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The Quiet Tsunami: The Ecological, Economic, Social, and Political Consequences of Ocean Acidification

Natassia Ciuriak
School of Public Policy and Administration, Carleton University

A large portion of the carbon dioxide emitted into the atmosphere is absorbed by the world's oceans. They become more acidic as they absorb the gas. This has far-reaching implications for the oceanic food web, biodiversity, and the global economy, particularly fishing and ecotourism industries in developing countries. This article briefly outlines the scientific evidence of ocean acidification and the implications of anthropogenic carbon emissions for marine ecosystems. It then assesses the economic, social, and political ramifications of ocean acidification and suggests a new strategy for the promotion of climate change policy. The "quiet tsunami" of oceanic climate change necessitates a policy shift away from the business-as-usual approach to reducing carbon emissions. The high stakes involved in this looming crisis may prompt unwilling governments to act in order to ensure food security and protect key economic markets around the world.

Introduction

Marine food resources have supported human civilizations from time immemorial. However, humanity's path to economic development over the past century has created a newly emerging threat to oceanic health. Humans have been dramatically increasing their emissions of carbon dioxide (CO_2) and other greenhouse gases into the atmosphere as population, industrial activity, and international trade and travel have grown. Emissions, which increase the atmospheric concentration of CO_2, continue unabated, driven in good measure by rising income levels and related energy-intensive privileges in some of the world's most populous countries, notably China and India. This reinforces the ongoing problem of global warming, which raises the temperature of ocean waters, the sea level (by melting continental glaciers), and, importantly for this discussion, the acidity of oceans. In fact, up to half of the total amount of CO_2 released because of human activities over the past two centuries has been absorbed by oceans (Royal Society 2005, 5).

A rapid increase in the absorption of CO_2 lowers the pH level of seawater—this is a phenomenon commonly known as ocean acidification—and decreases carbonate-ion concentration (Zeebe and Wolf-Gladrow 2001).

Of course, oceans are neither homogeneous nor static. The pH level of seawater varies with pressure and temperature, and thus is influenced by depth and latitude. Polar waters differ from temperate waters, coastal regions differ from open oceans, and different regions of oceans are affected differently by particular patterns of water circulation. For example, the pH level can be affected by horizontal flows such as the Gulf Stream, vertical interchanges in which surface waters sink in some places and nutrient rich waters upwell from the depths in others, and the influx of alkaline river waters. There are also diurnal, seasonal, and multi-year cycles. Over sufficiently long periods of time, measured in thousands of years, the equilibrium pH level of seawater is restored by kinetic, chemical, and biological processes (Caldeira et al. 2007).

The impact of CO_2 absorption on key parts of the oceanic food web is well established. As Richard Feely et al. (2008, 1490) explain: "The reaction of CO_2 with seawater reduces the availability of carbonate ions that are necessary for calcium carbonate ($CaCO_3$) skeleton and shell formation for marine organisms such as corals, marine plankton, and shellfish." Once formed, calcium carbonate dissolves if seawater is not sufficiently saturated with carbonate ions (CO_3^{2-}). Since calcium carbonate is more soluble at lower temperatures and at higher pressures, there is a saturation horizon below which calcium carbonate dissolves. Marine organisms that produce calcium carbonate, referred to as calcifiers, inhabit waters above the saturation horizon, the depth of which varies from place to place. Increased absorption of CO_2 by oceans thus both reduces the availability of the building blocks used by coral, plankton, shellfish, and other calcifiers and modifies the depth and temperature of the water at which these organisms can exist.

A large and fast change to the chemistry of oceans caused by anthropogenic carbon emissions threatens important oceanic ecosystems. Damage to plankton, which underpins the oceanic food web, and coral reefs, which house much of the planet's marine biodiversity, will have repercussions throughout the entire marine ecosystem. This is described by the Secretariat of the Convention on Biological Diversity (2009, 49): "Many calcifying species are located at the bottom or middle of global ocean food webs, therefore loss of shelled organisms to ocean acidification will alter predator–prey relationships and *the effects will be transmitted throughout the ecosystem* [emphasis added]."

