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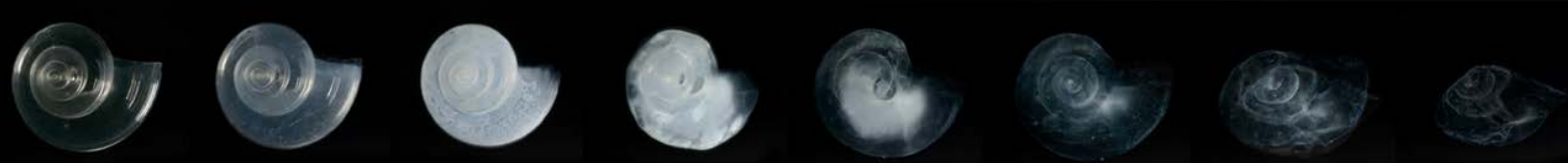
salish sea currents



TIMELY, LOCAL STORIES ABOUT ECOSYSTEM RECOVERY

SPECIAL REPORT
FOR PUGET SOUND POLICYMAKERS

2020 CLIMATE ISSUE

PUGET SOUND INSTITUTE

About The Puget Sound Institute

The Puget Sound Institute (PSI) was established at the University of Washington to identify and catalyze the science driving Puget Sound and Salish Sea ecosystem recovery. Since its founding in 2010, PSI has advanced our understanding of the region through synthesis, original research and communication in support of state and federal agencies, tribes and other organizations working in the region. PSI receives major funding from the Environmental Protection Agency.

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Introduction

Welcome to the 2020 edition of Salish Sea Currents magazine. This is the fourth issue of the magazine, and the first one dedicated to a single theme. All of the stories in this report address the impact of climate change on the Salish Sea ecosystem.

While this collection is not a report about climate change itself — we will not describe the underlying causes of global warming or even talk about how to reduce greenhouse gasses — it is a lens through which to view current ecosystem recovery efforts.

Taken individually, these stories represent some of the most critical research being conducted in the Salish Sea. In that spirit, they cross a wide variety of topics, from shoreline armoring to endangered orcas. Taken together, they are further evidence, if any were needed, that climate change affects almost everything we do.

The issue begins with an interview with Cornell University and Friday Harbor Laboratories scientist Drew Harvell on the subject of warming oceans and the rise of viruses and other pathogens affecting wildlife. Fittingly, we spoke with Harvell in the early stages of the coronavirus outbreak as it began to sweep over the United States (more on that later). In the midst of the current pandemic, Harvell reminds us that the swift impacts of disease are not just a problem for humans. They are also a major threat to endangered species such as orcas and Chinook salmon. As Harvell explains, “warmer seas are sicker seas,” and climate change and disease are inextricably linked. We have dedicated the first part of this issue to that subject.

Other stories take the reader outside and into the field. We follow scientists to remote places like Protection Island, where long-term studies of rhinoceros auklets are providing clues about the general health the of the Salish Sea. We journey by boat through one of the region’s last remaining tidal forests and look at how sea level rise could threaten hundreds of millions of dollars in habitat restoration projects. We report new discoveries about declining kelp beds and break important news about ocean acidification. In all, we offer 12 compelling stories, each influenced in some way by climate change and global CO_2 emissions.

You will notice that this year’s issue is divided into four sections: Disease, saltwater habitat, terrestrial habitat (terra firma) and ocean acidification. This is meant to make the collection easier to navigate, but it also shows the breadth of the subject. It can be argued that almost any environmental story is now a climate story. Global warming is not just global, it is pan-specific and crosses all environments, whether they are oceans or shorelines or mountains.

Finally, we could not talk about this collection without acknowledging the current crisis presented by the coronavirus. Many of the stories in these pages were written before the onset of the pandemic, but the parallels between global climate change and the world-altering impact of COVID-19 are hard to miss. No one knows how this crisis will ultimately affect Salish Sea research and policy, but we have seen enough to understand that it, too, like climate change, will be part of our story for a long time. We now know the hard truth that global environmental problems are also problems here at home.

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Disease

The connection between climate change and the spread of disease is well-known. A host of deadly pathogens affecting humans have been shown to thrive in warming climates or to accelerate during extreme weather events. The same can be said for diseases among wildlife. Scientists are increasingly alarmed by the potential of disease to devastate already compromised populations of species in the Salish Sea. In this section, we look at how this could affect a wide variety of organisms, from birds and fish, to mammals and plants. We need only consider our current situation under the coronavirus to understand that the impacts can be devastating.

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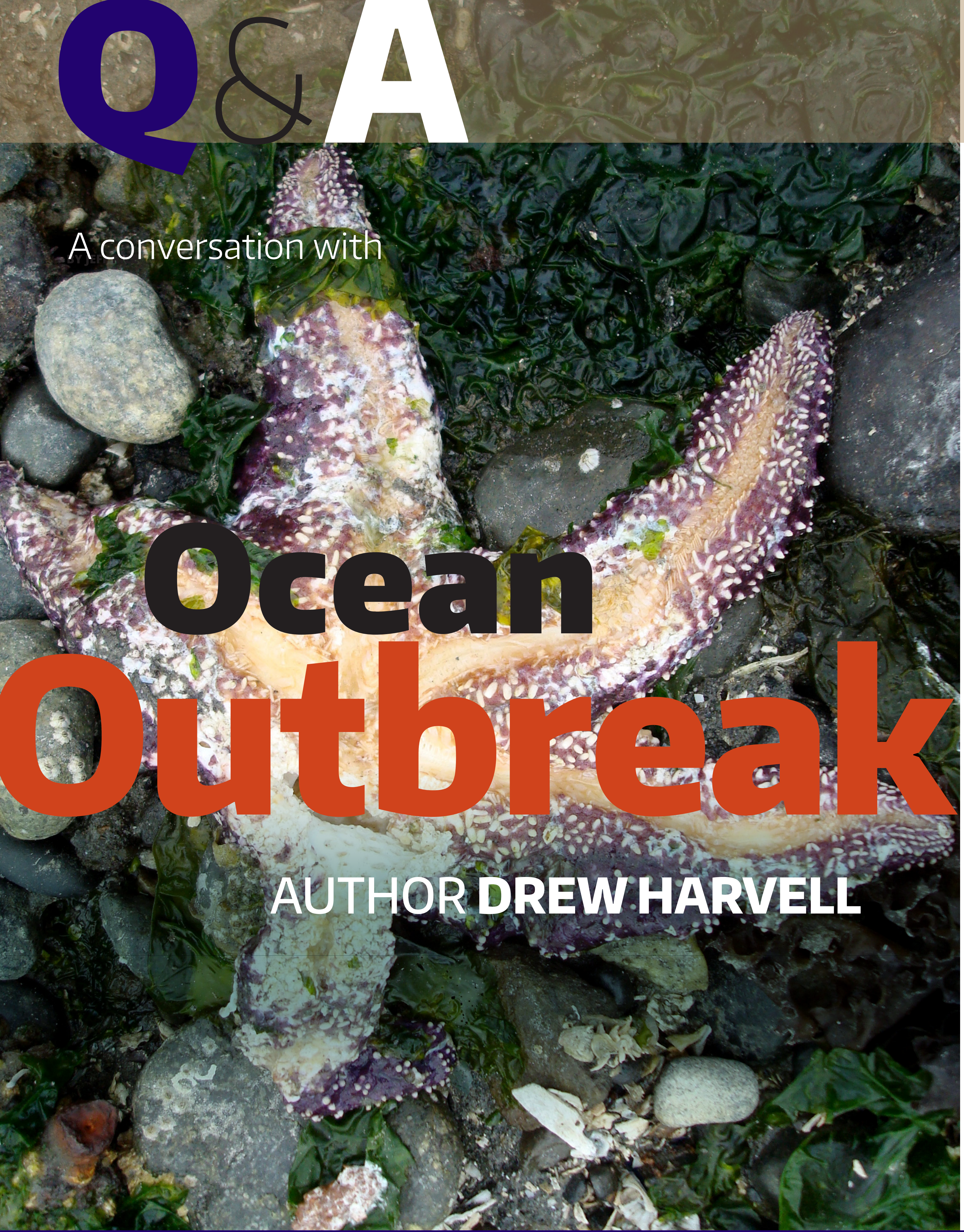


Q&A

A conversation with

Ocean Outbreak

AUTHOR **DREW HARVELL**

When Cornell University ecologist Drew Harvell wrote her book "Ocean Outbreak," she couldn't have known that 2020 would be the year of the coronavirus. But even as people around the world grapple with the effects of that disease on humans, scientists are keeping watch on potential disasters from viruses and other pathogens for species in the world's oceans. As the oceans warm due to climate change, scientists expect incidences of disease to increase dramatically in marine ecosystems including the Salish Sea. We asked Harvell about her new book and the need to address this rising challenge.

Salish Sea Currents: Right now, disease and the coronavirus are on everyone's mind. Can disease have the same effect on the ecosystem as it does on human populations?

Drew Harvell: You know, it's very similar. I call myself a disease ecologist, and that's essentially the quantitative study of how diseases act and how they outbreak, what the resistance factors are and how they are transmitted. We really study the same parameters whether it is a human coronavirus that's newly emerging or whether it's a new virus in a sea star. We're interested in how rapidly a disease spreads, how resistant are the hosts, what are the environmental factors that govern the spread rates of these diseases.

SSC: Is disease ecology a new field in science?

DH: I would say it's not new to be studying the environmental causes and consequences of disease, but we do have new tools. We are able to study it with a little bit more control and quantitative perspective than perhaps we could have 20 years ago.

SSC: Are there new environmental factors that are increasing the outbreaks of disease in the ecosystem? Your book talks a lot about the impact of climate change, for example.

DH: Yes. I think here in our waters in Puget Sound and into the Salish Sea, we're caught a bit in a vice grip. One arm is rapid climate change -- our waters are warming and they're becoming more acidified. At the same time, we're piling on human population. Those two factors act synergistically, and both put a lot of stress on our marine ecosystem. Both factors contribute to an increasing risk of disease as well as other problems with sustainable ecosystems.

SSC: I think you said in your book something to the effect of 'warmer seas are sicker seas.'

DH: That is actually a quote from a paper that we published in 2002 in Science where we said a warmer world is a sicker world. We talked about this across the board, whether it is in the ocean, or agricultural systems or whether it is with human disease. Of course, not all diseases are temperature sensitive, but in general warmer conditions can create more stress for a host. They also create higher replication rates for lots of infectious microorganisms. In the case of humans, that can also increase some of the vectors like mosquitos which have a wider range under warmer conditions.

SSC: With climate change and disease high on the radar, what are people trying to do in response?

DH: Well, we'd really like to see political change and see a slowing of our carbon dioxide emissions. It's certainly very worrisome to me that we are not really slowing it down enough. In the absence of that, surveillance is vital. Fortunately, we have NOAA, which does phenomenal satellite remote sensing. They provide us with minute by minute temperature forecasts that we can use to forecast and ground truth [ocean conditions]. I think we need to work much harder to improve our diagnostics for marine disease so we're in a better place where we really can pick up these rapidly expanding diseases.

I think everybody is very impressed — shocked and amazed — at the pace and the unexpectedness of the coronavirus outbreak. But you have to realize that things like that happen in the ocean too.

"Ocean Outbreak" is published by University of California Press. Drew Harvell is a Professor of Marine Ecology at Cornell University and affiliate faculty at the University of Washington School of Aquatic and Fishery Sciences where she conducts research at Friday Harbor Laboratories.

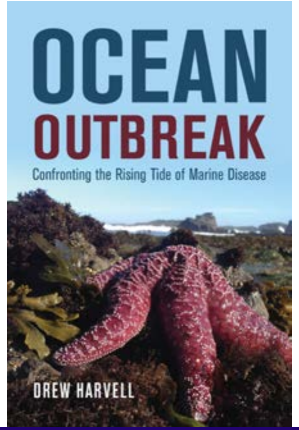


Photo left: Sea star wasting disease. PHOTO: ALISON LEIGH LILLY

A health check for seabirds

BY ERIC WAGNER

Scientists are still trying to understand what caused the deaths of thousands of rhinoceros auklets in the Salish Sea in 2016. Some studies point to disease as a central factor in that incident and potentially other large seabird die-offs along the coast. That is prompting a deeper look at what makes these birds sick, and how local populations are faring. We followed a group of researchers as they gave a health checkup to a breeding colony of rhinoceros auklets on Protection Island.

Picking the best spot to catch a rhinoceros auklet (or, ideally, several of them) can seem as much a matter of art as science. When the auklets fly in from the Strait of Juan de Fuca in a few hours to return to their burrows under cover of darkness, are they more likely to zip over the short rise here or the one over there? And if the net is at the crest of this rise, rather than just below it, will the auklets be able to see it well enough to avoid it? Place the net too low on the slope, though, and the auklets are liable just to fly over it. So: Much to mull.

"This looks like a good spot," says Scott Pearson, a biologist with the Washington Department of Fish and Wildlife. It is nearly dusk, and Pearson is standing waist-deep in grass on the south side of Protection Island, a national wildlife refuge a mile or so off the northern coast of the Olympic Peninsula. A few yards from him, Peter Hodum, a biologist from the University of Puget Sound, is looking between the water, from which the auklets will come, and the interior of the island, where they will go. "Yeah," he says. "It seems like they'd be kind of funneled up this way."

