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CLAREMONT MCKENNA COLLEGE

THE CONSEQUENCES OF INCREASING OCEAN ACIDIFICATION ON LOCAL AND GLOBAL FISHING INDUSTRIES

SUBMITTED TO

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AND

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BY

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Table of Contents

Chapter 1: Introduction to Ocean Acidification…….....……...…1

Chapter 2: Ocean Acidification in the Pacific Northwest…….....10

Chapter 3: Ocean Acidification in a Global Context…….....24

Chapter 4: Economic and Policy Recommendations to Mitigate the Impacts of Increasing Ocean Acidification……..…….35

Chapter 5: Conclusion…….……..…...42

References…….....48

Chapter 1: Introduction to Ocean Acidification

"Climate change may be all over the headlines, but it has an evil twin, caused by the same invisible gas carbon dioxide, with more measurable, rapid and seemingly unstoppable effects. By answering the main questions people have about ocean acidification, we intend to break through the ignorance and confusion that exist, so everyone is clearer on what is happening and why this is a matter of the highest global priority."[1]

- Dan Laffoley, Marine Vice Chair of IUCN's World Commission on Protected Areas.

Climate change is quickly affecting many social and economic sectors, both directly and indirectly. This is particularly true within the natural resource sector, as varying economic impacts call for changes in management policy. While many problems such as warmer temperatures and rising sea levels are attributed to increasing carbon dioxide (CO_2), there is one crucial problem that is often overlooked: Ocean acidification. As pH levels in the ocean fluctuate, there are devastating effects on sensitive marine ecosystems and individual species. Increased acidic conditions can pose threats to habitats, such as coral reefs and sea grasses[2]. These living habitats rely on calcium carbonate to form strong external structures, yet higher pH levels inhibit the organisms' ability to successfully absorb the compounds needed for this process. Additionally,

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[1] People & the Planet. *Ocean acidification a serious threat*, November, 2010, 1.
[2] Guinotte, J., and Fabry, V., 2009. Ocean acidification and its potential effects on marine ecosystems. Annals of New York Academy of Sciences, 1134, 320.

higher levels of ocean acidification can induce decreases in skeletal-forming compounds, diminishing entire populations of small ocean organisms such as crustaceans and phytoplankton.[3]

Chemistry of Climate Change

Before attempting to understand the complexities and problems associated with increased ocean acidification, it is important to have background knowledge of the greater climate change phenomenon. A buzz phrase of today's society, "climate change" can be mostly attributed to an increase in the gases which prevent heat from escaping into the atmosphere, therefore, causing global temperatures to be generally hotter. Although certain parties argue that this is a natural part of the earth's climate pattern, recent scientific evidence strongly points to human caused events and actions as explanations for the rapid increase in these gases and the generally perceived rising temperatures. The heat trapping gases include carbon monoxide (CO), carbon dioxide (CO_2), and nitrogen oxides (NO_x), collectively known as "Green House Gases" or "GHGs". Activities such as smelting, agriculture, from fossil fuel combustion, cement manufacturing, iron and steel production, municipal solid waste combustion and deforestation[4] are all activities that have been shown to contribute to the anthropogenic increase of greenhouse gases. However, while these activities do pose a concern to the chemical composition of the atmosphere, societies have evolved to the point where these activities are critical to daily life and standards of living. Further, in developing nations, there are likely to be more GHG enhancing activities as these countries are struggling to do what developed countries did a century ago; dramatically increasing production, urbanism, and energy.

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[3] Doney, S., Fabry, V., Feely, R., and Kleypas, J., 2009. Ocean acidification: The other CO2 problem. Annual Review of Marine Science, 1, 169-171.
[4] Guinotte, J., and Fabry, V., 320.

However, unlike a century ago, the base health level of the atmosphere is in far worse shape, increasing the negative effects of this growth from nations.

Chemistry of Ocean Acidification

From this understanding of the basics of the current climate change phenomenon, connections can be drawn to how human activities, particularly those that increase CO_2, directly contribute to the rise of anthropogenic ocean acidification. Simply stated, increased anthropogenic CO_2 in the atmosphere increases the amount of concentrated CO_2 in the ocean waters. Approximately one-third of the atmospheric CO_2 released will be sequestered in the ocean[5] at a rate of 22 million tons per day.[6] As the CO_2 in the water increases, however, the carbonate ion concentration decreases, as does the ocean pH, leading to increased acidity.[7] These changing conditions will have diverse effects on the oceanic ecosystems. The increase in acidity and consequential decrease in calcium carbonates is predicted to primarily affect plankton and calcifying shelled organisms. Yet, as many of these smaller organisms are keystone species, their abilities to successfully survive and reproduce can greatly impact larger species through trophic level interactions.

History of Ocean Acidification Research

The phenomenon that became known as ocean acidification was first described in the early 1970s. Scientists focused primarily on the basic chemistry between surface water and atmospheric CO_2 interactions and the thermodynamics of the ocean's carbon

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[5] Cooley, S., and Doney, S., 2009. Anticipating ocean acidification's economic consequences for commercial fisheries. Environmental Research Letters, 4, 1-2.

[6] Feely,R., Sabine, C., and Fabry, V., 2006. Carbon dioxide and our ocean legacy. Pew Charitable Trusts Science Brief, 1-3.

[7] Hauri, C., Gruber, N., Plattner, G., Alin, S., Feeley, R., Hales, B., Wheeler, P., 2009. Ocean acidification in the California Current System. Oceanography, 22: 60-71.

system. Doney *et al.* (2009) notes that while researchers were investigating was ocean acidification, the full causes and effects were still unknown at that point:

> "Although these early authors all presented calculations to show that CO_2 emissions would likely cause undersaturation with respect to aragonite and calcite at some point, their estimates of when this might happen varied greatly because of a lack of agreement on carbon system equilibrium in seawater at the time. As more laboratory and field results were published in the 1980s, it became clear that the high-latitude regions of the ocean would first become undersaturated…"[8]

In the 1990s, surveys and more intensified research were underway, as scientists strived to quantify the effectiveness of the ocean to serve as a carbon sink, absorbing anthropogenic CO_2 from the earth's atmosphere. More recently, the biological and physical effects of ocean acidification on ecosystems have been a focus of study. Due to extensive laboratory and field research, it is now know that many species, beyond calcifying organisms, may be negatively affected by changes in ocean chemistry.[9] Further, scientists were joined by both policy makers and economists in evaluating the impact that increasing acidity could have on individual communities and economies, as well as global markets.

Physical Environmental Consequences of Ocean Acidification in Marine Ecosystems

Ocean acidification also has underappreciated, though equally significant, physical impacts on oceanic ecosystems. Brewer and Hester (2009) studied how decreasing seawater pH can have significant impacts on the oceanic sound waves. Acidic water affects the populations of species which are heavily pH-dependent, such as borate and carbonate ions. As a result, the ability of these species to absorb acoustic waves

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[8] Doney, S., Balch, W., Fabry, V., and Feely, R., 2009. Ocean acidification: A critical emerging problem for the ocean sciences. Oceanograpy, 22, 16-17.

[9] Doney, S., Balch, W., Fabry, V., and Feely, R., 18.

changes, often dramatically with even minimal variations in seawater pH[10]. For example, the researchers found that by mid-century, the atmospheric CO_2 levels and resulting acidification could cause pH in waters to drop 0.3 units, causing "a 40% decrease in the intrinsic sound absorption properties of surface seawater."[11] Such substantial changes in sound properties could present problems for many of the oceans species, such as whales, which rely on sound waves for communication, mating, and hunting. Moreover, the military consequences of these changes could be problematic for naval units worldwide, as sonars and other oceanic tools rely on sound waves.

In addition to affecting the oceanic sound properties, it is possible that the light properties may also be influenced by changes in calcium carbonate concentrations brought upon by increasing acidity. The calcium carbonate particles in ocean water play a role in the scattering and trajectory of the light waves.[12] In such "decalcified" waters, the reduced light attenuation could result in deeper euphotic zones, the primary production regions where there is sufficient light exposure for photosynthesis to occur. It is possible that extension of the euphotic zones may have implications for biogeochemical aspects of the ecosystems. Millero, *et al.* (2009), examined how increasing both acidification and the photosynthetic range can change the interactions between metals and organisms in the ocean surface waters. The research showed that decreases in hydroxide and carbonate, as a result of increased CO_2 and decreased pH, can affect "the solubility, absorption, toxicity, and rates of redox processes of metals in seawater."[13]

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[10] Brewer, P., and Hester, K., 2009. Ocean acidification and the increasing transparency of the ocean to low frequency sound. Oceanography, 22, 86-93.
[11] Brewer, P., and Hester, K., 87.
[12] Balch, W., and Utgoff, P., 2009. Potential Interactions among ocean acidification, coccolithophores, and the optical properties of seawater. Oceanography, 22, 147-148.
[13] Millero, F., Woosley, R., DiTrolio, B., and Waters, J., 2009. Effect of ocean acidification on the speciation of metals in seawater. Oceanography, 22, 72-85.