Recognition that global warming is not detrimental everywhere in the world (UNFCCC 2011) has served to weaken national and international political responses to climate change, but there are no similar offsetting benefits when it comes to ocean acidification. Moreover, unlike with global warming, there is no debate about the anthropogenic cause of ocean acidification.[1]

Ocean acidification provides a unique opportunity for people who advocate for action on climate change to reinforce their demands on governments to take action. It is a direct and incontrovertible result of anthropogenic carbon emissions and will affect fishing and ecotourism industries. Accordingly, an emphasis on the major observable effects of climate change on the world's oceans, collectively described as the "quiet tsunami" (NRDC 2009, 1), can result in political action on climate change mitigation. To give but one example, concerns about the ramifications of ocean acidification on the Great Barrier Reef helped tilt the balance of votes in Australia toward the implementation of a carbon tax.[2]

The Government of Canada has thus far avoided action that would allow it to meet emissions reduction targets under the Kyoto Protocol, from which it withdrew in December 2011 citing costs and probable disruption of certain economic sectors (Delacourt 2010). All the while the government has ignored the cost of inaction (see McLaughlin 2011). This article demonstrates that while action on climate change may be perceived as costly, inaction will be costlier in the long run. It argues that there is a definite need for immediate action, since national and global problems related to climate change will only increase in number and severity should climate change and ocean acidification be allowed to continue unabated.

Literature Review

Research on ocean acidification is in its relative infancy. In 2009, 62 per cent of research papers on ocean acidification had been published since 2004 (Hood et al. 2009, 7). The 2005 report on ocean acidification by the Royal Society developed by a nine-member working group, which drew on submissions from 33 professionals in the field, provided a comprehensive review of the then-extant literature. It serves as a baseline assessment of the state of knowledge on the causes and effects of ocean acidification as well as marine organism and ecosystem responses and adaptation to elevated levels of acidity. The Royal Society (2005, 39–41) reached eight main conclusions:

- Oceans are absorbing the CO2 that is released into the atmosphere by human activities and this is causing chemical changes which make seawater more acidic.
- These changes in ocean chemistry will impact marine organisms and ecosystems.
- Oceans play a very important role in the global carbon cycle and Earth's climate system.
- The socio-economic consequences of ocean acidification could be substantial, given the effects on coral reefs and fisheries.
- The scale of future changes to the chemistry and acidity of oceans can only be reduced by preventing the accumulation of CO2 in the atmosphere.
- Unless global emissions of CO2 are reduced by twice their 2005 levels by the year 2100, the Southern Ocean will become under-saturated for aragonite, which is required by some organisms to make calcium carbonate skeletons and shells.
- The magnitude of ocean acidification can be predicted with a high level of confidence. Assessments of its impacts, particularly on marine organisms, are much less certain and require additional research efforts.

- Ocean acidification is a powerful reason, in addition to climate change, to reduce global CO2 emissions.

In 2009, the Secretariat of the Convention on Biological Diversity provided additional grounds for concern. It (2009, 9) confirmed that ocean acidification is a result of anthropogenic CO_2 emissions and that many of its effects on marine ecosystems will be variable and complex. Although evidence found that a few species, such as some phytoplankton, fungi, and bacteria, may experience certain benefits, the Secretariat (ibid.) warned that most ecosystems in acidified seawater are less diverse and missing those species that form their skeletons and shells from calcium carbonate. Further, it documented various sub-lethal effects of exposure to low pH on various organisms' developmental and adult phases. These effects vary depending on a species' genetics, pre-existing capabilities to adapt to changing conditions, and environmental factors.[3] Importantly, the Secretariat (ibid., 5) outlined the following:

> By 2100, 70% of cold-water corals, key refuges and feeding grounds for commercial fish species, will be exposed to corrosive waters. Furthermore, given current emission rates, it is predicted that the surface waters of the highly productive Arctic Ocean will become under-saturated with respect to essential carbonate minerals by the year 2032, and the Southern Ocean by 2050, with disruptions to large components of the marine food web.

The Secretariat (ibid., 9) concluded that acidification is "irreversible on timescales of at least tens of thousands of years, and substantial damage to ocean ecosystems can only be avoided by urgent and rapid reductions in global emissions of CO_2."

