WRITTEN TESTIMONY OF
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Climate Change: It's Happening Now

BEFORE THE
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Introduction

Good morning Chairman Boxer, Ranking Member Vitter and members of the Committee. Thank you for giving me the opportunity to speak with you today on climate change, the ocean carbon cycle and ocean acidification.

My name is Scott Doney, and I am a Senior Scientist at the Woods Hole Oceanographic Institution in Woods Hole MA. My research focuses on interactions among climate, the ocean and global carbon cycles, and marine ecosystems, and I have published more than 200 peer-reviewed scientific journal articles and book chapters on these and related subjects. I have served on the U.S. Carbon Cycle Science Program Scientific Steering Group and the U.S. Community Climate System Model Scientific Steering Committee. I was the inaugural chair of the U.S. Ocean Carbon and Biogeochemistry (OCB) Program and am currently on the steering committees for the Ocean Carbon and Biogeochemistry Program and the U.S. CLIVAR/CO2 Repeat Hydrography Program. I am also a convening lead author for the Oceans and Marine Resources chapter of the U.S. 2013 National Climate Assessment.

For today's hearing, you asked me to discuss how rising atmospheric carbon dioxide levels alter seawater chemistry, put at risk a wide range of marine life, and affect coastal communities and economies. My comments are based on my own extensive research and on a broad scientific consensus as represented in the current scientific literature and scientific assessments such as the 2013 National Climate Assessment, which was released this past winter in draft form for public comment (Doney et al., 2013; Walsh et al., 2013).

Over the past two centuries, human activities have resulted in dramatic and well-documented increases in atmospheric carbon dioxide and acidification of the upper ocean. Today the surface ocean is almost 30% more acidic than it was in pre-industrial times, and over the next few decades, the level of acidity of the surface ocean will continue to rise without deliberate action to reduce carbon dioxide emissions and stabilize

[1] The views expressed here do not necessarily represent those of the Woods Hole Oceanographic Institution

atmospheric carbon dioxide levels. Increasingly this will cause major problems for many marine organisms like shellfish and corals.

The ocean takes up roughly one quarter of human emissions to the atmosphere of carbon dioxide from fossil fuel burning and deforestation. Additional carbon dioxide uptake causes direct changes in seawater acid-base and inorganic carbon chemistry in a process termed ocean acidification. Acidification is independent of warming of the atmosphere but the two are linked through the underlying cause of elevated atmospheric carbon dioxide. Growing evidence suggests that ocean acidification will strongly impact many types of marine organisms, from microscopic plankton to shellfish and corals. Acidification and climate change will put further pressure on living marine resources, such as fisheries and coral reefs that we depend upon for food, tourism and other economic and aesthetic benefits.

Scientific observations show that ocean acidification is already occurring around the globe and is amplified in some coastal regions by changing ocean circulation, pollution, and land management practices. Recent near collapses of the oyster fishery in the Pacific Northwest, directly attributed to changing seawater chemistry, had substantial negative impacts on local jobs and economies.

In addition to ocean acidification, marine ecosystems are also already experiencing other large-scale trends linked to global change. Documented trends relevant to marine biota include increasing sea surface temperature, upper-ocean warming, rising sea-level, retreating Arctic sea-ice, and declining subsurface oxygen. Ocean warming is linked to poleward migration of commercial fish stocks and higher intensity and increased spatial ranges of marine diseases that attack corals, abalones, oysters, fishes, and marine mammals.

We have an opportunity now to limit the negative impact of ocean acidification in the future. Key elements include curbing human carbon dioxide emissions to the atmosphere, improved control of local pollution sources, reducing coastal habitat destruction, and better preparing coastal human communities to withstand the amount of ocean acidification and climate change that is unavoidable. At the State and local level, adaptation and mitigation strategies are being developed for ocean acidification. This topic is discussed more in the Adaptation and Mitigation section of the written testimony.

