excess heat in the ocean, and the associated thermal expansion, is in a surface layer only a few hundred meters deep (Domingues et al. 2008). Over time, this heat will diffuse downward to greater depths, increasing expansion and triggering further changes in sea level. Additional sea-level rise is caused by the melting of inland glaciers and continental ice sheets including those resting on Greenland and Antarctica. Recent studies conclude that mean sea-level rise of 0.5m-0.8m over 1990 levels by 2100 is likely and that a rise of more than one meter in that time is possible (Rahmstorf 2007; Pfeffer et al. 2008, Richardson et al. 2009). A change this significant causes storm surges and flooding to be more dangerous and to occur more regularly (McMullen and Jabbour 2009).

Extreme weather events are also affected by ocean warming. Heat is energy, so as hurricanes and typhoons form, warming sea temperatures boost their destructive energy (Webster et al. 2005; Hoyos et al. 2006). While it is unclear if the frequency of these storms is affected by climate change, their intensity is expected to increase with further change (IPCC 2007). This intensification puts both people and marine and coastal ecosystems at risk.

Additionally, with ongoing warming of the atmosphere and the ocean, key water masses could undergo major changes (Lozier 2009). Ocean currents are driven by the interactions among different water masses and between these masses and the atmosphere (Talley et al. 2009). The two most distinguishing characteristics of oceanic water masses are temperature and salinity (Stewart 2005; Talley et al. 2009). As the atmosphere warms, changes in the Polar Regions cause surface waters to become warmer and fresher. Such a change could have significant impacts on regional climate systems, including new current, wind, and precipitation patterns; increased ocean stratification (and the associated hindrances to vertical water movement); and alterations to upwelling and downwelling (Manabe and Stouffer 1993; Stocker and Schmittner 1997). These changes to the ocean-atmosphere coupled climate system have significant implications for marine ecosystems and for the people around the globe that depend on them for the services they provide (McGowan et al. 2003; Schmittner 2005, Sommerkorn & Hassol 2009).

Hurricane Katrina

- **Ocean acidification**

The ocean absorbs between one fourth and one half of all anthropogenic CO_2 emissions (Sabine et al. 2004; Keeling 2005; IPCC 2007). While absorption of CO_2 by the ocean slows the atmospheric greenhouse effect, it puts marine and thus human life at risk. Dissolved CO_2 lowers the ocean's pH and leads to acidification (see Figure 2.1). Since the beginning of the Industrial Revolution, surface ocean acidity has increased by 30% (Orr et al. 2005, 2009). The geochemical processes driving pH changes are highly predictable, but the impacts on marine biodiversity and ecosystems are less clear. A doubling of the atmospheric CO_2 concentration, which could occur within the next 50 years, would cause a velocity of change to marine chemistry (see Figure 2.2) and subsequent extinction events not seen for 65 million years (McLeod et al. 2008). Even the most optimistic future atmospheric CO_2 concentrations (e.g. 450 ppm) could be high enough to cause coral reefs to no longer be sustainable (Hoegh-Guldberg et al. 2007, Hoegh-Guldberg et al. 2009), large areas of polar waters to become corrosive to shells of some key marine species (McNeil and Matear 2008), and marine ecosystems to look nearly unrecognizable (Orr et al. 2009).

Additionally, experiments show that ocean acidification affects ocean physics by reducing sound absorption and allowing sound to travel much further (Hester et al. 2008). This reduced absorption causes ambient sound levels to rise significantly, harming marine life.

Finally, as the ocean continues to absorb CO_2 from the atmosphere, its ability to buffer changes to the atmosphere decreases. This increased absorption, together with ocean warming and changing wind patterns, reduces the ability of the ocean to take up additional CO_2 from the atmosphere (see section on 'Reduced capacity of the ocean to buffer climate change', page 28; Fung et al. 2005, Le Quéré et al. 2007). As the ocean's capacity to act as Earth's biggest carbon sink diminishes, the atmosphere and terrestrial ecosystems, including the human ecosystem, are less buffered from change and become even more vulnerable.

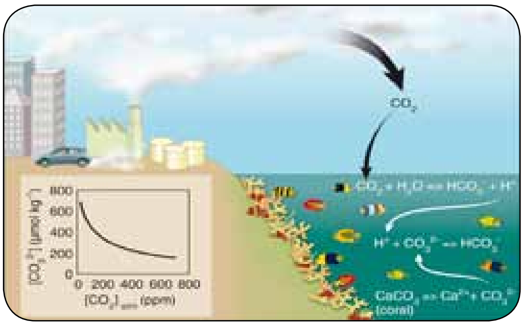

Fig. 2.1 Ocean acidification involves the dissolution of carbon dioxide in the ocean, where it forms a carbonic acid (H_2CO_3). The acid converts carbonate ions into bicarbonate, removing the carbonate building blocks shellfish and other organism need to generate their shells. The net effect on marine calcifiers such as reef building corals is that they slowly fail to calcify. If concentrations get too high, ecosystems such as coral reefs may begin to crumble and dissolved.

Reference: Hoegh-Gulberg et al. 2007

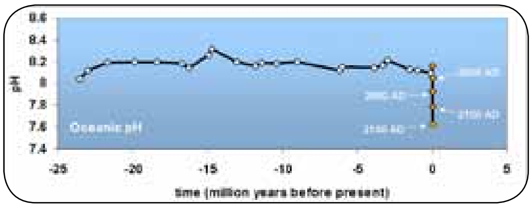

Fig. 2.2 Ocean acidity (pH) over the last 25 million years and projected to 2100.

Reference: Turley et al. 2006

Vulnerable biodiversity: ocean systems

The remarkable diversity of life in the ocean has evolved to fill habitats and niches created by its physical and chemical properties. Anthropogenic release of greenhouse gases leads to changes in these properties, in response to oceanic absorption of heat and CO_2, respectively. Shifts in marine life and the services it provides are associated with these changes in oceanography. These shifts may cross irreversible thresholds and become permanent. Changes are further amplified by the synergistic nature of greenhouse gas emissions and other human activities (e.g. agriculture, fishing, and coastal development) that weaken ecosystem resiliency, and threaten the survival of marine organisms (Brierley & Kingsford 2009).

- **Global Changes**

Nutrients and energy travel through ocean systems from microbes to whales (and people) through complex and precise food web dynamics. Changes to any part of the web can cause cascading effects that alter entire systems (Edwards and Richardson 2004; Frank et al. 2005).

The base of the ocean food web is comprised of a huge diversity of primary producers, ranging from microscopic plankton, to kelp, to seagrasses. Alterations to global oceanography could lead to changes in species composition and biomass in these communities (Gitay et al. 2002; Hays et al. 2005; Bjork et al. 2008) and affect all levels of marine food webs including the top: seals; whales; sharks; tunas; and people. Some of these changes are and will continue to be detrimental (Gitay et al. 2002). For example, when harmful or toxic algae succeed and become the most abundant species in the community, they can impact other resilient species even before climate change does directly. The boom and bust of individual species associated with disturbed ecosystems is buffered under normal, healthy conditions where other species offer checks and balances. Under increasingly altered systems, unpredictable swings in diversity and abundance of the planktonic community can be expected (Gitay et al. 2002; Hays et al. 2005).

The warmer, fresher surface water associated with a warming planet leads to stratification (Schmittner 2005; Jackson 2008) that can trap valuable nutrients in the deep ocean, thus separating them from the well-lit upper ocean where phytoplankton can transfer them into energy and make them available to higher levels in the food web. This phenomenon has implications for some of the most productive parts of Earth's oceans, where upwelling of deep waters and nutrients supports massively abundant surface ecosystems. If suppression of upwelling occurs to any degree, fisheries, and the people and wildlife that rely on them will certainly be negatively affected (Cheung et al. 2008).

In addition to changes in community composition and productivity in ocean ecosystems, warming temperatures will undoubtedly change the geographical ranges of marine species. Species are already migrating and occurring at higher latitudes than before (Perry et al. 2005) though not always at predictable rates (Perry et al. 2009). Geographic extensions of tropical species are being discovered regularly. As the tropics warm, it is unclear if these species will be able to adapt or if they will only be able to migrate, but recent research implies that heat tolerant species are already near the physiological limit of their temperature range (Tewksbury et al. 2008). Therefore, as they migrate poleward, there might not be populations or species available to replace them, nor suitable or sufficient prey species in their new locations. Furthermore, species endemic to closed basins such as the Gulf of California, the Red Sea or the Mediterranean Sea are not able to migrate easily and might simply be lost.

Similar changes in depth range can be expected, as species shift down in the water column to escape warming surface waters. While these migrations seem like viable adaptations, it is unclear how successful species can be when moving across these distances and depths. Life history characteristics that rely on other environmental cues, such as day length and tidal cycle, may not adapt fast enough for continued success.

Beneficial, aesthetically pleasing, or keystone species are not the only ones that will be able to extend their ranges with ocean warming. Dangerous invasive species, that cause disease and broad scale environmental destruction, can also migrate and are often more successful in weak, altered systems (Lotze et al. 2006). As these species move into other ecosystems, they can cause serious harm (Mooney and Cleland 2001) even before direct impacts of climate change are observable.

In addition to the effects associated with warming, marine ecosystems are expected to show drastic changes associated with ocean acidification within the next 50 years. Ocean acidification decreases the ability of many marine organisms to build their shells and skeletal structures and affects reproduction, behavior, and general physiological functions of some others (Orr et al. 2009). Several important planktonic primary producers rely on calcium carbonate to form protective shells. Under acidic conditions, calcium carbonate dissolves and these organisms are put at risk. Because these producers constitute the bottom of the food web, this risk can be expected to resonate throughout marine ecosystems, including important commercial fisheries and the communities who rely on them. A similar problem is expected for corals – both tropical and cold water – that rely on calcium carbonate for skeletal production.

- **Threatened ecosystems: Coral reefs, polar and coastal ecosystems**

The most well known example of a marine ecosystem at risk from climate change is the coral reef. Coral reefs are the most diverse ecosystem in the ocean and support at least several hundred thousand species. Corals are extremely vulnerable to climate change because of their narrow range of physiological constraints and close proximity to human population centers and the threats associated with those centers (Hoegh-Guldberg 2005; Knowlton and Jackson 2008). Millions of people around the world rely on coral reef fisheries and tourism for their livelihoods and coral structures for protection from dangerous ocean storms (Hoegh-Guldberg et al. 2007).

However, tropical corals are very susceptible to warming surface waters. They mostly live in shallow, surface waters that heat quickly, and they

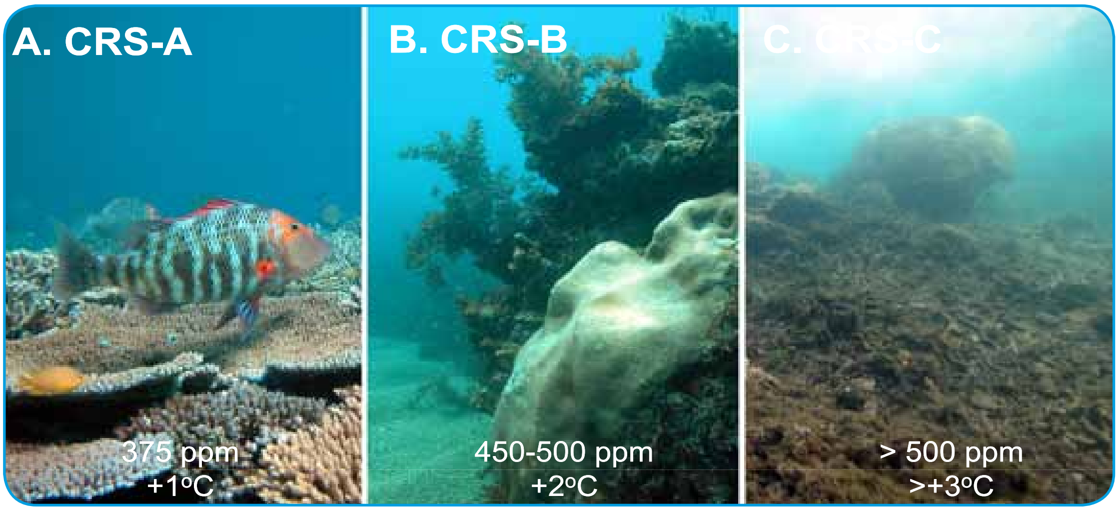

Fig. 2.3 Predicted scenarios for coral reefs under increasing amounts of atmospheric carbon dioxide. If concentrations of carbon dioxide remain at today's level, many coral dominated reefs will survive (left-hand panel) although there will be a compelling need to increase their protection from local factors such as deteriorating coastal water quality and overfishing. If carbon dioxide concentrations continue to rise as expected, reefs will become less dominated by corals and increasingly dominated by seaweeds (middle panel). If carbon dioxide levels continue to rise as we burn fossil fuels, coral reefs will disappear and will be replaced by crumbling mounds of eroding coral skeletons. In concert with the progression from left to right is the expectation that much of the enormous and largely unexplored biodiversity of coral reefs will disappear. This will almost certainly have major impacts on the tourist potential of coral reefs as well as their ability to support fisheries, both indigenous and industrial.

Reference: Hoegh-Guldberg et al. 2007

are adapted to live near the upper limit of their temperature range (Gitay et al. 2002). Even slight, temporary warming events can lead to coral bleaching (where the above-average temperature causes the breakdown of the crucial coral-microalgal symbiosis and leads to corals expelling the symbiotic algae that provide them with energy and pigment) and widespread mortality like that associated with the 1998 El Niño event, when 16% of the world's tropical corals were lost (Hoegh-Guldberg 1999; Knowlton 2001). Increases in global sea surface temperature imply that coral reef thermal thresholds will be exceeded more frequently and this is projected to result in more frequent and more intense coral bleaching events and subsequent widespread mortality. If current trends in greenhouse gas emissions continue, many of the remaining reefs may be lost to coral bleaching over the next 20 to 40 years (Wilkinson 2008).

Furthermore, coral reefs are under threat from changes in ocean chemistry. Corals build their skeletons (and massive reefs) out of calcium carbonate (a process known as calcification). Continual lowering of ocean pH associated with uptake of CO_2 (ocean acidification) and the subsequent decrease in availability of carbonate ions crucial for calcification are predicted to lead to decreasing calcification rates in scleractinian corals (Hoegh-Guldberg et al. 2007; Jackson 2008; Knowlton and Jackson 2008). Coralline algae (algae that photosynthesize and create calcium carbonate skeletons like corals) are also being affected. Coralline algae are crucial to reef ecosystems as the 'cement' that holds structures together and for facilitating the settlement of coral larvae. As calcification rates of corals and coralline algae decrease, it is likely that reefs will

Coral reefs: Interactions and synergies between local and global factors

Ove Hoegh-Guldberg - Global Change Institute, University of Queensland, Australia

Climate change is impacting coral reefs in a number of ways. Rising sea temperatures are driving increased coral bleaching and mortality (Hoegh-Guldberg 1999), while reduced concentrations of carbonate ions as result of ocean acidification is decreasing marine calcification (Kleypas and Langdon 2006). Other factors such as strengthening storms and changing weather patterns are damaging coral reefs through physical impacts and declining coastal water quality. These factors do not operate in isolation, and there is increasing evidence of interactions and synergies between them. A recent study by Anthony and colleagues, for example, found that ocean acidification increases the sensitivity of corals to thermal stress, with coral bleaching occurring at lower temperatures when exposed to lower pH. The implications of these interactions and synergies between factors are potentially serious and imply that we may have underestimated the impact of rising greenhouse gas concentrations on marine ecosystems such as coral reefs (Anthony et al. 2008).