Biological Consequences of Ocean Acidification in Marine Ecosystems

The biological effects of ocean acidification on marine ecosystems are complex and severe. As discussed, the main focus of research up until recently has been on the effects of organisms which require calcium carbonate to form shells and skeletal structures. When the ocean takes up CO_2, it combines with seawater to form carbonic acid, which in turn decreases the concentration of carbonate. Also, the joint presence of increased acidity and warmer oceanic temperatures affects the concentrations of calcite and aragonite saturation. In cases where the surrounding environment is undersaturated, these compounds are prone to dissolving, and calcium carbonate formation becomes unfavorable. The transitional areas between saturated and undersaturated waters, called saturation horizons, are becoming shallower with increasing oceanic CO_2 concentrations. This progression, referred to as shoaling, will therefore make coasts and coastal species more susceptible to the effects of ocean acidification.[14] The combination of lowered oceanic pH and decreased availability of skeleton and shell forming compounds generates a high corrosive ocean environment for species of shellfish, coralline algae, corals, and planktons. For these species, fluctuating levels of available aragonite and calcite greatly influence population size. For example, many bivalve crustaceans, such as scallops and clams, absorb the carbonate directly from ocean water. Therefore, even the slightest changes in water chemistry can result in very large complications for the population, especially with regards to reproduction and future generations.

Although calcifying organisms are more directly affected by ocean acidification, these predictions also have dangerous implications for many fish populations and, moreover, many fishery based economies. The impacts of increasing acidification on

[14] Guinotte, J., and Fabry, V., 320-336.

calcifying organisms will present particular challenges to markets which rely on commercially important shellfish species, such as clams, oysters, crabs, and sea urchins. Yet, elevated CO_2 concentrations in oceans can accelerate acidosis in tissues of marine organisms, causing hypercapnia in fish[15]. In an analysis of fish physiological responses to ocean acidification, Guinotte and Fabry (2008) found that short term impacts of increased CO_2 included alterations of the acid-base status, respiration, blood circulation, and nervous system functions. This is particularly dangerous to fish populations as the juveniles are more sensitive to environmental change, and population declines are caused by "a gradual reduction in population size and changes in marine ecosystem structures are unavoidable consequences when young individuals cannot survive."[16] Additionally, many fish farms rely on feed that is produced by smaller fish, such as sardines, that have been found to be negatively impacted by increasing acidification. If the fish stocks of these small fish decline due to decreased pH, the production of larger and more commercially valuable fish will also be scaled back.

Although the economic impacts of declining fisheries due to ocean acidification are difficult to predict and quantify, it is likely that fishing industries will experience diminishing revenues, increased investment and effort required to produce catches, and lowered economic resilience.[17] Global fisheries take in an estimated $85 billion annually, but the total economic impact is tripled, generating approximately $240 billion every

[15] Guinotte, J., and Fabry, V., 332.
[16] Guinotte, J., and Fabry, V., 332.
[17] Cooley, Sarah and Doney, Scott, 2009. Ocean acidification's impact on fisheries and societies: A U.S. perspective. Journal of Marine Education, 25, 15-24.

year. Essentially, every dollar of gross revenue that is generated by the global fisheries sector supports nearly $3 throughout the global economy.[18]

According the 2008 *State of World Fisheries and Aquaculture Report* composed by the United Nation's Food and Agriculture Organization (FAO), the percentage of fish proteins intake took off during the 1990's and continue to be a significant contributor to the overall global animal protein intake. However, aggressive over-exploitation of global fishery resources has led to dramatic decreases in populations; it is currently estimated that 70 percent of the world's fisheries have been depleted.[19] The devastating effects of unsustainable fishery management will be greatly exacerbated by increasing acidification, which will threaten the food security of many communities that depend on primarily on fish for protein. Moreover, areas that have little alternative to fish protein will be more affected and the effects will be more severe for areas that have larger fish resources. For example, in Southeast Asia and Africa, fish compose of 21 and 28 percent of the protein intake, respectively, whereas in North America, fish only account for 7 percent of the protein intake.[20]

This thesis will explore both local and global effects of ocean acidification, as well its implications for economies and policies. The second chapter examines ocean acidification from a local perspective and details the population, economic, and political impacts of increasing acidic waters in the Pacific Northwest region of the United States. The third chapter considers the same three criteria as the previous chapter, but does so from a global perspective. The next chapter outlines economic and policy

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[18] Dyck, A.J. and U.R. Sumaila. 2010. Economic impact of ocean fish populations in the global fishery. *Journal of Bioeconomics*, 10.
[19] United Nations' Food and Agriculture Organization. *World Review of Fisheries and Aquaculture.* State of World Fisheries and Aquaculture Report, 2008.
[20] Field, Barry. Natural Resource Economics. Waveland Press, 2008, 239-260.

recommendations in anticipation for the consequences of ocean acidification. The final chapter is a conclusion of the research, including an analysis of ocean acidification predictions and future areas of study.

Chapter 2: Ocean Acidification in the Pacific Northwest

Examining the waters of the Pacific Northwest provides an adequate indication of how ocean acidification may specifically impact the United States oceanic ecosystems and fishing industry. This region stretches from the coasts of California up to Washington and the edge of the Arctic region, and the economic scope of the fishing industry often expands to include the Alaska region. The Pacific Northwest region is responsible for annually producing millions of metric tons of pelagic fish and shellfish, comprising 25.4 percent of the American fish and aquaculture production.[21] This chapter will examine the anticipated effects of ocean acidification for the fishery populations in this region and the resulting implications for economies and policies in the Pacific Northwest.

Ocean Acidification's effects on the fishery populations of the Pacific Northwest

Although it is difficult to determine exactly what effects ocean acidification will have on the Pacific Northwest region, there are some predictions based on regional studies and experiments. In examining both the positive and negative impacts of increasing acidity, the first critical factor to consider is the results on fishery populations. As with most environmental variables, ocean acidification will be detrimental to some species. However, while some species may not be able to adapt, others may find these

[21] United Nations' Food and Agriculture Organization. *Fishery Country Profile: The United States of America*. 2005

conditions to be more favorable, thereby finding a competitive advantage in the presence of acidic environments. For example, studies have found that species which have already been exposed to high environmental pCO_2 will likely be less vulnerable to the effects of rising acidification.[22] Yet decreasing levels of pH and calcium carbonate, coupled with rising oceanic temperatures, create concern for the Pacific Northwest where many profitable fish stocks, among them, salmon, steelhead, cod, and trout, could be devastated.

Many studies have demonstrated that fish populations, including those of the Pacific Northwest, are highly sensitive to the immediate surrounding environment.[23] One example of this sensitivity is the fish population response to environmental changes from one stable state to another stable state. This occurrence, known as a regime shift, will often coincide with fluctuations in species populations or ecosystem changes.[24] A National Oceanic and Atmospheric Administration (NOAA) essay demonstrated that in the Pacific Northwest, climate regime shifts caused by the Pacific Decadal Oscillation (PDO) are responsible for notable growth in populations of pelagic species in the 1970s, followed by a restructuring of the complete ecosystem.[25] Climate factors that affect the physical environment of the fisheries thereby profoundly affect the corresponding populations, sometime causing entire reorganization of the surrounding ecosystem. The health of fisheries is also subject to noncyclical changes, including chemical composition. Thus conditions that are more acid are exacerbated by the natural sensitivity of fish

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[22] Melzner, *et al.*, 2009. Physiological basis for high CO2 tolerance in marine ectothermic animals: pre-adaptation through lifestyle and ontogeny? Biogeosciences, 6, 2313-2331.
[23] Noakes, D., and Beamish, R., 2009. Synchrony of marine fish catches and climate and ocean regime shifts in the North Pacific Ocean. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, 1, 155-168.
[24] Noakes, D. and Beamish, R., 156-159.
25 Bond, N., 2003. Recent shifts in the state of the North Pacific. Geophysical Research Letters 30, 2183.

populations to environmental variability. This is important when discussing changes in ocean pH, as the predicted change of 0.2 – 0.3 may appear inconsequential without the proper context. However, given that the ocean pH has decreased a mere 0.1 since the industrial revolution,[26] in the context of fish populations, a pH change to the magnitude of 0.3 could dramatically deplete stocks.

Additionally, studies have already been conducted to see how specific populations in the Pacific Northwest might react to ocean acidification. Salmon, an abundant species in this region, are particularly dependent on stable environmental conditions. Therefore, as climate change impacts the physical conditions of the salmon in the Pacific Northwest, it is likely that the salmon will respond. The range of these responses can span from nongenetic changes, such as fitness and plastic phenotypic changes, to evolutionary changes. It seems likely that evolutionary changes are possible due to past physiological and behavioral changes that occurred to adapt to local climates. However, these changes are difficult to prove, and therefore it is especially crucial to note the reciprocity of both genetic and plastic responses.

Crozier, *et al.* (2009) tested this theory with specific reference to the Colombia River Basin spring/summer Chinook (*Oncorhynchus tshawytscha)* and the sockeye (*Oncorhynchus nerka)* salmons. The life histories of salmon are complex and span over many different climatic conditions in the Pacific. This life history diversity displays "phenotypic plasticity in response to variable environmental conditions" and such plasticity permits salmon to establish new populations in various habitats and respond well to local environmental change. However, Crozier *et al*. anticipates that the two

[26] Feeley, R., Doney, S., Cooley, S., 2009. Ocean acidification: Present conditions and future changes in a high CO_2 world. Oceanography, 22, 36-47.

salmon species will be less able to easily adapt to climate change. The paper notes that three factors will affect the salmon with regards to climate change: rising ocean surface temperatures, changing water chemistry and nutrient composition from surface wind patterns, and increasing ocean acidification.