Social and Economic Impacts of Ocean Acidification

Acidification and climate change will likely affect many of the benefits people derive from the ocean–supply of seafood, recreation and tourism, protection from coastal flooding–as well as the jobs and livelihoods that depend on healthy marine ecosystems (Cooley et al., 2009; Halpern et al., 2012; Ruckleshaus et al., 2013).

Many economically and culturally important mollusk species are harvested in the United States, and a number of these species have been show to respond poorly to ocean acidification (Table 1). These include, for example, larval hard clams, oysters, and bay scallops (Talmage and Gobler, 2011), softshell clams (Green et al., 2009), and blue

mussels (Gazeau et al., 2010). Declines in these populations or delays in time to maturity could cost fishers, and dependent industries, millions of dollars (Cooley and Doney, 2009). Moreover, some additional impacts may still be identified; studies have not examined yet whether ocean acidification affects economically relevant harvest qualities of mollusks such as meat weight, appearance, and flavor. The commercial revenue numbers in Table 1 reflect what fishermen are paid at the dock for their catch and does not reflect the larger regional total economic impact of fishing, which can be several times larger.

Table 1: Commercial U.S. harvests in 2011 of mollusks with demonstrated negative responses to ocean acidification (Data: NOAA National Marine Fisheries Service, 2012).

Common name	**Scientific Name**	**Commercial revenue, dockside (millions)**
Hard clam, (Northern) quahog	*Mercenaria mercenaria*	$32
Eastern oyster	*Crassostrea virginica*	$91
Bay scallop	*Argopecten irradians*	$2
Softshell clam	*Mya arenaria*	$21
Blue mussel	*Mytilus edulis*	$7
Pacific oyster	*Crassostrea gigas*	$45
Olympia oyster	*Ostrea lurida*	$12
Sea urchins	several	$14

As atmospheric carbon dioxide levels continue to grow, ocean acidification may negatively impact the revenue derived from the commercial harvest of clams, scallops, oysters, mussels, and other calcifiers (like urchins). In 2011, harvests of calcifiers accounted for 19% of the $5.3 billion U.S. ex-vessel commercial fishery revenue. The biological responses to ocean acidification have not yet been determined for particularly valuable mollusk species such as sea scallop (*Placopecten magellanicus*), with national ex-vessel revenues for 2011 of $585 million, and Pacific geoduck (*Panopea generosa*), with revenues of $72 million. Similarly, early results suggesting red king (*Paralithodes camtschaticus*) and Tanner crab juveniles (*Chionoecetes bairdi and C. opilio*) fare poorly under ocean acidification are worrisome, given that the ex-vessel revenues from king crab (including red, blue, brown king crab) in 2011 were $111 million, and for Tanner crabs they were $15 million. “Snow crab,” referring to anything in the *Chionoecetes* genus, had revenues of $116 million in 2011.

Elevated seawater carbon dioxide levels appear to be the cause of repeated failures at Pacific Northwest oyster hatcheries from 2005-2009 (Barton et al., 2012). The source of the acidified, low pH water varies regionally; along the coast resulting from enhanced upwelling of carbon dioxide rich ocean waters (Feely et al., 2008) with additional contributions from local pollution sources (nutrients, soil erosion) in estuaries and Puget Sound (Feely et al., 2010). The oyster hatchery failures are especially of concern given that:

> “Washington is the country’s top provider of farmed oysters, clams, and mussels. Annual sales of farmed shellfish from Washington account for [more

> than $107 million, which is] almost 85 percent of U.S. West Coast sales (including Alaska) [2]. The estimated total annual economic impact of shellfish aquaculture is $270 million, with shellfish growers directly and indirectly employing more than 3,200 people [3]. Shellfish are also an integral part of Washington's commercial wild fisheries, generating over two-thirds of the harvest value of these fisheries [4]. Licensing for recreational shellfish harvesting generates $3 million annually in state revenue and recreational oyster and clam harvesters contribute more than $27 million annually to coastal economies [5]. Overall, Washington's seafood industry generates over 42,000 jobs in Washington and contributes at least $1.7 billion to gross state product through profits and employment at neighborhood seafood restaurants, distributors, and retailers [6]."

