Global Warming and Ocean Acidification's Effect on Pteropod Populations and Their Influence on Pink Salmon

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Abstract

Ocean acidification in Alaska is a significant environmental condition that is a product of human input of Carbon Dioxide into the atmosphere. How will increasing ocean CO2 levels and the subsequent change in ocean pH affect pteropods? Will this have an effect on salmon populations that consume pteropods as a food source? In this paper we will analyze the effects of ocean acidification on pteropods and the resulting impact on the pink salmon stocks in Alaska. We will describe the chemistry of ocean acidification, ocean pH, and the role and contribution of anthropogenic carbon to ocean acidification. Pteropods are macroscopic planktonic mollusks that produce shells of calcium carbonate. Current research indicates that a lowering of the ocean pH due to increased absorption of carbon dioxide has detrimental effects on pteropods and their ability to produce a viable shell. This will likely lead to decreased populations of pteropods in arctic and Alaskan waters. Pteropods are considered a staple food source for juvenile pink salmon. One species of pteropod in particular, the *Limacina helicina* can account for up to 50% of total zooplankton abundance in Arctic waters and can account for anywhere from 10-50% of a juvenile pink salmon's diet. We will look at what the possible effects a decline in pteropod population would have on pink salmon biomass and how that would translate to the fishing industry. In terms of pounds, pink salmon made up 27% of the total biomass of salmon caught in Alaska in 2016 . The pink salmon processing industry employed roughly 5,200 people in 2016. Reducing and slowing the rate of ocean acidification is at the forefront of research today. Finally, we will address some possible scenarios that could be employed in Alaskan waters to help maintain current pH levels, and possibly have an economic benefit for our state. These include the use of the mineral olivine and the establishment of kelp farms and growing areas.

Introduction

Our planet is going through a process of warming. Consumption of fossil fuels releases gigatons of carbon dioxide (CO_2) into the atmosphere every year. This greenhouse effect has resulted in systemic warming of the oceans, which has in turn created environmental issues related to sea ice loss, sea level rise, and coral bleaching. Another environmental consequence of increased CO_2 is ocean acidification. Around 25% of all the CO_2 released annually is absorbed into the oceans: approximately 25 million tons per day. As oceans absorb increasing amounts of carbon dioxide produced by humans releasing carbon through burning of fossil fuels, also known as *anthropogenic* carbon, the oceans become more acidic. Organisms whose life functions have evolved from dependence on existing ocean chemistry are faced with new challenges. Biologists are seeing detrimental effects from increased acidification on small pelagic marine snails called pteropods, which grow their shells from calcium carbonate. As the oceans become more acidic, it becomes more difficult for pteropods to pull carbonate from the water. Pteropods are a very important part of the food web, providing food for many organisms in Alaska. One such organism is pink salmon. We are analyzing the link between a potential declining pteropod population from ocean acidification and global warming and the impacts to pink salmon. We also suggest what can be done to reverse the negative effects global warming and ocean acidification have on pteropod populations in Prince William Sound and the rest of Alaska.

Ocean Acidification

Ocean acidification is a natural process in the oceans of the world. It is driven by the continuous uptake of CO_2 by seawater. The oceans absorb CO_2 by "the biological pump" which transfers CO_2 from the ocean's surface to the depths. Seawater is slightly basic; the average pH of the oceans historically has been 8.2. Today, it is around 8.1, a drop of 0.1 pH units. Annually, 9.5 billion tons of anthropogenic CO_2 is released into the atmosphere. In the oceans CO_2 is absorbed at the sea surface interface, moved vertically through thermohaline circulation and the "Biological Pump", a method of carbon dissolution thru the death of organisms like phytoplankton, which sequesters the CO_2 in the remains of the organism. The Global Ocean Conveyor belt is a large global system of multiple currents that regulates Earth's climate, and among other things, the dissolution of CO_2 in the water. The collections of currents churn the water at the surface creating a favorable environment for CO_2 dissolution at the sea surface interface. This global current system also is key in the distribution of CO_2 in the deep sea. This process of carbon being absorbed in the oceans is called the carbon export flux. Every year this flux totals to 6 petagrams or 6 billion metric tons of CO_2, or CO_2 containing particulate absorbed into the oceans (Boyd, 2014). The fact that the oceans absorb this much CO_2 per year has serious chemical ramifications on the prevalence of carbonate in the world's oceans.