Another study, conducted by Hauri, *et al.* (2009), looked at the specific impacts of ocean acidification on a variety of species within the range of the California Current System (CCS). These ecosystems are particularly prone to increased acidification due to the heavy presence of the eastern boundary upwelling system (EBUS), which increases coastal upwelling of water that is richer in nutrients and CO_2 and causes lower pH and oxygen levels at the ocean's surface. It is likely that the latitudinal location of the Pacific Northwest increases the vulnerability to acidification:

> "To date, attention has been focused on surface waters at high latitudes, which have a naturally low pH…because thermodynamic factors support high dissolved inorganic carbon (DIC) concentrations relative to alkalinity for the same atmospheric CO_2 levels."[27]

The study couples an ecological-biogeochemical model with a Regional Ocean Modeling System (ROMS) to gage the decreased pH and aragonite saturation. The results show low levels of aragonite along the coastal area, but particularly concentrated in the 41°N- 42°N region near the California-Oregon border. Further, the saturation levels have a position relationship with water depth and become deprived of aragonite at unexpectedly shallow depths. Hauri, *et al.* then predicted and assessed the vulnerability of regional species. The populations that are found to be most vulnerable are those that are highly sensitive to changes in calcification caused by more acidic conditions. It is significant to note that the

[27] Hauri, C., Gruber, N., Plattner, G., Alin, S., Feeley, R., Hales, B., Wheeler, P., 61.

species categorized as "High Vulnerability" are comprised of both flora and fauna, implying that the range of organisms affected is broad.

When examining the responses of vulnerable organisms to acidification, it is important to consider the prior exposure of organisms to water with lower pH and saturation levels.[28] If these organisms have sufficiently adapted to variability in ocean chemistry, than they may be more tolerant of future changes in acidic conditions. Yet, these predictions are only likely if the variability stays within a specific range and most all other environmental factors are stable. As Hauri, *et al.,* point out, "the growth and success of an individual species in a changing ocean depends on many environmental factors", including chemical composition, abiotic and biotic factors.

The Impacts of Ocean Acidification on the Economy in the Pacific Northwest

While ocean acidification continues to take a toll on oceanic ecosystems and fish populations, it also has dire implications for coastal fisheries and fish and aquaculture based economies. This section will examine the economic consequences that are expected to accompany ocean acidification. The majority of the markets and corresponding species discussed will be those which heavily rely on acid-intolerant calcium carbonates, such as shellfish and corals. However, due to the unique nature of oceanic ecosystems, changes that affect one species could potentially impact whole regions:

> "Beyond their direct commercial value, many calcifying species are located at the bottom or middle of the marine food web; therefore the effects of ocean acidification will likely be transmitted throughout ecosystems by predator-prey relationships. Nearly all commercially harvested wild finfish species prey to some extent on shellfish and crustaceans or their predators…This indirect pressure would likely reduce harvests of commercially important predators…"[29]

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[28] Hauri, C., Gruber, N., Plattner, G., Alin, S., Feeley, R., Hales, B., Wheeler, P., 67-69.
[29] Cooley, S., and Doney, S., 2.

Thus, the indirect effects of ocean acidification on food chains and larger pelagic species will also be considered in the economic analysis. Additionally, research on ocean acidification and individual economic regions is still largely fragmented. To gain a greater and more detailed understanding of the larger scope of the acidification phenomenon, this section will begin by examining the likely effects on the entire United States fishing industry. Following this overview, individual locations and species examples will be discussed to demonstrate the localized economic effects on the Pacific Northwest.

According to a 2005 report released by the FAO, the United States was the 4th largest fish producer exporter, annually producing a catch of over 4,320,00 metric tons, with 3,070,00 tons exported every year.[30] The monetary contributions of the nation's fishing industry are also notable: the primary sales (the amount paid to fisherman) in the United States during 2006 was approximately $4 billion, while sales totaled $70 billion, leading to a $35 billion net contribution of GNP.[31] The initial national concern with regards to ocean acidification is the loss of revenue from this thriving industry. The United States fishing industry is, like most nations, already suffering from over-exploitation and poor stock management. These hardships, coupled with the crippling effects of rising acidity, will result in most fish populations being depleted at an unanticipated, and unpredictable, rate. Additionally, as the fishing industry is a thriving global market, the production in the United States not only affects the national economy, but the global economy as well. Therefore, the impacts of ocean acidification are magnified as the scope broadens:

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[30] United Nations' Food and Agriculture Organization. *Fishery Country Profile: The United States of America*. 2005

[31] Cooley, S, and Doney, S., Ocean acidifications impact on fisheries and societies: A U.S. perspective, 15

> "Given the declining importance of marine capture fisheries in total global fisheries production, and the potential for ecosystem and human adaption, it seems reasonable to assume that the direct impacts associated with ocean acidification might eventually impose costs on the order of 10% of marine fishery production, perhaps on the order of $10 billion/year."[32]

In 2006, the US commercial fishing industry alone was responsible for approximately 70,000 fisherman jobs. In that same year, the wide scope of recreational fishing supported an estimated 530,000 jobs.[33]

In the Pacific Northwest, fishing is both a large scale commercial industry and a small, traditional way of life. In addition to sharing a region, the two sides of the spectrum share another similarity; both provide the region with a substantial amount of jobs. The fisheries in the Pacific Northwest serve as a dominant employer given the coastal location and close proximity to some of the nation's richest fish stocks. In 2007, the North Pacific area was responsible for generating approximately 35,000 harvesting and processing jobs.[34] The demand for fishing-related jobs and revenue has increased within the last few decades, as the local communities transition away from economies that had traditionally relied exclusively on logging.[35]

One area of the Pacific Northwest fishing industry that is in particular danger of facing large economic consequences is the market for shellfish. This market is composed of calcifying organisms that can be divided into two groups based on the process by which the carbonate structures are formed. The first group includes economically

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[32] Kite-Powell, H., 2009. A global perspective on the economics of ocean acidification. The Journal of Marine Education, 25, 25-29.
[33] Cooley, S, and Doney, S., Ocean acidifications impact on fisheries and societies: A U.S. perspective, 15-16.
[34] The Research Group, Corvallis Oregon. *North Pacific salmon fisheries economic measurement estimates.* Wild Salmon Center, Portland Oregon, 2009.
[35] Burkett, M. , 2008. "Is this picture in danger of disappearing?". *The Daily Astorian*, December 26, 2008, 1.

valuable mollusks, such as scallops and oysters, which directly deposit $CaCO_3$ into the shell walls and thus depend on a large amount of environmental carbonate concentrate and stable chemical conditions to successfully create a shell. Organisms that have higher biological control over calcification, including lobsters, crabs, shrimp, and sea urchins, are able to accumulate carbonate ions over extended times and are, as a result, less sensitive to water chemistry. However, both groups depend on carbonate concentrations, which are likely to decline with more acidic conditions. Although it is predicted that lowered concentrations will negatively affect the fitness of these shellfish, it is possible that some species may be able to form shells in high CO_2 conditions. Yet, the process would likely occur at a high energetic cost, which would further compromise both survival and the reproductive fitness of the species.[36]

The shellfish populations are vital to the fishing industry, with mollusks and crustaceans yielding 19% and 30%, respectively, of the annual US commercial fishing harvests.[37] Shellfish production in the Pacific Northwest is valued approximately $l11 million, making this sector vital to the fishing industry in that region.[38] In 2005, the Pacific Coast Growers Association estimated that over 106 million pounds of shellfish were produced in combined Washington, California, Oregon, and Alaska regions; further, 89 percent of the production was composed of oysters.[39] Future economic predictions demonstrate that regions which rely primarily on calcifying organisms can expect significant revenue losses from increasing seawater acidification. Cooley and Doney (2009), employed time-integrated net present values to project economic losses from

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[36] Cooley, S., and Doney, S., 5.
[37] Cooley, S., and Doney, S., 3.
[38] Nickel-Kailing, G. "Part 3: Shell fish production in the Atlantic and Pacific". *Food CEO*, June 2, 2010, 1.
[39] Nickel-Kailing, G., 1.

declined mollusk production in the year 2060 given various CO_2 and acidification situations. They found that, in the Pacific Northwest, the median range of economic loss resulting from a low-end 10 percent decrease of mollusk harvest was $71-177 million, whereas the median range of economic loss from the high-end decrease (25 percent) in harvests was $119-298 million. [40]

Fishery Management Responses to Ocean Acidification in the North Pacific

Currently there are several government agencies and programs that are devoted to preserving the integrity and health of the United States coastal waters. In the Pacific Northwest the responses to changing climate and ocean chemistry range from government backed councils, to legislative initiatives, to awareness increasing programs led by independent interest organizations. This section will identify the management systems and policies that are already in place to address ocean acidification. This section will also discuss the effectiveness of those management bodies and programs and evaluate problems that the Pacific Northwest will likely encounter in developing policies to address ocean acidification.

The overarching body responsible for fish and fishery management is the U.S. Fish and Wildlife Service (FWS), a bureau of the Department of the Interior. Since 2002, the Service has periodically produced different editions of management mission statements entitled "Fisheries Vision", which include goals, objectives, and plans for these resources on a national level.[41] With the emergence of acidification related

[40] Cooley, S., and Doney, S., 5.
[41] U.S. Fish and Wildlife Service, 2009. Pacific Region: Fisheries Program Strategic Plan.

problems and awareness, the subsections of this bureau will need to focus future plans on strategically addressing these concerns.