(Quotation from Washington State Blue Ribbon Panel on Ocean Acidification, 2012 and citations therein)

Washington State's story is the best-known story of economic losses due to ocean acidification so far. However, low pH levels in Maine sediments are increasing clam mortality and decreasing harvests, and harvest areas, to levels that are alarming Maine shellfish managers. The Maine shellfish industry is estimated to be worth $60 million a year (Koenig, 2011), and is particularly important in areas of the state where there may be fewer alternative economic opportunities. Potential economic and social impacts extend beyond domestic commercial fishing. Recreational shellfishing, which is typically managed at the local or state levels, supports important sources of seafood, recreational opportunities, and a substantial number of local jobs and coastal economies. Much of the seafood consumed in the United States is imported from abroad, and ocean acidification and climate change put at risk some aspects of global wild-harvest fisheries and aquaculture. Domestic processing, wholesaling and retailing of both domestic and imported seafood supports an important economic sector.

Coral reefs are important for human societies, often supporting locally essential artisanal reef fisheries, and reefs are some of the most valuable marine ecosystems because of tourism and recreation income and coastal protection (Cooley et al., 2009). Ocean warming, coral bleaching, and ocean acidification are highlighted as major risks for the Hawai‘i and U.S. Affiliated Pacific Islands region in the draft 2013 National Climate Assessment (Leong et al., 2013). Ocean warming and acidification could threaten the estimated $385 million Hawaiian coral reefs provide in goods and services annually (Cesar and van Beukering 2004) as well as put at risk subsistence fisheries in Pacific island communities (Maclellan 2009). Over the past decade, the Northwestern Hawai‘ian Islands experienced several mass coral bleaching events, the result of higher sea surface temperatures (Jokiel and Brown 2004; Kenyon and Brainard 2006), and acidification may make corals more susceptible to bleaching. Under business as usual scenarios, the continued loss of coral reefs will likely result in extensive losses in both numbers and species of reef fish; even with a substantial reduction in emissions, reefs could be expected to lose as much as 40% of their reef-associated fish by the end of this century (Pratchett et al. 2011).

Ocean and Global Carbon Cycle

Over the last two centuries, global average atmospheric carbon dioxide has increased by more than 40% from preindustrial levels, from 280 to 395 ppm (parts per million) by mid-2013 (www.esrl.noaa.gov/gmd/ccgg/trends/ Ed Dlugokencky & Pieter Tans, NOAA/ESRL). Temporary excursions to 400 ppm have already been recorded at the Mauna Loa Observatory in Hawai'i. The excess carbon dioxide can be definitively attributed to human activities using carbon isotopes and ice-core carbon dioxide measurements. Many economic and "business as usual" scenarios project atmospheric carbon dioxide values as high as 700 to 1000 ppm by the end of the twenty-first century, levels not experienced on Earth for the past several million years. Excess carbon dioxide persists in the atmosphere for decades to centuries, and the impact of carbon dioxide emissions are global in extent.

Detailed assessments are now available for the global carbon budget (Le Quéré et al., 2013; Global Carbon Project, www.globalcarbonproject.org/). The main source of excess atmospheric carbon dioxide is fossil fuel combustion with contributions from cement production, agriculture and deforestation. For the last decade for which data are available (2002–2011), fossil fuel emissions averaged 8.3 ± 0.4 billion metric tons of carbon per year and grew with time at a rate of 3.1% per year since the year 2000. Deforestation and land-use change accounted for an additional source of 1.0 ± 0.5 billion metric tons of carbon per year.