The amount of CO_2 that will be released by the end of the century under a business-as-usual scenario will be large and extremely rapid in the geological time scale. Data from Antarctic ice cores show that the concentration of CO_2 in the atmosphere over the past 650,000 years varied between a low of 180 parts per million (ppm) during cold glacial periods to a high of 300 ppm during warm inter-glacial periods (IPCC 2007, 465). By 2010, the mean concentration of atmospheric CO_2 at sea level was measured to be 389.78 parts per million by volume (ppmv) (NOAA 2011b). Current CO_2 concentration is in the range last recorded during the Pliocene (circa five to three million years ago), a period in which the global temperature was substantially warmer and sea levels were much higher (Pagani et al. 2010). The amount of CO_2 that will be released during this century will likely be greater than any amount recorded since the Palaeocene-Eocene Thermal Maximum (PETM) some 55 million years ago (Dickens, Castillo, and Walker 1997). That event caused widespread dissolution of seafloor carbonates (Zachos et al. 2005) and a mass extermination of seafloor ("benthic") species (Ridgwell and Schmidt 2010). Notably, the buildup of CO_2 during the PETM was much more gradual than the present buildup (Kump, Bralower, and Ridgwell 2009).

John Veron (2008) shows that the five mass extinction events which Earth has experienced so far were each associated with "reef gaps" in the geological record—extended periods during which there is no evidence of living reefs. These periods were linked to changes in ocean chemistry associated with atmospheric CO_2 levels. Veron (ibid., 459) argues that "The prospect of ocean acidification is potentially the most serious of all predicted outcomes of anthropogenic carbon dioxide increase . . . [and] has the potential to trigger a sixth mass extinction event." Similarly, an extensive literature review conducted by Scott Doney et al. (2009, 184) concluded that "[a] cidification impacts on processes so fundamental to the overall structure and function of marine ecosystems that any significant changes could have far-reaching consequences for the oceans of the future and the millions of people that depend on its [*sic*] food and other resources for their livelihoods."[4] Comparing the PETM to the current buildup, Andy Ridgwell and Daniela Schmidt (2010, 5) observe as follows:

> We infer a future rate of surface-ocean acidification and environmental pressure on marine calcifiers unprecedented in the past 65 [million years], and one that challenges the potential for surface-ocean plankton to adapt. For benthic organisms, rapid and extreme undersaturation of the deep ocean would make their situation precarious, and the occurrence of widespread extinction of these organisms during the PETM greenhouse warming and acidification event raises the possibility of similar extinction in the future.

Economic and Social Impacts of Ocean Acidification

Research on the economic impact of ocean acidification remains limited. Attempts at overall economic assessments of climate change either ignore this phenomenon (Tol 2002a; 2002b) or give it only a passing mention without incorporating its costs into the analysis (Stern 2006; Nordhaus 2008; Tol 2009). Accordingly, drawing attention to the economic impacts of ocean acidification is crucial when informing public opinion and, by extension, public policy.

The fishing industry is a small but significant component of the global economy. The total contribution of commercial capture fisheries, including marine and inland harvest and post-harvest subsectors, to global gross domestic product (GDP) was estimated at approximately US$274 billion in 2007 (World Bank, FAO, and WorldFish Center 2010), of which about 90 per cent can be attributed to marine fisheries, based on the value share of the capture. This figure is small in the context of a global economy valued at approximately US$62 trillion (IMF 2010), but it is not negligible. Aquaculture is the fastest growing animal food-producing sector and currently accounts for almost half of total food fish supply; approximately one-third of aquaculture production is marine-based (FAO 2011). While studies of ocean acidification have mainly focused on natural marine ecosystems, the issue has registered on the aquaculture industry's radar. In 2010, a brief session on ocean acidification was held at the triennial meeting of the World Aquaculture Society together with the U.S. National Shellfisheries Association.

The overall economic impact of ocean acidification on marine fisheries and aquaculture has not yet been systematically evaluated. Studies of specific types of marine organisms such as shellfish, on which aquaculture depends, demonstrate that the costs are substantial (Talmage and Gobler 2009; Narita, Rehdanz, and Tol 2011). Relative to the risks posed by climate change, however, the impact on any specific type of fishery is small in dollar value, commensurate with the share of fisheries in global GDP. For instance, the cost to shellfish production in 2100 would be about US$100 billion, which represents up to 1.5 per cent of the total expected damage caused by climate change and around 0.025 per cent of global GDP (ibid., 14).