When CO_2 is dissolved in seawater, it reacts to form a weak carbonic acid; H_2CO_3. The carbonic acid almost immediately breaks apart and releases hydrogen ions. These free floating ions lower the pH of seawater, and bond to carbonate (CO_3^{-2}) forming a compound called bicarbonate ($2HCO^{3-}$). Pteropods pull calcium ions (Ca^{+2}) from seawater and combine them with carbonate ions, also from seawater to form a complex crystalline calcium carbonate lattice structure, which makes up their shells (PBS). When carbonate molecules are converted into bicarbonate molecules, because of hydrogen ions bond to carbonate molecules, the carbonate is no longer available for pteropods. The affinity that hydrogen ions have for carbonate is greater than calcium's chemical affinity to carbonate. This excess of hydrogen ions in the water strips carbonates from already formed shells causing the shell of the pteropod to disintegrate or dissolve (Ocean Portal, 2016)(Figure 1). Pteropods must spend more energy seeking out carbonates for building their shells rather than using this energy for hunting and reproducing.

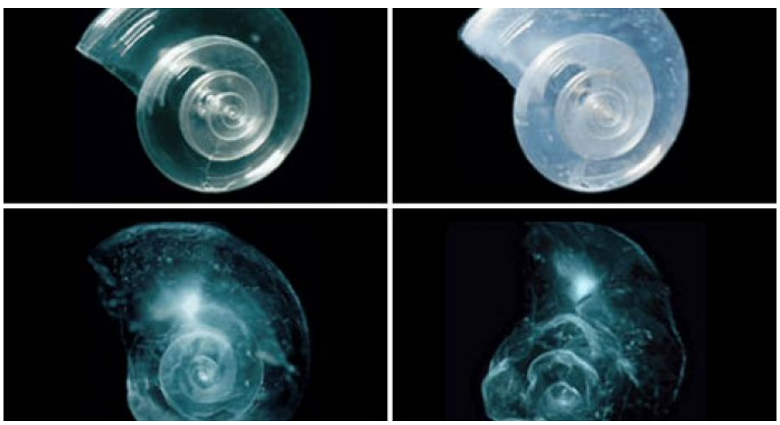

Figure 1: "Lab experiment, a sea butterfly (pteropod) shell placed in seawater with increased acidity slowly dissolves over 45 days." Source: Courtesy of David Littschwager/National Geographic Society, 2016; Smithsonian Ocean Portal, 2016.

Naturally, atmospheric CO_2 dissolves in the ocean and is absorbed by marine protists like phytoplankton, seaweed, and kelp. The CO_2 absorbed from the atmosphere, in cooler parts of the ocean, is more biologically active versus the CO_2 that is released back into the atmosphere in warmer areas is less biologically active. With the increase in anthropogenic, or human made CO_2, the amount of CO_2 dissolved in the surface waters of the oceans increases. The increase in CO_2 in the ocean decreases the pH, which leads to a higher acidity. The pH scale goes from 0-14. A pH of 7 is neutral. A pH less than 7 is more acidic and a pH greater than7 is basic (Figure 2).

