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CLIMATE -- Oswalt. While carbon pollution remains a troubling problem for the health of the earth, ocean acidification in Washington is a new area of research suggesting we need climate action now to save ourselves in the future. **4502.**

On a sunny day in Seattle, WA, the midnight blue water of Puget Sound sparkles with glints of light hitting its choppy, bouncy waves. While the fresh fish storefronts bustle with customers looking for the catch of the day, and lobsters sit in tanks to supervise the scene, the crisp sea breeze washes a scent of refreshing salt water through Pike's Place Market. Tourists join residents of the San Juan islands aboard ferry boats that cruise through the sound at mellow speeds. If they are lucky, they may even catch a glimpse of Orca whales or seals swimming in the water. Washington undoubtedly presents beautiful scenery with Mt. Rainier and Puget Sound surrounding the Seattle area. However, like the rest of the world, the looming ramifications of climate change are affecting the state's scenic beauty and wildlife.

Puget Sound has been facing negative impacts of water pollution for years now. This body of water is impacted by both saltwater and freshwater pollution and changes in chemical compounds which is why it sits at a much higher level of risk for impact from climate change. One of the rising issues for the area is ocean acidification.

To understand the impacts of ocean acidification, one must first understand the science behind it and how it started affecting Puget Sound in the first place.

By definition, acidification is an oceanic process "caused by the absorption of more and more carbon dioxide from the atmosphere," according to a 2018 symposium at the University of Washington. The ocean has always naturally absorbed carbon dioxide from the atmosphere and converted it into other compounds, like bicarbonate, within the water. However, as carbon dioxide levels have increased and accelerated from human use of fossil fuels and deforestation practices, so too have the levels of carbon in our oceans.

Puget Sound itself is a particularly interesting estuary because of its geographical location and build. Just 10,000 years ago, glaciers lined the sound, carving parts of its waterbeds to deeper levels in some areas while keeping the shorelines shallow. At its deepest, Point Jefferson, the sound reaches 930 feet below sea level, according to the Seattle Aquarium. This means water temperatures and pH levels will vary depending on the depth of the water in a given area. The sound is also extremely large, reaching from the Canadian border down to Olympia, WA.

According to the Encyclopedia of Puget Sound, an online guide to protecting the Puget Sound waterways, the ocean is constantly absorbing 25 to 30 percent of carbon dioxide from the atmosphere. In a healthy oceanic atmosphere, the carbon absorbed into the water would help the water carry out its natural buffering process. This essentially means the pH levels in the ocean would not rise to be too acidic, and the water would remain oxygen-rich. With ocean acidification, this buffering cannot happen at the speed it needs to; thus, the pH levels become abnormally acidic. More carbon dioxide present in the water can also cause hypoxia: a state of low oxygen. This can literally deprive marine life of adequate oxygen, causing them to run out of air.

The Washington coastline specifically falls victim to acidification because of a natural process called upwelling. The Pacific Ocean has ginormous currents constantly running from east to west and west to east. These currents help bring nutrients throughout the ocean. The main current that runs west to east, known as the North Pacific Current, slowly moves deep ocean water towards the coasts of Washington, Oregon, and California. Spanning all the way from the coast of Japan to the coast of Canada, this water movement runs across the entire Pacific Ocean. Due to the depths at which much of the nutrients in this current are coming from, the water we are seeing on the coasts now is actually water that absorbed atmospheric carbon from the late 1970's and early 1980's. Because of this time capsule-like effect, ocean acidification has only become a cause for concern in Puget Sound over the past ten years.

Micah Horowith, a scientist on the Environmental Assessment Program for ecology in Washington, has been running water tests to analyze the water health of Puget Sound for about three years. He says his team analyzes water levels by taking samples in water bottles. They then look at different compound levels in these samples to test for overall quality. Essentially, they want to see how much dissolved inorganic carbon is in those samples to observe how much pH, or acidity, is in the water of the sound.

Small shellfish species, like oysters, have been some of the hardest hit so far by acidification. This means aragonite saturation is another intrinsic level of water health the team tests. "Basically, when you have water with aragonite saturation state above one then oysters can build their shells fairly well. When it falls below one it's much more difficult for them to build shells,"

Horowith said. Luckily, Horowith and his team have received funding to continue these tests at 19 different stations across the state.