The ocean plays a critical service by removing excess carbon dioxide emitted to the atmosphere (Sabine & Tanhua, 2010). The global inventory and distribution of excess carbon dioxide in the ocean was first mapped using measurements from an intensive, international survey in the late-1980s and early 1990s. Ongoing observational programs and numerical models continue to document further ocean uptake of carbon dioxide over time. Over the same time period cited above (2002–2011) ocean carbon uptake is estimated at 2.5 ± 0.5 billion metric tons of carbon per year, 27% of global emissions (Le Quéré et al., 2013). Cumulatively since the beginning of the industrial age the ocean is estimated to have removed about 25-30% of total human carbon dioxide emissions. The physical mechanism for the dissolution of excess carbon dioxide into the ocean is well understood. The global ocean uptake rate is governed primarily by the atmospheric carbon dioxide excess and trend, and by the rate of ocean circulation that exchanges surface waters equilibrated with elevated atmospheric carbon dioxide levels with subsurface waters that have not yet been exposed to atmosphere since preindustrial times.

Climate warming is projected to reduce ocean uptake of excess carbon dioxide due to decreased solubility, increased vertical stratification, and slowing of cold deep-water formation (Arora et al., 2013). There is some evidence that climate change is already slowing ocean carbon dioxide uptake (Le Quéré et al., 2010).

Several other factors, including ocean acidification, may either increase or decrease the ocean uptake of carbon dioxide as the ocean warms and acidifies (Denman et al., 2007). The net effect of these other processes is not well known at this time but is thought

to be relatively small compared to overall ocean carbon dioxide uptake over this century (Gehlen et al., 2011). The concern is that the ocean's capacity to absorb excess carbon dioxide may decrease, resulting in an increased growth rates in the atmosphere.

Ocean Acidification and Changing Seawater Chemistry

The ocean uptake of excess atmospheric carbon dioxide, the excess above preindustrial levels driven by human emissions, causes well-understood and substantial changes in seawater chemistry that can affect marine organisms and ecosystems (Doney et al., 2009; Gattuso & Hansson, 2011). Carbon dioxide (CO_2) acts as a weak acid when added to seawater leading to the release of hydrogen ions (H^+) and bicarbonate (HCO_3^-) ions:

$$CO_2 + H_2O \Rightarrow H^+ + HCO_3^-$$

The reaction increases seawater acidity and increases the hydrogen ion activity, thus lowering seawater pH. pH is defined as the negative logarithm of the hydrogen ion activity, so that a 1-unit change in pH is equivalent to a 10-fold change in H^+. Most of the extra hydrogen ions react with carbonate ions (CO_3^{2-}) and lower their ambient concentrations:

$$H^+ + CO_3^{2-} \Rightarrow HCO_3^-$$

This second reaction is important because reduced seawater carbonate ion concentrations decrease the saturation levels of calcium carbonate ($CaCO_3$), a hard mineral used by many marine microbes, plants and animals to form shells and skeletons. Many organisms require supersaturated conditions to form sufficient calcium carbonate shells or skeletons, and biological calcification rates tend to decrease in response to lower carbonate ion concentrations, even when the ambient seawater is still supersaturated.

Long-term ocean acidification trends are clearly evident over the past several decades in open-ocean time-series and hydrographic survey data, and the trends are consistent with the growth rate of atmospheric carbon dioxide (Dore et al., 2009). From preindustrial levels, contemporary surface ocean pH is estimated to have dropped on average from 8.2 to 8.1, or by about 0.1 pH units (a 26% increase in hydrogen ion concentration), and further decreases of 0.22 to 0.35 pH units are projected over this century unless carbon dioxide emissions are significantly reduced (Orr et al., 2005; Bopp et al., 2013).