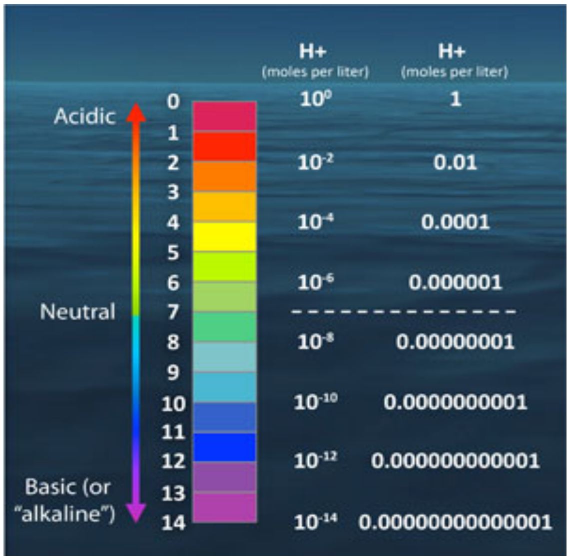

Figure 2: "Change of one pH unit represents an order of magnitude change in the hydrogen ion (H+) concentration. The hydrogen ion concentrations are shown in both scientific notation and decimal form." Source: Introduction to Ocean Acidification, 2015; Woods Hole Oceanographic Institute, 2016.

Over the last 15 million years, the oceans have had a pH consistent with 8.2; slightly basic. Over the past 200 years, ocean pH has dropped down to 8.1 which represents a 30% increase in acidity over the past two centuries. This rate of change is faster than at any time in the past 50 million years (Smithsonian Museum of Natural History, 2016). If current trends continue, by the year 2155 the expected pH could be 7.6 (Figure 3). "If we continue to add carbon dioxide at current rates, seawater pH may drop another 120 percent by the end of this century, to 7.8 or 7.7. Research being done along the coasts of Washington, Oregon, and California, has led to dynamic and intense carbon cycling. (pmel.noaa.gov,2010) Occurring are seasonal deflections of deep water to the surface waters (upwelling) from global ocean currents. The water coming to the surface is more acidic water with lower carbonate saturations. This may have deleterious consequences for marine organisms (pmel.noaa.gov,2010) In Alaska, there is no known seasonal component of pH, however the movement of water to the north Gulf of Alaska and Prince William Sound by the Alaska current adds to the complexity of the ocean acidification issue.

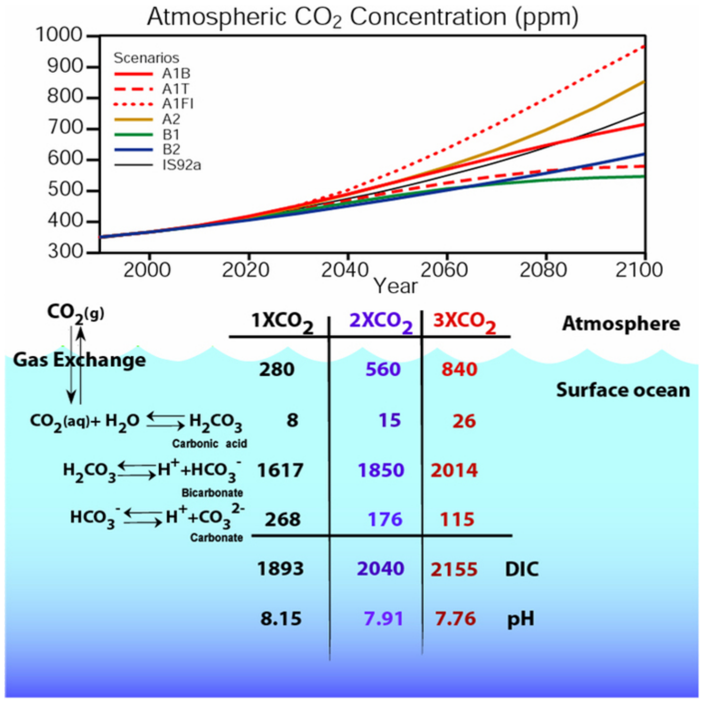

Figure 3: "Amount of CO_2 relative to preindustrial carbon dioxide levels, and chemical CO_2 to H_2CO_3 process" Source: PMEL Carbon Program,; NOAA, 2016