Specific economic impacts matter in politics. On average, the United States annually derives US$4 billion of primary value from commercial harvests from American waters and at-sea processing (NOAA 2011a). Approximately 24 per cent of this figure comes from harvesting fish that depend directly on calcifiers (Cooley and Doney 2009). Aquaculture, which also depends heavily on calcifiers, accounted for over US$1.2 billion in additional income in 2007. The National Oceanic and Atmospheric Administration calculated that one million jobs are associated with the American commercial fishing industry, which accounts for about US$32 billion in income annually (NOAA 2011a). Ocean acidification will negatively affect these figures and may have tangible political ramifications.

Impacts will certainly be felt in recreational fishing and marine tourism. While commercial fishing, including international trade, in the United States was valued at US$70 billion in 2009 (ibid.), recreational fishing contributed US$50 billion in sales impacts, US$23 billion in value-added impacts, and supported 327,000 jobs (National Marine Fisheries Service 2011, 8). Marine tourism has become one of the fastest-growing areas of the world's tourism industry (Hall 2001, 602). Australia's Great Barrier Reef receives roughly two million visits each year and generates about US$5.7 billion in tourism and fishing revenue, which sustains 53,800 full-time jobs (McCook et al. 2010). Tourism around the Hawaiian coral reefs accounts for about US$364 million annually in value-added economic activity, 84 per cent of which is generated from snorkelling and diving on reefs. Further added value from property accounts for US$40 million each year, generated by rising property values near healthy reefs (Royal Society 2005, 33).

The effects of ocean acidification on these industries could inform potent arguments that may prove to convince reluctant governments to act on climate change. For example, the Royal Society concluded that even under modest emissions scenarios, which predict an atmospheric concentration of 600 ppmv of CO_2 by 2100, climate change is predicted to cost the economy around the Great Barrier Reef a minimum of US$2.6 billion over 19 years to 2020 (ibid.). Under higher emissions scenarios with an atmospheric CO_2 concentration of 800 ppmv, losses will rise to over US$14.6 billion (ibid.). More recent estimates place the net present value of the Great Barrier Reef at US$51.5 billion and the cost of serious degradation of the reef system at US$39.2 billion, of which US$15.8 billion represents intrinsic value (Oxford Economics 2009).

Although these figures may seem small relative to the value of the global economy and costs thought to be associated with a shift from fossil fuels to renewable energies, they belie the importance of fishing and ecotourism to certain regions. Narrow sectoral impacts can have disproportionately large influences on national policies. For instance, Canada and Spain almost went to war over illegal overfishing on the Grand Banks in 1995 (Schaefer 1995). Furthermore, the roots of piracy in Somalia can be traced to concerns about fishing rights. As Patrick Lennox (2008, 8) writes: "[Somalian pirates] were acting at first to protect their territorial waters from illegal fishing and dumping by foreigners, which became progressively significant as it became more and more evident to outsiders that Somalia was not capable of patrolling its exclusive economic zone." Although these two examples are unrelated to ocean acidification, they highlight the value of the fishing industry to those that rely on it and the lengths that governments and individuals are willing to go in order to protect resources.

Ocean acidification, unlike illegal trawling or disputes over fishing rights, will affect every country that trades fish or fishery products because no waters will be exempt from this phenomenon, though the distribution of effects will by no means be even. Importantly, the countries with the greatest interest in marine fisheries include leading developed countries, such as the United States, the European Union, and Japan, and major developing countries, such as India and China, the latter of which accounts for about 16 per cent of total catch—by far the largest share (European Commission 2010, 16). The health of the fishing industry thus impacts most, if not all, countries with a coastline and threatens local economic activity and food security.

Challenges Faced by Developing Countries

The problem of ocean acidification has implications for global equity. Seafood makes up more than 20 per cent of consumed animal protein for 2.6 billion people worldwide and over 30 per cent in the developing world (Gupta 2006, 4). Coral reefs provide habitat for 25 per cent of total catch, increasing food security for one billion people in Asia alone (CDNN 2009). Developing countries provided approximately half of the total export value of trade in seafood products in 2006, with 80 per cent of all imports going to developed countries. Throughout the developing world, the fishing industry directly employs about 150 million people (Hauge, Cleeland, and Wilson 2009, 2).

In addition, fishing is a particularly important source of support for many households at the subsistence level. A Vietnamese case study showed that when subsistence fishing was taken into account, total marine capture was about 58 per cent higher compared to official statistics (which do not take into account subsistence fishing) (World Bank, FAO, and WorldFish Center 2010, 43). The study found that in 10 provinces adjacent to the Mekong

Delta more than eight million people relied directly on the capture of fish and aquatic animals to meet their nutritional needs. Disruption or collapse of the fishing industry would thus put considerable strains on social support networks and intensify urbanization pressures.