The two set up what are known as mist nets — named for their fine mesh, which is hard for birds to see in low light — jabbing tall poles into the ground and carefully threading the net's end loops onto them. Once fully opened, the nets are about forty feet long and six or seven feet tall, with several baggy shelves that create a loose pocket for the birds to truss themselves in. But as Pearson opens them to their full height, several large holes and tears appear. "These have... seen some action," he says, and chuckles before collapsing the nets. He and Hodum will come back later with the rest of their crew, which includes two wildlife veterinarians, and then the trapping will begin in earnest. After all, like most wildlife, auklets can be reluctant patients when it comes to getting a checkup.

A QUESTION OF HEALTH

Rhinoceros auklets are similar in size and girth to a small pigeon, with sturdy bodies and stubby wings. When breeding they sport white plumes above their eyes and across their cheeks, and grow a little stub of horn at the base of their bill. Otherwise, their plumage is a study of grays — dark above, light beneath. With other seabirds, they occupy key positions in the Salish Sea food web, and are considered to be one of the vital signs of the ecosystem's overall health.

Photo left top: Veterinarians Greg Frankfurter, UC Davis and Katie Haman, WDFW take a blood sample from the wing of a rhinoceros auklet. PHOTO: PETER HODUM

Photo left bottom: A hillside on Protection Island dotted with auklet burrow entrances. PHOTO: ERIC WAGNER

But what of the seabirds' own health? The status of that is a little less clear. "There are a lot of people looking at the abundance of seabirds in the Salish Sea," says Greg Frankfurter, a wildlife veterinarian with the Wildlife Health Center at the University of California-Davis. "But no one's really looked at the role disease might play in process." On top of that, disease itself is a big, generous term. "People mostly think of things like avian influenza, or massive bacterial infections, but there can be a lot of other things," Frankfurter says. "There is not a wild animal out there that doesn't have a parasite burden, from gastrointestinal parasites to ectoparasites, and blood-borne parasites are more common in seabirds than marine mammals."

Mounting evidence, however, shows that warmer seas are sicker seas. As Drew Harvell, a marine ecologist from Cornell University, wrote in her recent book Ocean Outbreak, humans have "created a perfect storm of outbreak conditions in the ocean." While birds are at risk, they are hardly alone. A 2015 study in the Proceedings of National Academies of Science found that the frequency of mass mortality events was increasing in everything from mammals to reptiles to amphibians to fish to invertebrates. "Across all animal taxa," the authors wrote, "causes of [mass mortality events] were most often associated with disease and were attributed to viral (44.5%), bacterial (18.3%), and fungal infections (12.2%)." This was greater even than what the authors called "human perturbation," which usually came in the form of environmental contamination, such as an oil spill.

WAITING FOR THE BIRDS

By 8:30 p.m. or so, Pearson and Hodum lead the group out to the capture site. Also along are Tom Good, a NOAA biologist; Sue Thomas, the refuge biologist from the U.S. Fish and Wildlife Service; Lilli Patton, one of Hodum's students at the University of Puget Sound; and the two vets, Katherine Haman, from WDFW, and Frankfurter, who is up from California. It is a large group, but Pearson is hoping all those hands will be necessary, and filled with auklets.

The sun is sinking and the wind is strong when the group reaches the nets. "Good night to be bundled up," someone says. "Too bad it's July," someone else responds, but it is hard to tell who is who under all the fleece hats.

Pearson and Hodum open the nets and settle into the grass a few feet uphill, so they can quickly extract any ensnared auklets. ("You want to be quick about it for the bird's sake," Pearson had said.) Haman and Frankfurter set up their equipment back on the road so they can process whatever auklets are caught. Everyone else spreads out along the hillside. They will try to catch by hand those auklets that evade the nets but still land in the area.

The sun has set for good now. Pearson and Hodum do a final check of the nets, which billow like spiderwebs, while Good, Thomas, and Patton move about by headlamp. Little points of light dance about the hillside as they get in position and make themselves comfortable. For a moment everyone's lights are stationary, like stars in a grounded constellation, and then each winks out one by one, and there is just the dark, and the wind blowing through the tall, dry grass.

IMPLICATIONS FOR HUMANS

Seabird health and their disease burden can have far-reaching implications, not only for the birds themselves, but also, as Frankfurter notes, for humans. The past decade or more has seen a steady parade of papers suggesting possible pathways for pathogens between birds and people. In 2008, for example, researchers in Portugal reported finding antibiotic-resistant strains of E. coli in gull feces collected on public beaches. In 2011, a French researcher reported similar results from Miami Beach in Florida. In 2016, researchers in Lithuania and Argentina both reported antibiotic-resistant strains of E. coli in herring gulls and kelp gulls, respectively, both of which are common and widespread. (The researchers suspected the gulls were exposed to the bacteria by eating garbage that contained either sewage or medical waste.) And just a few months ago, Australian researchers found antimicrobial-resistant bacteria in the feces of silver gulls, which are, they wrote somewhat ominously, "a gregarious avian wildlife species that is a common inhabitant of coastal areas with high levels of human contact."

To date, though, no one has really studied the prevalence of disease among the Salish Sea's seabirds. But there have been worrisome signs that disease may have a significant impact on their well-being. Near the end of the marine heat wave known colloquially as The Blob, rhinoceros auklets in the Strait of Juan de Fuca in the summer of 2016 experienced a mass mortality event. Hundreds of dead auklets washed up on area beaches; all told, thousands are thought to have died.

Subsequent necropsies of a few of their bodies suggested the auklets had been food-stressed, while also showing signs of a viral infection. Untangling which was cause and which was correlation has been tricky. Did the auklets get sick because they were already thin? Or were they thin because they had already gotten sick? It was, as Bob Friel of the SeaDoc Society would later call it, the "riddle of the rhinos."

IN THE NETS

You hear the auklets before you see them, the steady quick whirr of their wings as first one and then two more zip in overhead. It is a little after 9:30 p.m., and they fly low above the grass so as not to present a target to any waiting bald eagles. Landing for them is a haphazard affair; there is a thrashing sound as they smack into the grass, and then a dry shuffle as they scramble through the tussocks to the mouths of their burrows, which might be several feet deep. Crosswise in their bills they carry up to twenty small fish for their single chicks, which are several weeks old now; both parents will feed the chick each night.

Suddenly a headlamp — Hodum's — flashes on near the nets. It illuminates a twitching lump: An auklet dangling in the mesh and struggling to free itself. Hodum rushes over and secures the bird with one hand while delicately extricating it with the other. He then hustles it to Frankfurter and Haman, who are seated next to a large cooler — their workstation. As he does, two more auklets ensnare themselves; Pearson hops up and gets busy removing them.

For those people arrayed about the hillside, pursuit and capture is a bit more frenetic. When they hear an auklet land near them — five feet away, ten feet away — they bound up and turn on their headlamp, trying to illuminate it. If perfectly caught in a beam, the auklet might freeze, but more often than not it scampers away, obliging a brief but intense chase through the grasses. The auklet bobs and feints, but once a person claps a hand over it, it yields. (Whoever catches the bird scoops up the fish to analyze later.)

At the workstation, Patton and Thomas arrive holding auklets, with Good bringing one up behind them. The birds scratch with their sharp toe claws and bite with their strong bills, and when that does not work they moan their distress. An assembly line forms. Pearson measures auklets and bands them, and then passes them off to Frankfurter and Haman, who take a swab from their cloaca and draw a couple of drops of blood from a vein in the wing.

Back on the hillside, auklets are hitting the net with greater frequency. Hodum brings them over faster than Pearson, Frankfurter, and Haman can process them. There are eight of them now. The excess ones go into blue cloth bags until Pearson is ready for them. "I'm going as quick as I can," he says, trying to reassure them, but the bags still jerk and twitch and moan.

FINDING A BASELINE

Where Frankfurter's needs are perhaps more generally investigative, Katie Haman's have a more specific application: Oil spill response. "We want to establish some solid baselines with the assumption that there might be a massive oil spill in the area someday," she says. "Having those baselines would help wildlife health officials respond in such an event."

Initially, Haman's project was aimed at marbled murrelets, but she and her coworkers later decided to switch to rhinoceros auklets in part because they are far more abundant. Her work with them will focus on acute phase proteins. Acute phase proteins, she says, are a component of the innate immune response; they increase or decrease in response to inflammation. Researchers working in the early 1900s first identified them as initial reactants to infectious diseases. Studies by Carolyn Cray at the University of Miami, with whom Haman is collaborating, have shown that they are good biomarkers whose levels correspond with infection, stress, trauma, or other symptoms; and in some species, they can serve as prognostic indicators of survival.

"The goal is to show that we can establish baselines," Haman says. In the event of trauma, be it pathological or otherwise, the levels of those proteins increase detectably, enough so that they can establish a clinical variable. For although Protection Island is a wildlife refuge, sources of potential traumas surround it. Just across the border, near Vancouver, British Columbia, the Port of Vancouver is in the midst of building a second terminal. Combined with the eventual completion of the Kinder Morgan Trans Mountain pipeline promises a significant increase in area ship traffic.

Should there be an oil spill, wildlife health response officials could potentially triage birds based on their APP levels. The need for triage can be critical during such a catastrophe event, where hundreds, or even thousands, of alcids may strand. Already wildlife rehabilitation is an expensive enterprise, made more so by pouring scant resources into saving animals that are likely to die no matter how much help they receive. "A lot of times you're completely overwhelmed with sick animals," Haman says. "So it would be great to have a rapid screening test."

Whatever Haman finds with rhinoceros auklets could also be applied to other species of general conservation concern, such as marbled murrelets or tufted puffins. "The general state of seabird disease in Salish Sea is not well known," she says, laughing a little grimly.

"Honestly, that's what we've been saying for years. One of the biggest complaints of wildlife health is no one wants to do baseline work. But then we find ourselves in situations where a population is declining and we just don't know about its general health, and that makes recovery efforts all the more difficult."

LETTING THEM GO

At 11:30 p.m. or so, the action at the mist nets has died down. A few auklets buzz overhead from time to time, but they are bound for different parts of the colony. Some of these birds might also be non-breeders, coming in simply to prospect or socialize. They wander out in the open, their calls wafting over the slopes as they serenade one another: Waa-Waaaaa, Waa-Waaaaa.

Back at the workstation, Frankfurter and Haman are processing the night's final auklet. The effort was largely a success, in that thirteen birds have been caught and bled. For his work Frankfurter had wanted thirty, but thirteen will do. "It gives us something to work with," he will tell me later.

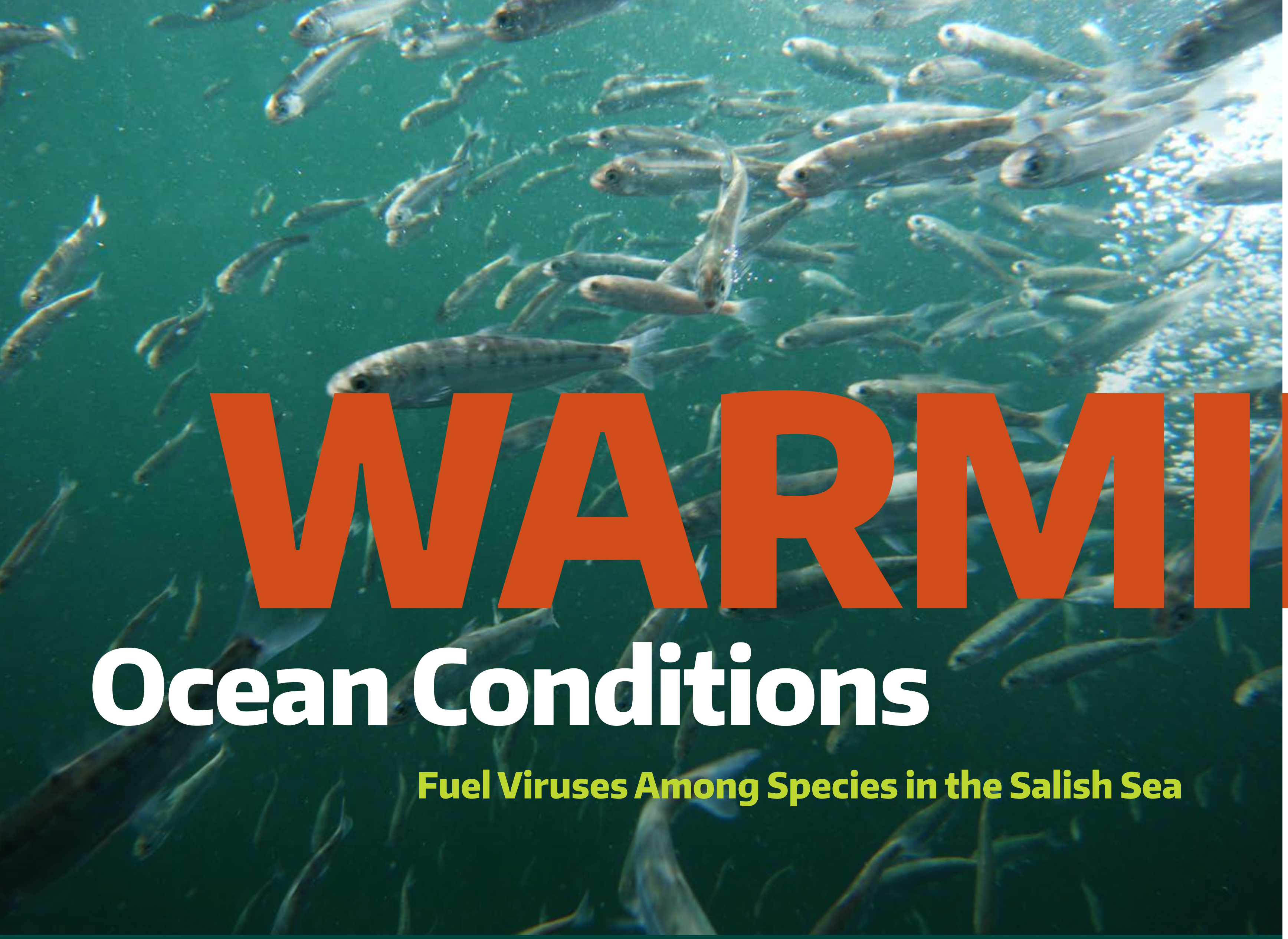
Haman takes blood from the auklet's wing and smears it on a slide, then holds an alcohol swab to the withdrawal site. When the bleeding stops, she cradles the bird, which looks a little nonplussed but is otherwise none the worse for wear. "Who wants to let him go?" she asks.