Another important aspect for scientists to be monitoring within Puget Sound's acidity levels is the presence of freshwater and the compound contributions it makes to the saltwater estuary. Horowith said, "The alkalinity that comes into Puget Sound ultimately comes from freshwater sources, and that's what buffers all of our waters against acidification." He then explained that temperatures rising in the atmosphere will ultimately shift Washington to have a much rainier climate versus its now snowy winters. Without snow melt, the time at which freshwater hits Puget Sound will shift, causing a disruption to when those buffering compounds are added to the acidified ocean water.

Kelly Ferron, a researcher for water quality in the Washington Department of Ecology, said, "We're both looking at nitrogen and carbon in the water, and because Puget Sound is this very developed area, we have a lot of nutrients and pollutants that are going into the water that are exacerbating ocean acidification that is already happening due to atmospheric carbon." The multitude of freshwater rivers and streams that flow into Puget Sound introduce other negative factors to the water body from substances like agricultural fertilizers and pesticides. Like Ferron said, these factors all combine to heighten the concern for acidification.

Scientists expect acidification to continue accelerating in the years to come due to the lapse in time we see with carbon being pulled through the Pacific ocean currents. If the water we are seeing right now from the 1970's and 1980's is already causing issues for marine life, it is fair to

assume more damaging effects will arise when water from our current moment is introduced 40 years from now.

Like most issues under the umbrella of climate change, ocean acidification poses multiple threats to marine species in Puget Sound and freshwater streams nearby. Ecosystems within these bodies of water may face impacts all the way up their food chains.

One of the most famed Washington species, Orca whales, may see the repercussions of ocean acidification firsthand in the future. The species was officially listed as critically endangered in 2005 according to the Washington Governor's office. As of December of 2020, the total population of Southern Resident Orcas in the Puget Sound was down to 74 individuals split between three pods: the J, K, and L groups.

The Lummi tribe in the San Juan Islands of Washington is fighting against the loss of Orca whales in Puget Sound. For the tribe, Orcas are closely related to their own ancestors and origin story. "Totem poles are carved with the orca's image, sometimes accompanied by a human rider as a symbol of rebirth. Tribal members talk of feeling the whales passing by, of a calling from their relatives," says an article from *The Guardian* in 2019. Climate change is not only threatening human survival globally, but for many Indigenous cultures, the land and species suffering the consequences are integral and beautiful parts of their cultures and traditions.

In a detailed 2019 report by the Orca Task Force for Gov. Jay Inslee, studies show the whale population is struggling to grow due to a lack of food resources. Chinook salmon cause a particular problem for the whale pods because they are the main source of food for Orcas.

According to the Whale and Dolphin Conservation, an organization working to protect whales and dolphins globally, 80 percent of a full-grown Orca's diet consists of salmon, and one individual needs to eat 18 to 25 daily to survive.

As a keystone species, the Chinook salmon also provide food for bears, birds of prey, and seals throughout the state's waterways. According to *National Geographic*, keystone species "are critical to the survival of the other species in the system." In total, more than 130 species rely on Chinook salmon as a source of food and would be negatively affected if the species went extinct.

Several recent studies on ocean acidification have shown Chinook salmon may be losing their ability to smell, and this poses a huge threat to their survival. Chase Williams, a researcher for UW, saw these findings in his study in 2018. He exposed Coho salmon to the same elevated carbon dioxide levels seen in modern ocean waters. Afterwards, Williams dropped a scent into the water to replicate that of the salmon's predators to test their reactions. The fish ignored it. Williams said, "They're still smelling odorant, but the way their brain is processing that signal is altered … Before, they would avoid this predator odor and now they're more indifferent to it."

Salmon also rely on their sense of smell in order to return back to their spawning grounds in freshwater streams to repopulate every year and find food. If Washington's construction of dams throughout its major rivers was not already decreasing salmon's chances at survival while swimming upstream, losing their sense of smell could prove detrimental to this keystone species; therefore, their downfall could decrease species's populations across entire food chains.

While bigger marine species are starting to suffer from acidification, shellfish were the first to be hit by the process. The reason oysters and other shell building animals are so sensitive to changes in the ocean's pH levels is because they use specific compounds from the water to create their hard calcified exteriors. To do this, hatchlings need a specific water temperature and pH level. As acidification alters these levels, it becomes harder for oysters to make it past this hatchling stage at all.