Southeast Asia and the Caribbean depend greatly on oceans for nutrition and incomes and are located near some of the most vulnerable waters in the world. The Philippines provides an illustrative case study of the impact of deteriorating coral reefs on developing countries, since the country is found in one of the world's most prolific coral-producing, though most acidic, areas. The Coral Triangle covers 1.6 billion acres of Southeast Asia and is the planet's most biologically diverse region in terms of marine biota (Hoegh-Guldberg et al. 2009, 5). Coral reefs are important to the Filipino people for nutritional and economic reasons, among others. Reefs provide habitat for fish species upon which the Filipino population depends for 50 per cent of its animal protein intake (White, Vogt, and Arin 2000, 598). These reefs provide livelihoods for over one million small-scale fishermen and contribute almost US$1 billion annually to the Filipino economy (ibid.). It is estimated that reef fish account for 20 per cent of total catch in the country (ibid., 599). A loss of fisheries-related incomes and employment would significantly stress national organizations and international bodies concerned with humanitarian needs, such as the United Nations World Food Programme. Furthermore, there would be a huge, albeit immeasurable, loss in the intrinsic value of a unique culture, a way of life, and some of the world's largest and most beautiful coral reefs.

Coral reefs are also crucial for the ecotourism industry, which encourages sustainable practices in local host economies while providing governments with additional tourism-derived tax revenue. Ecotourism has been shown to address certain dimensions of poverty and complement conservation efforts (Ministry of Population and the Environment of Nepal 2004, 209). Estimates suggest that ecotourism associated with coral reefs generates US$300,800/$km^2$ per year in revenue for the Filipino government (White, Vogt, and Arin 2000, 600). With a total reef area of 26,000 km^2, the Philippines could lose an important source of revenue because of ocean acidification.

Coral reefs are worth conserving because of the tangible nutritional and economic benefits that coastal communities derive from them as well as their intrinsic value. These fragile systems are under a variety of anthropogenic stresses, including dangerous fishing practices, effluent runoff, and most recently ocean acidification. Additional stresses hinder ecosystems' abilities to recover and remain productive. The reefs have been deteriorating over the past 30 years. In 2001, the United Nations Environment Programme reported that 97 per cent of Filipino reefs were under threat (Spalding, Ravilious, and Green 2001). By 2007, Reef Check, an international organization that assesses the health of reefs in 82 countries, stated that only 5 per cent of the Philippines' coral reefs were doing well, with the rest being damaged, diseased, or dead (Agriculture Business Week 2008).

The case study of the Philippines is just the tip of the iceberg. Coral reefs around the world are deteriorating because of anthropogenic stresses. Losses in economic value, among other things, are a main result. For example, Lauretta Burke et al. (2011, 78) found that the projected degradation of Caribbean reefs will result in relatively large annual economic losses: by 2015, reef-associated fisheries will lose between US$95 million and US$140 million in net revenues while ecotourism will suffer losses between US$100 million and US$300 million. Southeast Asia as a whole is extremely vulnerable to reef loss and consequent economic losses (ibid., 73). It bears repeating that ocean acidification causes much damage to coral reefs by corroding them and, due to the reduction in the availability of calcium carbonate, preventing new structural growth.

Global Equity and Climate Change

Global equity is a central aspect of the international climate change debate. While developed countries' carbon-intensive development is responsible for much of the climate change to date, developing countries are left to suffer many of the consequences with relatively little adaptive capacity. It is true that the contemporary carbon-based development of some populous developing countries is contributing to this problem, but as South African Minister of Environmental Affairs and Tourism Marthinus van Schalkwyk (2009) said: "[W]e cannot wish away historical responsibility for the problem. The fact of the matter is that the carbon space is finite and 70% of the 'safe' carbon space has already been used up, largely by industrialized countries." Most of the responsibility to act therefore lies with developed countries. They have the capacity and technologies to adapt to a warming planet and the duty to help developing countries adapt. Not only is this the right path to take environmentally, but economically there are benefits to the proliferation of clean-energy technologies.