"I'll take him," Sue Thomas says. She carries the last auklet out to the slopes, and tosses him up into the darkness. The bird flails through the air and tumbles down into the grass, before righting itself and lifting off in a flurry of wings, vanishing into the night.

Postscript: A couple of months later, Pearson will get word that rhinoceros auklets are having another unusual mortality event, with dead rhinoceros auklets found on beaches from northern California to Cape Flattery, Washington. According to Pearson, the die-off appeared to have started in August; by early November it had peaked, or perhaps not yet peaked. The cause is as yet unknown.

Photo left: Rhinoceros auklets near Protection Island.
PHOTO: PETER HODUM

Photo below: A rhinoceros auklet with sand lances.
PHOTO: PETER HODUM



WARMING Ocean Conditions

Fuel Viruses Among Species in the Salish Sea

BY JEFF RICE

As officials struggle to track and contain the outbreak of the novel coronavirus known as COVID-19, ecologists say widespread impacts from viruses and other pathogens are also a growing threat to the species of the Salish Sea ecosystem.

"We're all especially impressed with how rapidly [COVID-19] emerged, the pace of its spread and how massively it has changed our world already," said Dr. Drew Harvell of Cornell University speaking at the February 2020 meeting of the American Association for the Advancement of Science in Seattle. "Infectious outbreaks of ocean organisms are also fast and impressive in scale but they are a lot harder to detect and track and see underneath the ocean."

Harvell, who does much of her research at Friday Harbor Labs in Washington has studied the outbreaks of disease on ecologically important species such as starfish, corals and plants like seagrass. She is the author of the book "Ocean Outbreak" which looks at research on disease impacts in marine waters around the world, including the Salish Sea. She joined other scientists in a special session at the conference focusing on the impacts and responses to several diseases being studied in the region.

Harvell says that infectious disease outbreaks in the ocean are especially fueled by warmer water due to climate change. "Infectious agents are more virulent and grow faster at warmer temperatures," she said.

Scientists are looking in particular at how these conditions might affect the region's salmon populations. Dr. Kristina Miller of the Department of Fisheries and Oceans Canada who also spoke at the conference has been studying the emergence of a relative of COVID-19 that has been found in species such as Chinook and coho. Known as the pacific salmon nidovirus, it only occurs in salmon and there are no cases of its transference to humans.

"There are no examples of a virus being able to jump from a cold blooded vertebrate such as a salmon to a warm blooded human," Miller said. "So we don't have a zoonotic risk in terms of that kind of transmission. Our temperature profiles are way too different, and viruses actually are, most of them, somewhat specific to their hosts."

Despite these differences, Miller hypothesizes that the nidovirus may also cause respiratory stress similar to COVID-19 in its salmon hosts and may be one factor in salmon declines, especially if it affects fish at the vulnerable smolt stage when they transition from freshwater to marine environments.

"What we find is that as salmon move from freshwater to the marine environment, the condition of the fish that are leaving these habitats make a large difference in how well they are going to survive," Miller said. "So if you already have a fish coming out of the river that is already stressed — maybe it's by disease or other factors — if you can mitigate those stressors and put out the healthiest possible fish to go into that marine environment... they will survive better."

The nidovirus is just one of over 60 potential pathogens in salmon Miller and her colleagues identified in a study of thousands of wild, hatchery and farmed salmon. The true impact of such pathogens on salmon declines are not yet known, Miller said, owing to the difficulty of counting deceased fish. "The mere presence of a pathogen does not mean that a fish is diseased," she said. "Disease is hard to study in wildlife when mortality is unobservable. Salmon in the ocean simply drop off in the water column, largely in the mouths of predators."

But while counting deceased fish may be difficult, Miller and her colleagues are developing ecological models to estimate the level of mortality. "We are now employing this technology to explore the complex synergies between stress and disease and to identify regions along the coast where salmon are the most compromised," she said. The model will combine data from studies of infectious diseases in salmon with factors such as ocean temperatures, which Miller called "the most significant driver of infection."

"Infectious agents are more virulent and grow faster at warmer temperatures."

Photo left: Snake sockeye smolts Mike Peterson NOAA

Photo rigth: Coho smolt Paul_Kaiser USFWS

Virus related to measles could push PUGET SOUND ORCAS TO EXTINCTION

BY CHRISTOPHER DUNAGAN

Researchers studying the killer whales that frequent Puget Sound are growing increasingly concerned that a dangerous virus or other disease-causing organism could spread through the population and hasten extinction of these critically endangered southern resident orcas.

Without dramatic changes to their environment, extinction is already considered the likely future for the southern residents, as they continue to face shortages of food, high levels of chemical contamination and stress from the noise around them. Their numbers have declined from 98 animals in 1995 to 72 today.

New research suggests that extinction could come sooner if the whales were to become infected with a novel pathogen, such as cetacean morbillivirus (CeMV), which has killed thousands of Atlantic bottlenose dolphins on the U.S. East Coast but has not been seen in the Pacific Northwest.

Given its fragile state, it is unlikely that this population would recover from the sudden increase in mortality that would result from a majority of the population becoming infected with CeMV," states a 2020 report in the journal *Biological Conservation*.

Michael Weiss, a researcher with the Center for Whale Research and lead investigator on the study, said the prospect of CeMV in the southern residents can be compared in some ways to the recent outbreak in humans from the novel coronavirus: Just as humans lack immunity to the new coronavirus, the orcas have no history of exposure to CeMV, thus they are vulnerable to the worst effects of the organism.

"When I think of risks to the southern residents, I think the main risk is not getting enough food to remain nutritionally healthy," said Weiss, a doctoral candidate at the University of Exeter in England. "But an outbreak of cetacean morbillivirus would be a nuclear meltdown. It has a low probability of happening, but the results would be absolutely catastrophic."

Southern residents eat fish, primarily Chinook salmon — another species at risk of extinction. The lack of food, chemical contamination and stress can be thought of as contributing to the disease process among the whales. A high rate of inbreeding in this population also can affect immunity.

"The myth is that these animals are starving to death," said Joe Gaydos, a veterinarian with the SeaDoc Society. "You need to look at the bigger picture of what these animals are dying from" — and the causes are varied.

In the realm of infectious disease, an orca may not be able to fight off an infection if it is already weak from lack of food, Gaydos said. If the infection persists, the animal could have a hard time catching fish to eat; it could become disinterested in food; or it might even be unable to adequately process the food that it does eat.

Toxic chemicals, particularly the polychlorinated biphenyls found in killer whales, can reduce an animal's immunity, as can stress from noise or other causes. A whale in a weakened condition is more likely to succumb to any number of problems, including disease, congenital problems or trauma, such as being struck by a boat.

Strong social bonds among the southern resident killer whales can increase the opportunity for disease transmission, according to the new study published in the journal Biological Conservation. While CeMV is not the only organism that could threaten the population, Weiss said, the disease is frequently discussed as a significant threat.

Cetacean morbillivirus exists within a family of viruses that cause human measles, canine distemper and related diseases among cats and ruminants, such as goats, sheep and camels. The disease caused by the virus is highly contagious and can be spread through airborne droplets from the breath of an infected animal. Based on studies of other populations, CeMV is likely to kill 70-80 percent of the orcas that become infected, the new report says.

The study examined how infection could spread from one whale to another. In the wild, several orcas often surface together, exhaling plumes of mist that can be inhaled by a nearby whale. In the study, the frequency of close contact actually observed by whale researchers was factored into a new model, which can be used to predict how any infection could spread through the population from a single individual.

The initial infection could come from another species. Southern residents have been known to interact with harbor porpoises, humpback whales and Pacific white-sided dolphins — all known carriers of CeMV.

Above: Southern resident orca pair. Photo courtesy of NOAA.

Killer whales travel in family groups, led by an elder female and her descendants. Groups of these so-called matrilines make up socially related pods — specifically J, K and L pods among the southern residents. The new study showed that this modular organization could help reduce the spread of infection — but only minimally compared to groups of animals that interact in a more uniform pattern.

Using a variety of assumptions, the new model showed that occasionally the disease would fail to spread much beyond the initially infected individual, but in most cases about 90 percent of the orcas would come down with the disease and about 70 percent of those would die.

A vaccine to protect against cetacean morbillivirus has been tested, but not deployed, in bottlenose dolphins. If a vaccine were to be developed for the killer whales — and there are many challenges — one would need to vaccinate at least 42 of the 72 southern residents to substantially reduce the risk of a major outbreak, according to the analysis.

"The logistical challenges of vaccinating and monitoring individuals at sea and the potential stress these activities may cause the animals likely make the prospect of wide-scale vaccinations impractical, as well as potentially unethical," the report concludes.

Diving DEEPER

to understand eelgrass wasting disease

BY ROBIN MCLACHLAN

New studies show that eelgrass wasting disease is more common in warmer waters, leading to concerns over the future effects of climate change on eelgrass populations in Puget Sound.

As tides fall and mudflats are exposed in the Salish Sea, you can glimpse a puzzle that has left scientists and policy makers perplexed. In healthy environments, mats of green eelgrass will often stretch across the shallows, providing vital but fragile habitat for all manner of nearshore species, from Dungeness crabs to salmon. The aquatic plant is considered a fundamental link in the food chain, creating nursery habitat for young fish, stabilizing sediment, and filtering water. It can also inexplicably decline and rebound through space and time.

Scientists are looking at a variety of factors for these changes as they work toward a state goal of expanding eelgrass populations by 20% in Puget Sound. Among their concerns is eelgrass (or seagrass) wasting disease, a disease that leaves eelgrass blades covered in lesions and has triggered historical, devastating die-offs along eastern US and European coasts.

Olivia Graham, a PhD student at Cornell University has been studying the potential connections between climate change and eelgrass wasting disease in the Salish Sea. Her research involved a novel and literal approach: She dove deeper into the problem.

When Graham first started her graduate studies in 2016, there was no published work on wasting disease in seagrasses that looked deeper than the lowest tides. Scientists had only studied disease in intertidal eelgrass exposed at low tide because deeper eelgrass meadows were much harder to get to.

Graham and her colleagues took up the challenge and began scuba diving in eelgrass habitat in deeper waters where the waves whipped up sediment and clouded visibility. Graham had the “worst dive of [her] life” when she was face-to-face with her dive buddy in False Bay in the San Juan Islands but still couldn’t see her or manage to hold on to her samples or survey equipment.

After surveying both subtidal and intertidal eelgrass meadows spanning from Alaska to Puget Sound last summer, Graham found that subtidal eelgrass meadows were less prone to wasting disease than their intertidal counterparts that were left high, dry, and hot during low tides. Her findings suggest that colder temperatures in deeper water may offer a refuge against disease.

Graham says this partially-assembled puzzle gives us a picture of the future in a warmer ocean that can inform regional planners and eelgrass managers as to which eelgrass meadows are at risk. Graham and her colleagues hope to develop a well-informed model that can predict disease outbreaks based on temperature. This model may be key to developing targeted management plans as ocean temperatures continue to rise and cold-temperature refuges move deeper and deeper away.

Photo: A blade of eelgrass (Zostera marina) showing an area infected by eelgrass wasting disease (Labyrinthula zosterae). The dark spots created by the pathogen spread, destroying the plant,Äôs cells and preventing photosynthesis. PHOTO: OLIVIA GRAHAM/CORNELL UNIVERSITY

Saltwater habitat

In the previous section we described how warming oceans can lead to a rise in diseases across the ecosystem, but that is just one way that climate change is affecting saltwater habitats. In this section, we look at the degree to which cold-water organisms such as kelp may be pushed out of their normal ranges, with potentially disastrous consequences for the ecological balance of the Salish Sea. We also report on the potential effects of sea level rise on nearshore and estuarine systems. Transition zones such as beaches and tidal wetlands that connect or mix with rising saltwater are especially vulnerable.