Climate change may also interact with local factors such as overfishing, pollution and declining water quality. Coral communities which are subject to stress from local factors are more likely to succumb to the impacts of rising water temperatures and acidities. This was demonstrated by Hughes and co-workers who showed that coral reefs that had substantial populations of grazing fishes such as parrotfish on them recovered three times more quickly than those that did not. Grazing fishes crop algal communities and thereby allow the recruitment and growth of coral colonies, which is essential for the recovery of coral populations. Other factors such as pollution and declining water quality, will also lead to a shift in coral reef communities towards coral loss and/or algal-dominated systems. These observations also suggests an opportunity for coastal resource managers to increase the resilience of coral reefs to the impacts of climate change while the global community struggles to bring greenhouse gas emissions under control (Hoegh-Guldberg et al. 2007; Hughes et al. 2007).

It is important to note that increasing the resilience of coral reefs to climate change will only have an impact if dramatic cuts in greenhouse gas emissions occur over the coming decades. The management of local stresses will have little effect if the underlying problem of warming and acidifying oceans is not mitigated. In this respect, atmospheric carbon dioxide concentrations that approach and exceed 450 ppm will lead to a rapid loss of coral dominated reef systems (Hoegh-Guldberg et al 2007). If this occurs, at least half of the enormous biological diversity of coral reefs (~1-9 million species, Reaka-Kudla 1997) will disappear due to its heavy dependence on the presence of rich coral communities. These changes on coral reefs will also affect their primary productivity and ability to provide food and resources or several hundred million people who live in tropical coastal areas. The declining quality of coral reefs will also affect industries such as reef tourism and fisheries, potentially translating as the loss of billions of dollars of revenue for countries across tropical regions (Hoegh-Guldberg et al. 2009).

Further Reading

Hoegh-Guldberg, O. et al. (2007) Coral reefs under rapid climate change and ocean acidification. Science 318(5857):1737-42

Kleypas JA, Langdon C (2006) Coral reefs and changing seawater chemistry, Chapter 5. In: Phinney, J. et al. (eds) Coral Reefs and Climate Change: Science and Management AGU Monograph Series, Coastal and Estuarine Studies. Geophys. Union, Washington DC, pp73-110.

erode at a faster rate than they are created. Over time these three-dimensional matrices of habitat could become homogeneous flat sea bottom. This loss would have negative knock-on effects on the reproduction and life cycle of organisms that depend on it leading to potential loss of unique marine species, some of which may not yet have even been discovered by humans.

Coldwater corals are unique and important species that grow extremely slowly, in the deep sea. They can form rich reefs and other complex habitats supporting a wide diversity of deep sea organisms, including commercially important fishes, but are extremely susceptible to destructive fishing and marine climate change (Roberts et al. 2006). Like their shallow water counterparts, coldwater corals rely on calcium carbonate for skeletal production. This makes them also vulnerable to ocean acidification. Within the next 90 years, up to 70% of deep sea corals may be harmed by acidification alone (Guinotte et al. 2006). Without successful mitigation of CO_2 emissions, this ecosystem will be severely degraded.

Polar ecosystems, because they are at the other end of the temperature spectrum, face risks different from those in the tropics. The most dominant feature of the polar landscape is ice. Huge mountains of snow and ice rise above the ocean and the land surface at both poles. Above the water line, Arctic ice serves as essential habitat for polar bears, seals, and other marine tetrapods (birds, mammals, etc.) that use it for hunting, transportation, and reproduction. These species are at risk of endangerment or extinction if the ice

Deepwater corals and the other CO_2 problem

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There are approximately as many species of coldwater scleractinian (stony) coral species as there are species of scleractinian corals living in shallow tropical waters. Coldwater corals do not depend on a symbiotic association with photosynthetic algae (zooxanthellae) and hence are not restricted to near-surface waters; most, in fact, live in the deep sea. Because they depend for their food on small plankton and organic matter wafted past them by the currents, they are primarily found in deep-sea environments with strong currents, such as seamounts, continental margins and canyons. Six species of scleractinian coldwater corals form reefs, which, like their shallow-water coral counterparts, provide habitat to a diverse range of invertebrate and fish species. The largest deepwater coral reef, the Røst reef off Norway, is over 40 kilometers long and up to 30 m in height but was only discovered within the last ten years. Large tracts of deepwater coral habitats were lost to trawling activity before scientists and the public were aware of their diversity and extent.

Ocean acidification now presents a potentially grave but still poorly understood threat to this remarkable deep-sea habitat. Little is known directly about the physiological impacts of acidification on deepwater stony corals, but the ability of shallow-water corals to develop their calcified skeletons is strongly diminished at ocean pH levels anticipated over the coming century as atmospheric CO_2 concentrations approach 2 – 3x pre-industrial levels. There is suggestive evidence that ocean acidity already limits the distribution of deepwater stony corals: although there are extensive deepwater coral reefs in the South Pacific and North Atlantic, where the aragonite saturation horizon (ASH) is deep (>2000m), there are few records of these corals in the North Pacific, where the ASH is relatively shallow (500-600 m). (The ASH is the depth at which aragonite, one of the main forms of biogenic calcium carbonate, starts to dissolve.) It is estimated that due to shoaling of the ASH from acidification, 70% of known cold-water stony coral ecosystems will be in undersaturated water by 2100 and no longer be able to maintain calcified skeletal structures.

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Methane release from hydrate beneath the seabed

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Methane hydrate is a solid with the appearance of ice, in which water forms a cage-like structure enclosing molecules of methane. It is one of a large group of materials called clathrates. Methane hydrate is stable under conditions of low temperature and high pressure such as those found in regions of permafrost or under the ocean in water deeper than 300-600 metres, depending on the water temperature. The concentration of methane in the ocean is usually far too low for hydrate to form, but in the sediment and rocks beneath the seabed, methane concentration can be high enough to form hydrate. Favourable physical conditions for the formation of hydrate can exist up to several hundred metres beneath the seabed in great water depths. The thickness of the zone in which hydrate can form and be stable is limited by the increase of temperature with depth within the Earth. Methane from deeper hydrocarbon reservoirs or generated by bacteria from the organic material in the sediment migrates upward, as free gas or in solution in water, into the hydrate stability zone, where it forms hydrate. A large amount of carbon, possibly equivalent to that in all other source of natural gas and petroleum in the Earth, is trapped as hydrate in the sediment beneath the seabed.

Increases in ocean temperature reduce the depth extent of the hydrate stability zone, causing hydrate to dissociate into water and methane gas. In deep water, the seabed remains in the hydrate stability zone and methane released from its base, by the downward diffusion of heat from the warming ocean, may re-enter the stability zone and form hydrate again, limiting the amount that may escape into the ocean, but in the upper continental slope, where the upper edge of the hydrate stability zone retreats down slope, the methane released is free to migrate through the sediment to the seabed. Although hydrate is absent from most continental shelves, in the Arctic, hydrate exists in the shallow shelf, in and beneath permafrost, because of the very low temperatures inherited from when the shelf was permanently covered by ice or was land. There, the effect of temperature increase is enhanced by encroachment of the sea on the land caused by rising sea-level.

Over recent years, there has been increasing evidence of methane from hydrate entering the ocean as a consequence of warming, where it will contribute (through oxidation) to ocean acidification, but little that it is entering the atmosphere. It appears that in most locations the rate of release of methane is generally too slow to overcome its dissolution and oxidation in the ocean. Catastrophic gas venting or submarine landslides of hydrate-rich sediment might, however, be effective in releasing large amounts of methane over short periods of time. Yet, although the latter process has been widely cited as an agent of ‘geologically’ ancient increases in atmospheric methane, the potency of these processes on a global scale has still to be proven.

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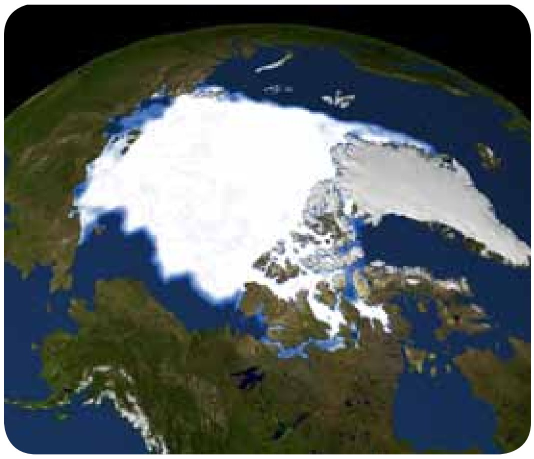
continues to melt at current rates. Below the water line, the interface between the ice and the seawater is a region of high primary production for the polar seas (Gradinger 1999). Algae depend on nutrients from the ice to grow and reproduce. Recent data imply that sea ice melting around the North Pole is happening faster than previously expected, and researchers predict the Arctic to be totally ice-free during the summer in less than 30 years (Wang and Overland 2009). Changes at the ice-water interface and expected increases in production associated with ice-free open water (Pabi et al. 2008) mean the overall productivity budget in the Arctic Ocean is changing and will continue to change with further ice melting. A recent study outlines that the warming of the Arctic will have climate feedbacks with global implications that are far worse than previous projections expected: severe flooding, damage to humans, fish and wildlife, increased greenhouse gas emissions, and extreme global weather changes (Sommerkorn & Hassol 2009).

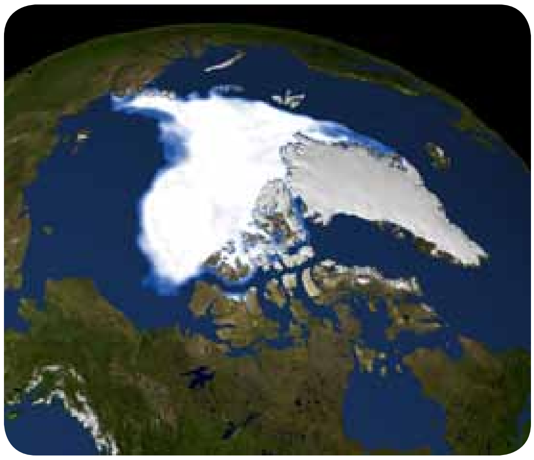
Additionally, with continued ocean warming, polar ecosystems are invaded by temperate species that migrate to higher latitudes (Perry et al. 2005). Much as species in semi-enclosed basins, polar species are essentially "enclosed" by their inability to travel to cooler regions. The forced interactions between polar species and temperate colonizers and lack of refuge could cause polar species to be lost under the physiological and ecological pressures that they face.

Melting Arctic sea ice also has indirect consequences for marine ecosystems by opening up large swaths of surface ocean and seafloor to human activities, including fishing, prospecting, drilling, shipping, and other development. Arctic countries are already exercising their rights under the UN Convention on the Law of the Sea to seek recognition of their extended continental shelves (Gamble 2009). These countries could extend additional protection to sedentary species on their continental shelves and thus improve conservation and management. Increases in exploitation activities would pose additional threats and future problems for Arctic marine ecosystems.

A final example of ecosystems that will be affected by continuing climate change and greenhouse gas emissions are those along coasts. Coastal ecosystems straddle the interface between the oceans and the continents and are often the most heavily impacted by human activity (Lotze et al. 2006). River deltas, coastal plains, coral atolls, barrier islands, lagoons, beaches, estuaries, salt marshes, and mangrove forests are some of the numerous systems along the ocean borders. With expected changes in sea level and higher intensity of oceanic storms, the primary threats from climate change to coastal ecosystems are physical in nature. Saltwater intrusion, inundation, and erosion will continue to threaten the structure of these systems. Because coastal species have adapted to live in a very narrow band of habitat, any alteration to this area could have serious negative consequences for these aesthetically, ecologically, and economically valuable systems.



Arctic sea ice minimum area for 1979



Arctic sea ice minimum area for 2007

Credit: NASA/Goddard Space Flight Center Scientific Visualization Studio. Thanks to Rob Gerston (GSFC)

Without carefully planned mitigation and adaptation strategies, all of the unique ecosystems discussed here are at risk of irreversible damage or loss.

Vulnerable biodiversity: people - displacement, conflict, disease, economic activities

On June 5, 2008, Anote Tong, president of the Pacific Island State of Kiribati, used World Environment Day to announce a plan to seek international refuge for all of his country's 97,000 people (Sanderson 2008). Kiribati is a country of coral atolls at the intersection of the equator and the International Date Line, and President Tong fears that these atolls will be uninhabitable within the next 50 years. Sea-level rise, saltwater intrusion, and changing weather patterns are altering Kiribati's landscapes, most of which are fewer than two meters above current sea level. The people of Kiribati may be the first high profile, population-wide, environmentally displaced people associated with a changing climate, but without timely mitigation and adaptation strategies, they will not be alone. With the loss of entire sovereign countries, there will be massive displacement of people and loss of culturally, ethnically, and industrially significant areas (Kelman 2008). National and international discussions on the rights, protection and remedies for climate change displaced people will be extraordinarily complex and expensive (see chapter on 'Climate Change Displaced Persons', page 58).

Thirteen of the world's 20 megacities lie along the coast, and nearly 700 million people live fewer than 10 meters above sea level (UN Habitat 2008). Many of these cities and people are in the developing world. Even moderate sea level rise will lead to regular flooding, saltwater intrusion, and erosion that will affect coastal infrastructure (e.g. development, transportation, energy facilities, ports), water supplies, agriculture, aquaculture, and urban and rural housing. Increasing storm intensity could be devastating to coastal population centers and could lead to considerable human displacement. In low-lying regions where reefs, mangrove forests, or other natural barriers have been degraded or removed through human activities, the impacts of sea-level rise and increased storm activity will be felt hardest. Furthermore, changing precipitation patterns will leave dry regions with even less rainfall, alter the replenishment of mountain glaciers and snow, and lead to intermittent destructive flooding interspersed with long, dry periods (IPCC 2007).

These direct effects of climate change on people could cause regional or international conflicts over needs as fundamental as drinking water and space. Under these conditions, ethnic and sectarian violence, along with associated political refugees, can almost certainly be expected to rise. Furthermore, as productive fisheries migrate from one jurisdiction to another (e.g. across national borders; Perry et al. 2005, Cheung et al. 2009), fishing fleets could face new and difficult challenges. International negotiations dealing with these types of issues will be long and difficult.

Even in regions where climate change will not force residents to migrate, human health is a concern. Increases in geographical range and lengthening of transmission seasons of coastal diseases and vectors will harm coastal populations (WHO 2007), and inundation by polluted seawater could create areas of contaminated water and disease (see section on ‘Direct health risks associated with climate change’ page 56).

Ocean related economic activities such as fisheries, aquaculture, coastal tourism, and shipping are especially vulnerable to changing seas. These industries are heavily influenced by physical, chemical, and biological processes of the oceans, many of which are at risk of change.

Fisheries and aquaculture provide food for billions of people worldwide. Fish provide nearly three billion people with at least 15% of their animal protein (FAO 2009). 400 million people obtain

Climate change and the Inuit people

Sheila Watt-Cloutier

Inuit are a people of the snow and ice. To us, the frozen ocean uniquely represents mobility; the ice serves as a highway between our communities, allowing us to move great distances and hunt and fish for the many terrestrial and marine mammals and fish that sustain our communities and our culture. Over millennia, we came to know the patterns of the ice and atmosphere, and taught our children to read those signs to see their way to safety. In the Fall and Spring, in many locations, traditionally our hunters would venture by skin boat to the edge of the ice to find the great migrations of animals who follow it. The early ice each year would form a natural sea wall during the heavy Fall storms. Lastly, the ice filled the passages across much of the North, largely preventing vessels from attempting the faster route through the fabled-Northwest Passage.

In the past several decades, all of this has changed. Our traditional knowledge has begun to lose its value in predicting ice conditions and the coming of dangerous weather, and our hunters have fallen through the melting ice and have been lost at sea by unpredictable storms. The cycles of the ice’s ebb and flow have shifted dramatically, meaning, in certain regions of the Arctic, we are often no longer able to reach the edge of the ice flow for long enough to harvest the rich food sources that feed our families. The ice walls that once protected our shores now never form, leaving us vulnerable to the ever more intense storms that cause devastating erosion under many of our communities. Lastly, as the edges of the Arctic Ocean quickly open, nations are already rushing to gain control over the rich mineral resources and shipping lanes. An ice-free Northwest Passage is an environmental disaster, and would mean a far greater risk of toxic spills across our homeland.