The phenomenon of ocean acidification raises the stakes for action on climate change. The choice is not one of comfort and convenience but rather one of survival because "[t]he harm is against humans, it is largely other-inflicted, and it is not life-*style-*, but *life*-threatening" (Müller 2002, 2). Damage done by ocean acidification will threaten the food security and incomes of billions of people. Many of those people live in developing countries that do not have the organizational, technological, or financial capabilities to handle food distribution and economic dislocation. Stresses will further slow development in key parts of the world, namely Southeast Asia and the Caribbean.

Ocean Acidification and Climate Change Policy

There is a disconnect between polluters and pollution victims when it comes to the issue of global equity in the context of a changing climate. Developed countries first acknowledged their obligation to provide financial support for developing countries' climate change mitigation and adaption efforts in the 1992 United Nations Framework Convention on Climate Change (UNFCCC)

(Demerse 2009, 1). Their sense of obligation is informed by two principles: (1) the polluter pays principle, which dictates that the polluter should bear the financial burden of repairing damage caused by pollution and preventing further pollution; and (2) common but differentiated responsibility, which refers to the globally shared responsibility to protect shared resources, with the caveat that responsibility is different depending on a country's contribution to an environmental problem and its capacity to address that problem (ibid., 5). Governments and firms tend to offer economic explanations for their adoption of a wait-and-see approach to climate change, often arguing that climate change mitigation is simply too expensive. Such arguments are baseless and hypocritical. Ocean acidification may prove to be the missing puzzle piece that enables local, national, and international climate change advocates to promote change in climate change policy-making.

The costs of ocean acidification have largely been ignored. North America in particular has been unwilling to change its business-as-usual approach. The United States has rejected internationally coordinated climate change policies, arguing that any deal that does not include large emitters such as China is not fair and the economic impact on Americans is unacceptable. In 2006, Canadian Prime Minister Stephen Harper emphasized industry worries that meeting emissions reduction targets would cost too much (Suzuki and Taylor 2009, 95–96) and has since pulled out of the Kyoto Protocol to avoid heavy penalties for his country's failure to act. However, as Ken Thompson (2010) argues, the cost argument hardly stands since unnecessarily high military budgets could be reworked to make more money available for spending to tackle climate change. Nicholas Stern (2006, xvii) demonstrates that inaction will raise the costs of adaptation and annual revenues of up to US$2.5 trillion can be generated by taking a low-carbon path.

The international movement for global co-operative action on climate change has also been hindered by denialism by conservative political parties, think tanks, and media corporations often funded to some degree by fossil fuel-related corporations (Suzuki and Taylor 2009; Dunlap and McCright 2010; Hoggan and Littlemore 2009; Monbiot 2006; Gutstein 2009). Among major political parties in developed countries, the Republican Party in the United States and the Harper Conservatives now stand practically alone in their refusal to address the problem of climate change. Anti-science and anti-intellectual trends are unfortunately gaining ground in the Republican Party, which, as Elisabeth Rosenthal (2011) argues, "has managed to turn skepticism about man-made global warming into a requirement for electability." The Harper Conservatives may not deny science, but their policy is the same: little, if any, action to reduce emissions. The United States and Canada have both pledged to reduce their emissions by 17 per cent from 2005 levels by 2020, an increase of 3 per cent from 1990 levels. Comparatively, the European Union has pledged a 20 per cent reduction from 1990 levels by 2020. Developing countries' pledges cover a wide range: China aims to reduce its emissions by about 7 per cent from 1990 levels, India is set to increase emissions by 30 per cent from 1990 levels, and Brazil, being the role model, pledged to reduce emissions by 36 per cent from 1990 levels (Climate Action Tracker 2011).

The international community continues to meet periodically as the Conference of the Parties (COP) to the UNFCCC. The 15th COP, which took place in 2009 in Copenhagen, did not live up to expectations that it would produce a successor agreement to the Kyoto Protocol. Countries agreed to the weak Copenhagen Accord which encourages signatories of the UNFCCC "to cap the global temperature rise by committing to significant emission reductions and to raise funds to help the developing world address climate change" (European Environment Agency 2010). The accord recognizes that climate change is "one of the greatest challenges of our time" and something must be done, but it does not require countries to abide by reporting mechanisms or binding targets for 2020 or 2050 (UNFCCC 2011). Oxfam International (2009, 9) indicates that, "[the accord] bundles the adaptation needs of the world's poorest people together with calls for compensation . . . for oil-producing countries that claim they will lose revenue when the world shifts away from fossil fuels." Global equity concerns played a large role in Copenhagen. Some developing countries refused to sign on to the accord, which would require poor and vulnerable developing countries to follow international procedures in order to gain financial support for their mitigation efforts, a process that has proven to be difficult for these low-capacity countries (Chandani 2010, 222).