<u>Pteropod Ecology</u>

The Limacinadeae are a family of small sea snails, which includes pteropods. Pteropods are snails whose muscular foot has evolved as a wing like structure that they use to swim. Some look like a snail with tiny wings while others look like angels. Pteropods eat phytoplankton, small zooplankton such as bacteria, dinoflagellates, and diatoms. Naked pteropods primarily eat shelled pteropods. Naked pteropods will grab their prey with small tentacle like structures around their mouth and fight with it until it tires. Phytoplankton and zooplankton feeder produce a large mucus web to capture their food. There are seven major species of pteropods living in Alaskan waters. *Clione limacina* is a common "naked" pteropod found in Arctic and north Pacific waters. It feeds on *Limacina helicina,* a prevalent shelled pteropod found in Arctic waters where it can account for 50% of total zooplankton abundance (EOL.org). Also found are *Clio. andrea*, *Clio. chaptalia, Clio. pyramidata lanceolata, Paraclione longicaudata,* and the *Thlptodon diaphanus*; five of these species were not thought to exist in Alaska until their discovery in 2013. Pteropods are one of the main food sources for many animals including salmon, krill, fish, and whales. They are at the bottom of the marine food web, just one level above phytoplankton. This means that pteropods either directly or indirectly influence a majority of the upper level marine organisms (see figure 4). Pink salmon like to eat pteropods, specifically *Limacina helicina,* because of their high fatty acid concentration. *Limacina helicina* have a high fatty acid concentration because the phytoplankton they eat have a high fatty acid concentration. Pteropods can help pink salmon grow quickly thus giving them a higher chance of surviving their first winter

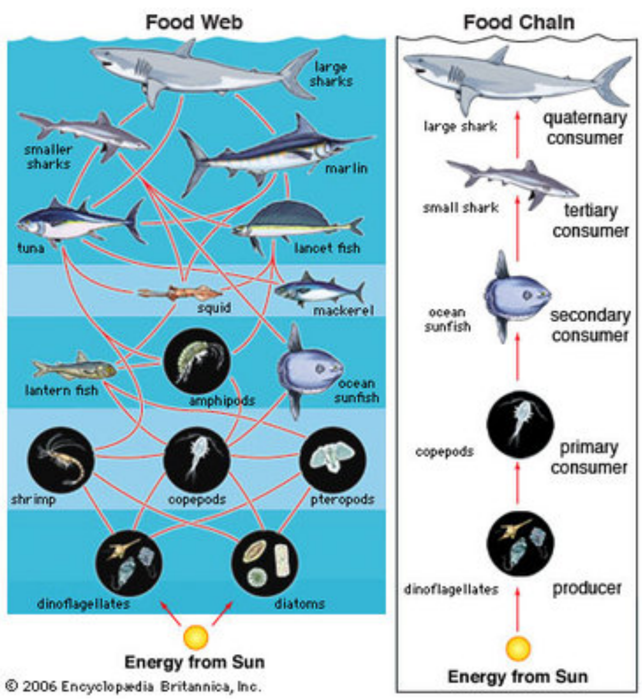

Figure 4: Food web featuring pteropods. Source: Encyclopedia Britannica Kids, 2009; Encyclopedia Britannica, Inc, 2016.

<u>Pink Salmon</u>

Pink salmon are the smallest of Alaska's five anadromous salmon species. They are one of the most economically important salmon in Alaska, and likely to be the most affected by a fluctuation in pteropod populations. Juvenile pink salmon are around 4-6 inches long. In the Bering Sea in the 1960's, juvenile pinks salmon diets consisted mainly of pteropods in comparison to the rest of their diet (42% of food weight). In the 2000's, about 5% of an adult pink salmon living in the Northwest Pacific Ocean relied on pteropods. Pteropods account for around 50 percent of a juvenile pink salmon's diet, according to a study by University of Alaska Fairbanks in 2009. A 10 percent decline in pteropod populations would correlate to a 20 percent decline in pink salmon body weight. Currently in the waters around Alaska, pteropod populations are not in a state of decline. However, the potential for pteropod decline with increasing levels of ocean acidity is a real possibility. It would be likely that underfed, thus underweight pink salmon may have issues when it comes to completing the spawning stage of their life cycle. A smaller underweight salmon would likely maintain a greater number of feeding relationships as the prey species through the marine food web, potentially lowering their numbers. Energy required for swimming upstream, sometimes to distances reaching seventy miles, energy required to produce viable egg skeins, and for successful mating may end up to be inadequate.