The key to slowing and reversing these trends is for our world to understand the deep interconnectedness between our environment, communities and industries through our shared atmosphere and ocean. Just as the melting of the Greenland ice sheet has begun to increase sea levels in the small island developing states, so too are the actions of industrialized economies far to the South dramatically changing our seas and impacting our very ability to subsist and survive as an indigenous people. Only once we realize these inter-relationships can we reconnect as a shared humanity.

more than half of their animal protein from fish and shellfish (World Bank 2004). This percentage reaches nearly 100% on small islands that depend upon subsistence fishing. In addition to the fish protein that they provide to billions of people worldwide, fisheries and aquaculture are the primary income sources for at least 43.5 million people (2006 estimate). Including individuals involved in processing, marketing, and services, this number rises to over 170 million. In fact, nearly 8% of the world's population is directly or indirectly involved with fishing or aquaculture or is dependent on someone who is (FAO 2009). Many of these people capture (or farm) fish in areas that are particularly vulnerable to a changing climate and ocean acidification, including coral reefs and coastal ecosystems, where alternative sources of income are often difficult to obtain. If predicted changes to global ocean productivity, fish populations, and weather patterns are realized, local, regional, and global fisheries and aquaculture can be expected to suffer, leaving some areas economically unstable.

Tourism is an alternative to fishing and aquaculture in ecologically important coastal and coral reef ecosystems. Ecotourists pay to see colorful fish and birds and the reefs and mangroves on which they depend. Tourism also relies on healthy coastal ecosystems for the services that they provide, such as clean water, healthy landscapes, healthy people, and aesthetically pleasing scenery. Each of these necessities could be in jeopardy given current trends. Shifting ecosystems and species, as well as increased erosion rates and storm events, will negatively impact the tourism industry, resulting in economic losses and potential unemployment.

Finally, more than 90% of all worldwide trade goods are transported on the ocean (IMO 2006). Changing ocean currents and weather patterns, as well as increased intensity of storm events, however, will decrease the shipping industry's efficiency. Ports, docks, and other loading/unloading facilities will also be affected by physical ocean changes, including sea-level rise, increased storm activity, and flooding. The industry itself recognizes storms, increased incidence of environmental-ship interaction (e.g. groundings, oil spills), sea-level changes, increased iceberg hazards (with changes to polar icecaps), and changing wind patterns (with associated fuel costs) as major issues that will raise costs and alter insurance policies, perhaps to a challenging degree (DLA Phillips Fox 2009). The shipping industry requires timely mitigation and adaptations strategies in order to continue providing global services and should also be considered more seriously in future emission reduction strategies.

All people, coastal and otherwise, are directly or indirectly vulnerable to ocean changes that are associated with Earth's climate. Many aspects of the relationships between people, the ocean, and the climate are clear and well understood. Our actions impact both the ocean and the climate, and changes to those systems often affect us. Without careful consideration of all three sides of this triangle, mitigation and adaptation strategies will be inadequate and should not be expected to succeed.

3. Action Recommendations for Mitigation Strategies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Climate change and ocean acidification will continue to have significant adverse impacts on the marine environment with damaging implications for people. As world leaders are discussing ambitious targets for reducing greenhouse gas (GHG) emissions in order to mitigate the worst impacts of climate change on the environment, human societies and our economies, marine impacts must also be seriously considered.

In order to achieve significant GHG emission reductions, different strategies are being developed and implemented. Climate change mitigation portfolios such as the climate stabilization wedges (Pacala et al. 2004) and the McKinsey greenhouse gas abatement cost curve (McKinsey 2009) demonstrate different paths to cutting emissions, to lowering the cost of each technology and strategy, and to increasing their reduction potential. This chapter will highlight the role of marine and coastal related mitigation approaches for such portfolios and detail the potentials and risks of other mitigation approaches applied in the marine environment.

SIGNIFICANTLY AND RAPIDLY CUT CO_2 EMISSIONS

The crucial role of CO_2 for the ocean

CO_2 plays a crucial role in the marine environment due its dissolution in the ocean, which leads to acidification. To avoid the possibility of major alterations to marine ecosystem functions and services due to changes in the ocean's chemical composition, CO_2 emissions must be significantly limited and restricted. While several management, conservation, and adaptation strategies may enhance the role of marine and coastal ecosystems as carbon sinks (see below), these must be accompanied by action within the framework of robust domestic and international emission targets. A range of coordinated mitigation actions are required now, targeting energy supply and demand, as well as emissions from land-use change, to allow adaptation measures to succeed and help preserve the numerous roles of the ocean in our lives.

Stabilization targets should reflect recent marine findings and observations (e.g. on ocean acidification) and fully account for the crucial role of the ocean in the global carbon cycle. It is therefore essential that an adequate number of marine climate change experts are involved in decisions on international and national emission targets and strategies.

Action Recommendations

Use ecosystem thresholds to inform discussions on international GHG emission stabilization targets and use evolving science and knowledge to improve targets in the near future.

Set targets for atmospheric CO_2 which adequately reflect the impacts of ocean acidification.

Review the effectiveness of the current set of mitigation strategies for reducing ocean acidification.

Enhance global action on mitigation in order to reduce GHG emissions by improving energy efficiency standards and reducing global energy consumption.

Include the environmental and social costs of ocean acidification in climate change mitigation actions.

Utilize marine climate change experts in decisions on international and national emission targets and strategies.

PROMOTE RESEARCH, MONITORING AND ASSESSMENT OF THE OCEAN IN THE GLOBAL CARBON CYCLE

Undervalued carbon sinks: marine and coastal ecosystems

UNFCCC, Art. 3 states that parties should cover all relevant GHG sinks – any process which removes GHG from the atmosphere – in order to mitigate the adverse effects of climate change. UNFCCC, Art. 4 states that parties should promote sustainable management and promote and cooperate in the conservation and enhancement of sinks and reservoirs of all GHG not controlled by the Montreal Protocol, including oceans and costal and marine ecosystems.

Marine and coastal ecosystems are regarded as vital global carbon stores, but their role for carbon management has been largely ignored in international climate change discussions (Thompson 2008, Laffoley & Grimsditch 2009). Coastal ecosystems, especially tidal marshlands, seagreass meadows and mangrove swamps, are important natural carbon sinks (Chmura et al. 2003, Pritchard 2009, Bouillon et al. 2009, Kennedy & Björk 2009). In these systems, tidal floodwaters contribute inorganic sediments to intertidal soils, reducing the potential for aerobic decomposition. Anaerobic decomposition is much less efficient and leads to the accumulation of organic matter in the soil. Seagrass bed carbon burial rates are about half as high as those for mangroves and salt marshes, by area, but are still significant (Duarte et al, 2005).

Furthermore, each molecule of CO_2 sequestered in tidal salt marshes and mangrove swamps likely has a greater relative “value” over molecules stored in other natural ecosystems due to a lack of production of other greenhouse gases (Chmura, 2009). In contrast to freshwater wetlands (Bridgham et al. 2006), marine wetlands produce little methane gas, which is more potent than CO_2 as a greenhouse gas (Forster et al. 2007). Building on current efforts (Laffoley & Grimsditch 2009), additional research activities should focus on the quantification of the carbon deposition rates of marine and coastal ecosystems. Proper regional and global carbon management and potential carbon off-set schemes could be developed upon such efforts.

Finally, recent findings present initial insights on the role of fish and the importance of their excretions in maintaining the ocean’s delicate pH balance (Wilson et al. 2009). More research is needed to further analyze and quantify the contribution of fish to the ocean carbon cycle and the possible implications of overfishing on this cycle.

The ocean as part of the global carbon cycle

The ocean covers more than 70% of the planet and is the largest biospheric reservoir of carbon (Turley et al. 2009). It is therefore not surprising that the ocean plays a dominant and vital role in the Earth’s global carbon cycle (see Fig. 3.1).

The ocean surface maintains an equilibrium with the atmosphere with respect to CO_2 via the so called solubility pump. Ocean circulation processes (thermohaline circulation and other regional mixing and overturning in the ocean) sequester CO_2 in deeper ocean layers until it is transported back to the surface decades to centuries later

More research is needed in order to quantify the potential of marine ecosystems as global carbon stores and to develop proper carbon management schemes.
Left to right: Kelp forest, seagrasses, mangroves and salt marshes

(Turley et al. 2009). Surface water temperature is one of the characteristics that determines how much CO_2 is absorbed or released by the ocean. Cooler temperatures increase the surface water's ability to dissolve CO_2; therefore, the Southern Ocean and the North Atlantic Ocean are generally characterized by an influx of CO_2 into the ocean (Denman et al. 2007). In tropical and subtropical upwelling zones, ocean masses rise from the deep, where they warm and release CO_2 back to the atmosphere (Turely et al. 2009).

Biological processes also regulate the transfer of CO_2 and other gases between the ocean and the atmosphere. The biological pump is driven by primary production in the ocean that creates particles which sink to deeper ocean layers. Microorganisms, such as phytoplankton, influence the oceanic carbon cycle by taking up CO_2 through photosynthesis (Turley & Findlay 2009). Most of this organic bound carbon is released into the surface ocean and returned to the atmosphere within days to months. However, some of this organic carbon sinks to the deep ocean where it is removed from contact with the atmosphere and stays 'trapped' for up to thousands of years (Rahmstorf & Richardson 2009). It is estimated that between 25% and 50% of total anthropogenic CO_2 emissions are absorbed by the ocean (Sabine et al. 2004. Keeling 2005, IPCC 2007).

Reduced capacity of the ocean to buffer climate change

Recent studies show the ocean's ability to buffer anthropogenic CO_2 will decrease in upcoming decades (Turley et al. 2009). Ocean warming reduces CO_2 solubility and therefore reduces the ocean's ability to store carbon. Increases in seawater temperature also lead to ocean stratification, which reduces the vertical mixing of water masses and the formation of deep-sea water, further limiting the ocean's ability to absorb atmospheric carbon.

Nevertheless, the ocean will continue to be a carbon sink as long as the atmospheric concentrations of CO_2 continue to increase (Turley et al. 2009). But as the long term ocean carbon storage capacity diminishes, atmospheric CO_2 may stabilize on a multi-century time scale at higher levels intensifying climate change (Fung et al 2005, Le Quéré et al. 2007). Denman et al. (2007) state that "small changes in the large ocean carbon reservoir can induce significant changes in the atmospheric CO_2 concentration" (p530).

The behavior of the ocean's carbon sink, as well as the impacts of increased ocean acidification need to be continuously monitored and assessed. Research programmes, such as the European Project on Ocean Acidification (EPOCA) and others[1] , are well-positioned to fill scientific gaps and also to provide more information and clarity to the policy-making process. Ongoing research and monitoring of the marine and coastal environment will help with the improvement and adjustment of current mitigation actions and support the development of the IPCC 5th Assessment Report. Any current gaps in the understanding of ocean acidification, the ocean carbon cycle, and the impacts of climate change on the marine environment, should not prevent significant early action.

Action Recommendations

Develop adequate carbon management schemes for marine and coastal ecosystems that are vital global carbon sinks and include them in broader climate change discussions.

Enhance the long-term monitoring and collection of ocean data, increase and support efforts to quantify the ocean's role in the global carbon cycle, assess the ocean's CO_2 uptake and project future trends in order to evaluate oceanic carbon storage potentials and effectively run prognostic climate simulations.

Focus additional research activities on the quantification of the carbon deposition rates of marine and coastal ecosystems.

Initiate research analyzing and quantifying the contribution of fish to the ocean carbon cycle and the possible implications of overfishing on the cycle.

[1] e.g. CarbOcean, Surface Ocean - Lower Atmosphere Study – Integrated Marine Biochemistry and Ecosystem Research (SOLAS-IMBER) Carbon Implementation Group (SIC), and the International Ocean Carbon Coordination Project (IOCCP2)

Climate change influences on the oceanic biological carbon pump

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Approximately half of the photosynthesis on Earth takes place in the ocean, resulting in draw down of carbon dioxide and production of oxygen gas. This biological process has transformed planet Earth, making it habitable to most of the life forms we know today, including humans. But what happens to the carbon compounds that are fixed biologically through photosynthesis? How much of this carbon will remain in the ocean, and for how long? Will climate change alter the amount of carbon that is sequestered in the deep sea? How will ocean acidification affect carbon sequestration potential?

Because the vast majority (~ 98%) of photosynthesis in the ocean is carried out by single-celled microscopic algae that drift freely with ocean currents, the answers to these questions begin with the small but widespread organisms of the marine plankton. The specific types of planktonic algae that predominate in different parts of the ocean set the stage for the rest of the food web: they influence the types of grazers and bacteria that consume most of the photosynthetically produced organic carbon, as well as the amount and forms of carbon that are exported into the ocean's interior. Collectively, these processes are known as the 'biological carbon pump:' the photosynthetic uptake of carbon dioxide, biosynthesis of reduced carbon compounds, grazing, sinking (and swimming) of organic matter into the deep ocean, and respiratory consumption of fixed carbon and its remineralization into simpler inorganic forms. The causes of variations in the ocean's biological carbon pump are a major area of research today, because of their fundamental importance to the modulation of earth's climate and because such variations set an upper limit to sustainable fisheries yields.

One area of current interest is changes in density stratification of the ocean and its effects on nutrient fluxes into the surface ocean and the biological carbon pump. Climate change-induced warming of the surface ocean increases stratification – i.e., the density difference between surface and deeper waters. For much of the open ocean, this increased density stratification can slow the rate of vertical mixing and upwelling, thus reducing the supply of nutrients from deeper waters into the sunlit surface layer where photosynthesis can occur. Increased stratification may be contributing to an increase in the areal extent of the large, permanently stratified open ocean gyres (Polovina et al. 2008), analogous to a growing desertification of the open sea. Over time, this process could reduce the ocean's potential for carbon sequestration via the biological pump. However, in higher latitude regions of the ocean, where dissolved nutrients occur in higher concentrations near the surface, increased density stratification may have a positive, stimulatory effect on primary production and enhance the export of carbon. Changes in ocean stratification, and other effects of climate change, may therefore reduce the efficiency of the biological carbon pump in some ocean regions and stimulate it in others. Sorting out where, when, and why these different effects occur is a major challenge for 21st century science. The problem is pressing because alterations to the oceanic biological carbon pump may in turn lead to feedbacks that serve to further accelerate – or decrease – the rate of planetary warming.

Further reading:

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Identify and address key gaps in our understanding of the impacts and ramifications of marine climate change and ocean acidification (environmental, social and economic) in order to adjust and update current mitigation actions; document changes in ocean chemistry and biogeography across space and time; determine sensitivity of marine organisms, communities and ecosystems; improve understanding of impacts on marine food webs and assess uncertainties, risks and thresholds in the marine environment.

Ensure effective action by improving communication between policy makers and scientists and by utilizing the various ocean acidification and ecosystem change research programmes currently underway to disseminate results and continue to raise awareness and trigger timely responses.

Encourage and support the IPCC in its 5th Assessment Report to prominently include marine and coastal topics with special attention to ocean acidification.