NEXT →

Kelp crisis?

Decline of underwater forests raises alarms

BY SARAH DEWEERDT

They rival tropical forests in their richness and diversity, but Puget Sound's kelp beds have declined steeply in recent decades. Scientists are just starting to understand the extent of these losses. What they are finding is bringing kelp to the forefront of Puget Sound's environmental concerns.

One day in 2017, Toby McLeod spread out a nautical chart at his father's house. The chart depicted the traditional territory of the Samish people in the San Juan Islands. McLeod, a Samish tribal member and field technician with the tribe's Department of Natural Resources, wanted his father's help mapping the historic location of bull kelp beds around the islands.

McLeod's father has been fishing commercially for salmon, crab, shrimp, and dogfish since the late 1950s. And fishers know where kelp is. The plant – technically a type of brown algae – grows in shallow water on rocky substrate, so its presence indicates a navigation hazard. Get too close to kelp and it can also foul a boat's prop, requiring a dip in unpleasantly chilly water to free your vessel. But at the same time, the edges of kelp beds are often prime fishing spots.

As luck would have it, McLeod's uncle, who had also worked as a commercial fisher, happened to be visiting that day. Between them, the two men had almost a century's worth of fishing experience. McLeod listened as they debated back and forth and drew on the map areas of agreement. "I was using them to kind of balance each other and come up with as clear a story as I could," he says.

The result was a portrait of kelp both familiar – such as the beds that fringe the western side of San Juan Island – and vanished: The men remembered a kelp forest filling a portion of Bellingham Channel, for example, that there's no trace of today.

The farther you get away from the open ocean – closer to human impacts and farther away from oceanic water – those are the areas where we're most concerned about kelp losses.

HELEN BERRY, WASHINGTON DEPARTMENT OF NATURAL RESOURCES

The map is also emblematic of a variety of recent studies, using diverse methods, that have documented kelp decline and disappearance in many parts of Puget Sound. It's a local story with links to global concerns, as kelp habitats off the coasts of California, Australia, and Tasmania have all experienced severe declines in recent years.

Top: A harbor seal hunts for prey in kelp forests.
PHOTO: FLORIAN GRANER (CC BY 2.0)

Volunteer Vernon Brisley surveys a bull kelp bed near Ebey's Landing on Whidbey Island as part of the Island County MRC regional monitoring project. PHOTO: RICH YUKUBOUSKY

"Luckily, we still have areas where [bull kelp] occurs" in Puget Sound, says Helen Berry, manager of the Nearshore Habitat Program at the Washington Department of Natural Resources. "But we really need to focus on figuring out what's going on, what the main stressors are, and what we can do about it."

CANOPY COVER

Bull kelp (Nereocystis luetkeana) is one of 23 species of kelp found in Puget Sound. It's the largest species and the only one capable of forming a surface canopy that occurs in inland waters. Dense stands of canopy-forming kelp are known as kelp beds or, if they are particularly large, kelp forests.

"Kelp is awesome for the same reasons that coral reefs and eelgrass and mangrove forests are awesome," says Max Calloway, a biologist working on kelp projects with the nonprofit Puget Sound Restoration Fund (PSRF). That is, it's an enormously productive habitat teeming with life.

Kelp forests can rival tropical rainforests in primary productivity, meaning the amount of the sun's energy transformed into living organisms in a given amount of time. Kelp freely shares the energy it captures through photosynthesis, constantly releasing dissolved sugar and sloughing bits of tissue into the water, providing a foundation for the food web near the shoreline. Studies suggest that between one-third and two-thirds of carbon in the bodies of rockfish in the North Pacific may ultimately be derived from kelp.

This abundance of food and places for hiding and hunting draws a host of species to kelp beds. "You look down and a Chinook salmon swims by, there's forage fish in hiding among the leaves of the kelp," says Alan Clark, a Sequim resident who is part of a citizen-science project to monitor kelp beds in the Strait of Juan de Fuca by kayak. Other species that can be spotted in and near kelp beds include river and sea otters, harbor seals, sea lions, and southern resident orcas.

"You really get an idea of just the sheer number of species that are in some way dependent on our kelp beds," Clark says. "This is a vital spot for all kinds of animals in our region."

So far, however, kelp has received less attention by conservationists than other species and habitats such as eelgrass, which is listed as a 'Vital Sign' of Puget Sound health by the state's Puget Sound Partnership. One reason may be that kelp is harder to study. Bull kelp is an annual plant, growing anew from a microscopic beginning each spring, and being washed away by storms in the autumn. Plus, kelp was thought to be more resilient than other types of nearshore vegetation.

EMERGING CONCERNS

Over the last decade, that view has changed. In 2010, three species of rockfish found in Puget Sound were listed as threatened or endangered; all three are found in kelp beds and one of them, bocaccio, is especially dependent on kelp as rearing habitat. The listing highlighted gaps in kelp knowledge. "In general, there's not very good data – precise spatial data – about the location and species assemblages of kelp in Puget Sound," says Dan Tonnes, a NOAA Fisheries biologist working on rockfish.

And concern was bubbling up from other places as well. Anglers wondered where bull kelp beds had gone. Samish tribal members told their Department of Natural Resources staff that they were having trouble finding kelp to wrap salmon in as part of a traditional way of preparing the fish. Scientists noticed kelp beds they'd long known as reliable landmarks shrinking or disappearing altogether. And so it went around the Sound.

The first task was to get a handle on where exactly kelp beds were located, how big they were, and how they have changed over time. For this, Samish Department of Natural resources scientists turned to aerial photography. They used a computer GIS program to outline the location of kelp beds on high-resolution aerial photographs of the San Juan Islands taken in 2016.

The unique shape and distinctive green shade of kelp plants is easy to recognize in the photographs, says Casey Palmer-McGee, a GIS specialist with the tribe. But digitizing the photographs still took two months of painstaking work – "click, click, click, click, click," he says, mimicking the repetitive computer mouse motions involved in tracing each bed.

The team compared their data with those from a 2006 study of the same area that also used aerial photography. This showed a loss of 305 acres, or roughly 36% of all bull kelp in the San Juan Islands, over the course of a decade.

At first, it wasn't clear that there was a big problem: Kelp beds can vary by up to 30% from one year to another. But as the researchers looked closer, a more alarming picture emerged. On average, each island had lost half its kelp area. And some had experienced even more devastating losses: Kelp had declined by 62% around Shaw Island, 72% around Blakely Island, and 77% around Patos Island.

The map of tribal elder knowledge that McLeod worked on adds another dimension to the findings. "We think that loss has been going on for quite a bit longer" than a decade, says Samish DNR head Todd Woodard.

SHRINKING BOUNDARIES

Aerial photographs aren't available for all of Puget Sound's shorelines, so the Northwest Straits Commission developed a protocol for measuring the size of kelp beds by kayaking around the perimeter with a GPS device. Individual county Marine Resources Committees then recruited citizen-scientist volunteers to survey a handful of kelp beds in each jurisdiction.

"It's a nice way to go out and paddle around, get to know your local waters close up, and you have a purpose," says Linda Rhodes, a microbiologist with NOAA who lives on Whidbey Island and coordinates the kayak survey program in Island County.

Participants survey each bed once a month, usually from June through September, and take photographs and record water temperature and depth as they kayak the perimeter of the bed. Dana Oster, the Northwest Straits Commission's marine program manager, estimates that roughly 70 volunteers kayaked more than 770 miles between 2015 and 2018. In summer 2019, the program was active in six counties – Clallam, Island, Jefferson, Skagit, Snohomish, and Whatcom.

Snohomish County has emerged as an area of particular concern, Oster adds. Beds near Mukilteo and Meadowdale have shrunk to the point of no longer having a perimeter to kayak around – now, they're just scattered clumps of kelp.

These are the southernmost of the roughly 25 to 30 beds being tracked in the program. Farther South in Puget Sound, kelp is in even worse shape, as state DNR researchers have established.

Berry led a team that surveyed four South Sound kelp beds in 2013, 2017, and 2018. All four beds – at Squaxin Island, Brisco Point, Devil's Head, and Fox Island – declined significantly over that time, according to their report released earlier this year. The Brisco Point and Devil's Head beds were absent altogether by 2018.

"The farther you get away from the open ocean – closer to human impacts and farther away from oceanic water – those are the areas where we're most concerned about kelp losses," Berry says.

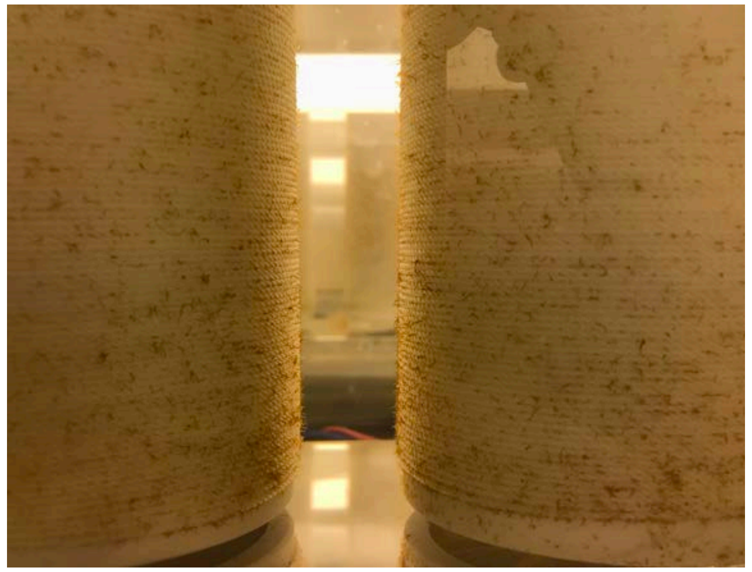
PILOT EXPERIMENT

For a few weeks in the summer of 2019, full-grown bull kelp plants waved languidly at the surface of the water in Smith Cove near Seattle. This small and unlikely kelp bed – buffeted by the wakes of huge cruise ships, with the Space Needle as its backdrop – was the result of a pilot experiment in kelp restoration carried out by PSRF.

Months earlier, PSRF divers had attached lengths of twine, coated with a brown fuzz formed by millions of millimeter-long young kelp plants, to concrete anchors they had placed on the sea floor. Calloway jokingly likens the process to "underwater basket weaving."

More broadly, kelp restoration isn't all that different from forest restoration on land, although kelp has a more complicated and less well understood life cycle than a tree does. That life cycle includes two distinct phases, known as the gametophyte and the sporophyte. Kelp beds are formed by mature sporophytes. Kelp overwinters as either gametophytes, which are microscopic and may be able to persist in the environment for multiple years, tiny sporophytes, or a mix of both.

The first task when PSRF began working on kelp restoration several years ago was to figure out which life stage to outplant, and at what time of year. A series of field experiments suggested the best approach would be to set out immature sporophytes in late winter, just as the days begin to lengthen and daytime low tides return. This gives the young plants enough light to get established, early enough to avoid getting swamped by other aquatic vegetation.



PVC pipes wrapped in twine inoculated with kelp spores support young kelp plants (juvenile sporophytes) that will be outplanted in the ocean. PHOTO: MAX CALLOWAY/PSRF

The Maiden of Deception Pass carved by Tracy Powell tells the story of Qw'elqw'o7lewut *[pronounced phonetically as Ko-Kwal-alwoot]*, a Samish woman who goes to live underwater to save her people from starvation. PHOTO: CODY LOGAN (CC BY-NC-SA 2.0)

The kelp planted at Smith Cove didn't stick around for very long, but it was still proof of principle that the method could result in a mature kelp bed. In 2020 PSRF plans to carry out a larger kelp restoration project at Jefferson Head off the Kitsap Peninsula, the site of a former kelp bed that has disappeared in recent years.

The next question is whether restoration efforts can produce a kelp bed that comes back for a second year. "Our ultimate goal is to figure out the most cost-effective way to go out and do one planting in an area that will then restart that natural process and get you a naturally persistent kelp bed," Calloway says.

DIVING DEEPER

To answer that question, and to halt and reverse kelp loss more broadly, scientists will likely need to know more about the factors that are causing kelp to disappear in the first place, and what life stages are most affected. For now, researchers have a lot of hypotheses, but few clear causal links.

It could be that increased sedimentation is smothering young kelp plants or covering up the bedrock and cobbles that they need to attach to. Excess nutrients in agricultural and urban runoff could be enabling other species like turf-forming algae to outcompete kelp. Competition with the invasive alga Sargassum muticum may also be a factor.

Researchers have observed large numbers of kelp crabs feeding on kelp in struggling South Sound beds. Could there be an overabundance of these herbivores, perhaps due to a lack of their own predators, such as rockfish?