The total pink salmon run forecast in 2016 was 40.9 million fish. Of this,19.6 million were from Prince William Sound Agricultural Corporations (PWSAC) hatcheries, 17.4 million were from Valdez Fisheries Development Association (VFDA), and 3.8 million were wild fish. There are three hatcheries in Prince William Sound that release pink salmon: Wally Noerenberg Hatchery, Cannery Creek Hatchery, and Armin F. Koernig Hatchery. In 2013, there were 4.35 million pink salmon smolt released into Prince William Sound from the three hatcheries. Of that, around 3.78 million pink salmon returned (Prince William Sound Aquaculture Corporation, 2016). For 2016, the Prince William Sound catch amounted to 51.56 million pounds with an ex- vessel price of $14.338 million dollars. Throughout the entire state of Alaska the catch amounted to 106.23 million pounds with an ex vessel price of $37.77 million dollars. An 86% return rate as a function of hatcheries greatly reducing the egg, alevin, and fry mortality. The pink salmon industry is a crucial economic driver for Alaska. In 2016, fewer than 4,900 people were employed in the seafood processing industry in the gulf coast region (Department of Labor and Workforce Development, 2016). That means that almost 5,000 people in 2016 partially supported themselves by the pink salmon fisheries. A decrease in Pink salmon available for harvest would result in lower catch production by fisherman.

	Species					
Fishing Area	Chinook	Sockeye	Coho	Pink	Chum	Total
Southeast Alaska						
Natural Production		1,273	2,831	34,000	2,270	40,373
Hatchery Production[a]					9,079	9,079
Southeast Region Total	[b]	1,273[c]	2,831[c]	34,000	11,349	49,452
Prince William Sound						
Natural Production	21	1,636[d]	236[e]	3,840	226	5,959
Hatchery Production[f]		1,761	30	19,599	2,874	24,263
Upper Cook Inlet	7[c]	4,100	160[c]	393[c]	184[c]	4,844
Lower Cook Inlet						
Natural Production	0[c]	56[c]	2	324	66[c]	448
Hatchery Production		256[g]		149		405
Bristol Bay	29[c]	29,520	118[c]	796[h]	762[c]	31,224
Central Region Total	57	37,329	546	25,101	4,111	67,143
Kodiak						
Natural Production	17[c]	3,296[i]	217[c]	11,900[j]	571[c]	16,001
Hatchery Production		396[k]	116	4,300[g]	74	4,886
Chignik	6[c]	1,767[l]	71[c]	849[c]	150[c]	2,844
South Peninsula & Aleutians	16[c]	2,158[c]	219[c]	13,394[m]	742[c]	16,529
North Alaska Peninsula	1[c]	1,421[n]	50[c]	28[h]	206[c]	1,706
Westward Region Total	41	9,038	673	30,471	1,743	41,966
Arctic-Yukon-Kuskokwim Region Total	2	94	365	575	1,480	2,516
Statewide Total	99	47,733	4,415	90,146	18,683	161,077

Note: Columns and rows may not total exactly due to rounding.

Figure 5: "Projections of 2016 Alaska commercial salmon harvests, by fishing area and species, in thousands of fish." Source: Alaska Department of Fish and Game, 2016

Roughly 120,000 people (or about 17 percent) rely on subsistence fishing in Alaska. Subsistence is the act of maintaining or supporting oneself at a minimum level. Many cultural groups in Alaska live a subsistence lifestyle and will be affected by the potential lack of pink salmon.

Salmon fishers get money not by quantity of fish but by the weight of the fish they catch. Decreasing numbers of pteropods raise several ecological and environmental problems due to a decrease in the body weight of pink salmon. If the current trends of ocean acidification and temperature continue, we could face a future where pink salmon no longer have the same economic value that they used to, and where pink salmon lack the nutrients they once had because of a decline in pteropod populations.