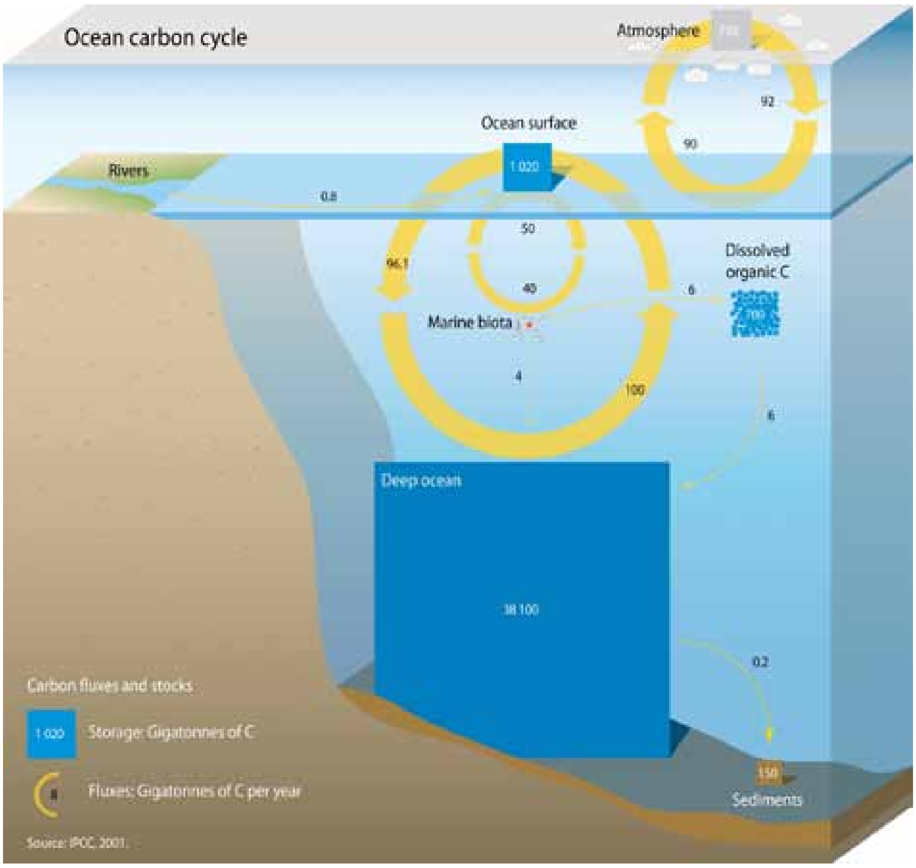

Fig 3.1 The ocean and its ecosystems play a critical role for the global biological sequestration of carbon. The uptake capacity in the ocean is however decreasing. It is important to retain, maintain and recover marine and coastal ecosystems and their carbon management functions.

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RETAIN, MAINTAIN AND RECOVER NATURAL CARBON SINKS

Valuable natural carbon sinks lost at rapid rate

Recent studies show a reduction of carbon sinks in coastal margins due to human activities and their environmental impacts (Duarte et al. 2005). Marine ecosystems and species are being altered and lost at rapid rates. For example, mangroves have been reduced to about 30%-50% of their historical cover (Spalding et al. 1997, Valiela et al. 2001), and the spatial extent of seagrasses has dropped by 50% in just the last 15 years (Duarte et al. 2005, Waycott et al. 2009).

The characteristics of degraded marine ecosystems include loss of coastal vegetation (deforestation), sedimentation, reclamation, dredging, filling, drainage and general unsustainable coastal development. Other negative impacts stem from reclamation of marine and coastal ecosystems for other uses such as aquaculture or saltpond construction, overfishing and destructive fishing practices, ocean and land-based pollution and other marine resource extraction activities such as oil and gas or mineral resources. Such human activities disrupt habitats and release carbon back into the atmosphere, exacerbating climate change and ocean acidification. Lost or degraded marine and coastal ecosystems not only reduce their capacity to absorb and store carbon but also reduce their ability to continue to provide marine ecosystem services such as shore protection and important food and income resources on which people depend.

For the ocean to remain an efficient CO_2 sink rather than becoming a global CO_2 source, sound management approaches must be implemented to keep the ocean as healthy as possible. Studies indicate that healthy ecosystems, characterized by high natural species diversity exhibit increased ecosystem functions (Worm et al. 2006). In order to retain, maintain and recover marine natural carbon sinks, it is essential to build on current marine conservation strategies and develop more effective marine management regimes that address the oceans in the bigger carbon management scheme. By building on existing practices such as marine protected areas, and by reducing other human induced stressors, it will be possible to maintain and recover marine carbon sinks while simultaneously supporting climate change adaptation strategies (see chapter 4 on 'Ecosystem-based Adaptation').

Action Recommendations

Use and improve upon simulation models, in collaboration with field studies, to develop tools for improving and enhancing management plans for ecosystems protection, rehabilitation and restoration, including optimal scenarios for carbon allocation, CO_2 uptake and carbon management schemes.

Build on and effectively apply current marine and coastal conservation and restoration strategies such as marine protected areas and integrated coastal management as a way to increase the world's natural carbon sinks and develop more effective marine management regimes that integrate the ocean into larger carbon management schemes.

Retain, maintain and recover ecosystem resilience and marine natural carbon sinks by reducing other human induced stressors (see below).

SIGNIFICANTLY REDUCE OTHER HUMAN STRESSORS

Healthy ecosystems support climate change mitigation and adaptation strategies

Healthy ecosystems are vital to the implementation of both mitigation and adaptation strategies. Well-functioning ecosystems, with high natural biodiversity, are able to sequester more carbon than degraded natural systems and human structures. Furthermore, healthy ecosystems continue to provide ecosystem services that help people adapt to the adverse effects of climate change (see below) and exhibit high resilience to other problems.

Marine ecosystems are heavily impacted and degraded by many unsustainable human activities, including fisheries, pollution and habitat destruction (Halpern et al. 2008). In combination with climate change and ocean acidification, these effects not only alter marine ecosystems, but they threaten the livelihoods of people who rely on coastal and marine resources, and undermine previously successful conservation strategies. To maintain the critical role of marine ecosystems and to improve their resiliency, it is essential to actively reduce destructive marine and coastal practices. The management of human marine activities should consider the interactions between changing climate conditions and the broad range of human activities rather than attempting to disentangle their effects and address each separately (Perry & Barange 2009).

The following sub-chapters on fisheries and aquaculture, marine and land-based pollution, and nonrenewable resource prospecting and extraction will provide some recommendations of how other human induced stressors on the marine environment can be significantly reduced.

Fisheries

For millennia, we have fished. And with continued increases in human population numbers, improvements in fishing technologies, and globalization of seafood markets, we have achieved levels of industrialized fishing that the ocean cannot support. As a direct result of human fishing pressure, several species have become commercially, ecologically, or biologically extinct (see Jackson et al. 2001) and large predatory fishes have decreased by 90% (Meyers and Worm 2003). This loss of biodiversity and biomass threatens the ocean's ability to continue providing food and other ecosystem services to billions of people around the world (Worm et al. 2006). Added pressure from a changing climate and changing ocean increase the impacts of fisheries on marine biodiversity and ecosystems, and fishing decreases a system's resilience to change (Planque et al. 2009). Seventy nine percent of the world's marine fish stocks are now fully exploited, overexploited, depleted or recovering (see Fig. 3.2) (FAO 2009).

Even small changes in reproduction, growth, or migration caused by climate change and ocean acidification could further endanger fish stocks and fisheries. Currently sustainable or successfully managed fisheries may no longer continue to be so when faced with continuing ocean change. Furthermore, overfishing and other destructive fishing practices (e.g. poison, dynamite, bottom

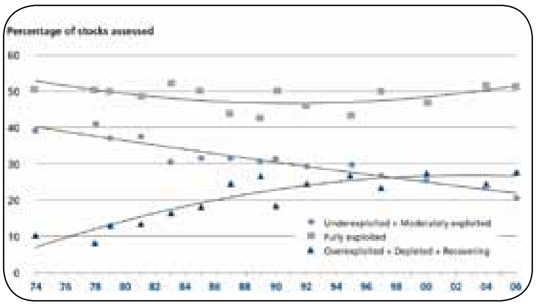

Fig. 3.2 Global trends in the state of world marine stocks since 1974 © FAO (2009)

trawling) and irresponsible fishing practices (e.g. improper quota size or illegal, unregulated and unreported fishing (IUU)) threaten potential natural carbon sinks, such as soft bottom ecosystems, and fish stocks, themselves (Perry et al. 2009, Wilson et al 2009).

Fisheries management methods need to consider climate change impacts and habitat destruction as added threats to marine populations in order to sustain healthier ecosystems, mitigate threats to the ocean, and ensure that ocean-dependent people are able to adapt to changes.


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Action Recommendations

Strengthen existing national and international management measures including those adopted through RFMOs by including climate change impacts on fisheries.

Incorporate fisheries management measures into other climate change mitigation and adaptation strategies, (e.g. enhance mathematical fisheries models with chemistry and temperature-driven climate change and acidification figures, based on species specific observational studies, to help determine appropriate harvest levels for many fisheries).

Establish and enforce fully protected reserves in all coastal and marine environments, including areas subject to national jurisdiction, along the continental shelf, in the deep sea, and on the high seas, that serve as refugia for fished and unfished populations and species.

Prevent the exploitation of new fishery development areas, such as those that may become available with continued polar ice melting in the Arctic, until effective regulatory regimes are in place.

End government fuel and boat subsidies and tax exemptions for the fishing sector in order to counter overexploitation of fisheries resources, destruction of marine ecosystems, and inefficient greenhouse gas emissions from the industry.

Fully implement the UNFSA and the FAO Code of Conduct for Responsible Fisheries and IPOAs.

Promote effective enforcement of international and national measures for responsible fisheries and develop sanctions or incentives that encourage "flag of non-compliance" states to adhere to them.

Implement ecosystem-based management of fisheries, set and enforce quotas and eliminate overfishing.

End illegal, unreported and unregulated fishing.

Minimize capture and discard of unwanted individuals (by-catch).

Ban destructive fishing techniques, including bottom trawling, that harm or are likely to harm vulnerable marine ecosystems, and implement gear restrictions.

Implement market traceability, catch documentation schemes and catch certification schemes.

Support market-driven sustainable and climate-proof practices in the seafood industry by increasing public awareness on the state of the ocean and educating food distributors and preparers on the importance of utilizing sustainably-caught fish and shellfish products.

Aquaculture

Capture fisheries can no longer support the world's demand for seafood. Aquaculture now supplies nearly half of the world's consumed fish and shellfish and is the fastest growing animal-based food source (FAO 2009). Since 1970, it has been growing faster than the human population, leading to more food being available for people (FAO 2009). However, the conversion of coastal ecosystems (most notably mangrove forests) into aquaculture facilities destroys naturally occurring carbon sinks (Laffoley & Grimsditch 2009) and exacerbates problems for coastal people associated with ocean change, such as increased flooding, intensity of storms, and sea level rise. This lack of natural barriers will also threaten the facilities themselves, possibly undermining food production strategies. Furthermore, pollutants (e.g., nutrients, drugs, invasive species) associated with aquaculture weaken coastal ecosystems, potentially lowering resilience to climate change. Finally, much of the feed used in aquaculture operations comes from capture fisheries, so these two sectors are connected to each other and to climate and ocean change.

Action Recommendations

Integrate aquaculture projects into broader land and coastal zone management and marine spatial planning strategies in order to support a holistic approach to coastal and offshore development.

Reduce the conversion of valuable coastal ecosystems to aquaculture facilities.

Only permit new facilities after thorough environmental impact assessments that determine the carrying capacity of the area under consideration and internalize the effects on the surrounding systems.

Manage facilities to minimize effluent pollution by applying food and drugs responsibly, supporting polyculture (e.g. raising plants and animals together), and in some cases actively filtering waste water.

Promote the use of native species in all aquaculture projects to prevent accidental introduction of alien, invasive species.

Support culture of herbivorous species over carnivorous species that require wild caught fish for food and therefore combine the negative impacts of aquaculture with those associated with capture fisheries into one food item.

Ensure that facilities take necessary steps to prevent escape of cultured individuals.

Marine Pollution

Marine pollution is a serious problem that affects all marine organisms and ecosystems, no matter how remote. Beaches on tiny islands in the middle of the Pacific thousands of kilometers from the nearest major population center can be covered with plastic. Tissues in marine mammals that live in the Arctic, far from any factories, contain some of the highest levels of industrial pollutants of any animals on the planet. People who rely on these beaches for income or animals for food suffer the consequences of decisions made far from them. Inuit mothers unknowingly feed their babies' breast milk containing toxic substances (Solomon & Weiss 2002). Fish eaters all over the world risk ingesting heavy metals.

To maintain the critical role of marine ecosystems and to improve their resiliency to climate change impacts, it is essential to actively reduce marine pollution. Marine pollution is not limited to garbage and toxic chemicals. The numerous pollutants that

affect the ocean can generally be divided into two groups: marine-based and land-based sources. Marine sources of pollution include garbage and sewage from ships, accidental fuel/cargo spillage and noise from ship travel. Species and disease introduction through cargo/ballast water is also of concern. Land-based sources account for approximately 80% of marine pollution globally (UNEP-GPA 2009) and are often a result of land-use practices. Land-based marine pollution originates from both point and non-point sources. Point sources include sewage systems and factories. Examples of non-point sources include agricultural, urban, and suburban water run-off and atmospheric deposition. Major pollutants include plastics, excess nutrients, pesticides and other harmful chemicals, oil and gas, untreated sewage, sediments, and heavy metals.

Most human activities, regardless of distance to the coast, have the potential to pollute marine environments and threaten the populations that rely on them. Physical and chemical pollutants, regardless of the source, weaken coastal and marine ecosystems and could potentially undermine climate change mitigation and adaptation strategies unless they are seriously considered in comprehensive management plans. Coastal and oceanic dead zones, plastic islands, and changes to marine food webs are among the numerous consequences of marine pollution. Finally, pollution acts in combination with climate change and other human activities to put coastal ecosystems and people at risk.

Action Recommendations

Reduce land-based sources:

Implement the Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities.

Manage agriculture, aquaculture, and forestry practices and promote sustainable food/wood production to prevent the flow of fertilizers, pesticides, and sediment into the marine environment.

Ensure the proper disposal, treatment and handling of garbage and sewage in both rural and urban communities.

Ensure that coastal and watershed development areas are equipped to properly dispose, treat, or handle the waste and sewage associated with their existence.

Replace harmful industrial and port operations with environmentally sound facilities, enforce environmental protection regulations and standards and apply strong management controls.

Carefully assess and locate future industrial development.

Reduce marine-based sources:

Strengthen, ratify, and enforce existing regulations regarding ship-based pollution, including MARPOL, the International Convention on the Control of Harmful Anti-fouling Systems on Ships, and the International Convention for the Control and Management of Ships' Ballast Water and Sediments.

Promote effective enforcement of international measures and develop sanctions or incentives that encourage "flag of non compliance" states to adhere to international measures to reduce marine pollution.

Eliminate the purposeful discharge of harmful physical or chemical contaminants.

Incorporate the newest technology and best practices to prevent or minimize accidental discharge of harmful physical or chemical contaminants or loss of cargo from ships.

De-contaminate and rehabilitate affected sites.

Develop policies that minimize ship-based and other industrial sources of noise.

Marine Nonrenewable Resource Extraction

In addition to the obvious pollution hazards associated with mining and drilling of marine nonrenewable resources discussed above, there are other direct physical ramifications of these activities. Dredging of deep-sea rocks or drilling for minerals, including sand and gravel or sub-floor oil and gas deposits, damages the sea floor and may alter important benthic habitats and ecosystems. Furthermore, the large organic and inorganic carbon sinks in the deep-sea could be disturbed by mining, dredging, or drilling.

Methane hydrates (pockets of methane gas contained in deep-sea sediments and ice) contain thousands of gigatons of carbon, on a similar order of magnitude as all of the world's known coal reserves (Milkov 2003). Given methane's potency as a greenhouse gas, the disturbance of these hydrates could have serious implications for the climate and for ocean chemistry (Forster et al. 2007). Without careful consideration of the consequences of marine mining, dredging, and drilling operations, these activities could release huge amounts of organic and inorganic carbon into the ocean and atmosphere and weaken deep-sea ecosystems, further diminishing resilience to climate change.

Action Recommendations

Support research into the effects of disturbing or mining methane hydrates and other inorganic carbon sinks.