Many regional programs, including the Pacific Region Fisheries Program, have already recognized the need for dynamic management in the face of increasing atmospheric CO_2 and related consequences. In the 2009-2013 Fisheries Program Strategic Plan, the Pacific region acknowledges the complications that climate change can present, and introduces "Rising to the Challenge", a plan to focus on "population analysis, habitat conservation, and monitoring and evaluation". In achieving these objectives, the region will partner with the United States Geological Survey (USGS) to predict the impacts of a changing climate, including warmer and more acidic waters, on water quality and the viability of populations of trust species. The Pacific region also has raised awareness of ocean acidification as a problem separate from wider climate change, one which requires more detailed attention. The website for the Pacific division of the FWS identifies ocean acidification as a major and pressing environmental concern:

> "Virtually every major biological function has been shown to respond to acidification changes in seawater, including photosynthesis, respiration rate, growth rates, calcification rates, reproduction, and recruitment…An increase in ocean acidity is likely to result in a decline in the ability of coral reefs to maintain their calcium."

However, while the region realizes the weight of ocean acidification on coastal ecosystems, the unpredictable nature of this crisis makes it difficult to decide how to best use limited resources to effectively conduct research and implement management techniques. Yet, as more information becomes available, the coastal fisheries of the Pacific Northwest will likely look to use the FWS subdivisions as a valuable resource for management and policy recommendations.

Additionally, in 2009, the United States passed the Federal Ocean Acidification Research And Monitoring (FOARAM) Act, which aims to "formulate a strategy for an integrated national research program ocean acidification."[42] As part of H.R. 146: Omnibus Public Land Management Act of 2009, the FOARAM Act also authorized government funding for ocean acidification. Although the money has yet to be appropriated, the expected funding is as follows: "[For the] fiscal years 2009, 2010, 2011, and 2012 at $14 million, $20 million, $27 million, and $35 million per year, respectively (this is broken down for NOAA and NSF)."[43] This act represents a step in the right direction for policymakers with regards to the challenges facing the oceans of the United States.

Recently the North Pacific council has taken measures to address the changing oceanic chemistry and global climate. First, a fishery management plan (FMP) has been established to protect the Arctic fishery stocks that are becoming more accessible to fishers as the warmer climate allows for easier vessel transportation in the icy, glacier ridden waters. As the Arctic is relatively pristine with little commercial activity, the effects of increasing CO_2 and the resulting acidification are causing the area to experience a significant change in ecosystem composition. This motion to close the Arctic water to commercial fishing will be in effect until additional research into the specific characteristics of the underexploited area is completed, indicating that the concern lies with not only particular species but entire ecosystems:

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[42] Doney, S., Balch, W., Fabry, V., and Feely, R., 22.
[43] EPOCA. "The federal ocean acidification research and monitoring (FOARAM) Act". *Ocean Acidification*, March 26, 2009.

> "Management measures are being developed to respond adaptively to varying distributions of target and bycatch fish species, because of changing climate in the North Pacific, and a pilot Fishery Ecosystem Plan (FEP) has been developed for the Aleutian Islands, which maps interactions among climate factors and ecosystem component and suggests indicators for the Council to monitor"[44]

The North Pacific Council has also motioned to close selective trawls in order to prevent rapid northern fishing expansion. These precautionary measures began in 2007, when the Council made the decision to conserve benthic fish habitat by "freezing the footprint of bottom trawling", including 47,000 nautical square miles of bottom and basin sea area as well as the Northern Bering Sea Research Area, which consists of 85,000 nautical square miles. [45]

Further, many non-governmental ocean acidification research and advocacy groups exist in the Pacific Northwest. For example, the Pacific Science Association recently established a Task Force on Ocean Acidification in the Pacific (TFOAP), which aims to provide a forum for regional collaborative research to expand the scientific knowledge of ocean acidification and its impacts on ecosystems and societies. This task force will also produce periodic reports that will address the immediate goals of the organization: indentifying knowledge gaps in scientific understanding of the ocean acidification phenomenon and assessing the social and economic impacts.

As discussed, one major problem facing many regulative organizations is determining which negative fishery trends are solely results of ocean acidification and which are from other causes, such as fishing and climate warming. Perry, *et al.* (2010) looked specifically at the conceptual issues that involve the impact of both humans and

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[44] Stram, D. and Evans, D., 2009. Fishery management responses to climate change in the North Pacific. ICES Journal of Marine Science: 1-7.

[45] Stram, D. and Evans, D., 2-4.

climate changes to the fishery systems, including whether overfishing increases the sensitivity of ocean ecosystems to changing water conditions and composition. Isolating the separate impacts of each system factor should help policymakers create management plans to effectively control each influence. Perry *et al.* also stresses the importance of combating sensitivity to increasing CO_2 and related chemical changes by forming management objectives around preserving biodiversity. "Loss of biodiversity, including large individuals and top predators, extirpating genetically distinct population sub-units, losing the spatial patterns of these sub-units, and increasing the overall level of fishing mortality,"[46] which the authors point out, create conditions that make marine systems more vulnerable to the synergistic effects of both fishing and products of climate variability.

Another problem facing policymakers in the Pacific Northwest is how to transition from regulating individual species or populations to regulating the entire ecosystems that ocean acidification effects. One useful tool may be implementing fishery ecosystem plans (FEP) in the Pacific Northwest to address the increasing acidity on multiple trophic levels. FEPs are primarily applied to create more flexible management plans and to serve as an educational resource for policymakers and the public. Although there are many similarities between FEPs and FMPs, the FEP is less rigid and does not contain any specific policy measures that govern fishing activity. If the Pacific Northwest were able to impose a large-scale FEP, one example to consult is the Aleutain Islands in Alaska. The purpose of the FEP was to integrate information on ecosystem dynamics to

[46] Perry, I., Cury, P., Brander, K., Jennings, S., Mollmann, C., Planque, B., 2010. Sensitivity of marine systems to climate and fishing: Concepts, issues, and management responses. Journal of Marine Systems: 427-435.

identify key ecosystem interactions that are of interest to fishery managers.[47] The interactions were then monitored and utilized as warning systems to alert fishers and policy makers about increased effects from acidification and other oceanic conditions. From this plan emerged management priorities, including recognizing the distinctions between different ecosystem properties and processes, and the implementation of the FEP was viewed as successful for the region. As the assets and characteristics of the ecosystems in the Pacific Northwest vary based on location, this may be a viable management option, although difficulties could arise from the grand geographical expanse of the region.

While the Pacific Northwest region has taken preliminary steps to addressing the consequences of ocean acidification, there is still much that policymakers can do to ensure that fisheries and societies are better equipped to handle the effects of rising acidity. In Chapter Five, strategic international management techniques and suggestions will be recommended for further policymaking in the Pacific Northwest.

[47] Stram, D. and Evans, D., 3-5.

Chapter 3: Ocean Acidification in a Global Context

As ocean acidification emerges as one of the most dangerous threats to oceans ecosystems, different nations have taken unique approaches to take preventative measures. The specific nature of the fishing industry and the role it plays in each society requires that plans be detailed to match the needs of each nation. However, a few fish-depend nations have established particularly innovative policies to control the effects of ocean acidification— policies which could be useful references for the Pacific Northwest fisheries. This chapter will highlight and analyze the different ocean acidification effects, economic consequences, and policy techniques abroad. In examining the influence of increasing acidic water on both ecosystems and economies of various nations, particular attention will be paid to how the combined societal implications can further force policymakers to accelerate fishery and coastal ecosystem management.

The Range of Ocean Acidification Effects in Highly Vulnerable Nations

It is difficult to pinpoint precisely where the impacts of climate change will be the most severe. However, due to the sensitive nature of aquatic ecosystems, identifying which areas are most vulnerable to the effects of rising temperatures and fluctuating pH levels is critical. Climate change and its related processes will present a host of challenges to areas that rely on oceanic resources and have fishery dependent economies.

Further, as the global fish stocks are approximately 75% depleted, the combination of overfishing and unfavorable climate and chemistry conditions will likely lead to increased economic hardships and over- or under- allocations to fishing industries. It is therefore crucial that areas that are most vulnerable to these effects be recognized, so that ample time is allocated towards preparing for such occurrences and revising policies.

Allison, *et al.* (2009), examined the likely vulnerability of fishing nations to climate change and the implications that these changing conditions would have. They defined vulnerability by looking at three factors: exposure, sensitivity, and adaptive capacity. Nations that have high exposure and sensitivity to the physical consequences of climate change (including rising acidity levels) and low adaptive capacity (due to poor infrastructure and limited capital and government resources) will be more vulnerable to the negative effects of climate changes.[48] In these countries, the fishery populations are critical to social and economic advancements, but at a higher risk due to increased dependence on the stocks and lowered resources to mitigate the environmental damages to fisheries.

The process involving how oceans retain more CO_2 through atmospheric absorption and increased acidity is more or less universally uniform throughout all oceanic communities. However, the specific consequences and ecosystem effects are usually dependent on the characteristics of the location and species. For example, both regions with an abundance of corals and regions with an abundance of shellfish will be impacted by ocean acidification, though those impacts will be felt to different degrees.

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[48] Allison, E., Perry, A., Badjeck, M., Adger, W., Brown, K., Conway, D., Halls, A., Piling, G., Reynolds, J., Andrew, N., Dulvy, N., 2009. Vulnerability of national economies to the impacts of climate change on fisheries. Fish and Fisheries, 10, 173-196.