Solutions

The most effective means of reducing or reversing ocean acidification is to reduce global CO_2 output .(Jessica Cross, NOAA PMEL) A start would be a movement away from coal (Jessica Cross, NOAA PMEL) and utilizing more forms of alternative energy to reduce our 9 petagram (9 billion metric ton) carbon output. To bring this carbon emission number down, the 2015 UN climate change conference set a goal to raise the global temperature no more than 2^0C pre-industrial levels. This would mean net CO_2 production of zero by 2050. (UN Climate change 2015) Forms of alternative energy such as geothermal, wind, hydroelectric, wave energy, and ocean current power generation show potential to as collective sources of clean energy power.

Geothermal energy shows a high potential as an alternative energy form because of its numerous sources point around Alaska. Alaska has more geothermal surface structures than anywhere else in the United States. Wind power is another potential source of alternative energy as Alaska's 6,000 miles of coastline, and other favorable high-energy environments offer opportunity for remote harvesting of wind power. Wave power and energy production through current generation is a new and emerging form of energy that is created when a buoy system is constructed off a coastline. With every passing swell, the buoy moves up and down powering a generator. Theses buoys could be positions anywhere along our extensive coastline, where ice will not freeze over the buoys. Ocean current power generation uses turbines spun by underwater currents, which could be positioned off of any coastline in Alaska as they can be mounted on the seafloor and send the generated electricity through a cable to the shore. Together these clean forms of energy production can act to slow down the process of ocean acidification because of their zero carbon output properties. In addition to these potential sources of power, there are some measures that can be taken to combat ocean acidification in the short term. One such method is the use of olivine.

Olivine is a magnesium iron silicate mineral, rich in iron, silicon, and magnesium. Olivine is one of the most abundant minerals in the Earth's mantle, making it present in most volcanic rock. When olivine is exposed to CO_2 it combines to make a powder of magnesium-carbonate and silicic acid, trapping CO_2. In medium to low energy environments such as shallow seafloors, the agitation of Olivine pebbles and sands by current action. CO_2 combines with olivine to form Magnesium carbonate in the following reaction:

$$Mg_2SiO_4 + CO_2 + H_2O \rightarrow Mg_3Si_2O_5(OH)_4 + MgCO_3$$

This reaction occurs more slowly in cold water. Olivine can be found in multiple mines and deposits near the Alaskan coasts. These reactions occur slowly over time however, so the use of Olivine is not considered a significant solution to ocean acidification.

A second option for reducing ocean acidification and atmospheric/oceanic carbon concentrations is the commercial farming of kelp (Center for Collective Intelligence, 2014). Kelp has thrived in a more CO_2 rich environment demonstrating its ability to adapt as a response to rising ocean acidity. The structure of the cell wall structure in kelp is central to their ability to store carbon long term. Commercial kelp farming in Alaska could easily be established and could reduce CO_2 concentrations and overall ocean acidity. kelp forests create an environment for hundreds of different organisms and fish species, while being farmed to create cheaper and cleaner biofuel (Alaska Dispatch News, 2016, Center for Collective intelligence, 2014). Kelp farming not only can reduce CO_2 , it can also provide a huge incentive amounting to a $10 billion US dollars globally (Alaska Dispatch News, 2016). “In the remote waters of Larsen Bay, off the coast of Kodiak Island, an experiment is underway. Two types of kelp are strung on lines in the ocean waters, and researchers, investors and commercial fishermen are all watching to see if they grow.” (Alaska Dispatch New, 2016)

Conclusion

Through our research, we have found that pteropods are essential to the Alaskan marine ecosystem. They benefit us environmentally and economically. Pteropods are essential to the food web, supplying food and energy to all the consumers higher up in the food web, including pink salmon. Pink salmon also supply food and energy to many higher consumers, including humans. Alaskan communities benefit from pink salmon. They represent a healthy protein source, and help to drive local economies. Without pteropods, we could not have the plentiful resource that is the Alaskan pink salmon fishery. That is why it is of paramount importance to protect the pteropods from decreasing pH levels of the ocean. Reducing ocean acidification must begin now. The threshold level for pH of organisms like pteropods has been reached. Lowering Carbon Dioxide output is the single most immediate and important first step. To do this will involve finding and incorporating alternative energy strategies to fossil fuels, and a worldwide reduction of coal consumption.

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