Strengthen, ratify, and enforce existing regulations regarding seabed prospecting and nonrenewable resource extraction, both within and outside of areas under national jurisdiction, including the outer continental shelf, as well as in the seabed beyond national jurisdiction (the Area).

Promote enforcement of national and international measures to carefully manage non-renewable resource operations and develop sanctions or incentives that inhibit "flag of non compliance" states.

Take all necessary steps to prevent spillage of crude oil or release of natural gas to the atmosphere by non-renewable resources operations.

Ensure that effective regulatory regimes are in place to carefully manage the exploitation of newly emerging oil/gas/mineral grounds, such as those that will become available with continued polar ice melting in the Arctic.

Develop policies that minimize drilling/mining-based ocean noise.

PROMOTE AND INVEST IN ENVIRONMENTALLY SOUNDS MARINE RENEWABLE ENERGY PROJECTS

The ocean as a renewable energy source

The ocean's potential for renewable energy resources is vast. The ocean receives more than 70% of the Earth's available sunlight, and almost 90% of the world's wind energy occurs over the ocean (Czisch 2005). Today's commercially applied marine renewable energy resources include wind, wave and tidal energy. However, only a fraction of this theoretically available energy is currently technically and cost-effectively available (Schubert et al. 2006, Kempton et al. 2007) – marine-based renewable energy accounts for less than one percent of the global primary energy demand (IEA/OECD 2008).


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In order for the widespread implementation of renewable energy sources to be viable in the long-term, positive and negative environmental aspects must be recognized and managed. High-density installation of large numbers of ocean renewable energy systems could lead to negative environmental impacts that include considerable habitat changes, noise, seabed and shoreline disturbances, wildlife entanglement, invasive species and other effects such as underwater cables (Wilhelmsson et al. 2006, Spalding & de Fontaubert 2007). Additionally, the competing uses of coastal areas significantly reduce the potential of sustainably operating marine renewable energy devices. Positive effects associated with marine renewable technology include the creation of artificial habitats and fisheries closures, leading to areas which can potentially support local juvenile fish communities. This could better enhance fish stock management and support conservation interests (Langhamer & Wilhelmsson 2009). In some cases, smaller fishing vessels could continue to operate in and around offshore wind farms, so these structures could support local income and food availability.

Action Recommendations

Make informed decisions regarding the deployment of marine renewable energy projects and their likely impacts on the marine environment, based on life-cycle analyses, performance and cost of the marine energy extraction devices and strategic and environmental impact assessments that compare short versus long-term effects.

Use best available information regarding environmental impact assessments and apply guiding principles to ensure best private sector practices.

Design conflict resolution frameworks for marine renewable energy siting and development, including through marine spatial planning processes, to ensure that facilities are designed and located to minimize any adverse effects on marine ecosystems.

Facilitate the development of marine renewable energy resources through regional cooperation such as site and grid planning between nations, energy regulators, transmission system operators, and other relevant stakeholders.

Develop, promote and disseminate efficient regulatory frameworks for marine renewable energy installations to overcome development obstacles, minimize adverse impacts and support investments.

Support market deployment, by assuring guaranteed prices, creating incentives for early and large investments (e.g. feed-in tariffs or renewable energy payments), assuring an administrative infrastructure, and devising a competitive market framework that adequately internalizes any externalities.

Explore and provide viable sources of capital funding for ocean based renewable energy programs.

Encourage further research on the development of new technologies for the extraction of renewable energy from the oceans.

INCLUDE THE SHIPPING INDUSTRY IN CO_2 EMISSIONS REDUCTION STRATEGIES

Emissions from shipping

Ships contribute to and exacerbate both the greenhouse gas effect and ocean acidification by emitting CO_2, black carbon (BC) and nitrogen oxides (NOx) (Harrould-Kolieb 2008). The international shipping industry, together with domestic shipping and fishing, is responsible for more than 3.4% of all global emissions of CO_2 (IMO 2009). With estimated total emissions of 1.12 billion metric tons of CO_2, the global shipping industry, if it was its own state, would be the sixth largest producer of GHG emissions in the world (Harrould-Kolieb 2008).

Without explicit regulation of CO_2 emissions from this sector, global shipping emissions are forecasted to grow significantly over the coming decades (IMO 2009, UNCTAD 2009). Despite being the most efficient means of transporting goods and driving global trade, coastal and ocean shipping should be regulated with respect to CO_2 emissions.

Action Recommendations

Regulate CO_2 emissions generated by ocean shipping as part of the global effort to reduce the impacts of climate change and ocean acidification.

Implement technical and operational measures and management improvements, such as the IMO Ship Energy Efficiency Management Plan, that contribute both to abating ocean pollution and preventing atmospheric CO_2 emissions. Such improvements include speed restrictions, weather routing, fuel switching, specialized hull coatings, increased efficiency of logistics, improved fleet management and voyage planning.

Support and implement longer-term measures to reduce global warming, such as fuel and energy efficient design of new ships, engines created specifically for slow steaming or the use of sail or kite-assisted propulsion.

Create market-based incentives, as well as mandatory regulations for management plans and ship efficiency and design.

Expand existing regulations and promote technical measures which include a substitution of alternate fuel and the introduction of fuel efficiency measures.

Increase the availability and use of green energy resources to reduce direct emissions in port areas through connection to shore-based power grids.

Increase the industry's supply chain efficiency by improving in-port ship handling and implementing other efficiency strategies.

Increase local economic activity to reduce demand for large scale shipping of goods and associated CO_2 emissions.

Reducing the emissions from the fishing sector:

Eliminate inefficient fleet structures (e.g. excessive capacity, overfishing).

Include and develop less energy-intensive fishing technologies that use less fuel.

Combine reduced fuel strategies with fisheries management schemes; efficient fuel-use strategies should coincide with reducing fishing effort, safeguarding fish stocks and improving their resilience to climate change.

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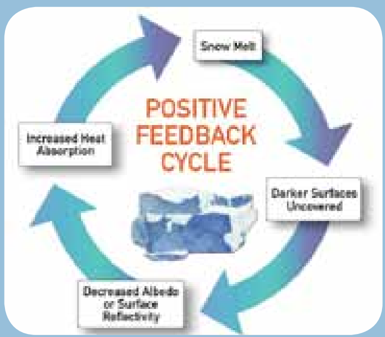
Black carbon and shipping

Ellycia Harrould-Kolieb - Oceana, USA

Black carbon (BC), commonly called soot, is made up of fine particles released by the incomplete combustion of fuel, such as oil or coal and contributes to the warming of the atmosphere: Firstly through direct absorption of heat in the atmosphere, and secondly by lowering the Earth's albedo, or reflectivity (Reddy & Boucher 2006). Unlike greenhouse gases, BC is a solid and warms by absorbing sunlight. Once deposited on snow or ice the darker particles can reduce the lighter surfaces' albedo (McConnell et al. 2007). Therefore less solar radiation is reflected back into space and is instead absorbed, thereby heating the Earth's surface.



Black carbon: Positive feedback cycle © Oceana

BC deposition has the ability to trigger positive feedback loops. As BC warms by absorbing sunlight it melts the snow or ice upon which it is deposited. As the ice melts, BC particles can become more concentrated on the surface, further reducing albedo and prompting more melt (Flanner et al. 2007). In addition, melting of snow and ice can uncover darker surfaces, such as water, vegetation or ground, resulting in further warming and melting (McConnell et al. 2007).

As a result, BC may be second only to carbon dioxide in terms of direct contribution to global warming (Chameides & Bergin 2002), with a warming effect as much as 55 percent of that of carbon dioxide (Ramanathan & Carmichael 2008). In fact, as much as 0.3-0.4°C of current global warming may be attributable to BC (Andreae & Gelencser 2006).

BC is not emitted uniformly around the globe, and since it is short-lived in the atmosphere, its impacts on the climate can vary spatially. Unfortunately, one quarter of all black carbon occurs in environmentally sensitive regions like the Arctic (Lack et al. 2008) where it has a unique ability to exacerbate warming. BC is likely responsible for 30 percent of Arctic warming (Zender 2007). This is particularly important since the Arctic is currently warming at twice the rate of the rest of the world (IPCC 2007a).

International shipping contributes about 133 thousand metric tons of BC to the atmosphere each year (Lack et al. 2008), approximately 1.7 percent of global anthropogenic BC emissions (Ramanathan & Carmichael 2008). BC from shipping can travel great distances and deposit on areas far from the initial emission source.

While preventing dangerous climate change and stopping ocean acidification requires massive reductions in global CO_2 emissions, the removal of black carbon can contribute to a significant reduction in warming since reductions in BC will result in almost immediate cooling (Ramanathan & Carmichael 2008). The elimination of all black carbon generated by fossil fuel use could reduce total global warming by 8-18 percent within 3-5 years (Jacobson 2002). Such reductions will also have important public health and air quality benefits. The ability to realize immediate cooling benefits from the reduction of black carbon emissions is an important step in our efforts to solve the climate crisis, and in particular save the Arctic; however, it should not be seen as an excuse to delay other important actions, most significantly the reduction of carbon dioxide emissions, which is critical.

Further Reading:

Chameides, W. & Bergin, M. (2002) Soot Takes Center Stage, Science 297:2214

Lack, D. et al. (2008) Light Absorbing Carbon Emissions from Commercial Shipping, Geophysical Research Letters, 35:L13815

Ramanathan, V. & Carmichael, G. (2008) Global and Regional Climate Changes due to Black Carbon, Nature Geoscience, Advanced online publication.

APPROACH CARBON CAPTURE AND STORAGE WITH EXTREM CAUTION

Carbon Capture & Storage

CSome consider Carbon Capture and Storage (CCS) to be one of the critical technologies in the worldwide portfolio of mitigation actions for the stabilization of CO_2 concentrations (Scottish Center for Carbon Storage 2009). CCS is a process that separates CO_2 from industrial and energy-related sources, transports it to a permanent storage location and isolates it from the atmosphere (IPCC 2005, Schubert et al. 2006). Its use, however, is contentious. Possible impacts on marine biodiversity may be severe and have not been fully evaluated. This lack of sufficient data should be a determining factor in the selection of specific CCS methods and sites.

The ocean may be an unsafe place to intentionally store carbon. Due to the fast outgassing and interchange of the ocean with the atmosphere, sequestration of CO2 in the water column is not viable. Injection into the deep sea could ensure a longer residence of the carbon in the sea (IPCC 2005), but could disrupt deep-sea chemistry and harm adjacent marine environments and organisms (Ishimatsu et al. 2006, Lal 2008, Yamada et al. 2008).

Another option involves injecting CO_2 into geological formations such as saline aquifers hundreds of meters below the sea floor. This method theoretically isolates it from the atmosphere and sensitive biological systems.

The uncertainties regarding the environmental sustainability of sequestration include the risk of accidents during transportation and the potential risk of slow escape of stored CO_2 and its direct impacts on marine ecosystems. The choice of geological reservoir (for example choosing strata below sealed caprock) plays an important role in reducing the risk of escaping CO_2. Potential impacts are dependent on the amount of escaping CO_2 and its dilution (Blackford et al 2009). Elevated CO_2 in benthic systems could cause high rates of mortality in sediment dwelling organisms (Barry et al. 2004) and, if leakage should occur, have harmful consequences for local coastal and shelf communities (Widdicombe & Needham 2007, Blackford et al. 2009).

The 1972 London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter and its London Protocol require more comprehensive rules governing sequestration activities. Caution should prevail at both the regional and national level in regard to the implementation of CCS projects. Discussions under the UNFCCC on the accounting of CCS under the Clean Development Mechanism (CDM) should be carefully undertaken.

The potential benefits and negative consequences of sequestration technologies need to be evaluated vis-à-vis other mitigation strategies such as improving energy efficiency and increasing the use of renewable energy sources. CO_2 sequestration should not be thought of as an alternative for, but rather as a complement to, more sustainable emissions reduction strategies. Intensive utilization of renewable energy resources, energy efficiency strategies and an overall reduction in the use of energy are the preferred climate change mitigation strategies. Before CCS projects are allowed to proceed, it is critical to consider all possible benefits and limitations and employ great caution, consistent with the precautionary approach, to ensure that the benefits outweigh the costs.

Action Recommendations

Refrain from direct injections of CO_2 into the water column or the deep-sea as this will change the physical and chemical characteristics of the seawater and will impact the adjacent marine ecosystems and organisms.

Refrain from setting investment incentives that could divert investment from the development and deployment of other more environmentally friendly and less risky mitigation strategies.

Increase incentives and support the deployment of more sustainable emission reduction strategies such as renewable energy sources and energy efficiency standards.

Include the real abatement costs for CCS in analyses/assessments, including monitoring and surveillance costs as well as the opportunity costs of failing to invest in energy efficiency and renewable energy options.

Adopt effective measures and regulations on global, regional and national scales to ensure that potential risks of CCS schemes have been carefully considered in advance and, if allowed to proceed, are subject to permits based on prior environmental impact assessments, advance notification and consultation and use of independent scientific reviews (e.g. CCS permit, requirement to use best available techniques).

Ensure that CCS risks posed to ocean ecosystems do not outweigh any potential climate mitigation benefit and include the following indicators in environmental risk assessments: the probability of CO_2 escape; the extent of chemical perturbation relating to any given scenario; and the impacts of the resulting chemical perturbation, which can be measured by ecological, economic, or social criteria.

If CCS projects are allowed to proceed, reduce the risks to the marine environment by siting CCS in areas that are not determined to be ecologically sensitive.

Require continuous monitoring, reporting and inspection of CCS sites to prevent and address leakage issues and to plan a course of action for the post-closure period.

Update and regularly review CCS regulations and requirements.

Address the issue of purity of any CO_2 streams in advance to ensure that they are not mixed with other materials that may also be harmful to the marine environment.

APPROACH LARGE-SCALE OCEAN FERTILIZATION ACTIVITIES WITH EXTREME CAUTION

Ocean fertilization

Ocean fertilization is another method proposed for sequestering CO_2 in the oceans. Ocean fertilization seeks to stimulate net phytoplankton growth by adding (or pumping) nutrients such as iron into the ocean surface. It is hypothesized that dying plankton will then sink and become trapped in sediments on the seabed (Smetacek & Naqvi 2008). However, there are many questions regarding this process and the legitimacy of sequestering carbon in this manner (Lampitt et al. 2008, Zeebe & Archer 2005).

Ocean fertilization requires a solid scientific basis prior to its large-scale use. Currently, information about sequestration potential and environmental impacts is limited, but the negative consequences could be significant (De Baar et al. 2008). Potential impacts include increased emissions of biogenic gases to the atmosphere, decreased oxygen content of the underlying waters, and alteration to the living marine community - from microbes to megafauna – leading to significant alterations in the structure and function of marine ecosystems and the marine food web (Cullen & Boyd 2008, IUCN 2009).

Researchers have undertaken several experiments in the open ocean to test the validity of ocean fertilization. Overall, sequestration efficiencies from artificial iron fertilizations have been relatively low (ACECRC 2008). The latest findings from the Southern Ocean demonstrate this transfer of CO_2 from the atmosphere to the ocean to be less efficient than originally predicted. In this most recent study, only modest amounts of CO_2 sank out of the surface layer by the end of the experiment (AWI 2009).

Some investors consider ocean fertilization to be suitable for the carbon trading market. However, there is currently no way to measure or verify sequestration; thus carbon credits should not be available for this activity. Commercial interests in funding the scientific research may bias the reported outcomes and influence the voluntary carbon market. The sale of carbon offsets for such research is premature.

Under general principles of international law, states have the obligation to 'protect and preserve the marine environment' (UNCLOS). Parties to the Convention on Biological Diversity as well as the London Convention and Protocol have called for a prohibition on ocean fertilization activities until there is a sufficient scientific basis on which to justify such activities (CBD Decision IX16, Resolution LC-LP.1 2008). Parties to the London Convention and Protocol are currently developing guidelines to assess research proposals to ensure that "legitimate scientific research" projects proceed in an environmentally acceptable fashion. The Kyoto Protocol to the UNFCCC requests parties to protect and enhance carbon sinks and reservoirs, and to research, promote, develop and increase the use of sequestration technologies. Though marine ecosystems are not specifically mentioned, the obligation under the UNFCCC to minimize adverse effects of mitigation projects on the environment – including the ocean (Art. 4) – should not be undermined.