Taylor Shellfish Farms, a hatchery based in Shelton, Washington, saw firsthand the impacts ocean acidification had on the shellfish industry. Bill Dewey, oyster farmer for forty years and Director of Public Affairs for Taylor Shellfish Farms, shared some insight into his firsthand experience with this problem as a shellfish industry worker. Back in 2007, Dewey and his coworkers had no way of knowing it was acidification that was causing their larvae to die. "Putting a finger on it and saying, 'Well that one died because of OA, and this one died because of this and this, you know you can't do it. It was really hard to quantify. But that said, during that time period, 2007 to 2009 in that range, both Whiskey Creek and Taylor, our oyster larvae production was off by about 75% probably," said Dewey. Being two of the biggest oyster hatcheries on the west coast, their losses were substantial for the industry.

In total, the downfall cost the oyster economy an estimated 110 million dollars throughout the late two thousands, according to Michelle Hampson in her article about Whiskey Creek Hatchery. Despite this tremendous loss in revenue for the hatcheries, their story gained momentum and sparked a movement in science. Researchers and politicians wanted to know what was going on. Much of the research on ocean acidification we have now is attributed to the oyster industry.

Horowith describes how the process typically works when hatcheries collect water to use. Before acidification became a known problem in the industry, hatcheries usually gathered water from deeper parts of Puget Sound through pipes that pumped it into their enclosures. They would simply pull in this deeper water, not knowing it was significantly higher in carbon dioxide levels.

To combat this issue, Horowith said hatcheries had two options. “One of them is just changing the time that they pull water into the hatchery. If you pull it during the daytime, that’s when it is naturally higher in pH because of photosynthesis,” said Horowith. The second option is to mechanically change the chemical compounds in the water being pulled in.” To make this work, he said, “They pull it into this big holding tank, they dump a bunch of calcium carbonate, lye, or what have you into the water, then they confirm that the pH is way up, and only then do they send it to the tanks where they’re rearing the oysters.”

Oregon State University tried removing two supposedly harmful bacteria from Whiskey Creek’s water tanks and saw no better results in larvae survival. Dewey said the idea of ocean acidification was called into question as the potential culprit after none of their suspicions were proving right. In 2008, Richard Feely, a leading scientist on OA in Seattle at the time, reached out. It became clear to the industry, after Feely’s talk on ocean acidification at a Growers Conference that year, that acidification was the issue.

“I missed his talk, but I got there a little bit late, and when I walked in everybody was kind of walking around with their chins on the floor like somebody has just died or something,” said Dewey. “We’re not gonna convince the world to stop emitting carbon dioxide.”

Dewey says there are two things a baby oyster must do in its first two days of life. “It’s gotta build a shell to protect itself, and it’s gotta protect a velum which is the organ it feeds and swims with in order to be able to get more energy to continue to grow. And it’s got to do that with the energy that’s stored within the egg. When there’s not enough carbonate ions, it struggles to build that shell.” The hatcheries needed a solution, fast.

So the sobering news did not stop Dewey and other farmers from searching for answers and solving their problems. They knew ocean acidification was only going to intensify and become a regular problem as more carbon-soaked water inevitably upwells in the future, even if we stopped all carbon emissions today. Dewey said this “grand collaboration” between industry and university scientists formed, and teams from Oregon State University, University of Washington, and the National Oceanic Atmospheric Administration (NOAA) joined forces. This is when Burke Hales, an OSU scientist, invented the Burkolator. This is a machine the hatcheries are able to use to test their water’s carbon chemistry in real-time. It is helpful because they can see what conditions create certain pH levels in the water. “We learned that we can treat that water by adding certain carbonate to it and adjust the carbonate chemistry to make it right for oysters to build their shells. It was a long evolution over a couple of years to learn what was going on,” said Dewey.

After receiving headlines in big media like the *New York Times,* Dewey felt perplexed as to why the story picked up so much momentum. “It’s an industry that people can relate to because it’s food, it’s jobs, it's a novel industry, and for whatever reason our story was popular and got broadcast. You know I say it drew a lot of attention to the issue. We got OA into people's

vocabulary pretty quickly, and I think a lot of that is attributed to that oyster story," said Dewey. The story caused waves in the research behind ocean acidification.

The Burkolator soon circulated in the state governmental policy talk, and then Gov. Gregoire passed a 3.2 million dollar budget item to go towards ocean acidification as she left office in 2013. When the current Washington State governor, Jay Inslee, stepped into office, he allotted 1.8 million of that budget towards the spread of Burkolators to hatcheries. This has enabled oyster farmers like Dewey to proceed successfully in their businesses and continue profiting off their industry.