Further, as each location has species which are more responsive to different carbonate chemistry parameters, the chemical composition of regions can increase vulnerability to negative effects associated with varying pH levels. Thus, *Acropora Cervicornis*, a coral species, which is dependent on aragonite to form skeletons, will be more affected by changes in carbonate saturation states than will non-calcifying organisms, such as small fish species. Impacts from ocean acidification can also vary based on water and surface temperatures: "…The stability of both minerals [calcite and aragonite] is affected by the amount of CO_2 in seawater, which is partially determined by temperature. Colder waters naturally hold more CO_2 and are more acidic than warmer waters."[49]

Due to its extensive reefs and high biodiversity, the northeastern coast of Australia is one area that is often a focal point of acidification research. When analyzing the coral reefs, the health of coral species tend to be highlighted, occasionally overshadowing other important aspects of reef ecology such as calcifying macroalgae. One genus that is highly developed in the Great Barrier Reef region is *Halimeda*m a green alga with that spans an area upwards of 2000 km^2.[50] As part of the reef foundation, *Halimedam* sediments fill gaps in the reef structure. Additionally, this particular alga serves as a habitat for mature fish and occasionally is used as a nursery spot for reproducing fish and invertebrates. In some studies done on the Great Barrier reef, *Halimedam* has demonstrated a negative response to decreased pH levels from 8 to 7.5 units, likely in part to the decline in calcium carbonate production: "Calcifying macroalgae produce biogenic calcium carbonate… high-magnesium calcite, aragonite, and calcite; all of these forms are susceptible to the negative effects of decreasing

[49] Guinotte, J., and Fabry, V., 320-326.
[50] Guinotte, J., and Fabry, V., 328.

carbonate saturation."[51] Therefore, the worry for this particular region of Australia is as CO_2 absorption increases and carbonate saturation levels decrease, the reproductive fitness of macroalgae will suffer and the reef habitat will be damaged.

Although cooler waters are naturally more susceptible to increasing acidification, the warmer waters of the tropic regions also have unique challenges that increase the impact of ocean acidification on ecosystems. In Trinidad and Tobago, the coastal reef regions are at risk as corals have been declining from increasing water temperatures and acidity. However, these islands face additional threats from hurricanes, the impacts of which are more dangerous when the coral reefs are unable to act as a coastal defense. In addition, the hurricanes further damage the structure of the reefs, impeding the resilience of the coral reefs of coastal communities.[52]As the hurricanes create barriers to increased quality of life and hinder future development, there may be less emphasis on preserving the reefs and fishery resources and more focus on harvesting maximum amounts to compensate for natural disasters. The governments of these nations are therefore forced to maintain equilibrium between development and conservation.

Economic Implications of Ocean Acidification Abroad

In countries where the livelihoods and economic growth depend on fisheries, the consequences of ocean acidification pose a serious threat. The countries that are the most vulnerable are those which are highly reliant on natural resources and have a lowered accessibility to global economic capital. Often considered "developing nations", these countries face barriers to ocean acidification adaptation and mitigation due to limited infrastructure, inadequate policy, and societal constraints:

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[51] Guinotte, J., and Fabry, V., 328.

[52] Tompkins, E. and Adger, W., 2004. Does adaptive management of natural resources enhance resilience to climate change? Ecology and Society, 10, 6-9.

> "Most of the countries that are most vulnerable to climate change impacts on their fisheries are also the poorest: they contribute only 2.3% of global GDP and 22 of the 33 countries in the most vulnerable quartile are classified as Least Developed Countries. The inhabitants of vulnerable countries are twice as dependent upon fishes for food as those of other nations, with 27%of dietary protein derived from fish…"[53]

However, developed and industrialized nations will also face significant economic consequences because of decreasing oceanic pH and carbon sequestration. Globally, ocean acidification has been shown to impact the not only the fishery markets, but also tourism and other economically valuable sectors. Therefore, economic valuation needs to act as a catalyst to motivate policymakers to work with scientists to devote adequate resources towards ocean acidification research.

Although coastal ecosystems serve as key habitats for the world's fisheries, the ecosystems themselves also provide services that prove to be both economically and culturally valuable. Apart from fish, some ecosystems provide other marketable goods, such as pearls, shells, and coral pieces for art and jewelry.[54] These additional goods are produced by ocean calcifiers that are directly negatively impacted by increasing acidity. Other contributions of coastal ecosystems are not as tangible, such as coastline protection and shoreline stability provided by coral reefs. While this regulating service cannot be physically sold, it plays a large role in preserving the shores during natural disasters and providing a foundation for coastal development and real estate. Cooley, *et al.* (2009) estimated that the coral reefs worldwide provide $9 billion per year in shoreline protection and regulation services. The authors also examined the specific predicted economic value of reef fortification in three coastal countries: St. Lucia, Tobago, and

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[53] Allison, *et al*., 191

[54] Cooley, S., Kite-Powell, H., Doney, S., 2009. Ocean acidification's potential to alter global marine ecosystem services. Oceanography, 22, 172-181.

Belize. Various sources have estimated that the monetary value of shoreline protection is $28-50 million, $18-33 million, $120-180 million for the three nations, respectively. Cooley *et al.* (2009) expressed concern that the negative impacts of ocean acidification on the calcifying foundational corals, will cause reefs to rapidly deteriorate, as demonstrated in many increased acidification models. Should the buffer of the reefs crumble, the coasts that depend on the regulating services will presumably suffer greater losses from harsh weather, like waves and tsunamis, and foregone coastal development and real estate expansion[55].

One global commodity that may experience severe alterations is fishmeal, made from small pelagic fish populations, which is supplied for both carnivorous and herbivorous aquaculture. Driven by a global supply and demand equilibrium, the demand for fishmeal is expected to increase in the future. Chile and Peru serve as two of the world's leading pelagic fish producers; Peru contributes it entire national production to global fisheries and Chile devotes around 25% of its sardine production to national salmon and trout aquaculture. As ocean acidification begins to affect the reproductive fitness of these smaller fish populations, less fishmeal will be available to the world's largest salmon, trout, freshwater and crustacean farms in China, Thailand, and Norway. In producing a globalized market model, Merino, *et al.* (2010), found that because the economic module is driven in part by ecosystem production, negative shifts in the health of ecosystems and thus fishmeal supply result in increasing costs of production, and thus steadily raise international market prices for aquaculture fish. Initially, the fish catches and fishmeal supply remain at similarly stable scenario. However, projecting the model further into the future, fish stocks are approximately 23% of its pristine levels at 10 years

[55] Cooley, S., Kite-Powell, H., Doney, S., 177-179.

out and the combination of negative environmental conditions and increased global demand for fish leads to fish stocks that are reduced in size, "…until the value of the exploited fraction is less than the cost of exploiting the scarce resource." [56]

One example economic losses due to ocean acidification can be seen in the extreme coral reef degradation is the coastal reefs of Indonesia. Covering approximately 5.8 million km^2, the reefs of the greater waters of Indonesia are extremely diverse, comprising of a third of the world's coral reefs, and a quarter of the world's reef fish species. The vast expanse of the reefs, which include barrier, fringing, and patch reefs, make Indonesia one of the world's most popular destinations for snorkeling and scuba diving. The reefs, therefore, play a large part in the Indonesian economy, as Indonesian tourism revenues were approximately $7.1 billion in 2008. Yet, these coral reefs face the same dire diagnosis within the context of ocean acidification. Already, the World Bank concluded that less than 30% of the region's coral reefs were in acceptable health conditions. The poor health of the existing corals, coupled with the overwhelming negative effects of ocean acidification on coral skeletal structure, create a scenario in which 86% of the reefs are at either a medium or high danger level.[57] Studies and models have shown that the synergistic effects of ocean acidification and poor coastal management in Indonesia result "…[estimated] loss to the fishery sector from reef degradation and over fishing to be $410,000 per km2…[studies suggest that] Indonesia has already lost 40% of its reef fisheries resource, yielding an estimated economic loss of

[56] Merino, C., Barange, M., and Mullon, C., 2010. Climate variability and change scenarios for a marine commodity: Modeling small pelagic fish, fisheries and fishmeal in a globalized market. Journal of Marine Systems, 81, 196-205.

[57] USAID. "An analysis of opportunities for USAID Indonesia's water and energy team to incorporate global climate change activities in the natural resource management and energy sectors". December, 2008, 8-14.

$30 billion over 25 years." [58] The dramatic loss of revenue, particularly in a developing nation, requires that policies be changed and that mitigation measures be adapted as soon as possible to offset these losses.

Although increasing acidification will devastate some countries and coastal regions, it is important to note that there are some countries which may either directly or indirectly benefit from increasing temperatures and variability in seawater acidity.

Policy and management strategies from abroad

The recent developments in knowledge of ocean acidification have resulted in many nations taking actions to address the urgency of this environmental issue. Individual nations have stepped up to reform management techniques and devote resources towards research programs and concerned citizens have established nongovernmental organizations. However, from a global perspective, it is critical that nations also work in conjunction to increase awareness and further cooperative research. This section will outline the various management measures adopted by individual countries, as well as the collaborative efforts of groups of nations to promote additional research and joint mediation programs.

International conferences have been an invaluable first step in increasing international cooperative research and expanding global knowledge of ocean acidification. These meetings not only bring together hundreds of world experts and policymakers, but often result in one or many strategies for assessing and coping with increasing acidity in global waters. For example, in 2008, 26 nations convened at the Second International Symposium on the Ocean in a High – CO_2 World to discuss the state of the world's oceans and the measures that should be taken to compensate for the rapidly

[58] USAID., 8-14.

rising carbon levels in the atmosphere and ocean[59]. Ultimately, it was decided that ocean acidification was a threat so serious that immediate action was required, leading to the drafting of the Monaco Declaration. Signed by 155 scientists present at the Symposium, the Monaco Declaration expresses the deep concern about the severe changes in ocean chemistry and the resulting effects on marine ecosystems, food webs, biodiversity, and fisheries. The Declaration goes on to qualify ocean acidification and present key facts to support the claims that "ocean acidification is underway" and "ocean acidification is already detectable". Further, the Monaco Declaration stresses the urgency of rising acidity to economically valuable markets and highlights the socioeconomic impacts that are predicted. Lastly, in recognizing that recovering from increasing acidity will be an extremely slow, perhaps even thousands of millions of years, the scientists of the Monaco Declaration call for policymakers and governments "…To act quickly to incorporate these concerns into plans to stabilize atmospheric CO2 at a safe level to avoid…dangerous ocean acidification."