Action Recommendations

Prohibit large-scale ocean fertilization activities until there is a sufficient scientific basis on which to justify such activities, and ensure that all research projects comply with the assessment framework under development by Parties to the London Convention and Protocol.

Refrain from selling or offering carbon credits or offsets (or other related instruments of financial value) for ocean fertilization or other geo-engineering projects unless and until their safety, long-term effectiveness and net environmental benefits have been established.

Fill the knowledge gaps of potential environmental impacts of ocean fertilization.

Develop and implement a transparent and effective regulatory mechanism for geo-engineering related research activities to ensure that research activities are subject to appropriate control and consultation.

Approach all geo-engineering schemes with extreme caution and do not allow them to proceed before their safety, long-term effectiveness and net environmental benefits have been established.

4. Action Recommendations for Ecosystem-based Adaptation

Coral reefs build extensive ramparts made of calcium carbonate which act as barriers to the power of oceanic waves. Without coral reefs, other natural ecosystems such as mangroves and sea grass meadows, as well as human infrastructure lying in coastal regions, becomes vulnerable to ocean waves. (Coral reefs on the southern Great Barrier Reef)

While mitigation is absolutely essential to avoid long-term future climate change and ocean acidification, their impacts are already seen and felt by humans and natural ecosystems in many regions of the world. Even with the most far-reaching mitigation strategies, climate change impacts will continue to become more pronounced for decades to come (Ramanathan and Feng 2009). Therefore, it is necessary to adapt to current and future climate change in order to minimize impacts and increase resilience in both human societies and natural ecosystems. Adaptation has become an indispensable complement to emission reduction and other climate change mitigation strategies.

USE EbA TO HELP PEOPLE ADAPT TO CLIMATE CHANGE

What is Ecosystem-based Adaptation?

Ecosystem-based Adaptation (EbA) is the sustainable management, conservation and restoration of ecosystems in order to assure the continued provision of vital services that help people adapt to the adverse effects of climate change[2]. EbA complements general adaptation portfolios by using biodiversity and ecosystem services in a variety of local, national and regional climate change adaptation projects and programs.

EbA increases ecosystem resilience to reduce human vulnerability in the face of climate change and can be applied specifically to coastal and marine ecosystems to ensure that they are able to continue to provide vital services on which people rely. Coastal environments, such as mangrove forests and coral reefs, play a crucial role in protecting the shoreline from flooding, erosion and other impacts of extreme weather events. Well-functioning marine and coastal ecosystems provide resources for subsistence and commercial fishing, purify water and air, attract tourists, and provide cultural inspiration. The conservation of healthy ecosystems and the restoration of degraded systems are key elements of EbA (see detailed recommendations below).

EbA strategies can be more cost-effective than hard infrastructures and engineering solutions and are often more easily accessible to the rural poor (Sudmeier-Rieux & Ash 2009). EbA uses natural capital as well as traditional and local knowledge to assist communities in their climate change adaptation efforts, while simultaneously achieving development objectives and reducing disaster risk (Hale et al. 2009). By implementing EbA, policy makers can enhance the protection of communities by supporting the conservation and sustainable use of biodiversity, natural resources, and ecosystem services. Healthy, well-managed ecosystems provide an opportunity to better mitigate many of the negative effects of climate change and non-climate human activities and natural threats.

Furhermore, EbA can reinforce climate change mitigation actions by conserving or enhancing marine carbon stocks and reducing emissions from ecosystem degradation and loss. As mentioned in the previous section on mitigation, healthy, well-functioning ecosystems support both climate change mitigation and adaptation strategies (see section on 'Significantly reduce other human stressors', page 32). For marine ecosystems to continue providing key services and maintain resiliency, it is essential that other human induced stressors, such as unsustainable fisheries and pollution, are significantly reduced.

In the face of continuing ocean change, EbA uses natural assets to enhance societies' adaptive capacity and prepare for future (sometimes unpredictable) alterations to their surroundings. EbA projects and programs have to incorporate potential trade-offs between the management of one service at the expense of another. Given limits to human and financial resources, EbA programs should be subject to vulnerability and risk assessments, scenario planning and adaptive management approaches to ensure that the best projects and programs are implemented.

[2] *This definition draws from and is consistent with: Connecting Biodiversity and Climate Change Mitigation and Adaptation - Report of the Second Ad Hoc Technical Expert Group on Biodiversity and Climate Change under the Convention on Biological Diversity (CBD).*

Action Recommendations

Maintain and restore key marine and coastal ecosystems to support the continued provision of critical ecosystem services and to reduce social and economic vulnerabilities of human communities.

Enhance the sustainable use and management of natural resources as a food and income source in order to reduce human vulnerability to climate change.

Integrate the full suite of EbA actions into poverty reduction and sustainable development plans and strategies, where appropriate.

Increase ecosystem resilience and ensure continued provision of ecosystem services by reducing other human stressors on the marine environment, such as pollution, destructive fishing practices, habitat destruction and unsustainable coastal development (see page 32).

Utilize, strengthen and adjust existing marine and coastal management tools and activities, such as the integrated coastal management approach, in order to integrate them with adaptation strategies, including EbA.

Identify priority areas for protection, restoration, and management by using regional marine assessments, spatial mapping tools and other visualization tools to understand the distributions of marine ecosystems, habitats, species, and human uses.

Protect natural buffers (see MPA section page 50) and plan for inward migration of coastal ecosystems such as mangroves or wetlands.

Integrate climate change impact predictions into new development activities.

Eliminate subsidies and other incentives for unsustainable coastal and marine development projects and replace them with economic rewards for projects that undertake EbA or apply the Ecosystem Approach to development.

Address fragmented or overlapping governance structures by creating formal liaison positions between climate change and marine experts and regulative bodies, for example.

Support and expand education and training programs that develop sustainable, alternative livelihoods for individuals currently involved in environmentally harmful activities that compound the effects of climate change.

Incorporate local and indigenous knowledge into the design and implementation of EbA strategies.

CONDUCT VULNERABILITY ASSESSMENTS

Prioritizing implementation actions

A community's or ecosystem's vulnerability to climate change can be described as a combination of its exposure and sensitivity to negative impacts and its adaptive capacity (IPCC 2007, Marshall et al. 2009). EbA can enhance resilience and reduce vulnerability by limiting exposure and building adaptive capacity. Furthermore, the complex interconnectedness and buffering capacity associated with EbA can lead to healthier marine ecosystems that reduce sensitivity to the pressures of climate change, continue to provide a buffer against changes to sea level and storm intensity, and provide multiple ecosystem services to surrounding communities. Vulnerability assessments are an important first step in designing adaptation strategies because they help policy makers and resource managers determine the areas of highest priority for early action (Marshall et al. 2009). Given the limited nature of human, financial, and natural resources, it is imperative that vulnerability assessments are used to provide contextual information for the management of climate change impacts and the development and testing of adaptation plans.

Action Recommendations

Conduct vulnerability assessments to obtain information regarding the relative magnitude of social and environmental costs of climate change.

Develop EbA plans with properly targeted scenarios and strategies, prepare for adaptive management responses and include them into overall adaptation strategy.

Test, evaluate and exchange best practices of sustainable management, conservation and restoration practices.

Assess the resilience and vulnerability of coastal and marine ecosystems using new and existing assessment tools such as rapid assessment protocols for coral reefs and other systems.

Identify priority areas for conservation, restoration, and adaptive management that show evidence for long-term success.

INCLUDE EbA STRATEGIES INTO RISK MANAGEMENT PLANS

Using ecosystems as natural risk reduction mechanisms

Risk management, including risk assessment and analysis, is the process of identifying potential risks associated with climate change and managing environmental, socioeconomic, and institutional resources in an effort to reduce the impacts and likelihood of occurrence of these risks. Successful risk management plans should incorporate ecosystem-based disaster risk reduction strategies, which manage and conserve coastal and marine ecosystems (Sudmeier-Rieux & Ash 2009). For example, well-managed coastal ecosystems (e.g. mangrove forests) act as a natural barrier to climate change impacts (e.g. extreme weather events such as sea-level rise, storms and flooding).

Action Recommendations

Reduce human vulnerability to climate change by maintaining and restoring natural infrastructures, such as mangrove forests, coral reefs and sand dunes, which can provide cost-effective natural protection for humans and ecosystems.

Enhance the capacity of ecosystems to act as natural risk reduction mechanisms by reducing other human stressors and protecting natural buffers.

Eliminate subsidized insurance and other benefits for development projects that alter natural systems to an extent that increases risk.

Institute a permitting process and a development code (with required environmental impact assessments) that take into account expected hazards associated with climate change (e.g. increasing storm intensity, rising sea levels, and periodic flooding).

Introduce benefits (e.g. subsidies) for development projects that utilize ecosystem-based coastal protection measures.

Establish national and regional committees that link climate change adaptation with disaster risk reduction plans and incorporate ecosystem-based disaster risk reduction strategies.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DEVELOP ADEQUATE FINANCIAL SUPPORT FOR EbA

Funding EbA

EbA is an efficient way to protect vulnerable communities and ensure that natural marine systems continue to provide numerous services. It can also be more cost-effective than large infrastructure development because it supports long-term solutions, avoids mal-adaptation and builds on the capacity of local people. In that regard, financial resources for EbA should be developed at adequate, sustainable levels in order to provide predictable, long-term solutions for vulnerable people.

Action Recommendations

Adequately fund EbA strategies through predictable, stable funding sources that support local people.

Manage climate related socioeconomic issues with traditional development goals to ensure that both can be achieved without competing for limited human and financial resources.

Develop ocean communication strategies and guidelines in order to encourage funding institutions to support marine and coastal projects.

Design new, creative funding opportunities that benefit managers who utilize a complete, holistic approach to climate change adaptation.

Commit a portion of natural resource development taxes/permit fees to fund EbA projects.

Use funds for ecosystem restoration projects instead of shoreline alteration.

Introduce appropriate ecosystems service user fees (see page 56).

Integrate EbA strategies, where relevant, into the policies of regional and international development banks to ensure adequate implementation and funding of EbA.

Coastal ecosystems as natural infrastructure

Imen Meliane, The Nature Conservancy, USA
Mark Spalding, The Ocean Foundation, USA

Sea-level rise is likely to become one of the major impacts of climate change over the coming century. It will cause gradual inundation of lowlands; increased rates of erosion in many areas, even of higher elevation shores; and the salinization of ground-water in many coastal and small island territories. With a likely increased frequency and intensity of storm events linked to warmer oceanic waters, the threat of impacts from storm surges will be considerably increased in many areas. Altered patterns of precipitation inland will further influence coastal dynamics through changes in estuarine flows and sediment delivery. The costs of these hazards to human communities are increasing as coastal development continues and natural buffers, such as coastal wetlands and dunes, are lost.

Many strategies to protect coastlines from sea-level rise involve hard engineering, including the building of costly sea walls and flood barriers. Such artificial coastal defences may not offer the most cost-effective solution in adapting to sea-level rise and inundation: they are costly to build and maintain; they will have a limited life-span given accelerating rates of change; they often degrade or destroy natural ecosystems and in so doing also reduce concomitant benefits of other ecosystem services.

By contrast there are growing and powerful arguments for the appropriate use of natural ecosystem structures as a form of soft engineering. In some cases natural vertical accretion may enable such ecosystems to keep pace with rising sea levels, thereby maintaining current coastlines. Saltmarshes and mangroves offer excellent examples of natural ecosystems which are able to baffle water movements and bind sediments into the soil. Even away from vegetated shores, natural coastal flows can support the redistribution of sediments allowing barrier islands, beaches and deltas to grow in the face of minor increases in sea level. Where or when rates of change are too great for natural adaptation, active accretion still occurs, and, combined with natural and uninhibited realignment of the coast into adjacent terrestrial habitats, may still offer a cost-effective response to rising seas. Natural systems may still slow the rate of loss compared with adjacent managed coastlines.

Certain coastal ecosystems also offer a powerful buffer during extreme storm events, greatly mitigating storm surge and flood impacts and reducing costs of recovery in adjacent lands. Across the globe, there are numerous examples of the important role that eco¬systems such as mangroves, wetlands, shellfish reefs, and coral reefs play in dissipating wave energy. The analyses of recent disasters, such as the December 2004 Indian Ocean tsunami, demonstrate the importance of habitat protection and natural resource management in de¬creasing vulnerability to extreme events. Mangrove restoration in Vietnam has been shown to attenuate wave height and thus reduce wave damage and erosion. In Malaysia, the value of intact mangrove swamps for storm protection and flood control has been estimated at US $300,000 per kilometer, which is the cost of replacing them with rock walls.

The benefits provided by maintaining and restoring costal ecosystems for shoreline protection stand alongside the continued supply of other critical ecosystem services such as fisheries. In many cases the beneficiaries of these ecosystem services are among the socially or economically vulnerable, and the societal benefits from maintaining or improving food security are at least as important as the direct benefits of coastal protection.

CREATE COMPREHENSIVE NETWORKS OF MARINE PROTECTED AREAS (MPAs)


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Increasing ecosystem resilience

To date less than one percent of the ocean is protected (Wood et al. 2008). The creation of Coastal and Marine Protected Areas (MPAs) is one of the tools used to enhance and support natural and social adaptation while restoring and protecting ocean life. MPAs help buffer climate change impacts and increase ecosystem resilience (Smith et al. 2009). There are many different MPA models that vary in size, location, connectivity, and level of protection (Dudley 2008), but in general, the areas with the greatest enforcement and least human activity are also the most resilient to climate change (IUCN-WCPA 2008). By protecting entire ecosystems and all the species within them, MPAs ensure that the systems continue to act naturally and provide services, including natural carbon storage, clean water, and food, to the surrounding environment and people (IUCN-WCPA 2008).

Action Recommendations

Significantly increase the size and number of fully protected areas to allow ecosystems to recover their full suite of services.

Increase effectiveness of existing MPAs and ensure proper implementation of new MPAs.

Develop management plans for multiple-use areas that increase the resilience of impacted marine and coastal ecosystems and maintain areas that have not yet been adversely affected.

Protect multiple replicates of marine habitats/ecosystems to prevent biodiversity from being lost as a result of isolated disturbances.

Encourage connectivity synergies between coastal and marine ecosystems by protecting ecological corridors such as those connecting mangrove forests, seagrass beds, and coral reefs.

Establish "Predictive Protected Areas," which provide some level of protection for areas expected to be future refugia and areas that have demonstrated some resilience to the effects of climate change.

Create limited-use buffer zones for transitions between fully protected and open access areas.

Develop and implement new, creative enforcement mechanisms, e.g. locally empowered enforcement processes.

Incorporate a wide range of stakeholders into MPA design, implementation, and enforcement to ensure ownership and commitment to the projected outcomes of the product.

RESTORE FRAGMENTED OR DEGRADED ECOSYSTEMS, AND REESTABLISH CRITICAL PROCESSES

Maintaining ecosystem services

Restoration of marine ecosystems is often necessary to help an area recover from overuse, environmental degradation, or habitat alteration. While sound management and protection of natural resources are preferred (and often more cost effective), restoration is an additional tool that can be applied to ecologically and economically important areas, ecosystems that exhibit some resilience to climate change impacts, and areas of potential future refugia. Furthermore, active restoration of coastal and marine ecosystems can help support subsistence and commercial fisheries and tourism operations that provide vital income to coastal people. Community-based restoration efforts demonstrate the effectiveness of incorporating local people into restoration efforts as well as other adaptation strategies (Pender 2008, NOAA Fisheries 2009, TNC 2009). Finally, in regions where aquaculture and coastal development have led to destruction of natural shoreline protection, restoration efforts offer a quick and relatively inexpensive alternative to large-scale environmental control projects or natural recovery.