Other evidence implicates water temperature. Kelps are cold-water organisms, and bull kelp does best in water between about 5 and 17 °C. Historical data suggest that Salish Sea kelp beds track climatic fluctuations such as El Niño events. Now, increasing average water temperatures, stronger El Niños, and marine heat waves such as "the Blob" may be pushing kelp into the danger zone more often – a problem that is only likely to get worse as climate change intensifies.

"If that is the problem, it's going to be a hard one to fix at a local level," says Tom Mumford, a retired state DNR kelp biologist. "The solution is not going to be a Washington solution," he says, "it's going to be a global solution."Various agencies, tribes, and nonprofit groups are strategizing about how to investigate these hypotheses. For example, the Samish DNR will use an ROV to gather clues about stressors that might be affecting local kelp beds next summer.

Their high-tech plan has a resonance with traditional teachings. The Samish and other Coast Salish tribes have a story about a woman who marries a man from beneath the sea. She comes back to visit her home village once a year, but as the years go by, the woman becomes more and more a being of the sea. Barnacles grow on her skin, her hair is transformed into kelp, and she seems increasingly unhappy on land. Eventually, her family releases her from her obligation to return. She stays underwater, her presence there ensuring that the people will always have abundant seafood and clean water.

In English, the woman is usually referred to as the Maiden of Deception Pass. But her Samish name, Qw'elqw'o7lewut (Ko-Kwal-Alwoot), best translates as "lots of kelp attire." To the Samish, the story emphasizes the importance of taking care of the environment so that it may take care of the people.

"Whether you look at it from an Indigenous perspective or a modern ecological perspective, kelp is a critical habitat for a lot of other species," McLeod says. Not the least of which is us.

Shoreline armoring

in puget sound gets new scrutiny from the Army Corps of Engineers

BY CHRISTOPHER DUNAGAN

« BEFORE AFTER »

As the earth's polar ice caps melt and sea levels rise, tides will continue to grow higher along Puget Sound's shoreline. That is expected to overrun many seawalls and bulkheads, shrinking the size of beaches and destroying critical habitat for forage fish and other species. Now these structures, known as shoreline armoring, could come under more extensive review and permitting as the result of a revised shoreline policy announced by the U.S. Army Corps of Engineers.

The revised policy, which resulted from a federal lawsuit, now requires a Corps of Engineers permit for shoreline construction below the high-tide line. The previous line of jurisdiction was lower on the beach, effectively exempting most shoreline armoring from federal permits.

One of the key results of the policy change is to bring shoreline armoring under the purview of the Endangered Species Act, said Amy Carey of Sound Action, one of three environmental groups bringing the lawsuit against the Corps.

"Until this change was made, the Corps was not looking at the impacts to endangered salmon and orcas (from bulkheads)," Amy said, noting that shoreline armoring can reduce spawning habitat for forage fish, such as surf smelt and sand lance. Since salmon depend on forage fish and orcas depend on salmon, shoreline armoring can affect a significant part of the food web.

The effort to get the Corps to change its policy and better protect the shoreline ecosystem has been a five- to six-year battle, Carey said. The new policy better aligns the federal shoreline jurisdiction (under the Clean Water Act) with state and local jurisdictions (under the Shoreline Management Act and the State Hydraulics Code).

Above left: Shoreline along Cornet Bay in Island County before removal of armoring.

Above right: Shoreline along Coronet Bay after removal of timber bulkhead, regrading of bank, beach nourishment, backshore revegetation, and limited anchoring of large wood in 2016.

The Endangered Species Act, which requires studies of biological effects before a project is approved, is a powerful "tool" for protecting the environment, Carey said, and it's not directly available to state agencies.

State agencies, including the Puget Sound Partnership, have made a concerted effort to inform the public about damage from shoreline armoring. State and local regulations have been updated to prevent new bulkheads unless absolutely necessary to protect a structure from shoreline erosion. Shoreline property owners have been encouraged to replace old bulkheads with more natural methods of erosion control, such as large logs and rocks anchored to the beach. This is called soft-shore protection.

The Washington Legislature also has focused on the issue, last year granting the Washington Department of Fish and Wildlife increased authority to oversee bulkhead construction for single-family homes. And this year, lawmakers are considering a bill to require property owners to analyze the feasibility of soft-shore protection before replacing an aging bulkhead.

Previously, the Seattle District of the Corps, a federal agency, declined to regulate construction — including shoreline armoring — proposed in areas above a line defined by the average of the highest tide of each day — known as "mean higher high water" since there are two high tides each day. Most bulkheads are built above this line.

About one out of four high tides in the Seattle area exceed the mean higher high water mark used by the Corps since 1977, according to legal pleadings by the environmental groups. A more suitable line for regulation would bring about 8,600 acres under Corps' jurisdiction, the plaintiffs argued.

By moving the line of jurisdiction higher on the beach, the Corps is now expected to review most proposed bulkhead projects, along with other shoreline structures. Docks, floats and other construction close to the water have been subject to federal permitting since the Clean Water Act went into effect in the 1970s.

The new line of jurisdiction is called simply the "high tide line," defined by changes in vegetation, deposits of shells and debris, along with other evidence marking the highest tides under normal conditions. That's similar to state jurisdiction under the Hydraulics Code, which goes up to "ordinary high water."

The revised policy will bring federal jurisdiction and regulations to structures built above the previous boundary line up to the observed line formed by the highest tides. That will affect mostly bulkheads but sometimes stairs to the beach and other structures.

Avoiding new shoreline armoring and removing existing armoring wherever possible has been a longtime goal of the Puget Sound Partnership, which was created in 2007 to coordinate recovery of Puget Sound. A "Shoreline Armoring Implementation Strategy," adopted in 2018, spells out a series of programs and actions to reduce shoreline impacts — including incentives, technical support, revised regulations and increased enforcement of existing rules.

The issue of shoreline jurisdiction by the Army Corps of Engineers was discussed by a multi-agency review team that developed the strategy, noted Aimee Kinney, policy analyst for the Puget Sound Institute, who worked on the strategy.

One question is whether the Seattle District has adequate staff to handle the increased workload for permits, Kinney noted. The Seattle District averaged just 17 permits per year for "bank stabilization" from 2012 to 2017, she said. Meanwhile, in 2015 and 2016, the Washington Department of Fish and Wildlife issued an average of 165 permits per year for new, replacement or repair of marine-shoreline armoring, she said, pointing out that this is just a rough approximation of what the Corps may be facing because of differences between the two agencies.

To streamline the process, the Corps could develop a "regional general permit" to cover most conditions in Puget Sound, thus allowing for rapid approval, provided that a project is built to specified standards, including mitigation.

In the end, moving the line of jurisdiction a short way up the beach might not seem like a big change, but it could have profound effects on future shoreline-armoring projects and the survival of certain Puget Sound species.

Tidal forests offer hope for SALMON

BY JEFF RICE

Can scientists bring back the lost tidal forests of Puget Sound? It could take generations but restoring this rare habitat will pay big dividends for Puget Sound's salmon.

The rain is coming down in sheets as NOAA scientists Josh Chamberlin and Anna Kagley ease the outboard through a narrow channel on the Snohomish River. We're headed to a small island just southeast of Marysville, but for all practical purposes this is a trip straight into PugetSound's past. As we drift through, we look up at 200-year-old Sitka spruce trees. Tall reeds and grasses that hang over the slow-moving water give the place the feel of a southern swamp.

The island is only accessible by boat, and the pelting winter rain all but assures that we won't have much company today. Hidden among the trees, the place feels as remote as a wilderness, but occasionally, in a corner of the horizon you can see the smudge of headlights as cars make their way down Interstate 5 through the mist.

The interstate aside, much of the region once looked like this. Hundreds of years ago, old-growth cedar and spruce loomed over estuaries and bottom lands throughout Puget Sound, creating what are known as tidal forests. These forests were the Pacific Northwest's answer to the Everglades — giant spongy swamps with a touch of saltwater that covered about 20 square miles in the Snohomish delta alone. Now most of what remains is limited to this island, some of the finest salmon habitat in all of Puget Sound.

Above: On their way out to sea, young salmon may spend up to a year feeding in channels through the tidal forests of Otter Island where fresh water mixes with salt water from Puget Sound. PHOTO: JEFF RICE.

Right: Otter Island in the Snohomish River delta.

THE SALMON FACTORY

In the spring, the slow, blind channels around Otter Island will be jumping with juvenile coho and Chinook. At various points, almost every type of salmon in the region will be found here, from coho and Chinook to chum and pink and sockeye.

They will come here to rest and fatten up. Then, after as much as a year, they'll move on to the open water and eventually the ocean.

"It's like breaks on a road trip," Kagley tells me. "They just tuck into these spots to feed and grow and rest from the current."

Here, the freshwater of the Snohomish River mixes with water from the incoming tides of Puget Sound. The saltwater is almost undetectable, but it is enough to classify this as an estuary and, by any measure, a fish factory. This tidal mixing is critical to the young salmon as they begin their transition from freshwater to marine environments.

Estuaries, where freshwater mixes with saltwater are a signature feature of Puget Sound. In fact, Puget Sound is itself a vast estuary — the second largest by area in the U.S. behind Chesapeake Bay — fed by more than a thousand streams and rivers like this one. This tidal mixing by itself is not unusual, but there are a few things that set this place apart.

WEIRD GEOMETRY

We bump against the bank and jump out onto one of the few patches of flat, (mostly) solid ground. Otter Island is built like a pick-up sticks-style logjam bound together by centuries of sediment and peat moss. Trees grow on top of other trees ("nurse logs") and assorted vegetation is tangled everywhere, making any sort of clear pathway out of the question. To complicate things, the ground is riddled with deep, hidden pools that seep up from the river.

While the conditions may be less than ideal for a hike, they are perfect for rearing salmon. Coho and Chinook in particular are drawn to Otter Island because of its complexity — the island's "weird geometry" as one botanist described it.

"You see all the vegetation hanging over?" asks Chamberlin."The forest's three-dimensional structure provides shade and protection from predators." It also means food. Overhanging branches drip bugs and other nutrients onto the water below, and the tidal sediments that gather around the island are a buffet of amphipods and crustaceans. All these conditions add up to bigger, stronger salmon that are more likely to survive when they swim out to Puget Sound.

WHAT WE'VE LOST

In that sense, Otter Island and other estuaries like it are at the center of the high-profile race to save Puget Sound's threatened salmon. Before their decline, tidal forests were part of the mosaic of habitats that produced so many salmon that the region's iconic southern resident orcas evolved to prefer one species — Chinook — over any other.

That began to change more than a hundred years ago as much of the land was diked for farming and other development. The story is familiar: As the habitat declined, so did the fish. Chinook are now listed as threatened and the southern residents are critically endangered and facing extinction.

It's not just tidal forests that have disappeared. Tidal wetlands of all types have declined by an area of about 116 square miles — roughly 3.4 times the size of Lake Washington. That includes habitat such as tidal mud flats, scrub shrub wetlands and emergent marshes, each

with their own special characteristics. Tidal forests are some of the hardest hit of these, having decreased by more than 90 percent. Significantly more exist on Washington's outer coast and the Columbia basin, but most of what remains in this region can be found here on the Snohomish delta.

In essence, that means 150-acre Otter Island and a smaller 20-acre plot at nearby Heron Point. Otter Island is owned and managed as conservation land by Snohomish County. Heron Point just to the north was recently purchased by the Tulalip Tribe which intends to protect the habitat forever.

THE LONG GAME

Protecting what remains is now paramount for biologists. So far, holding the line is working. Otter Island and Heron Point remain much as they have been for centuries.

The next step may be more difficult. What can be done to bring back the lost 90%?

"It's a long game," Chamberlin says. Tidal forests were built layer upon layer, tree upon tree over centuries. "We can't just come in and suddenly make this type of habitat," he says. It's going to take some time. Maybe lifetimes and generations.

What scientists can do is make an approximation. Recently, the state breached several dikes in this area, opening up miles of new salmon habitat along the Snohomish.

During our float over here we see what's possible. The area known as the Smith Island restoration is now flooded along with the nearby Qwuloolt estuary. Both areas are parts of an EPA-funded plan to preserve estuaries throughout Puget Sound. The goal is to restore about 7,380 acres of estuarine habitat in Puget Sound by 2020. The newly formed estuaries may not match the full richness of Otter Island, but scientists are optimistic.

Playing the long game could also include planting trees as has been done on the Nisqually delta, a place seen by many as the crown jewel of estuary restoration in Puget Sound. There, ecologists have started to approximate tidal forests along the sloughs that might one day provide shade and sustenance to salmon. Scientists now argue that it's not enough just to identify and restore old habitat. They need to manage future habitat.

LOOKING AHEAD

Factors like climate change and sea level rise in particular have forced scientists to take a broader view of habitat restoration. Rising tides from the earth's melting ice caps could impact places like Otter Island and potentially most other restoration projects in the area. More saltwater incursion could upset the delicate balance of life here.

"These trees — the Sitka spruce — are salt tolerant but they're only tolerant," Chamberlin says. "If you raise the sea level to a point where they are inundated for a longer period of time or the salinities change, you could potentially negatively impact them. I think it's one of the questions that needs to be evaluated."