Despite Washington having a Republican majority in the Senate at this time, Dewey believes ocean acidification is a non-partisan issue. He said whether these officials were ready to address climate change was unimportant in his messages for them. "What's more important to us is you help us with these monitoring funds, help us with the research so we can try to understand how we can adapt to these changing conditions. And you know, help the state understand how it's impacting other important marine organisms to Washington's residents," said Dewey. Ultimately, he wanted to ensure funding and awareness.

Washington started implementing more policies and creating systems for the oyster industry to continue. "We started to monitor that water and that really, like our governor at the time [Christine Gregoire] was like, 'Wow this is a really big problem. Let's gather scientists, policy makers, we need to understand and invest in science so we can protect shellfish farms and our coastal economy," said Ferron. So people set out to understand and learn what was going on.

The Department of Ecology developed a model in which scientists could test different levels of pH and other changing compounds in the Puget Sound to better understand what the future of acidification might look like. This oceanographic model is called the Salish Sea Model, and Ferron's team created it.

Ferron and the team can essentially use their preexisting knowledge on tidal influxes and hydrology to learn about the past patterns and predict future ones. "It's ideal to have a model where you can play around with like, 'Okay, well let's say we can reduce nutrients and carbon dioxide this amount. What does that do to the water quality?' and you can toggle and play around with that," Ferron said. She explained it in terms of going to the doctor and checking vital signs. The water has vital signs, like aragonite saturation, pH levels, oxygen, and bacteria levels, that are constantly being checked in order to determine its health and favorability for species.
Her team also uses the most sensitive species in the area to base their predictions and recommendations off of. Ferron said, "An oyster is really sensitive and needs a specific temperature and pH level, and that's more sensitive than a salmon. We'll use those levels to set what we think is clean water and that's the level we want our water to be at." These processes ultimately help the Department of Ecology decide whether the current situation needs policies behind it to set forth plans for future prevention.

Due to ocean acidification being a fairly new topic in the world of scientific research and data collection, there is still lots to learn about the issue and what species may ultimately be impacted by its harmful effects. Ferron said communicating the depravity of the issue to the public is challenging too because acidification is not an easy topic to understand, but she believes for

people to actually vote for policy to improve an issue, they must know how it works first and grow an awareness of it.

The University of Washington's environmental school has an entire program dedicated to protecting the ocean in Puget Sound. The Washington Sea Grant lists easy ways for the public and the fishing community in the area to help stop the acceleration of acidification. The group advises people to share rides to reduce carbon emissions, picking up after pets to ensure no feces pollute the waterways, and to reduce the amount of animal proteins being consumed since the meat industry uses almost ten times more fossil fuel energy that grains do to produce.

Washington's progress both economically and politically towards environmental sustainability, specifically within the realm of ocean acidification, has motivated other states to initiate plans for their coastlines. Dewey said the Pacific Coast Collaborative was started in 2013 which unites California, Oregon, Washington, and British Columbia under the central goal of being environmentally conscious. Dewey has also spoken at numerous United Nations conferences on his experience at Taylor Shellfish Farms and has met with growers in international locations like New Zealand and Thailand to promote the need to fight against OA. Dewey recently helped found the Shellfish Growers Climate Coalition. He said the group unites "Growers from 20 different states that are all collaborating to tell our stories about how climate change and changing ocean chemistry is impacting our businesses." Dewey's voice is clearly a key component in the charge ahead for a fight against ocean acidification.

Gov. Jay Inslee has also helped put new policies into place to make Washington move towards a clean energy future. The Clean Transportation Policy, introduced in 2019, sets goals for the state

to introduce more electric vehicles and ferries in order to bring carbon emissions down. Inslee's Electric Vehicle Fleets Initiative set a requirement for 50 percent of new vehicles being owned in the state to be electric by 2020 and to have at least 50,000 electric vehicles in the state by 2020, too. In 2019, there were 43,047 electric vehicles in the state. A new bill was also introduced to incentivize electric vehicles and make them more affordable in Washington. On top of this, the state also eliminated sales tax on the purchase of electric bus tickets. While making efforts to decrease carbon pollution in Washington, Inslee also signed five bills to help protect and recover the Southern Resident Orca pods. Executive Order 18-02 established an entire task force team to protect the state's whale population in 2018.