Action Recommendations

Undertake marine ecosystem restoration projects (e.g. seeding, transplanting, or assisting colonization of coastal and marine plants, eliminating invasive species, demolishing unnecessary or unused structures, etc.) where appropriate.

Develop and strengthen community-based restoration programs.

Include sustainable use of ecosystem services as part of the design, implementation and management of restoration projects and sites.

Significantly reduce anthropogenic stressors (e.g. coastal development, pollution, destructive fishing practices) that undermine restoration projects and prohibit accomplishment of the missions of these projects.

STRENGHTEN EXISTING AND DEVELOP NEW, LONG-TERM MONITORING AND RESEARCH PROGRAMS

Ensuring long-term adaptive management

In order to implement successful adaptation strategies, including EbA strategies, it is vital to operate a monitoring and research program. Conducting vulnerability assessments, determining system resilience, quantifying risk, and locating future refugia all require extensive data collection and analysis, which a well-established monitoring program can provide. Furthermore, following design and implementation of EbA strategies, continual monitoring of outputs and developments ensures that successes happen early and often and allows for strengthening and revision of adaptive management and sustainable development strategies.

Enhanced knowledge of the physical, biological, and social sciences behind EbA is a critical component of proactive management. Continual support of both pure and applied science (e.g. climate science, oceanography, conservation biology, energy technology, computer science) will lead to accurate, confident predictions of the behavior of the atmosphere, the ocean, and coastal ecosystems with ongoing greenhouse gas emissions. These predictions allow for swift, precise actions that deal with specific problems and provide tangible solutions. Gaps in current understanding of atmosphere-ocean interactions, sea ice-seawater dynamics, and ocean biogeochemistry (e.g. acidification) need to be filled, and public and private research institutions are already working on these issues. Finally, scientific and socioeconomic research has the potential to develop new and creative ways to adapt to the changing climate.

Action Recommendations

Design and implement socioeconomic monitoring programs that identify potential risks or hazards for coastal people.

Incorporate climate change resilience and adaptation into existing environmental monitoring projects.

Ensure long-term monitoring to allow for adaptive management actions, e.g. for MPAs and restoration measures.

Build the capacity of local and regional monitoring programs by providing adequate human and financial resources.

Make continual environmental and socioeconomic monitoring a top priority for international development agencies and banks.

Design monitoring programs that not only help prepare officials for future actions, but also evaluate ongoing actions.

Determine top research priorities and support the most appropriate existing institutions in their implementation.

Create new centers, when necessary, to address specific problems by attracting the top people and providing state of the art technologies and facilities.

Incorporate research findings into updated national and international climate change adaptation strategies.

Support local and regional scientific institutions so that low-resolution global findings can be applied to local and regional stakeholders.

5. Action Recommendations for Cross-Cutting Issues

CAPTURE THE ECONOMIC VALUE OF ECOSYSTEM SERVICES

The costs of policy inaction

Several studies have highlighted that the economic damage resulting from future climate change will be much higher than the costs for current climate change mitigation and adaptation actions. The Stern Report states, for example, that the concentration of greenhouse gas emissions at a level of 550ppm would cost around 2% of global GDP (Jowit & Wintour 2008). A Yale University study concludes that climate change without intervention will be on the order of 2.5% of world output (Nordhaus, 2008). Another study, which focuses on the cost of policy inaction with regard to biodiversity loss, predicts that by 2050 the world is expected to have lost ecosystem services in a business-as-usual scenario worth around 7% of world GDP (Braat and Brink 2008). This report stresses climate change as one of the drivers responsible for the worldwide loss of biodiversity. The impacts of ocean acidification and the associated economic losses will increase the overall costs of CO_2 emissions (Held 2009).

Although it is extremely difficult to present exact economic numbers on the costs of inaction, they will be substantial. Many reports outline the value that ocean economic activities (e.g. tourism and recreation, transportation, living and mineral resource extractions; CI 2008) contribute to both national economies and foreign exchange receipts, government tax revenues and employment (OECD 2008, Emerton & Pabon-Zamora 2009). In the U.S., for example, the ocean economy is responsible for the creation of over 2.3 million jobs and contributes over $138 billion to the nation's GDP (Kildow et al. 2009). The fisheries sector, as one of the various ocean economic activities in Cambodia, the Maldives and Kiribati, contributes more than 10% to each of those countries' national GDPs (OECD 2008).

Examples from U.S. fisheries indicate that ocean acidification will most likely have severe socio-economic consequences; revenues will decrease considerably, jobs will be lost and indirect economic costs will occur (Cooley & Doney 2009). The U.S. fishing industry supports nearly 70,000 employees and generates up to $35 billion per year (NOAA Fisheries Office of Science and Technology). However, this industry relies on natural resources, which will be heavily impacted by ocean acidification and climate change, and is therefore likely to suffer significantly. For example, ocean acidification is exacerbating problems associated with the oyster fishery. Eighty-five percent of oyster reefs around the world have already been lost to coastal development, destructive fishing practices and other harmful activities (Beck et al. 2009).

Avoiding the future costs of inaction projected in business-as-usual scenarios and investing in mitigation and adaptation actions brings other benefits. The advantages of reducing coastal habitat destruction include protection of biodiversity, livelihoods security for local and indigenous people, research and development possibilities and coastal protection from extreme weather events.

The need for ecosystem valuation

The valuation of current activities directly contributing to the ocean economy only reflects part of the economic picture. Some values, such as shoreline protection, recreation, and aesthetics, are less tangible in monetary terms. Despite the role of coastal and marine ecosystems in supporting economic development and social welfare, particularly in developing countries, current analysis of market activity does not consider all of these contributing factors (Kildow et al. 2009). Ecosystem services with life supporting roles include coastal buffer zones, such as mangroves and coral reefs, that help reduce coastal communities' vulnerability to storm surges or extreme weather events, control beach erosion, provide healthy habitats for fish stocks, and offer carbon storage potential. The exploitation and degradation of these unique services and resources impose real social costs, which need to be considered. Several studies have estimated the value of these services .

Economic valuation is playing an important role for policy makers, private corporations and international institutions that undertake investments in sustainable management, conservation and protection of ecosystem services (Evans 2009). However, indirect ecosystem services do not send price signals to markets and are therefore often not addressed in policy and business decisions that affect how ocean resources and services are used or misused. While some of the value of intact ecosystems can be captured by the markets, the loss of entire ecosystems due to climate change and other impacts is difficult to unambiguously and wholly calculate in economic terms.

Focusing solely on economic estimates greatly underestimates the urgency for reducing GHG emissions and conserving ecosystems (Vergara et al. 2009). When financing and implementing climate change mitigation and adaptation strategies, it is important to understand and demonstrate the dependence of world economies on healthy ecosystems, both in terms of their market and non-market values, and what is at risk if those ecosystems continue to degrade or are lost permanently.

Governments cannot afford to ignore proper management and conservation strategies or overlook nature-based solutions for climate change mitigation and adaptation strategies. Investments in the management, conservation and protection of ecosystems and their services will not only help to build social resilience to climate change but will provide vast development returns by reducing poverty, strengthening livelihoods and supporting sustainable economic growth. Investments in risk reduction strategies are within the commercial interests of private landowners and the tourism and insurance industries. Furthermore, projected additional impacts of climate change on fish populations should serve to warn the fisheries sector of the risk to the industry and the importance of conserving current stocks. For example, only one year after the establishment of the Kulape-Batu-Batu marine sanctuary in the Philippine Tawi-Tawi province, fishing incomes increased by approximately 20% (IUCN 2009a). Protecting the ocean from climate change and other threats returns high dividends.

Payment for Ecosystem Services (PES)

Winnie Lau, Marine Ecosystem Services (MARES) Program, Forest Trends

PES and other market-based strategies provide a mechanism for capturing some of the value well-functioning ecosystems provide, and thereby, aid in their protection. Healthy marine ecosystems play a crucial role in ensuring human well-being; however, they are inadequately protected—partly due to lack of policy and political will and partly due to lack of financial incentives and sufficient financing. While ecosystem valuation informs policy development and can generate political and financial incentives, PES operationalizes the valuation efforts and delivers innovative and sustainable financing sources to the conservation arena. Because ecosystem service payments are conditional on continual service delivery, PES systems directly connect users (buyers) with the stewards (sellers) of the service, avoiding the disconnects that often undermine conventional coastal and marine management. The PES transaction is at once financing and awareness-raising, which can help generate further political will for marine conservation.

PES can be a cost-effective mechanism for implementing the mitigation and adaptation strategies needed to minimize climate change impacts on the oceans. Payments for marine ecosystem services that focus on protecting coastal water quality, marine biodiversity, coastlines and beaches, and fish nurseries, for example, can help reduce those stressors, such as pollution, overfishing, and habitat destruction, that compound the impacts of climate change, and increase the resilience of marine ecosystems. Mangroves and sea grass beds are also emerging as potential marine carbon sinks whose value can be captured in the fledgling carbon markets and whose conservation will contribute to mitigation strategies. More often than terrestrial ecosystems, marine ecosystems have the potential to deliver multiple environmental services in a bundle, thereby providing multiple opportunities to capture some of the value as well as to generate private sector funding such as through the fisheries, tourism, and insurance industries.

There is no doubt that some of nature's worth can never be captured in economic terms. Nonetheless, PES and other market-based mechanisms can be powerful tools for capturing those values that can be quantified, and bring much needed new and sustainable sources of funding to marine conservation, freeing up traditional conservation funds to safeguard those ecosystems, their services and the associated communities that are invaluable and cannot be captured by markets.

Further reading:

MA (Millennium Ecosystem Assessment) (2005) Ecosystems and Human Well-being: Synthesis. Island Press, Washington.

Worm, B., et al. (2006) Impacts of Biodiversity Loss on Ocean Ecosystem Services. Science 314, 787-790.

Forest Trends (2008) Payments for Ecosystem Services: Getting Started. A Primer. http://www.katoombagroup.org/~katoomba/documents/publications/GettingStarted.pdf

Engel, S. et al. (2008) Designing payments for environmental services in theory and practice: An overview of the issues. Ecological Economics 65, 663-674.

Action Recommendations

Internalize environmental externalities (e.g. through Payments for Environmental Services (PES) schemes that levy water fees on industries to reduce unsustainable water consumption, rebates for cleaner waste water treatment processing, or entry fees for marine protected areas).

Remove perverse incentives and price controls which undervalue ecosystems and their functions and contribute to their degradation, and move toward achieving appropriate stewardship of ocean services and resources.

Ensure sufficient financing and incentives for nature conservation by balancing and accounting for the total cost of management (e.g. enforcement, monitoring, and adaptive management) and the opportunity costs (e.g. economic alternatives).

Broaden the range of models and scenarios to assess the value of ecosystems and biodiversity across all their services.

Value ecosystem services with respect to their initial state.

Increase dialogue and collaboration amongst economists and natural scientists to provide more accurate policy-relevant valuation of ecosystem services.

Increase environmental training of local economists to carry out economic valuation studies.

Use a participatory approach that includes stakeholders and local coastal communities in consultation processes to ensure long-term benefits from coastal and marine services (e.g. revenues from protected areas).

Use valuation of ecosystems as a way to analyze conflicting goals and trade-offs but include a combination of other social and environmental qualitative and quantitative information.

REDUCE CLIMATE CHANGE IMPACTS ON HUMAN HEALTH

Direct health risks associated with climate change

Direct detrimental impacts on human health arise through extreme weather events, such as storm surges, heavy rainfall, flooding, and severe winds. These events often result in significant damage and mortality and can cause an overall decrease in public health through increased poverty and the loss of housing, hospitals, and public sanitation systems (Fenical et al. 1999). Furthermore, rising sea levels and more severe storm surges will lead to salt water intrusion into freshwater systems on land, which may significantly reduce the quality and availability of drinking water.

Ocean-derived pathogens: Harmful Algal Blooms

Harmful algal blooms (HABs) are excessively growing aggregations of phytoplankton in aquatic environments, which cause illness or death if consumed by humans and other organisms and adversely affect the local ecosystems (Kite-Powell et al. 2008, Moore et al. 2008). Primary health risks to humans occur through exposure to the toxins produced by HABs by contact with contaminated water, eating contaminated seafood or by inhaling contaminated aerosols (Lopez 2008). Worldwide each year, more than 60,000 cases of HAB illness incidents are reported, and the overall mortality rate is 1.5% (Van Dolah, 2000). HABs also affect local and national economies. In the U.S. the annual economic costs for public health effects from HABs have been estimated to be at least $20 million (Kite-Powell et al. 2008). Economic consequences include fish mortality, decreased demand for fish products, habitat loss and alterations to recreation and tourism (Hoagland et al. 2002).

The direct impacts of climate change on the ecology of HABs are still poorly understood (Laws 2008). However, as monitoring data accumulates, evidence is emerging that climate change has an impact on the frequency, duration and geographical range of these phenomena (Glibert et al. 2005, Moore et al. 2008).

Ocean-derived pathogens: Cholera and other waterborne diseases

Extreme weather events, which are predicted to increase with global warming, are correlated with outbreaks of enteric diseases, many of which originate in marine environments (Rose et al. 2000). Temperature has the most direct and significant effect of all physical factors on the ecology of bacteria and has implications for bacterial pathogens that will be exposed to rising ocean temperatures (Lipp et al. 2002).

Vibro cholerae, the bacteria that causes cholera, is an example of an emerging and expanding disease affected by climate change. Outbreaks of *V. cholerae* have been strongly correlated with warm water temperatures and zooplankton blooms in summer and early fall and during El Niño Southern Oscillation (ENSO) climate events (Motes et al. 1994, Lobitz et al. 2000). Experts expect that without proper public health measures, cholera will increasingly spread and pose a threat to human populations in currently unaffected areas with continuing climate change (Lipp et al. 2002).

Action Recommendations

Enhance the capacity and resilience of ecosystems to act as natural risk reduction mechanisms by restoring ecosystems, protecting natural buffers and by reducing non-climate impacts.

Restore upland and wetlands areas to naturally filter waters released into the ocean.

Proactively reduce the impacts of HABs through public health surveillance, HAB monitoring and prediction, event response strategies, education and information dissemination, to prevent human exposure.

Research the links between climate change, HABs and public health.

Enhance research on the links between climate change, HABs and public health.

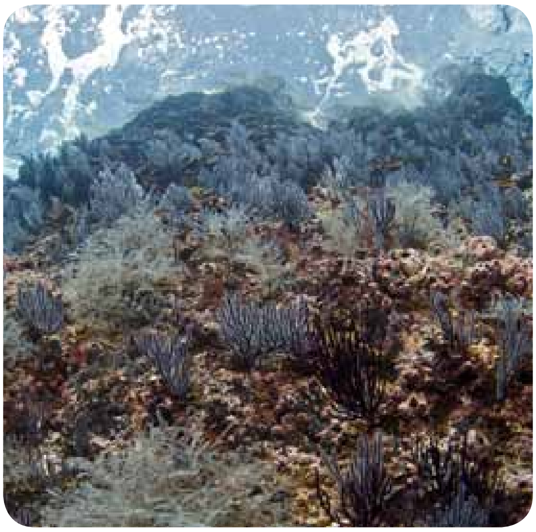
Expand capabilities for protecting ocean seafood resources.

Develop more effective bacterial threat detection and monitoring systems.

Enhance research on the causes and epidemiology of ocean-related health threats.

Improve public health outreach related to cholera outbreaks in developing countries.

Improve water sanitation techniques in communities at risk for waterborne pathogens.