The first large-scale research organization to address ocean acidification is the European Project on Ocean Acidification (EPOCA), which comprises of nine various western European nations and over 27 partner institutions. EPOCA pursues four objectives that attempt to advance knowledge of ocean acidification: changes in ocean chemistry and biogeography, biological responses, biochemical impacts and feedbacks, and synthesis, dissemination, and outreach.

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[59] Second International Symposium on the Ocean in a High- CO_2 World. "Monaco Declaration". *Research Priorities for Ocean Acidification*, October, 2008, 1-4.

Through the first "theme" of research, changes in ocean chemistry and biogeography, the EPOCA scientists look at past variability in ocean chemistry to gauge how the effects visible today compare to past trends. These types of analysis will hopefully shed light on the seriousness of present-day ocean acidification. This section serves mainly as the observational component of the EPOCA, and the samplings and explorations continue to add to the global knowledge of ocean acidification. In addition to examining the chemistry aspect of acidification, EPOCA also focus on the specific biological responses of ecosystems to these changes. This focus of study is the largest research theme of EPOCA. Through laboratory and field experiments, key organisms are studies, and the biological response is quantified, providing a basis for measuring the adaptive and acclimation potentials for key species. The third theme, biogeochemical impacts and feedbacks, asks the question, "To what extent will ocean acidification alter ocean carbonate chemistry, biogeochemistry, and marine ecosystems over the next 200 years, and what feedbacks will these changes generate to the climate system?" Essentially drawing from both themes one and two, models are constructed to predict the future significance of variations in nutrient cycles, including carbon, nitrogen, sulfur, and iron, in the presence of increasing levels of acidification. These findings can assess the many ways in which ocean acidification can influence ecosystems, which establishes a relationship between this theme and theme two. The last area of focus, synthesis, dissemination, and outreach, essentially serves as a forum to discuss the conclusions drawn from the previous three themes. The information gained from the first three themes is communicated to policymakers, expert groups and committees, and the general public to raise awareness. To execute this outreach, EPOCA formed the Reference User Group

(RUG), which is made up of stakeholders that advice the organization on how to effectively provide information in a way that communicates the key findings and main concerns of ocean acidification.

The formation of EPOCA was revolutionary in the field of ocean acidification research. Through combining resources, the nations and organizations that comprise of the group are able to conduct more large scale research experiments and spread the knowledge and findings on rising ocean acidification to a much larger audience then each nation would be able to do on an individual basis. There are several things that EPOCA does to make it an efficient organization for approaching the international policy issues involved with the chemistry change in the oceanic waters. First, there is international collaboration between EPOCA and other continental partners. This ensures that research conducted by EPOCA is coordinated with other international research, allowing projects to compare techniques and build upon one another. EPOCA also has been effective in choosing key campaigns that will have the most impact of ocean acidification analysis. In 2009, the organization performed a large-scale field experiment in Svalbard, an archipelago in the Arctic region. During the campaign, the effects of both current and projected oceanic acidification on Arctic species, including echinoderms, mollusks, and crustaceans, were studied. In opting to study on Svalbard, which is particularly prone to acidification consequences due to its high latitude location, EPOCA demonstrated the importance of choosing research experiments that address the most vulnerable regions of the earth.

Chapter 4: Economic and Policy Recommendations to Mitigate the Impacts of Increasing Ocean Acidification

Economic Recommendations

Fisheries are an invaluable natural resource that provide food and job security to a large portion of the earth's citizens. Yet, as CO_2 emissions continue to rise and oceans become more acidic, the social and economic benefits that fisheries provide are at risk. Further, the synergistic effects of over exploitation due to poor management and decreasing populations from rising acidity will deplete fisheries to levels that will negatively affect many developing communities. As these fishery responses are currently predicted to be unavoidable, both federal and local governments must act now to prepare and adjust for economic losses. This section will evaluate the different economic approaches the Pacific Northwest fisheries can adapt in the wake of ocean acidification, applying both techniques outlined by various nations in Chapter Three and policies suggested by various studies.

On of the most basic ways to attempt to maintain the economic benefits of fisheries is to limit catch size in hopes of preserving the resilience of the populations.

However, from an economic perspective there are both pros and cons to reducing the amount of fish caught annually.

If the physical effects of ocean acidification become too severe to sustain certain fish populations, some communities may begin to shift from open water fishing to aquaculture. Aquaculture refers to the breeding and harvesting of species in either natural or manmade environments, the former being most cost effective but the later being more effective in controlling variables that could harm the harvest.[60] Globally, aquaculture continues to rapidly grow at an average rate of 8.8 percent per year since 1970 and currently accounts for approximately 33 percent of global fish supplies.[61] In 2002, the United States produced 393,400 metric tons of fish from aquaculture, generating about $866 million in revenues. However, the U.S. currently relies less on aquaculture than many fish producing nations, ranking 10th in the world[62] for total aquaculture production. Although increasing aquaculture in the Pacific Northwest could increase employment, labor income, and GDP, there are significant obstacles that the fishing sector must face to implement additional aquaculture.

The first major barrier to increasing aquaculture is the high costs and low sustainability associated with many of the current systems. Increased investments must therefore be made in order to improve the inefficiencies of different systems before aquaculture can become a viable large scale alternative to open water fishing. Another challenge connected to increasing aquaculture is the management difficulties that arise

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[60] National Oceanic and Atmospheric Administration. "What is Aquaculture?" *Aquaculture Program*, 2010, 1.

[61] United Nations' Food and Agriculture Organization. *World Review of Fisheries and Aquaculture.* State of World Fisheries and Aquaculture Report, 2008.

[62] United Nation's FAO, 2006. State of the world aquaculture 2006. FAO fisheries technical paper, No. 500, 134 pg.

with continuing intensification and diversification of the sector. Lastly, many aquaculture farms continue to depend on feed that is comprised of small pelagic fish. The rising demand for this feed as fish farms increase may actually put additional pressure on open water fisheries to increase production of wild fish for feed.[63]

International research has shown that ocean acidification has the most detrimental effects on communities that largely depend on fisheries for employment, food, and export revenues. Although most of the Pacific Northwest has the capital and resources to support economies should the fishing industry be severely hit by ocean acidification, the cases from abroad demonstrate the significant advantage of diversifying economic revenues.[64] Particularly for smaller fishing communities, it would be beneficial to begin to shift a percentage of employment away from fishing. This shift both preserves the natural resource by decreasing the catch size of fisheries and allows for greater economic and job security if the fisheries were to dramatically decline or collapse due to ocean acidification.

Changing the amount and type of investments in the fishing industry will also be instrumental in preserving the role of fisheries in smaller Pacific Northwest economies. As discussed earlier, the synergistic effects of ocean acidification and overfishing are accelerating the depletion of economically valuable fish populations. The open access nature of fishing has lead to higher effort levels and increased participating individuals than is economically efficient.[65] Reducing the amount of capital put into the catch effort would cause fishers to scale back catches and production and remove stress from

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[63] Naylor, R., et al., 2000. Effect of aquaculture on world fish supplies. Nature, 405: 1017-1024.
[64] Allison, E., Perry, A., Badjeck, M., Adger, W., Brown, K., Conway, D., Halls, A., Piling, G., Reynolds, J., Andrew, N., Dulvy, N., 182-191.
[65] Field, B., 247-249.

struggling populations. However, losses from ocean acidification may actually increase the amount of investments in the seafood industry. Some analysts believe that the grim ocean acidification predictions may cause certain fishers to shift the focus from conservation of fish stocks to maximizing reliable earnings while the stocks are still present. According to Warren (2009) the reasoning behind this "run on the bank" of fish populations lies in the uncertainty of long-term returns on fishery investments; as the viability of populations is variable under acidic conditions, it may be best to receive the greatest payoff possible now if the stocks may be depleted in the future. However, this option is not sustainable for economies which rely on fisheries. Therefore, Pacific Northwest communities should implement restrictions on investments, such as more vessels and expanding production, to attempt to salvage fish populations in acidic waters.

Policy recommendations

As a general method to approaching the consequences of ocean acidification, the policymakers of the Pacific Northwest should consider the four initiatives outlined by the Monaco Declaration. First, in order to create efficient management plans, there needs to be a greater understanding of the effects of ocean acidification, which requires that further extensive research be conducted in this field. Although organizations in the Pacific Northwest, such as Pacific Science Association and Pacific Marine Environmental Laboratory, are dedicated to investigating the effects of ocean acidification, increased cooperative efforts between these groups and the local governments is required to promote more studies, tests, models, and research of ocean acidification. Second, links between economists and scientists should be established to analyze the socioeconomic impacts and costs of ocean acidification and the costs and

benefits of attempting to prevent ocean acidification. Third, communication between scientists and policymakers must be improved so that policies will be based on scientific findings. Lastly, management techniques need to ambitious and implementation must be immediate to reduce anthropogenic carbon emissions and curtail the critical damages from ocean acidification.