Global upper-ocean chemistry trends driven by human carbon dioxide emissions are more rapid than variations in the geological past (Hönisch et al., 2012). For example, atmospheric carbon dioxide grew by approximately 30% during the transition from the most recent cold glacial period, about 20,000 years ago, to the current warm interglacial period; the corresponding rate of decrease in surface ocean pH, driven by geological processes, was approximately 50 times slower than the current rate driven largely by fossil fuel burning. Many marine organisms appear to be physiologically adapted to relatively constant local acid-base conditions and are sensitive to relatively small variations in pH and the saturation state of calcium carbonate.

Present-day ocean surface waters are supersaturated for the major carbonate mineral forms used by marine organisms, including the more soluble form aragonite (corals, many mollusks) and the less soluble form calcite (coccolithophores, foraminifera, and

some mollusks). However, calcium carbonate saturation states of both mineral forms are declining everywhere. Polar oceans are of particular concern because cold surface waters naturally hold more carbon dioxide and started off with lower calcium carbonate saturation states. Model simulations indicate that polar surface waters will become undersaturated for aragonite in the near future for the Arctic (atmospheric carbon dioxide of 400-450 ppm) and by mid-century for the southern ocean off the Antarctic (atmospheric carbon dioxide of 550-600 ppm) (Orr et al., 2005; Steinacher et al., 2009). This is expected to result in major changes in polar ecosystems.

Other ocean regions also may be more susceptible to aragonite undersaturation because of elevated background levels of carbon dioxide. These include eastern boundary current upwelling systems such as those off the U.S. west coast along coastal California, Oregon and Washington (Feely et al., 2008; Gruber et al., 2012), deep-sea and subsurface oxygen minimum zones (Brewer & Peltzer, 2009), and coastal waters that are already experiencing excess nutrient levels (eutrophication) and low dissolved oxygen (hypoxia) due to human-driven nutrient pollution from land-based activities (Feely et al., 2010; Cai et al., 2011). Nutrient overloading near shore encourages algal growth that is consumed by microbes, using up dissolved oxygen and releasing even more carbon dioxide locally. Coastal, estuarine, and coral reef systems also experience high levels of temporal variability on diurnal to weekly time-scales (Hofmann et al., 2011), challenging both observational efforts and interpretations of biological experiments.

In addition to ocean acidification, marine ecosystems are also already experiencing large-scale changes in physical climate and reduced subsurface oxygen (Doney, 2010; Gruber, 2011; Doney et al., 2012). Documented physical trends relevant to marine biota include rising sea surface temperature, upper-ocean warming, sea-level rise, altered precipitation patterns and river runoff rates, and sea-ice retreat in the Arctic and west Antarctic Peninsula (Bindoff et al., 2007).

Observations and numerical models show strong links between upper ocean temperature and the distributions of marine organisms. Based on satellite data, warming leads to declining tropical and subtropical productivity of phytoplankton at the base of the marine food web as well as expansion of the area of surface waters with very low plankton biomass (Behrenfeld et al. 2006; Polovina et al. 2008). Warming over the past few decades has resulted in the migration of commercial fish stocks poleward and in to deeper water (Nye et al. 2009), and productivity of fisheries is predicted to decline in the lower 48 states, while increasing in parts of Alaska (Cheung et al. 2009). Climate change also influences the spread and impact of marine diseases and parasites (Harvell et al., 2002). Marine disease appears to be on the rise with time, with warmer sea surface temperatures linked with higher intensity and increased spatial ranges of diseases that attack corals, abalones, oysters, fishes, and marine mammals (Ward & Lafferty, 2004).

Biological Impacts of Ocean Acidification

Ocean acidification and climate change effects arise both directly, via effects of warming, elevated carbon dioxide, and lower pH and carbonate ion concentrations on individual organisms, and indirectly via changes to the ecosystems on which they depend

for food and habitat (Doney et al., 2009; Doney et al., 2012). The potential biological consequences due to acidification are slowly becoming clearer at the level of individual species, but substantial uncertainties remain particularly at the ecosystem level (Gattuso et al., 2011). Ocean acidification and climate change acts as a stress on marine ecosystems will likely also exacerbate other human perturbations such as over-fishing, habitat destruction, pollution, excess nutrients, and invasive species.