A 2018 report from the Washington Coastal Resilience Project does just that. The report, titled "Sea Level rise considerations for nearshore restoration projects in Puget Sound," recommends that restoration projects should "consider the extent to which there is upland space to accommodate landward migration of nearshore habitat."

Redirecting rising salinity away from Otter Island could be one step, but scientists also wonder if they can go even further: Make new habitat. Could they identify other forests higher in the watershed that might one day be in the path of rising tides? In some cases, that might bypass the need to plant more trees. It's a long shot, they say, but a potential strategy under consideration.

Whether tidal forests will one day make a return to Puget Sound remains an open question, but for now, Otter Island continues to remind us of what we once had and what we still stand to lose.

Heron Point, north of Otter Island, is a tidal forest protected by the Tulalip Tribe. PHOTO: WASHINGTON STATE DEPARTMENT OF ECOLOGY.

Researchers netting salmon in the Snohomish River delta for study. PHOTO: NOAA

SEA LEVEL RISE visualization tool

Sea level rise from global warming is expected to have widespread impacts on the Puget Sound shoreline, increasing risks of flooding, erosion and storm surge. But despite the global scale of climate change, no two parts of Puget Sound will experience the phenomenon in quite the same way.

A new visualization tool from the University of Washington Climate Impacts Group is designed to help planners and homeowners understand the level of sea level rise impact they can expect locally.

The tool uses data from a 2018 report from Washington Sea Grant, the Climate Impacts Group and others that provides updated figures based on projected greenhouse gas emissions and naturally occurring vertical land movement along the coast. Different visualizations allow the user to explore the range of potential future sea level change – from the virtually certain (low end) to the less certain, higher-end projections – under both high- and low greenhouse gas scenarios. Although the state-wide average estimated rise is about 5 to 10 inches over the next 30 years, some parts of Puget Sound will be hit harder than others, facing steep rises of several feet.

To find out how sea level rise might impact your beach or community, type "Interactive Sea Level Rise Data Visualizations" into your favorite search engine or visit the visualization tool website directly at https://cig.uw.edu/our-work/applied-research/wcrp/sea-level-rise-data-visualization/.

Above: Olympia high tide, Dec 28, 2010.
PHOTO: JOHANNA OFNER (CC BY-NC-SA 2.0)

Terra firma

The Salish Sea ecosystem is not just about saltwater and beaches. Terrestrial and freshwater environments such as forests and streams are a critical part of the equation. Thousands of rivers and small inlets flow into the Salish Sea, providing habitat for salmon and creating the unique mixture of fresh and saltwater that defines this massive estuary. In this section, we look at some of the impacts of climate change on the region's snowpack. Reduced snowfall in mountainous areas threatens to undo salmon migration patterns and compromise city water supplies. We also examine the changing fire season in Western Washington. Historically, the eastern part of the state has seen the largest impacts from fires, but climate change is now increasing the risk west of the Cascades. That could have big implications for many rural communities throughout Puget Sound.

NEXT →

BY CHRISTOPHER DUNAGAN

Fire danger

returning to Western Washington

Climate change is expected to dry out the forests, increasing the number and size of wildfires that could threaten thousands of homes.

The summer of 2015 brought hot, dry winds blowing into Western Washington from the east. Ominous breezes parched the forests, promoted wildfires and foreshadowed a future of increased fire danger on the "wet side" of the Cascade Mountains.

On Aug. 10 of that year, a lightning strike on Mount Ross in North Cascades National Park ignited a slow-moving fire on a precipitous slope. The blaze smoldered along for more than a week before it blew up on Aug. 19, when strong winds pushed the flames toward the small town of Newhalem. The fire grew from about 100 acres to about 3,200 acres in a single day.

Newhalem is a company town owned by Seattle City Light. Employees who live there operate the extensive Skagit River Hydroelectric Project, which provides power to the Seattle region. Cynthia Stahlecker, operations secretary, recalled the intense flames, smoke and heat as the fire approached.

"You could see the fire coming over the hill," she said, "and then it jumped the river and circled the town. The smoke was so thick that I couldn't see out the back door. The sound was like a great big jet engine taking off. I have never experienced anything like that, nor do I ever want to again."

That night, as firefighters battled the smoky blaze at the edge of town, emergency officials organized an evacuation of Newhalem residents as well as those living in nearby Diablo. The North Cascades Highway was blocked to the west, so a convoy of vehicles escaped over the mountains into Eastern Washington.

The convoy, originally bound for Winthrop, was diverted to Wenatchee to avoid an extreme forest fire that has been called the Okanogan Complex Fire. During August of 2015 — the hottest year on record — Eastern Washington suffered through a series of forest fires that burned a record 1.1 million acres, killing three firefighters and destroying 123 homes.

Historically, the evacuation of Newhalem and Diablo stands as one of the few fire-driven escapes from populated areas west of the mountains. But researchers who study the risk of wildfire say a warming climate in Western Washington could bring an increasing number of fires to the doorsteps of more than a million homes scattered through the woods or clustered in small communities throughout Western Washington.

MARITIME CLIMATE CHANGING

Western Washington — between the Pacific Ocean and the Cascade Mountains — is known for its cool, moist breezes blowing in from the sea. For the past 300 years, wildfires have been rare and relatively small, thanks to moist vegetation and infrequent lightning storms. Early loggers talked about their discovery of "asbestos forests," which would provide a vast supply of quality lumber to a growing nation.

When it comes to fire behavior, Eastern and Western Washington are recognized as "different worlds with very little overlap," according to Dave Peterson, who studies fire science and climate change at the University of Washington's School of Environmental and Forest Sciences.

Under natural conditions, fires on the east side tend to be less intense but more frequent. Dry conditions produce less vegetation to fuel the flames. At the same time, lightning strikes occur more often in Eastern Washington, providing the sparks for recurrent fires. This natural cycle can be disrupted when humans put out the fires, allowing fuels to build up. The ultimate consequence is larger and more intense fires.

Meanwhile, the wetter conditions of Western Washington encourage dense vegetation to grow quickly. Potential fuels accumulate over time, not only from the prosperous growth of living trees and underbrush but also from fallen logs, dead brush and decaying "duff" that builds up on the forest floor. As fuels pile up, fire waits for the right conditions — specifically a long dry spell, a source of ignition and winds to fan the flames.

If humans don't ignite a fire, a century or more may come and go before all the right conditions come together in Western Washington for a widespread fire to take off and burn with great intensely.

Understanding the differences between Eastern and Western Washington has led some fire researchers to propose a separate strategy for combatting fire hazards on the west side of the mountains. Actively thinning forests and reducing fuel loads may work in Eastern Washington, where such efforts are currently underway. But in Western Washington, vegetation generally grows back too fast for thinning to be an effective treatment, researchers say. Besides, thinning the dense plants that fuel fierce west-side fires could eliminate a variety of species that depend on this special habitat.

ANCIENT FIRES OF WESTERN WASHINGTON

Over the past 1,000 years, three major burn periods in Western Washington have been identified by scientists, who estimate fire dates by studying the age of trees growing on the landscape and by examining the "burn scars" left among tree rings, as seen in the cross-section of a log.

One large fire or a series of smaller fires swept across Western Washington around 1308, followed by another great burning period from 1448 to 1538, when several fires occurred. The latest period of conflagration involved a pair of major fires, one about 1668 and the other about 1701.

Because each of these intense "stand-replacing" fires consumed evidence from the ones before, the best documentation comes from the 1701 fire, which burned an estimated 3 million to 10 million acres across Western Washington, according to a technical report developed for the U.S. Forest Service. For comparison, 10 million acres is roughly equivalent to the entire Puget Sound watershed or about 10 times the size of Olympic National Park. Many of the old-growth trees that

supplied lumber for a burgeoning industry in the 1800s got their start soon after the 1701 fire wiped out much of the vegetation that existed at the time.

For the past 300 years, fires in Western Washington have been small compared to the great fires of ancient times. They usually occurred during drought years, and the larger fires were generally accompanied by strong winds from the east. Such was the case with the 1902 Yacolt Burn, the largest fire in Washington state history up until 2014. The fire, near the Columbia River, scorched 239,000 acres of forestland in Southwest Washington and nearly that much across the river in Oregon.

Since 1985, Western Washington has seen 11 fires of more than 1,000 acres, which have burned about 50,000 acres in total. That includes the 6,632-acre Goodell Creek fire, which led to the evacuation of Newhalem and Diablo in 2015, as well as the 51,000-acre Norse Peak Fire in 2017 near Mount Rainier, a fire that burned equal areas (about 25,000 acres) in both Eastern and Western Washington.

Compared to Western Washington's 11 fires that scorched 50,000 acres since 1985, Eastern Washington has experienced 461 fires of over 1,000 acres each, burning a total of about 5.5 million acres — including some areas affected by fire more than once.

While nobody expects climate change to turn Western Washington into Eastern Washington, climate experts say the wetter side of the state may be transitioning out of a period of relatively small and low-intensity fires.

Perhaps aside from climate change yet adding to the concerns, recent weather conditions suggest that Western Washington may be moving out of a fairly long period of sustained dampness that began in the 1930s, according to Peterson.

"We do know that droughts were a lot more common — and lasted longer —prior to 1900," Peterson said. "There is plenty of fuel out there. If we get back to a more normal drought cycle, we could expect to see those fuels dry out more often."

Such conditions on top of climate change could lead to an increasing risk of a devastating wildfire across Western Washington, as well as an increasing number of smaller fires.

MEASURING RISK

Predicting the future of wildfire in Western Washington is a real challenge, researchers say, because there are so few fires to be studied. A similar challenge confronts emergency managers who try to convince residents who live in wooded areas that they need to take steps to protect their families and property from wildfire.

"The general public seems to think that fire is not something they need to worry about," said Kevin Zerbe, state mitigation strategist for the Washington Emergency Management Division. "It's hard to communicate the level of risk, because there are few historical events we can point to."

Among the 11 western states, Washington has the greatest amount of residential property in wooded areas, known as the wildland-urban interface, according to the state's "Enhanced Hazard Mitigation Plan."

It is not hard to find communities surrounded by nearby forests in Western Washington. Some look much like the town of Paradise, Calif., where in late 2018 a raging wildfire killed 86 people, destroyed 18,000 buildings and burned 150,000 acres. Most of Paradise became piles of ash that previously had been homes and personal belongings.

The blaze, named the Camp Fire, started from an arcing power line. Some experts say climate change contributed to the tinder-dry conditions that led to the most destructive fire in California history.

Northern California is different from Western Washington in many ways, Zerbe said, "but I don't think it is entirely out of the question to have a fire like that in Western Washington. From a purely exposure standpoint, I think it is possible."

Although well known for its rains, Western Washington has its moments when extreme drought and high heat come together to dry out the forests. Large amounts of fuel already exist. All that is needed is wind and something to spark a blaze — either a human source or a bolt of lightning.

Brian Potter, a research meteorologist for the U.S. Forest Service, says strong east winds associated with extreme fire conditions are often generated from a thermal trough, which develops along the coast beginning in Northern California and gradually extends into Western Washington. This low-pressure region brings strong and shifting winds up and over the Cascade Mountains, compressing the air in the Puget Sound lowlands and causing even hotter and dryer conditions. The trough is often associated with few clouds and no precipitation.

During fire season, California is generally known for having stronger and more sustained downslope winds than Western Washington. In Southern California, the winds are called Santa Ana winds, while in Northern California they are known as Diablo winds. In recent years, months of summer drought in California followed by extreme dry winds have led to unstoppable fires that have torched entire communities.

Because east winds play a powerful role in Western Washington wildfires, emergency managers would like to know how climate change could affect the frequency and force of the winds. Some climatologists speculate that warmer, more uniform temperatures might even weaken the winds to some degree. A new climate study, just getting underway, could help determine how future winds might alter the threat of a catastrophic wildfire.

THE GREAT FORKS FIRE

In Washington state, strong east winds during the summer of 1951 were blamed for an inferno on the Olympic Peninsula that raced through 18 miles of forestland in a single day and led to the evacuation of hundreds of residents from the town of Forks.

"The fire made everyday heroes out of men and women who grabbed hoses and watered down houses and businesses," wrote Mavis Amundson in her 2003 book "The Great Forks Fire."

The initial fire was ignited on Aug. 6 by a steam-powered logging train traveling through Olympic National Forest. It took dozens of firefighters, some with bulldozers, to bring the fire under control after it had burned 1,600 acres. Fire crews then spent weeks mopping up and putting out the hot spots before no signs of smoke remained. But the fire was not done.

The ominous east winds returned, stronger than ever, on Sept. 19. Somewhere in the burned debris a smoldering ember reignited the blaze, which moved so fast that fire crews had no defense.

"It blew over our heads and jumped ahead of us," said Lew Evans, an assistant district ranger for the Forest Service, as quoted by Amundson, who went on to describe the fire that headed directly for Forks with flames hundreds of feet high. Although most people were evacuated, some remained in town where they scrambled to extinguish fires caused by falling embers.

"Loggers, sawmill workers, firefighters, shopkeepers, retirees and others helped save their town from the advancing fire," Amundson wrote. "With little more than bulldozers, shovels, garden hoses, some outdated firefighting equipment and a pitiful water supply, these heroic townspeople helped hold back the forces of nature."