Other than governmental scientists and policymakers signing bills into action, there are myriad ways to get involved on an individual level in helping monitor species' health. One of these methods is iNaturalist. Mary Ellen Hannibal, environmental journalist and author, believes strongly in the power of being a citizen science so much so that she wrote a book about it called, you guessed it, *Citizen Scientist*. She is a big proponent of iNaturalist. It is an app where anyone can simply take photos of a plant or animal species, submit it to the database, and then the app can help identify what species it is. This helps the California Academy of Science and National Geographic monitor how many of a certain species there are and in which locations. "Big data is really the only way that we can take our individual observations, and we can donate them to the cause of seeing what the whole globe is. That is the incredible beauty of citizen science is that it approaches the problems of nature at the scales at which nature operates which is both very local and very global," said Hannibal.

Dorothy Kidd, a media studies professor at University of San Francisco and climate activist, studies how the media impacts our awareness of environmental issues. “Media intervention is really what’s making people more conscious of that [climate change],” said Kidd. “Not only has there been an increase in interest in terms of social media, but a lot of the groups on the frontlines have been using social media really really effectively, and definitely a lot of the indigenous groups.” Kidd believes social media gives people a more diverse range of opinions to hear about on certain issues.

Standing Rock, for example, is a Sioux Tribe in North and South Dakota using the Internet to fight for the protection of their land. The huge Dakota Access Pipeline runs through this land, and they have been raising awareness of this issue through Facebook, Tumblr, and Instagram. Their website is also extremely informative and is an example of how a grassroots organization has been able to use the Internet to gain momentum and an audience.

However, environmental ethics and theology professor for the University of San Francisco, Sam Mickey, argues technology might be driving a disconnect between humans and nature. He said many older traditions and religious practices call for humans to appreciate nature and find a sort of oneness with it. But with the turn of the Industrial Revolution, people no longer needed a close relationship with nature to survive. “The way capitalism has reoriented people toward brands and commodities, we’ve totally forgotten our intimate connection to plants and animals and lakes and rivers and oceans,” said Mickey. “So to me the big change then is we used to think there was something called ‘away.’ That you could throw something *away,* and now we’re realizing that there is no *away*. Everything is interconnected. So that thing that you call ‘away’ will eventually come back and hit you.”

Living in an oil-based economy also makes it harder to mobilize a movement toward electric vehicles and environmentally-friendly lifestyles. Mickey says while grassroot organizations are important to be involved in on local levels to make change, we also need to elect policymakers who will take steps away from oil dependency. Mickey said, “The driver is gonna be people waking up and realizing these changes are an imminent threat. It’s an existential threat to human life and really all life one earth.”

Ferron agrees with this viewpoint. “If we want to make these big urgent changes and reductions in CO2 emissions that we need, we need big systemic change. That’s going to come through strategic policy and good leadership. Whether that’s like your community leader, you know even starting from city council, up to your state leaders up to the federal level, that’s really how we’re going to address these big climate issues,” she said. Dewey has seen this work in his time as an outreach worker for the shellfish industry. Supporting policy makers who will seek environmental change and less carbon emissions in the future is the best way to make an impact.

Mickey shared there was to be an ancient Greek myth that said “the sea could wash away all evils.” The idea that we could throw our problems away into the big waves of a mysterious, gigantic body of water and forget about them is whimsical, but it is unfortunately not our reality. Human fossil fuel emissions are causing issues like ocean acidification on a global scale. Since water health and land health are closely related, 40 years from now we could be facing irreversible damage from the acidification we are inevitably accelerating with our constant carbon emissions.

As Horowith said, there are not yet any documented cases of acidification completely wiping out any species population fully, but the concern comes in when we start to consider the future of our ocean's health and how acidification will cause untreatable damage to food chains and ecosystems by then. "Even if we stopped emitting all carbon dioxide right now as a humankind, acidification would continue to get worse on the West coast of the United States for the next 40 to 50 years because that conveyor belt is very slow moving," said Horowith. The time to act is now while we still have time on our side.

Editors

I am pretty happy with where this is at right now, but I am aware that it is long. I have tried to condense it to my best abilities, but I do not want to leave gaps in the reporting. My biggest qualm right now is that my interview with Micah Horowith contained a lot of valuable information, but I feel like I cannot fit it into the story very well as I am worried about length and word count. I also tried really hard to stick to my initial outlining for the story and deliver the information in a way that makes sense, but if you feel I am jumping around or there are areas that need more detail, please let me know!

Lizzie, really great piece! You have *a lot* here which shows how much you researched this, so good for you!!! It leans a little closer to an academic paper at times, but I don't know if that can be helped because you're writing about a very science heavy topic. I put some notes on where I thought some graphs could be cut or combined, hopefully without ruining the flow of the paper. I appreciate that you took the time to explain each scientific detail like acidification because otherwise it'd be very confusing.