After examining the global response to increasing ocean acidification, the main prevention measure that will be critical in the Pacific Northwest is curbing carbon emissions. Although this objective requires international cooperation, there are measures that individual regions can take to reduce the amount of human-induced atmospheric CO_2. A carbon tax can be a beneficial means of discouraging excessive emissions. These taxes can be implemented on a local and state level, allowing for implementation to take place in specific areas with little federal bureaucracy. The states that are encompassed in the Pacific Northwest region could impose a tax similar to that of the San Francisco Bay Area. In 2008, the Bay Area Air Quality Management District passed a carbon tax that requires over 2,500 companies and agencies to pay 4.4 cents for every metric tons of CO_2 that is emitted. [66]

Although it is critical for policymakers to take necessary steps to prevent ocean acidification by reducing human-produced atmospheric carbon, certain proposed measures to curb CO_2 may actually amplify water acidity. Climate geoengineering, a method of stabilizing global temperatures by injecting aerosols into the atmosphere to reflect radiation waves, may indirectly affect the pH levels in the ocean.[67] However, while this may be effective in controlling temperature, Matthews, *et al*. (2009) confirmed

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[66] Zito, K. "Air quality board to fine Bay Area polluters." *The San Francisco Chronicle*. May 22, 2008, 1.
[67] Matthews, C., Cao, L., Caldeira, K., 2009. Sensitivity of ocean acidification to geoengineered climate stabilization. Geophysical Research Letters, 36, 1-5.

that climate engineering will not help ocean acidification. One obstruction presented by geoegineering is changes in the global temperature may impact the amount of CO_2 absorbed by terrestrial biospheres, in turn varying the amount of CO_2 that is taken up by oceans, which would influence the rate of acidification. Further, while climate engineering has no effect on ocean pH, a stimulation of "prescribed atmospheric CO_2 emissions" in conjunction with climate engineering showed that aragonite saturations were substantially reduced due to high levels of dissolved inorganic carbon in the surface water.

One precautionary measure that could be effective in preserving the fisheries of the Pacific Northwest is reducing catch size now to maintain resiliency of fish populations in more acidic conditions.[68] As the pH levels of ocean environments continue to drop, fish populations that are already being depleted by overfishing will face additional reproductive challenges. Additionally, acidified waters may cause fish populations to lose the ability to recover from stock decreases that result from overfishing. Limiting commercial catches could facilitate more stable populations, particularly if the adolescent fish are able to reach the reproductive age. The fisheries of the Pacific Northwest have, and continue to be, overfished, which makes this precautionary catch curtail a good management option in the presence of rising acidity. The challenge for policymakers, however, will be setting these catch limits at a size that will help revive fish stocks but not significantly distress the livelihood of fishers.

Warren (2009) emphasizes that increasing acidification widens "the bands of uncertainty" that are used to determine decisions on catch size. The full extent of ocean

[68] Warren, B., 2009. The Big Seven: Acidification risks and opportunities for the seafood industry. Journal of Marine Education, 25, 20-24.

acidification's effects on specific fish species is unknown, making it difficult to predict the size of future fish populations and the maximum sustainable yield for fisheries. Inevitably, this uncertainty results in erroneous decisions in management; some fisheries will overexploit populations, while some will underexploit the resource. In either situation, the end result is economic inefficiency, which creates problems for both fishers and consumers. However, some analysts argue that setting limits to preserve the reproductive capacity of fish populations will only be effective in situations where ocean acidification has a moderate impact on the ecosystems.[69] In situations where stocks are clearly threatened by extinction, the best use of the resource may be to overfish until the fish are completely depleted. This option would depend greatly on the level of certainty of extinction and a cost-benefit analysis of unrestricted harvesting of the threatened fish stock.

Finally, it will be crucial for policymakers in the Pacific Northwest to increase the effectiveness of coral reef management to confront the challenges caused by ocean acidification. Due to the particularly destructive impacts of ocean acidification on coral health and structure, Hoegh-Guldberg *et al.* (2007), recommend that regions with reefs must attempt to lessen the effects of increasing dissolving by reducing local stressors.[70] In the Pacific Northwest, reefs and coralline corals that are core components of ecosystems are additionally threatened by coastal pollution and overexploitation. By decreasing these local pressures, it is possible that reefs will be better equipped to endure increasing ocean acidification.

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[69] Warren, B., 21-22.

[70] Hoegh-Guldberg, O., Mumby, P., Hooten, A., Steneck, R., Greenfield, P., Gomez, E., Harvell, C., Sale, P., Edwards, A., Calderia, K., Knowlton, N., Eakin, C., Iglesias-Prieto, R., Muthiga, N., Bradbury, R., Dubi, A., and Hatziolos, M., 2007. Coral reefs under rapid climate change and ocean acidification. Science, 318, 1737-1742.

Chapter 5: Conclusions

Although ocean acidification is still a relatively new phenomenon and research is still in its infancy, the threats posed by lowered ocean pH level are immediate and ominous. Moreover, analyses have demonstrated that ocean acidification must be addressed from a local scale to pinpoint location and species specific characteristics and a global scale due to the universal nature of both oceans and CO_2 emissions.[71] Examining the localized effects in the Pacific Northwest illustrated the importance of understanding the specifics of ecosystem dynamics and employing management programs to fit the needs of individual ecosystems. The information available on the impacts of ocean acidification in the localized economies of the Pacific Northwest suggests that the economic losses will likely affect the majority of that region. On the other hand, investigating increasing ocean acidification from a global perspective displayed the truly universal nature of this crisis. As CO_2 emissions are increasing from essentially all corners of the earth, there needs to be an emphasis on international cooperation to reduce anthropogenic atmospheric carbon. As ocean acidification is already in effect, the best

[71] Allison, E., Perry, A., Badjeck, M., Adger, W., Brown, K., Conway, D., Halls, A., Piling, G., Reynolds, J., Andrew, N., Dulvy, N., 173-191.

strategies from a global standpoint are those which revolve around prevention and minimizing the acceleration of acidification.

The relationship between the Pacific Northwest and its ocean resources has been significant in both the past and the present, to the point that fishing is an integral component of the region's culture. The negative impacts of ocean acidification on the regional fisheries will not only endanger the fish populations, local economies, and job security, but will further put a damper on the traditions and customs of the Pacific Northwest that appeal to both residents and visitors. For example, in the case of rural Wallowa County in Oregon, ocean acidification and warming trends are predicted to cause stock declines of the 50 – to 100- percent magnitude[72]. As this rural area is considered to be a "Mecca for coldwater fishermen", this prediction would not only destroy the livelihoods of fishers, but also negatively impact the tourism industry and small businesses that depend on visitors to the area.

The Pacific Northwest case study demonstrated the necessity for the effects ocean acidification to be evaluated within the context of individual ecosystems. Although the effects of ocean acidification are widespread, the specific consequences will differ based on factors such as latitudinal and geographic location, water temperature, existing pH levels, and ecosystem characteristics. For example, a keystone starfish species, *Pisaster ochraceus*, actually thrives in high acidic conditions.[73] However, Gooding *et al.* (2009) found that while rising acidity is beneficial for the species, increasing populations of this starfish negatively impact the food chains and ecosystem functions. This example demonstrates the need for local communities and governments to formulate management

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[72] Burkett, M., 1.
[73] Gooding, et al, 2009. Elevated water temperature and carbon dioxide concentration increase the growth of a keystone echinoderm. PNAS 106, 9316-9321.

plans that will cater to the specifics of the oceanic ecosystem. Yet, some measures to ease the effects of ocean acidification, such as carbon taxes and incentive based programs to reduce atmospheric carbon, are more efficient with federal implementation, and therefore larger government mitigation plans and policies should also be considered.

Using the Clean Water Act to Combat Ocean Acidification

The U.S. policies to mitigate future ocean acidification need improvement, however, advocates have recently been attempted to apply established legislation to include ocean acidification management. Perhaps the most notable legislation that pertains to this phenomenon is the Clean Water Act. The concept of including ocean acidification in a revision of the Clean Water Act stems from a 2009 lawsuit involving the Environmental Protection Agency (EPA) and the United States Center for Biological Diversity (CBD). The suit was brought by the state of Washington CBD, who argued that the EPA had failed to recognize the hazardous effects of ocean acidification on the coastal waters of the Pacific Northwest. Later that year, the EPA issued a Notice of Data Availability (NODA), which provides the public with information and also solicits additional information or studies that have been done on ocean acidification.

If addressed under the Clean Water Act, ocean acidification would likely fall under section 304(a), which covers agency procedures in response to new act amendments, "…On the factors necessary to restore and maintain the chemical, physical, and biological integrity of all navigable waters, ground waters, waters of contiguous zone, and the oceans. (B) on the factors necessary for the protection and propagation of shellfish, fish, and wildlife…".[74] This title require the Administrator to publicly publish information on the above criteria after consultation with Federal and State agencies and

[74] United States Clean Water Act, 1977.

the public members with interest in the new subject. The EPA has said that waters that have been impacted by ocean acidification should be indentified under the Clean Water Act by the states. It is the hope of the CBD that if all coastal sates identify their waters as damaged by ocean acidification, then the Clean Water Act may be enacted to curb the major pollutant, CO2 emissions, to prevent further damages to these areas. Further, under Section 303(d) areas that are found to be "impaired" will be listed under an established Impaired Waters Listing and Total Maximum Daily Loads (TMDLs) will be set, acting as quotas for emissions.[75] The TMDL requires that a maximum amount of each pollutant be developed by the state, such that the water in question can "meet applicable water quality standards"[76]. As the atmospheric CO2 emissions that are causing the decreasing pH cannot be traced to specific polluters, the TMDL for CO2 are considered to be "non-point sources" and would implemented through either incentive-based programs or other local, state, or federal implemented. However, in an EPA memo issued on ocean acidification, the agency stresses that it is difficult to say whether a TMDL is a realistic option for acidified waters :

> " Currently, the EPA believes that not enough information is available to develop OA-related carbon TMDLS, and is deferring development of TMDL guidance related to OA listings until more information becomes available in the future. States may want to take this information into account in setting the priority ranking for TDML development for any waters identifies due to OA."