And yet, despite their efforts, the townsfolk came to realize that they could not overcome the searing forces of the main fire as it neared the edge of town. Forks appeared to be doomed, Amundson wrote.

"Then, out of the west, came a fresh wind that blew in off the Pacific Ocean, cool and moist, and just strong enough to stop the fire's advance. The town was spared."

Remarkably, nobody was killed or seriously injured in the Great Forks Fire, which destroyed about two-dozen homes and burned through 33,000 acres of valuable timberland.

The remains of homes that burned during the 2018 Camp Fire in Paradise, California. PHOTO: CALOES

THE WORST FIRE YEAR

On both sides of the Cascade Mountains, extremely dry weather during 2015 produced wildfires that turned out to be extraordinarily intensive and widespread. Some climate researchers have declared the 2015 fire season in Washington to be a likely "harbinger" of future conditions as the climate grows warmer.

In Eastern Washington, 42 fires each larger than 1,000 acres burned some 1.1 million acres during 2015. Both the number of fires and the amount of area burned in 2015 broke the record for modern times. That eclipsed the previous record of 415,000 acres burned the year before, when the 276,000-acre Carlton Complex Fire dominated the news.

The 2015 fires in Eastern Washington included the 219,000-acre North Star fire on the border of Okanogan and Ferry counties plus three fires to the west, sometimes lumped together as the Okanogan Complex: Tunk Block, 180,000 acres; Lime Belt, 137,000 acres; and Twisp River, 11,000 acres.

Meanwhile, in Western Washington, Olympic National Park officials kept watch over a rare fire in the Queets Rainforest, a wilderness area where the fire was allowed to burn throughout the summer. After covering 2,800 acres, the fire went out during November rains.

The Goodell Creek Fire, which led to the evacuation of Newhalem and Diablo, began on Aug. 10 from a lightning strike in North Cascades National Park. It grew slowly until Aug. 19, when high winds pushed the flames across the Skagit River just east of Newhalem. From there, residents could see the blaze approaching the town from both the north and south.

Cody Watson, named as fire chief for the community less than a year before, scrambled to direct Seattle City Light employees, who were running sprinklers to dampen the lawns amidst the dense smoke while putting out spot fires caused by a rain of embers.

"The fire went from small to huge very quickly," Watson said. "I knew it was bad when I could hear the embers coming down.'

As the fire advanced toward Diablo, employees evacuated the power plant, which is part of the Skagit River Hydroelectric Project. Diablo residents were evacuated to the east, joined by staff from North Cascades Institute's Environmental Learning Center and Ross Lake Resort. Some Newhalem residents left with them and some remained.

Firefighters focused on protecting the power facilities along with dozens of houses and administrative buildings in Newhalem.

Fortunately, a few months before the fire, the community had joined the Firewise Communities program, which is all about creating "defensible space." Workers cleared out flammable plants and materials from around buildings well in advance and then removed remaining materials as the flames approached.

The fire skirted Newhalem and advanced toward Diablo. With about a mile to go, the winds suddenly shifted and the air cooled. Heavy rains soon followed to put the fire out. No structures were lost, and no serious injuries were reported.

"We were fortunate on many levels," Watson said. "I'm grateful that, as close as the fire came, we were able to make it through."

EFFECTS OF A WARMING CLIMATE

It turns out that the extreme temperatures recorded in 2015 — about 1.7 degrees higher than normal — are within the range of average temperatures projected for midway through this century, according to a research report titled "The 2015 drought in Washington State: a harbinger of things to come?"

"Our results show that the drought conditions of 2015 occurred despite near-normal winter precipitation," according to the study led by Miriam Marlier, an environmental scientist at the University of California, Los Angeles. "Given the general similarity between 2015 and projected future conditions, this suggests a transition from precipitation to temperature control in future droughts."

Fire danger, as measured by fuel dryness, is expected to increase over time as climate change contributes to more frequent drought conditions.

In the Northwest, average annual temperatures have increased by about 1.6 degrees Fahrenheit since the 1920s — with most of that coming in the past 30 years. Over the next 30 years or so, average temperatures are projected to go up another 2.9 to 5.4 degrees, provided that greenhouse gas emissions are brought down. At the upper extreme with higher emissions, average temperatures could rise by more than 7 degrees, according to some models.

Most climate models suggest that the largest temperature increases will come in the summer months, when extreme temperatures — such as 95 degrees — become ever more common. Future summers also are projected to become drier.

Hot summers are expected to trigger both a larger number of fires and an increasing extent of areas burned. Snows that accumulate during winter will melt away earlier in the year, not only because of higher temperatures but also because more precipitation will fall as rain.

The so-called fire season — when forest fuels are most flammable — can be expected to begin earlier in the spring and extend later into the fall.

While it is easy to think of Western Washington as a continuous forest apart from Eastern Washington, scientists are quick to point out that the west side is actually made up of a variety of biotic communities where different types of trees dominate. Topography, elevation and rainfall are key determiners in the type and growth rate of trees and associated undergrowth.

In particular, the Puget Sound lowlands are characterized by more frequent and less severe fires than the slopes of the Cascade Mountains to the east or the Olympic Peninsula to the west.

Fire behavior is affected by multiple conditions, the sum of which determine whether a fire creeps along the ground, burns upward among "ladder fuels" to reach higher branches, or grows into an inferno, with flames racing through the crowns of trees and burning everything on the ground below.

WESTERN WASHINGTON STRATEGIES

Across much of Washington state, logging and forestland management have altered the condition of the forests — including the type and diversity of tree species. In the face of climate change, many forest ecologists and silviculturists advocate managing forests for future conditions.

"I think we're getting the message out that we need to thin our dry forests in Eastern Washington," said Josh Halofsky, a forest researcher for the Washington Department of Natural Resources. But in Western Washington, he argues, the story plays out much differently.

Fuel removal is simply not practical where vegetation grows so rapidly that frequent treatment would be needed across a vast area. Furthermore, such treatments would disrupt the ecosystem for west-side species dependent on the natural vegetation.

In an article published in the journal Ecosphere, Halofsky and five other researchers described a different management approach for a region affected by fewer fires with greater destructive potential.

STRATEGY 1

Attack fires while small in areas close to man-made structures or to protect commercial timber values, municipal watersheds or critical habitat, such as an old-growth forests containing endangered species. Elsewhere, consider whether managed wildfire might have ecological benefits.

In some areas of Western Washington, lightning-caused fires have been allowed to burn. The idea is that fire, which is a natural part of ecological history, can alter habitat in positive ways and reduce the risks of more intense fires in the future.

Such fires may have some ecological benefits, the researchers said, but they are unlikely to have much effect on fuel loading, and they run the risk of turning into a much larger fire if weather conditions change. So all factors should be considered.

STRATEGY 2

Pending the inevitable large fires, manage for appropriate species diversity. Ideas include promoting habitat connectivity, controlling invasive species and promoting genetic diversity to help maintain forest health in the face of climate change.

"For example, retaining an abundance of broadleaf species in stands and across the landscape may provide several important ecosystem benefits," the article states. "Deciduous hardwood species can reduce the flammability of forests and landscapes dominated by conifers, add to resilience by sprouting in response to disturbance, use less water than evergreen conifers resulting in more streamflow, and enrich forest habitat for many biota.

"Depending on management objectives and rotation length, diversifying the landscape can also sustain the economic viability of timber production in an uncertain future," the article continues, adding that older, larger trees are more likely to survive a fire and can provide seeds for the next generation.

STRATEGY 3

After a major fire, land managers should use the opportunity to grow a forest more suitable to changing climate conditions while learning from the process. For actively managed forests, having a post-fire plan in place will help to ensure an effective response.

Rather than harvesting trees that survive after a fire, surviving patches of trees can become part of a future forest mosaic and can facilitate ecosystem recovery.

Depending on management objectives, one could allow some stands to regenerate naturally. Otherwise, one could replant with climate change in mind, perhaps with less density and with a variety of species tolerant to lower moisture conditions, especially on dryer south-facing slopes.

The rare, devastating fires of Western Washington can strike without warning and create conditions for a new forest. Where fire takes place, the adaptation to climate change may come suddenly.

"Careful planning now," the article concludes, "will allow organizations to articulate a range of future possible responses ..., setting reasonable expectations for what management can and cannot do to foster resilience."

Puget Sound's 'warm snow'

BY: DAVID B. WILLIAMS

makes region vulnerable to climate shifts

Climate models project that if carbon emmisions continue as they are now, the vast majority of watersheds feeding Puget Sound will receive more rain and far less snow by 2080, causing increased flooding and other dramatic changes to the freshwater ecosystem. We look at the past and possible future of the region's snowpack and what this might mean for salmon and other species — including humans.

Read through the journal entries of early visitors to the Puget Sound region and it's clear they were impressed with the snow-clad mountains. In a May 1792 description of Mount Rainier, Peter Puget wrote: "The Snow was yet, notwithstanding the Heat more than 2/3 down & its Summit perfectly white appeared to reach the clouds." Forty-nine years later on the first American expedition into Puget Sound, seaman Joseph P. Clark marveled at the mountains covered "with everlasting snow...a striking contrast to the valleys near the sea, which are covered with verdure."

If they had arrived in the winter of 2015, particularly in late spring, these men may have had far different impressions. That year, warmer than normal temperatures had more often brought rain instead of snow to the higher elevations: On April 1, the date researchers have established as a standard of comparison, the mountains held a near record low snowpack.

When scientists carefully measured what they called the snow water equivalent (SWE), or amount of water contained within the snowpack, the numbers were five to 42 percent of normal, and, in the Olympics only three percent. Instead of the scenery that previous generations had enjoyed, the mountains had lost their lovely mantle of snow, as well as the benefits that melting snow provides to the Puget lowlands.

THE SNOW DROUGHT

The effects of the 2015 "snow drought," as researchers call the low snowpack, were immediately clear. There were warmer streams and rivers carrying less water, which resulted in crops with reduced yields and the death of 1,647,000 juvenile salmon, steelhead, and rainbow trout at 11 state hatcheries. Not only did the salmon suffer that year, the effects rippled through subsequent generations. The warm, low flows led to fewer eggs hatching, more predation of juveniles, and less fit adults heading into Puget Sound's marine waters. The salmon struggled in part because their life histories, or adaptions to the specific conditions in their natal stream, made them more susceptible to change than many other organisms. (A project by the Tulalip Tribes that is actively trying to address these issues involves relocating beaver to the Skykomish River watershed, where their dams create habitat—deep pools and slower moving side channels—beneficial to salmon.)

Perhaps an anomaly at present, the 2015 conditions were considered by many to be a dress rehearsal for the future. "They will be the normal conditions in another fifty years," says James Rufo-Hill, Climate Science Advisor for Seattle Public Utilities (SPU). "I can't imagine what below normal will be like." The effects, experts say, will play out in drinking water, flooding, fire, hydropower, agriculture, and wildlife.

"WARM SNOW"

Historically, the Puget Sound rainy season began in October, when the rains returned after the dry summer months. As fall and winter progressed, precipitation turned primarily to snow in the mountains and started to build the snowpack, which would accumulate until about April 1, when the snow would start to melt, enter streams, and flow into the Sound. With climate change, however, the snow window has started to close with snow melting earlier because of spring warming. Researchers project that the maximum amount of water in the snowpack will occur 20 to 40 days earlier by the 2080s. The models further show that the greatest decreases for this maximum are at elevations between 1,000 and 1,400 meters; above, the temperatures remain below freezing despite climate change, and below, little snow accumulates.

Harriet Morgan, a climate researcher at the University of Washington's Climate Impacts Group, refers to our snow as "warm snow" because it forms and persists right around the freezing point. "This means our snow is hypersensitive to any temperature rise," she says. This is crucial, she adds, because the majority of our streams are fed by a combination of snow and rain. (If greater than 40 percent of winter precipitation falls as snow, the stream is snow dominant; at the opposite end are rain-dominant streams.) Climate models project that by 2080 the vast majority of watersheds feeding Puget Sound will be rain dominant, which will result in increased flooding, earlier spring stream peaks, and reduced summer minimum lows.

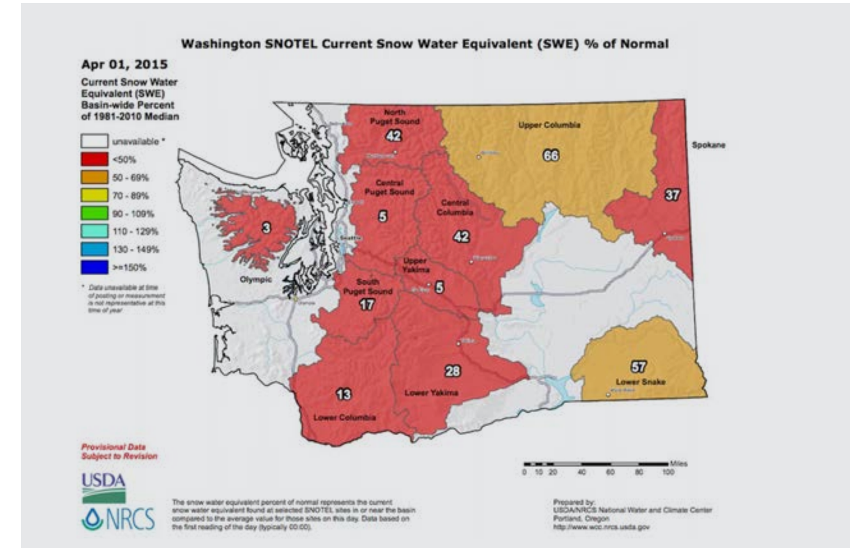
In these scenarios, it is not just salmon that will feel the sting of a changing climate. Humans depend on the snowpack too.