DESCRIBE MARINE BIODIVERSITY BEFORE IT MAY DISAPPEAR

Jeopardizing healthy marine assets

Genetic, physiological, and biochemical research of marine organisms has great potential to develop new and effective medicines to combat illnesses such as cancer or infectious diseases, which have become resistant to existing drugs (Fenical 1997). Today, the ocean's enormous biological diversity is the most prolific source for new chemical compounds for the development of natural drugs (Fenical 2009). Promising marine organisms include sponges, ascidians, mollusks, bryozoans and bacteria (Fenical 2006). Though microbial species have barely been studied for medicinal purposes, these immensely diverse groups may become the most important sources for marine-based pharmaceuticals in future years, particularly for the development of new antibiotics (Chivian and Bernstein 2008, Fenical 2009).

Marine organisms as models for medical studies

Aquatic species are used for experiments within molecular biology, analytical chemistry, biochemistry, physiology, embryology, immunology, microbiology, and genetics. Five Nobel Prizes have been awarded for discoveries that were based on aquatic animal models (Hinton et al. 2009). For example, green fluorescent proteins were discovered in sea sponges in 1962 and are a powerful tool in molecular biology (Chivian and Bernstein 2008).

In addition to serving as sources of biomedical research tools, the unique biology of marine species make them excellent models for understanding human processes. Bivalves, a class of mollusks, are used to study aging processes, including metabolic activity and environmental stressors (Abele et al. 2009). Hagfish and lampreys lack an adaptive immune response and are important organisms for understanding innate immunity and the evolution of adaptive immunity (Uzzell et al. 2003). It is estimated that 95% of the ocean remains unexplored (NOAA 2000), so many marine organisms may disappear before they are discovered. Losing biodiversity through climate change could decrease the chances of combating human diseases by limiting the species available for medicinal research and as models for biomedical studies related to human health.

Action Recommendations

Preserve and manage marine biodiversity through the use of marine protected areas and by reducing human stressors on ocean ecosystems.

Enforce effective monitoring and management of key organisms and their ecosystems.

Protect key plants, animals, and microbes that may contain useful biomedical compounds.

Ensure responsible use of wild organisms by establishing codes of conduct for the sustainable collection of non-vulnerable and non-threatened species.

TAKE IMMEDIATE ACTION ON CLIMATE CHANGE INDUCED MIGRATION

Climate Change Displaced Persons

TThe Office of the UN High Commissioner for Refugees estimates that by 2050, adverse effects associated with global climate change will result in the displacement of between 50 and 200 million people (UNHCR 2009a). Currently 23% of the world's population lives both within 100 kilometers of the coast and less than 100 meters above sea level. Rising sea levels will force the flight of hundreds of millions of people from low-lying coastal or island nations (IPCC 2007, Sachs 2007) and other low-lying areas. Storm surges will cause seawater inundation and coastal erosion. Sea-level rise will trigger saline intrusions and other coastal hazards. Ecosystem-dependent livelihoods, e.g. local fisheries, will be increasingly affected. Populations will be forced into seasonal migration to find places that can support livelihoods.

These consequences of climate change have created a new category in human rights law: "Climate Change Displaced Persons" (CCDPs) (Hodgkinson et al. 2009). CCDPs are defined as individuals who are involuntary displaced because of hydrological and meteorological disaster or environmental degradation (UNHCR 2009a). Within this classification there exist subsets of CCDPs: those threatened with statelessness after the loss of their country and those threatened by internal displacement (UNHCR 2009a, UNHCR 2009c). An example of potentially stateless persons would be the residents of Tuvalu were their country to be inundated by sea-level rise. Internally displaced individuals are displaced but able to migrate elsewhere within their home state. The Inuit of Canada may be classified as a group potentially threatened with internal displacement (UNHCR 2009b). Stateless persons face a range of legal issues, not the least of which has to do with their citizenship, while those internally displaced will nevertheless face concerns regarding cultural preservation (UNHCR 2009a).

For both stateless and internally displaced persons, these classifications are not prompted until after the loss of homeland has occurred. There exists no convention on how to protect CCDPs in the event they are forced from their home countries (Hodgkinson et al. 2009). There have been efforts made to capture CCDPs within the framework of international refugee law, but the use of the 1951 Convention relating to the Status of Refugees provides ineffective protection to CCDPs and could prove detrimental to others protected under the Convention (Masters 2000, Baird et al. 2007).

Because the definition of 'refugee' is restricted to those driven from home for reasons of race, religion, nationality, membership of a particular social group or political opinion, the Convention is thought not to cover CCDPs. A separate legal instrument and new political solutions may be necessary (Hodgkinson & Burton 2009).

Action Recommendations

Improve the management of the environmental migration processes that are already happening.

Recognize that early action and planning are urgently needed and that reactive intervention is not sufficient.

Expand the understanding and recognition of potential migration issues through better analysis, better data and better predictions.

Create remedies for national and cross border displacement and migration at both the national and international level.

Incorporate human mobility – permanent and temporary, internal and cross border – into international and national climate change adaptation plans.

Implement a risk management strategy to protect citizens from climate change while concurrently assessing whether mitigation strategies should be abandoned in favor of evacuations.

Facilitate, where appropriate, the return of disaster-affected populations to homes and ensure adequate reconstruction efforts.

Prepare and secure funding for permanent resettlement of villages, towns, and in some cases entire nation states from low-lying, coastal regions that become inundated by both temporary (i.e., storm surge) and permanent sea-level rise.

Prepare to act to avoid or curb sectarian and ethnic violence associated with changes to natural resource availability, ownership, and geographic distribution.

SIGNIFICANTLY INCREASE CAPACITY BUILDING EFFORTS

Awareness, training and expertise

In order to effectively implement action recommendations suggested throughout this report, enhanced efforts in capacity building will be necessary. The strengthening of many institutions and organizations and the development of personal skills and expertise will be required (USAID 2009, IUCN 2009). This can be achieved through increased education and training as well as through ongoing access to relevant information, tools and technologies.

The impacts of climate change on the marine environment – from the coast to the deep sea – are still relatively unexplored and require further support. In the governmental, public and private domains, ocean related climate change issues are rarely fully recognized. A substantial advance of human and institutional capacity must be achieved to manage and implement adequate climate change solutions in marine related fields such as marine renewable energy sources, possible carbon sequestration methods and ecosystem-based adaptation approaches.

In some cases, an additional strengthening of the appropriate policy and legal frameworks is necessary. In order to make capacity building efforts as effective as possible, periodic needs assessments are recommended. Also, securing long-term financial support and evaluating the progress of capacity building efforts with standardized criteria is vital.

Action Recommendations

Disseminate information on marine climate change issues within relevant government institutions and other public and private stakeholders.

Ensure effective coordination, organization and communication among agencies that share jurisdictions and responsibilities and create marine climate change liaison officers to ensure ongoing information exchange and advice.

Encourage full and active participation among different stakeholders by arranging, for example, roundtables with stakeholders from different sectors to inform and discuss marine climate change solutions.

Conduct training for practitioners with regard to vulnerability assessments of coastal and marine ecosystems, the identification of priority areas for conservation and restoration activities, and the implementation of ecosystem-based adaptation.

Build capacity on the local, regional and national levels for design, management and monitoring of marine protected areas and restoration sites, the use of marine spatial planning and integrated coastal management in times of climate change.

Develop and enhance marine managers' networks to exchange information on pilot projects and best practices as well as other resources.

Increase awareness of the state of the ocean amongst the private sector and encourage industries to include climate change considerations in their management methods.

Enhance public awareness within local communities (schools, universities, media etc.) on the role of healthy marine ecosystems for climate change mitigation and adaptation solutions and their role in reducing other human stressors such as pollution and habitat destruction.

Support and expand education and training programs for individuals in need to develop alternative sustainable livelihoods.

Determine and support research on marine mitigation strategies and technologies: the role of marine and coastal ecosystems in the global carbon cycle, marine-based renewable energy sources, and geo-engineering methods

Ensure collaboration among economists, social and natural scientists to allow a full understanding of marine ecosystem services, including their economic value.

Secure long-term funding and periodic program assessment for capacity building programs.

6. Summary and Conclusion

The ocean covers more than 70% of our planet's surface and contains over 90% of the inhabitable space. Interactions between oceanic water masses drive the climate; about half of all atmospheric oxygen is derived from oceanic sources; and large sectors of the global economy depend on ocean-related commerce, including fisheries, tourism, and shipping. People, the ocean, and the climate are inextricably linked.

Climate change and ocean acidification are already impacting the ocean and will continue to cause harm unless successful mitigation and adaptation strategies are implemented rapidly. Humanity's dependence on the ocean for so many goods and services means that ocean change affects us. Permanent sea-level rise and periodic flooding inundate freshwater supplies and affect coastal soils. Increasing storm severity endangers small communities, as well as large cities, along our coasts. Poleward migrations of commercially important fish stocks impact fishers and require expensive international diplomacy. Melting Arctic ice influences global ocean circulation and currents, weather patterns, and marine resource distribution. Ocean acidification weakens coral reefs and other calcium carbonate-dependent systems. The food supply, standard of living and economic status of many ocean-dependent communities around the world are at risk. Some of these places constitute the poorest on Earth. The need and urgency to act on global climate and ocean change is pervasive.

To date, the ocean has played only a minor role in international climate change discussions. Due to its importance in the global carbon cycle, as well as its potential for climate change mitigation and adaptation, it is necessary to include the ocean more clearly and prominently in future negotiations. For example, it is essential to consider both ocean warming and ocean acidification when setting greenhouse gas stabilization targets, as these two processes do not happen in lockstep (i.e., continued measurable acidification could occur even after emission targets are reached if CO_2 is not made a primary concern).

Climate change mitigation strategies include several potential marine and coastal opportunities. Seagrass beds, mangrove forests and salt marshes play a critical role as natural carbon sinks, and this ability to store carbon emissions should be further recognized and quantified so that appropriate carbon management schemes can be developed. Management of these systems for carbon purposes requires a reduction of other human stressors, such as habitat destruction, unsustainable development or fishing, and pollution. Furthermore, possible coastal and marine sources of renewable power are vast. Currently, less than one percent of the global energy demand is covered by marine sources. Environmentally sound renewable energy projects, including wind, wave and tidal developments, have the potential to supply much of humanity's power and should be made more technically and economically available. The integration of detailed environmental impact assessments and marine spatial planning into facility design ensures that marine renewable energy projects attain their full potential as sustainable alternatives to fossil fuel-based power.

There has recently been an emergence of new technologies and large-scale geo-engineering projects, such as Carbon Capture and Storage (CCS) and ocean fertilization, intended to mitigate our greenhouse gas activities. These measures should be approached with extreme caution, as the potential costs and benefits associated with these strategies are currently insufficiently known. It is imperative that geo-engineering activities are not viewed as alternatives to emission reduction strategies, such as renewable energy, energy efficiency and reduction of energy demand. Instead, these types of projects should be undertaken only after sufficient scientific, environmental, and socioeconomic data support their implementation.

Some marine activities, such as shipping and fishing, contribute to the climate crisis. The international shipping industry is responsible for more than 3.4% of all global CO_2 emissions. In fact, if the industry were an independent state, it would be the world's sixth largest producer of greenhouse gases. It is imperative to include these emissions in future reduction targets. Technological advances and emissions standards could help the shipping industry continue to be the most efficient form of transferring goods, while reducing black carbon and other forms of pollution.

While mitigation is absolutely essential to avoid long-term future climate change and ocean acidification, their impacts are already seen and felt by humans and natural ecosystems in many regions of the world. Therefore, adaptation has become an indispensable complement to emission reduction and climate change mitigation strategies. Ecosystem-based Adaptation (EbA) is the sustainable management, conservation and restoration of ecosystems in order to ensure the continued provision of vital services that help people adapt to the adverse effects of climate change. EbA complements general adaptation portfolios by using biodiversity and ecosystem services in a variety of local, national and regional climate change adaptation projects and programs. EbA strategies can be more cost-effective and efficient than physical infrastructures and engineering solutions and are often more easily accessible to the rural poor. EbA uses natural capital and traditional and local knowledge to assist communities in their climate change adaptation efforts, while simultaneously achieving development objectives and reducing disaster risk.

Marine Protected Areas (MPAs) are one example of how to implement EbA. By protecting entire ecosystems and all the species within them, MPAs ensure that these systems continue to act naturally and provide services, including natural carbon storage, clean water, and food, to the surrounding environment and people. While this type of proactive management is preferred, restoration of degraded systems is another tool that can be applied to ecologically and economically important area. Risk management, consistent funding and monitoring/oversight are ways to ensure that EbA strategies successfully help people adapt to climate change.

Impacts on marine ecosystems and the associated threats to human welfare are not the only effects that climate change has on coastal peoples. Tainting of food and freshwater supplies and increased likelihood of disease epidemics, expected to occur with further warming and sea-level rise, will threaten the wellbeing of rural and urban populations, especially the poor. Furthermore, climate change induced migration could require millions of people to move from their homes (estimates as high as 200 million by 2050). In some cases, this forced migration will place people at risk of ethnic, political or resource persecution. In other cases, entire sovereign states could be lost, leading to heretofore unnecessary international cooperation. Currently, there are no legal and financial channels in place to handle the movement of entire populations across international borders as a consequence of environmental change. Threats to human health and forced migration are just two of many indirect consequences of ocean change that affect coastal peoples.

The reasons to include the ocean in future climate change mitigation and adaptation strategies are numerous and clear. Neither the ocean nor the atmosphere exists in isolation from the other, and interactions within and between the two regulate Earth's climate. Therefore, changes to the atmosphere associated with human activities lead to changes in the ocean. The biological and ecological systems within the ocean have evolved under very specific environmental characteristics. These life-support systems are vulnerable to ocean change, and the people that rely on the goods and services that healthy marine biodiversity and ecosystems provide are also at risk. It is essential that we go forth with an understanding that the ocean plays a large role in regulating climate and is extremely vulnerable to continued business as usual. It is essential that all future discussions surrounding our need to mitigate and adapt to continuing global climate change include the consideration of the ocean.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Acronyms and Abbreviations

BC	*Black carbon*
CARBOOCEAN	*Marine carbon sources and sinks assessment*
CBD	*Convention on Biological Diversity*
CCDPs	*Climate Change Displaced Persons*
CCS	*Carbon Capture and Storage*
CDM	*Clean Development Mechanism*
CO_2	*Carbon dioxide*
EbA	*Ecosystem-based Adaptation*
ENSO	*El Niño Southern Oscillation*
EPOCA	*European Project on Ocean Acidification*
FAO	*Food and Agriculture Organization*
GDP	*Gross Domestic Product*
GHG	*Greenhouse Gas*
HABs	*Harmful Algal Blooms*
IEA	*International Energy Agency*
IMO	*International Maritime Organization*
IOCCP	*International Ocean Carbon Coordination Project*
IPCC	*Intergovernmental Panel on Climate Change*
IPOA	*International Peace Operations Association*
IUCN-WCPA	*IUCN-World Commission on Protected Areas*
IUU	*Illegal, Unregulated and Unreported Fishing*
MARPOL	*International Convention for the Prevention of Pollution from Ships*
MEPC 59	*Marine Environment Protection Committee 59th session*
MPA	*Marine Protected Area*
NOAA	*National Oceanic and Atmospheric Administration*
NOx	*Nitrogen oxides*
OECD	*Organization for Economic Co-operation and Development*
PES	*Payment for Ecosystem Services*
SOLAS-IMBER	*Surface Ocean - Lower Atmosphere Study – Integrated Marine Biochemistry and Ecosystem Research*
UN	*United Nations*
UNCLOS	*United Nations Convention on the Law of the Sea*
UNCTAD	*United Nations Conference on Trade and Development*
UNEP/GPA	*UN Environment Progamme/ Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities*
UNEP-WCMC	*UN Environment Programme - World Conservation Monitoring Centre*
UNFCCC	*UN Framework Convention on Climate Change*
UNFSA	*UN Fish Stocks Agreement*
UNHCR	*UN High Commissioner for Refugees*
USAID	*United States Agency for International Development*
WHO	*World Health Organization*

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