A year later, the 16th COP in Cancún was under pressure to lay the groundwork for binding targets for all countries, including the United States, which many countries insisted must be brought into an agreement (Pew Center on Global Climate Change 2010, 2). The meeting was also expected to develop a multilateral financing mechanism to channel hundreds of billions of dollars to developing countries to help them mitigate emissions and adapt to the effects of climate change (Snegaroff and Cuenca 2010). The meeting resulted in the Cancún Agreements, a deal which does not obligate governments to take new steps, though provided a foundation for a deal with binding targets to be reached at the next meeting.

In 2011, signatories of the UNFCCC met in Durban for the 17th COP, which resulted in the Durban Platform outlining a course of action that would see the development of a new treaty which covers all major emitters. In addition to extending the Kyoto Protocol's first commitment period, the parties "explicitly recognised the global gap between countries' existing emissions reduction pledges out to 2020, and the global goal of limiting average temperature increases to below 2 degrees [Celsius] above pre-industrial levels" (The Carbon Report 2011). The Durban Platform stated that a new treaty must be finalized by 2015 and come into force in 2020.

Despite countries' acknowledgment that there is a need to shift toward low-carbon societies, a timely agreement that significantly and rapidly curbs emissions is unlikely because fossil fuel-related interests have substantial influence on political decisions in key countries. Global fossil fuel subsidies in 2008 amounted to $557 billion (IEA 2010, 1) and continue to be high. For instance, the Pembina Institute estimated that the Government of

Canada provides CAD$2 billion per year in financial support to the fossil fuel industry (Demerse 2010). Politicians in North America tend not to cut support to this industry since fossil fuel-related corporations have a history of funding political parties that pander to their interests (Gutstein 2009; McQuaig 2004). This reduces the probability that countries will act to address ocean acidification.

The fact that ocean acidification is an observable direct result of CO_2 emissions is fortunate because that may be important in motivating governments to act. The U.S. government passed the Federal Ocean Acidification Research And Monitoring Act of 2009 to develop research and monitoring capabilities within the National Oceanic and Atmospheric Administration (Buck and Folger 2009). Fisheries and Oceans Canada is examining the issue, though no specific policy actions have been taken (Fisheries and Oceans Canada 2011). The Oslo and Paris (OSPAR) Commission, administrator of the OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic, addresses fisheries issues for the European Union and lists ocean acidification as a concern (OSPAR Commission 2011). Ocean acidification is evidently under consideration by key governments, but action appears to be restricted to research and discussion.

The lack of consensus and concerted global action indicates that advocacy is necessary. A driver for action on climate change is co-operation by multiple stakeholders to counter industrial lobbies. The Advocacy Coalition Framework argues that stakeholders want to convert their convictions into policy and will seek allies and form advocacy coalitions to do so (Weible 2006, 99). A number of stakeholders that have been or will soon be affected by ocean acidification have been identified. First, there are activists and educators—environmentalists, conservationists, and marine scientists—who are committed to public education on ocean acidification. Second, there are direct economic stakeholders, such as capture fisheries, aquaculturists, and the marine ecotourism industry. Third, there are myriad stakeholders in the alternative energy industry, who are keen to secure government subsidies and tax exemptions to help develop economies of scale for their technologies. Fourth, there are those who have a desire to maintain oceanic biodiversity for its intrinsic beauty and interest, including snorkelers, divers, scientists, and members of the general public. Finally, there are certain governments that are confronted with sectoral or regional pressures because of ocean acidification, such as those which depend on fisheries for nutrition, incomes, and economic growth. Many stakeholders are willing to advocate on this issue, whether it be for financial, humanitarian, or symbolic reasons.

The Advocacy Coalition Framework identifies two conditions that facilitate policy change: "changes in beliefs of a dominant coalition or changes in available resources and venues [that] are brought about by external shocks, policy-oriented learning, or hurting stalemate" (Weible 2006, 101). Given the far-reaching consequences of climate change and ocean acidification, policy change driven by external shocks, such as widespread coral death and fisheries collapse, is not desirable. The focus must be on influencing the beliefs of the dominant coalition, currently formed by reluctant governments and the general public. Although research on and high-level acknowledgment of ocean acidification have increased attention to the problem, the need for immediate action has yet to be accepted by key countries. The salience of the issue must be elevated in the minds of the public with education campaigns through the media and at the national level.