Ocean acidification studies have been conducted for many economically and ecologically important species from both water-column (Riebesell & Tortell 2011) and seafloor or benthic (Andersson et al., 2011) environments. Most biological impacts are measured from short-term manipulation experiments in the laboratory where organisms are exposed to elevated carbon dioxide. In a recent meta-analysis of available scientific literature studies up until 2012, Kroeker et al. (2010; 2013a) found the following statistically significant effects:

calcifying algae	decreased abundance and photosynthesis
coral	decreased abundance and calcification
coccolithophores	decreased calcification
mollusks	decreased growth, calcification, and survival
echinoderms	decreased growth
fleshy algae	increased growth
diatoms	increased photosynthesis and growth

Recently published laboratory studies indicate additional potential negative ocean acidification effects for juveniles of valuable Alaskan crustacean species (Long et al., 2013a; 2013b).

red king crab	decreased growth and molting success
Tanner crab	decreased survival

Pteropods, a group of small planktonic marine mollusks, appear to be especially sensitive to ocean acidification (Orr et al., 2005). Pteropods are abundant in temperate and some subpolar waters and are important prey for juvenile fish. In shipboard incubations, elevated carbon dioxide levels causes dissolution of the shells of living pteropods, and in the present-day Southern Ocean there is evidence that pteropod dissolution is already occurring in some subsurface locations where seawater is undersaturated with respect to aragonite, the more soluble form of calcium carbonate (Bednaršek et al., 2012). A similar phenomenon may arise in the future in the North Pacific and off the U.S. West Coast as seawater conditions become more acidic.

A number of factors may influence the sensitivity of organisms to ocean acidification. Growing evidence indicates that warming amplifies sensitivity to ocean acidification (Kroeker et al., 2013a). Organism response also may vary with life-history stage; juvenile mollusks, for example, are often more susceptible than adults. Nutritional status may be important, and well-fed organisms may be better able to adjust to ocean acidification (Holcomb et al., 2012; Thomsen et al., 2013). In general, some species may be able to accommodate elevated carbon dioxide but at an additional energetic cost with negative consequences for development, reproduction and fitness. However, a recent

study looking across ocean regions with naturally low pH found that several species within a major group of stony coral (genus *Porites*) were not able to acclimate to ocean acidification at least with respect to skeletal growth and development (Crook et al., 2013)

Tropical corals appear to be particularly susceptible to the combination of ocean acidification and ocean warming, which would threaten the rich and biologically diverse coral reef habitats (Hoegh-Guldberg et al. 2007). Coral polyps are small animals that contain symbiotic algae. The coral-algal symbiosis is sensitive to minor increases in maximum seasonal temperature, and warming of as little as 1°C can cause coral bleaching, the expulsion of the colored algae that weakens the coral and can lead to coral death (Hoegh-Guldberg et al. 2007, Donner 2009). Acidification appears to make some corals more sensitive to thermal bleaching (Anthony et al., 2008) as well as making it more difficult for corals to secrete and maintain their skeletons (Salvat & Allemand 2009). Acidification is also a threat to other important reef calcifying organisms, such as crustose coralline algae that help build reef frameworks (Kuffner et al. 2008; Anthony et al., 2008; Johnson & Carpenter 2012).

Stony corals help build and maintain coral reefs, and decreases in growth can leave them less able to rebound from natural breakdown processes. In preindustrial times, nearly all coral reefs in or bordering the open ocean were located in water with sufficient carbonate ion concentrations to building hard skeletons (aragonite saturation state above 3.5) (Ricke et al., 2013). But by mid-century, model projections with even rather modest increases in atmospheric carbon dioxide (by 2050 about 475 ppm carbon dioxide) indicate that 50% or fewer of these coral reefs will still be surrounded by ocean waters with carbonate ion concentrations above this threshold to which they acclimated for thousands of years.