Plans to set CO2 limits have already been attempted by trying to enact the environmental legislation, particularly the Clean Air Act. In this case, the state of Massachusetts, along with 12 other states and multiple organizations, brought suit against the EPA in an effort to have the EPA take responsibility for regulating CO_2 and GHGs as

[75] United States Environmental Protection Agency. "Questions and answers on ocean acidification and the Clean Water Act 303 (d) Program". November 15, 2010, 1-5.
[76] United States Environmental Protection Agency, 2-4.

critical pollutants. The Supreme Court found that the Clean Air Act does indeed include GHGs as part of the purposefully, broad term "air pollution". However, the court ruled that while Massachusetts had standing, the EPA could have the opportunity to prove that its inaction on regulation was warranted. In doing so, the EPA would have to demonstrate that the decision to refuse regulation was made with particular attention to the impact of GHGS on climate change. The same challenges may arise for curbing emissions under the Clean Water Act.

From an international perspective, the most effective means of lessening the effects of ocean acidification is through setting carbon emission limits and forging international agreements to meet lower CO_2 targets. Although governments in developing nations face the dilemma between increasing development and increasing conservation, methods such as carbon trading programs could promote decreasing carbon emissions, while simultaneously increasing sustainable production and better technology. Additionally, as poorer regions are likely to be more vulnerable to the negative impacts of ocean acidification[77], identifying the potential costs of ocean acidification can help nations either accelerate mitigation strategies or adapt to lower pH levels. Ideally, nations could utilize coupled ecosystem and socioeconomic models that would, "…compare outcomes of different management choices and [quantify] economic losses due to stressors like ocean acidification."[78]

Further, many international meetings and symposiums have demonstrated the need for increased research collaboration among nations.[79] As ocean acidification

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[77] Allison, E., Perry, A., Badjeck, M., Adger, W., Brown, K., Conway, D., Halls, A., Piling, G., Reynolds, J., Andrew, N., Dulvy, N., 184-191.
[78] Cooley, S., Kite-Powell, H., Doney, S., 172-180.
[79] Monaco Declaration and EPOCA

research is still young, a greater understanding of the causes and effects can be gained by combining the knowledge and resources of different regions. The variability of increasing acidity also requires that there be a high level of awareness and comprehension so that the policies constructed will be effective. All nations, though particularly coastal countries, need to recognize that high levels of CO_2 emissions are contributing to increasing acidity in oceans at a precarious rate. In order to protect local and global ecosystems and economies, nations must engage in productive cooperation to decelerate ocean acidification and regard this phenomenon as a global crisis that requires immediate action.

References

Allison, E., Perry, A., Badjeck, M., Adger, W., Brown, K., Conway, D., Halls, A., Piling, G., Reynolds, J., Andrew, N., Dulvy, N., 2009. Vulnerability of national economies to the impacts of climate change on fisheries. Fish and Fisheries, 10, 173-196.

Balch, W., and Utgoff, P., 2009. Potential Interactions among ocean acidification, coccolithophores, and the optical properties of seawater. Oceanography, 22, 147-159.

Bond, N. A. (2003). "Recent shifts in the state of the North Pacific". Geophysical research letters 30, 2183.

Burkett, M. , 2008. Is this picture in danger of disappearing?. *The Daily Astorian*, December 26, 2008, 1.

Cooley, S. and Doney, S., 2009. Anticipating ocean acidification's economic consequences for commercial fisheries.

Cooley, S. and Doney, S., 2009. Ocean Acidification's Impact on Fisheries and Societies: A US Perspective.

Cooley, S., Kite-Powell, H., Doney, S., 2009. Ocean acidification's potential to alter global marine ecosystem services. Oceanography, 22, 172-181.

Crozier, L.G., Hendry, A.P., Lawson, P.W., Quinn, T.P., Mantua, N.J., Battin, J., Shaw, R.G., Huey, R.B., 2007. Potential responses to climate change in organisms with complex life histories: evolution and plasticity in Pacific salmon. Blackwell Publishing: 252-270.

Doney, S., Fabry, V., Feely, R., and Kleypas, J., 2009. Ocean acidification: The other CO2 problem. Annual Review of Marine Science, 1, 169-171.

Doney, S., Balch, W., Fabry, V., and Feely, R., 2009. Ocean acidification: A critical emerging problem for the ocean sciences. Oceanography, 22, 16-14.

EPOCA. "The federal ocean acidification research and monitoring (FOARAM) Act". *Ocean Acidification*, March 26, 2009.

Feeley, R., Doney, S., Cooley, S., 2009. Ocean acidification: Present conditions and future changes in a high CO_2 world. Oceanography, 22, 36-47.

Field, Barry. Natural Resource Economics. Waveland Press, 2008, 239-260.

Gooding, et al, 2009. Elevated water temperature and carbon dioxide concentration increase the growth of a keystone echinoderm. PNAS 106, 9316-9321.

Guinotte, J. and Fabry, V., 2008. Ocean Acidification and its Potential Effects on Marine Ecosystems

Hauri, C., Gruber, N., Plattner, G., Alin, S., Feeley, R., Hales, B., Wheeler, P., 2009. Ocean acidification in the California Current System. Oceanography, 22: 60-71.

Kite-Powell, H., 2009. A global perspective on the economics of ocean acidification. The Journal of Marine Education, 25, 25-29.

Matthews, C., Cao, L., Caldeira, K., 2009. Sensitivity of ocean acidification to geoengineered climate stabilization. Geophysical Research Letters, 36, 1-5.

Melzner, *et al.*, 2009. Physiological basis for high CO2 tolerance in marine ectothermic animals: pre-adaptation through lifestyle and ontogeny? Biogeosciences, 6, 2313-2331.

Merino, C., Barange, M., and Mullon, C., 2010. Climate variability and change scenarios for a marine commodity: Modeling small pelagic fish, fisheries and fishmeal in a globalized market. Journal of Marine Systems, 81, 196-205.

Millero, F., Woosley, R., DiTrolio, B., and Waters, J., 2009. Effect of ocean acidification on the speciation of metals in seawater. Oceanography, 22, 72-85.

National Oceanic and Atmospheric Administration. "What is Aquaculture?" *Aquaculture Program*, 2010, 1.

National Oceanic and Atmospheric Administration, 2008. Ocean Acidification. State of Science Fact Sheet: 1-2.

Naylor, R., et al., 2000. Effect of aquaculture on world fish supplies. Nature, 405: 1017-1024.

Newman, M., Compo, G., Alexander, M., 2003. ENSO-Forced Variability of the Pacific Decadal Oscillation. Journal of Climate, 16: 3853-3857.

Nickel-Kailing, G. "Part 3: Shell fish production in the Atlantic and Pacific". *Food CEO*, June 2, 2010, 1.

Noakes, D., and Beamish, R., 2009. Synchrony of Marine Fish Catches and Climate and Ocean Regime Shifts in the North Pacific Ocean. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 1, 155-168.

People & the Planet. "Ocean acidification a serious threat". November, 2010, 1.

Perry, I., Cury, P., Brander, K., Jennings, S., Mollmann, C., Planque, B., 2010. Sensitivity of marine systems to climate and fishing: Concepts, issues, and management responses. Journal of Marine Systems: 427-435.

The Research Group, Corvallis Oregon. "North Pacific salmon fisheries economic measurement estimates". Wild Salmon Center, Portland Oregon, 2009.

Second International Symposium on the Ocean in a High- CO_2 World. "Monaco Declaration". *Research Priorities for Ocean Acidification*, October, 2008, 1-4.

Stram, D. and Evans, D., 2009. Fishery management responses to climate change in the North Pacific. ICES Journal of Marine Science: 1-7.

Tompkins, E. and Adger, W., 2004. Does adaptive management of natural resources enhance resilience to climate change? Ecology and Society, 10, 1-14.

United Nations' Food and Agriculture Organization. *Fishery Country Profile: The United States of America*, 2005.

United Nation's Food and Agriculture Organization, 2006. State of the world aquaculture 2006. FAO fisheries technical paper, No. 500, 1-134.

United Nations' Food and Agriculture Organization. *World Review of Fisheries and Aquaculture.* State of World Fisheries and Aquaculture Report, 2008.

USAID. "An analysis of opportunities for USAID Indonesia's water and energy team to incorporate global climate change activities in the natural resource management and energy sectors". December, 2008, 8-14.

United States Clean Water Act, 1977.

United States Environmental Protection Agency. "Questions and answers on ocean acidification and the Clean Water Act 303 (d) Program". November 15, 2010, 1-5.

United States Fish and Wildlife Service, 2009. Pacific Region: Fisheries Program Strategic Plan.

Warren, B., 2009. The Big Seven: Acidification risks and opportunities for the seafood industry. Journal of Marine Education, 25, 20-24.

Zito, K. "Air quality board to fine Bay Area polluters." *The San Francisco Chronicle*. May 22, 2008, 1.