Advocacy coalitions and educational efforts are in nascent stages. An international network of research and environmental stakeholders has already been formed and is active in policy advocacy. Two symposia on oceans in a high-CO_2 world, organized by the Scientific Committee on Ocean Research, United Nations Educational, Scientific and Cultural Organization, and International Geosphere-Biosphere Programme have been held since 2004 and a third is set to take place in September 2012 in California. Ocean acidification has been raised as a major issue by the United Nations Environment Programme, which cites it as a threat to food security (UNEP 2010), and briefs aimed at policy-makers have been issued. The issue of ocean acidification was also raised at the 16th COP, where the point was made that targets for limiting atmospheric CO_2 concentrations are dangerously in excess of the amount that causes oceanic damage (Harrould-Kolieb 2010). Although the issue is relatively new on the international scene, action evidently must not be delayed.

Education campaigns will not be effective until governments eliminate subsidies and tax exemptions for fossil fuel-related corporations. In particular, Canada should remove subsidies to corporations that operate in Alberta's tar sands, since oil production is responsible for a significant increase in Canada's greenhouse gas emissions (Environment Canada 2011, 19–20). Subsidies should instead be provided to clean and renewable energy companies to ensure that inexpensive alternative energy options exist. Funds can also be put toward protecting coastlines and reducing or eliminating harmful fishing practices. Such actions would send an important message to Canadian citizens and corporations that the government is taking climate change seriously.

Conclusion

After completing the Millennium Ecosystem Assessment, 1,360 leading experts in a variety of scientific fields concluded in 2005 that "over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history . . . . This has resulted in a substantial and largely irreversible loss in the diversity of life on Earth" (Hoggan and Littlemore 2009, 11). Ocean acidification is just one problem caused by climate change, but it is a problem that a policy of adaptation will not sufficiently address. Addressing it requires direct confrontation with CO_2 emissions. In addition to the threat that ocean acidification poses to the global biosphere, oceanic biodiversity, and humans' food security, the potential of the phenomenon to inspire action by governments should make it an integral part of efforts to address climate change more generally.

Notes

1. Some observers argue that oceanic ecosystems have the capacity to cope with future climate change. See, for example, Maynard, Baird, and Pratchett (2008) and a response by Hoegh-Guldberg (2009). Hendriks, Duarte, and Álvarez (2010) argue that biological processes allow marine organisms to handle pH changes. See Dupont, Dorey, and Thorndyke (2010) for a response.
2. The Australian Parliament voted 74-72 in favour. Prior to the vote, the government had received a report that documented damage to the Great Barrier Reef by uncontrolled CO2 emissions.
3. Many effects of lower pH on marine biota have been documented in the literature. These include stunted growth (Bechmann et al. 2011), weakened reproductive performance (Havenhand et al. 2008; Kurihara 2008), and weakened immune system responses (Bibby et al. 2008). Hofmann et al. (2010) identify impacts of ocean acidification on photosynthesis, respiration, acid-base regulation, aspects of behaviour, and tolerance of other stressors. Kroeker et al. (2010) conclude that "[o]cean acidification is a pervasive stressor that could affect many marine organisms and cause profound ecological shifts . . . [T]he biological effects of ocean acidification are generally large and negative, but the variation in sensitivity amongst organisms has important implications for ecosystem responses." Albright (2011) finds that ocean acidification has "the potential to impact multiple life history stages of corals, including critical processes independent of calcification." Examining the effects of ocean acidification on early life history of invertebrates, Dupont and Thorndyke (2009, 3122) conclude that "many species and ecosystems will experience profound modifications with severe socio-economic consequences." Compounding the effects of ocean acidification are various pressures such as pollution and exploitation of resources (Secretariat of the Convention on Biological Diversity 2009, 53).
4. Other studies also conclude that there exists a threat of massive disruption to oceanic ecosystems. See Dupont, Dorey, and Thorndyke (2010), Barnard and Grekin (2010), Hofmann et al. (2010), Beman et al. (2011), and Veron (2011).

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