Coral and coralline algae losses decrease the structural complexity of the coral reef seascape and therefore the capacity of reefs to provide shelter and other resources for other reef-dependent species of fish and invertebrates (Alvarez-Filip et al. 2009). Because one-quarter of all marine species associate with coral reefs, the ecological impacts of changing climates and chemistry on overall marine biodiversity are potentially severe and widespread. About 75% of the world's coral reefs are threatened due to the interactive effects of climate change and local sources of stress, such as overfishing, nutrient pollution, and disease (Burke et al. 2011; Dudgeon et al. 2010; Hoegh-Guldberg et al. 2007; Hughes et al. 21 2010). In Florida, all reefs are rated as threatened, with significant impacts on the valuable ecosystem services they provide (Mumby and Steneck 2011). Caribbean coral cover has decreased from 50% to only 10% historic reef areas, an 80% reduction in less than three decades (Gardner et al., 2003).

Effects of ocean acidification on many natural populations and communities have been difficult to detect so far. An exception is studies of natural high-carbon dioxide environments, such as shallow volcanic vents, that generally support the conclusions found in laboratory studies (Hall-Spencer et al., 2008; Fabricius et al., 2011; Inoue et al., 2013). For example, Kroeker et al. (2013b) report on pH effects for benthic ecosystems surrounding seafloor carbon dioxide vents in the Mediterranean Sea. Ambient seawater in

the study region had a pH of 8.0 while acidified, low pH waters has a pH of about 7.7, roughly equivalent to surface ocean conditions expected at the end of this century under business as usual emission scenarios. In low pH waters, mollusks and crustaceans were less abundant, invertebrates with little or no calcification in their exoskeletons were more abundant, and the food web became simplified with more generalist species present. Kroeker et al. conclude that ocean acidification reduces the diversity, biomass, and food-web complexity of benthic marine communities. These high-carbon dioxide, low pH environments may be a window on the future under elevated atmospheric carbon dioxide conditions.

Adaptation and Mitigation Strategies

We have an opportunity now to limit negative ocean acidification impacts that are already underway and address future impacts that are expected to grow over the next several decades because of increasing atmospheric carbon dioxide levels. This will require a comprehensive strategy that balances adaptation to the amount of ocean acidification that is unavoidable and mitigation to reduce the further rise in atmospheric carbon dioxide. Decisions should incorporate precautionary considerations to account for the fact that potential carbon dioxide thresholds are presently unknown for many aspects of ocean acidification. Implementing adaptive management is also warranted because it can take advantage of new information as it becomes available. Further, it is important to recognize that many of the geoengineering strategies being proposed to mitigate future climate change, such as stratospheric aerosols to control solar albedo, will not reduce ocean acidification.

The Washington State Blue Ribbon Panel on Ocean Acidification (2012) outlined a series of recommended actions that could form the framework for action at the state, national and international levels. Critical tasks include:

- Reduce emissions of carbon dioxide to the atmosphere through a combination of increased energy efficiency, switching to renewable energy sources, and exploring the potential and challenges of carbon sequestration approaches;
- Reduce local land-based contributions to ocean acidification including excess nutrients from fertilizers and agriculture, organic matter from soil erosion, and local acidifcation from atmospheric deposition of pollutants;
- Increase our ability to adapt to and remediate the impacts of ocean acidification including approaches to sustain wild-harvest fisheries and aquaculture;
- Invest in our ability to monitor and investigate the causes and effects of ocean acidification;
- Inform, educate, and engage stakeholders, the public, and decision makers in responding to ocean acidification;
- Reduce other human disturbance factors such as overfishing and coastal habitat destruction to allow more time for ecosystems and social systems to adjust to ocean acidification and climate change.

Thank you for giving me this opportunity to address the Committee, and I look forward to answering your questions.

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