"What I worry about is that we have long operated around embedded climate assumptions," says Morgan. The size of bridges and culverts. The location of roads. Crop irrigation. Floodplain management. How we think about all of these issues is dictated by historic climate patterns and those numbers are becoming less valid year by year. For example, Morgan notes that models show that by the 2040s the stream flows associated with 100-year floods on the Skagit River will occur every 22 years, and 30-year floods will strike every 7 years. "If we don't adjust the assumptions that are pretty pervasive across these systems the climate impacts we experience will be more severe than if we take the time to expose these unexamined assumptions and adjust the systems accordingly."

DRINKING WATER

Adapting to the new climate conditions is a prime concern for Rufo-Hill and his SPU colleagues, particularly in regard to the reduced snowpack and its effects on drinking water. Seattle has two sources of water, the Tolt River and Cedar River watersheds, both of which are within the zone of greatest loss of available water due to declines in the snowpack. Each watershed contains a dam, used to create a reservoir that stores the city's drinking water. SPU also relies on snowpack, or what Rufo-Hill calls the "third reservoir." It plays a critical role in the system by acting like a sponge and slowly releasing water when it is most needed, in the parched summer months.

Opposite: Snowmelt on Hurricane Ridge, Olympic Mountains, WA.
PHOTO: BETH JUSINO (CC BY-NC 2.0) HTTPS://FLIC.KR/P/9WRS8J



Top image: Map of Washington showing snow water equivalent measures on April 1, 2015. MAP: USDA/NRCS

Lower image: Coho salmon spawning on the Salmon River. PHOTO: BLM (CC BY 2.0)

Not only does SPU have to worry about the shrinking snowpack, and the expected loss of this water source—researchers project that by 2080 the third reservoir might not exist because of anthropogenic warming—they also have to worry about the changing precipitation season. Historically, SPU would leave room in its reservoirs to provide a "pocket" for flood management, which led to smaller floods because the water remained behind the dams and didn't overwhelm the riparian environment. With climate warming, however, managers will have to balance the need to save as much water as possible given that the third reservoir will be empty. "It's like having too much and not enough water at the same time," says Rufo-Hill.

Flooding is only expected to become more profound in the future because of heavier rains and increased areas of runoff due to a higher snowline. One study projects that by the 2080s, 100-year floods in Puget Sound will carry between 12 and 55 percent greater flows. More water means a greater ability to erode and an increased risk of landslides, both of which generate increased sediment loads. When this material ends up on stream beds, it reduces the carrying capacity of the river and leads to greater flooding. Of equal concern, if the sediment is fine enough, it can smother and cut off the supply of oxygen and

food to salmon redds, or the stream bottom depression where salmon lay their eggs. The sediment can also fill in interstitial spaces between cobbles and boulders that had provided a safe haven for young salmon.

Morgan says that flooding will also become more problematic because rising sea levels will make it more difficult for rivers and streams to drain into the Sound. As a result, floodplains close to saltwater will experience deeper, more widespread, longer lasting floods.

Warming temperatures and reduced snow cover also translates to increase fire potential, which is particularly problematic for Rufo-Hill. Part of what makes Seattle's drinking water special is the pristine nature of the Cedar River Watershed. Unlike most large cities, Seattle entirely owns its primary drinking water source, which means no residential, commercial, or industrial development. Because of the environmental conditions, SPU is unique in the country in not having to filter its water. If a large enough fire hit the watershed, SPU could conceivably have to implement a filtration system, which takes time and money. "This could mean the temporary loss of the Cedar River water, or about 70 percent of Seattle's drinking water," says Rufo-Hill.

"I think that people understand how climate change affects trees and animals, but they find it harder to wrap their heads around how society is affected," says Morgan. They understand that ski seasons are getting shorter and perhaps see campgrounds that had not previously been flooded but they may not understand the additional transformations that are coming. "We are experiencing a change in the fundamental characteristics of our hydrology. We are going to have more water in winter when we don't need it and less water in summer when we do."

ADAPTING AND PREVENTING

Rufo-Hill thinks that the lack of concern can be blamed in part on how the issue has been framed. During past drought conditions, the urban centers of Puget Sound often got depicted as not experiencing the droughts. "There's this cognitive dissonance that Seattle and Tacoma and Everett are somehow not part of the ecosystem and have enough water," says Rufo-Hill. "People need to realize that we may have enough right now but it's going to keep getting harder and harder to provide water, particularly if people don't recognize that the water cycle involves plants, animals, and themselves."

Rufo-Hill and Morgan both stress that the projections are just that—projections. We cannot stop the changes that are occurring, because the warming is "already in the pipeline," says Morgan, but if we can act immediately and rapidly scale up the reduction of CO_2 emissions, we have the opportunity to reduce the climate impacts. If we care about future financial, ecological, and societal problems, she says, there is little recourse but to act.

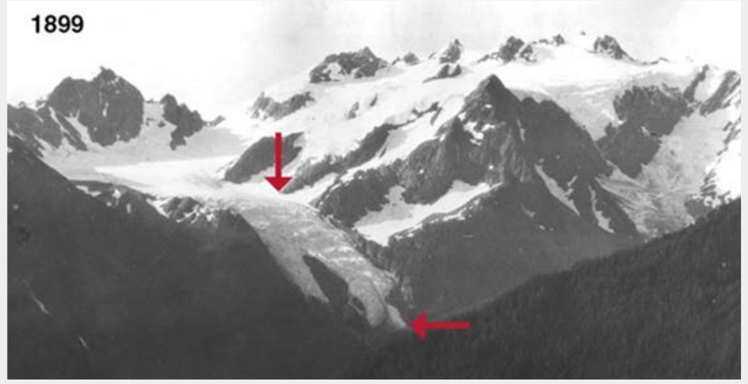
What about the glaciers?

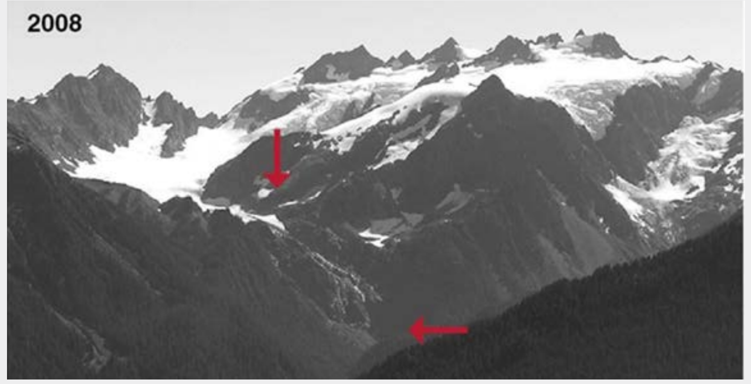
Although Mount Rainier has lost more than 20 square miles of glacial and perennial ice (about 39 percent of its total) and the North Cascades and Olympic National Parks have experienced even greater losses—more 50 percent reduction in ice in each park—since 1900, the glaciers are not predicted to vanish any time soon. At least at higher elevations such as on the volcanoes. Lower down though, the ice is expected to be greatly diminished by 2100, says Jon Riedel, glacial geologist at North Cascades NP.

With shrinking glaciers comes increased flooding, primarily because the less ice that covers the ground, the more surface area available for runoff. More open ground then makes the problem worse because the darker soil and rock warms more readily than white ice, which leads to warmer temperatures and more melting. And because the glaciers feed so many lowland streams, the ripple effect of their loss will spread all the way down to salt waters, adds Riedel.

Read more about thawing glaciers in the new "Shifting Snowlines and Shorelines" by the Climate Impacts Group at the University of Washington.

BLUE GLACIER, OLYMPIC NATIONAL PARK





Comparison photos show thinning and retreat of the Blue Glacier, Olympic National Park, WA. PHOTOS: NPS

Ocean acidification

The same greenhouse gasses that are warming the planet are making the oceans more acidic, threatening marine life everywhere. Experts say the Salish Sea is especially vulnerable and may experience some of the worst effects sooner than other parts of the world. This section features an in-depth article describing results from a 2019 symposium on ocean acidification conducted at the University of Washington. Without urgent action to reduce carbon emissions, scientists say that ocean acidification will accelerate quickly. Salmon may lose their ability to smell, leaving them more vulnerable to predators. Shelled creatures such as oysters, copepods and Dungeness crabs are likely to decline, as will tiny zooplankton at the base of the food web. The story looks at these and other future conditions as well as what might be done to turn things around.

NEXT →

Rate *of* Ocean ACIDIFICATION may accelerate, scientists warn

BY CHRISTOPHER DUNAGAN

Experts warn that wildlife in the Salish Sea, from salmon to shellfish, may start to see significant effects from changing water chemistry within the next 10 to 20 years. Ocean acidification from increasing CO_2 in the atmosphere could affect the ability of salmon to smell, disrupt critical eelgrass habitat and have other wide-ranging effects on the food web.

Ocean acidification, which threatens sea life throughout the world, is affecting Pacific Northwest waters — including the Salish Sea — sooner than most regions around the globe, scientists say.

Even more alarming is new research now causing oceanographers to predict that the changes in ocean chemistry will soon pick up the pace, causing the rate of ocean acidification to accelerate.

"If we continue down the road we are on, we will see very dramatic changes in the next 10 to 20 years," said Richard Feely, senior scientist at NOAA's Pacific Marine Environmental Laboratory in Seattle.

Ocean acidification, caused by the absorption of more and more carbon dioxide from the atmosphere, can affect the survival, growth and behavior of all kinds of sea creatures. New evidence suggests that ocean acidification impairs the sense of smell in salmon, impedes growth in herring and other critical prey species, and can affect plankton populations, thereby altering the food web.

Most notable in the struggle for survival amid ocean acidification, are species that form shells of calcium carbonate — including succulent oysters that support a vast industry, solitary corals that live in local waters, and a wide variety of tiny animals that serve as food for others.

These new predictions are the result of a growing understanding of the chemical changes taking place in different parts of the ocean, said Feely, who presented his findings during a 2019 Ocean Acidification Science Symposium in Seattle. Of particular concern, he noted, is what could become a dangerous weakening of the ocean's buffer system — an elegant set of chemical reactions that have so far inhibited an even faster rate of ocean acidification.

OCEAN CHEMISTRY

Over several decades, scientists throughout the world have been joining forces to better understand ocean acidification and its ecological consequences. The Global Ocean Acidification Observing Network, known as GOA-ON, has been compiling and sharing data from a vast array of sources —from stationary monitoring buoys to ocean-going research vessels to merchant ships that carry sensors while delivering cargo around the world.

Researchers have long understood that the ocean is far from uniform when it comes to absorbing and transforming excess carbon dioxide, said Feely, who has been studying ocean acidification for 37 years. New information is helping to explain why Northwest waters are so vulnerable to acidification and why the perils are growing greater as time goes by.

As carbon dioxide increases in the atmosphere from the burning of fossil fuels and from deforestation, about 25 to 30 percent of it gets absorbed into the ocean, where it is transformed into other carbon compounds.

In the North Pacific, subsurface currents along the West Coast carry acidified water northward, where upwelling brings corrosive low-oxygen water up from the depths. That's why shell-bearing creatures in Washington, Oregon and Northern California are especially vulnerable to ocean acidification.

New studies on pteropods — free-swimming sea snails — have revealed that the shells of these tiny animals collected along the coast are fully one-third thinner than those of pteropods collected in the open ocean, says Nina Bednaršek, senior scientist at the Southern California Coastal Water Research Project. Such studies raise concerns not only for the survival of pteropods but also for the multitude of species that eat them.

New evidence also suggests that acidification has already begun to upset the chemical balance of the ocean, including its ratio of buffering chemicals, which so far have helped to quell the rate of acidification. But buffering has its limits. Once a threshold is reached, the rate of acidification is expected to accelerate, like a brakeless freight train on a downhill track.

Above: In laboratory experiments, a pterapod shell dissolved over the course of 45 days in seawater adjusted to an ocean chemistry projected for the year 2100. PHOTO: NOAA ENVIRONMENTAL VISUALIZATION LABORATORY

The chemistry of the ocean is complex, but buffering can be viewed as a balance between two closely related compounds — with carbonate and bicarbonate being the key partners. They can readily change form from one to the other as acidity increases or decreases. This partnership helps to maintain a fairly stable pH — the common measure of acidity.

Buffering comes into play as the ocean absorbs carbon dioxide through direct contact with the atmosphere. As CO_2 gas enters the water, it readily converts to carbonic acid and begins to influence the buffer, turning carbonate into bicarbonate. As carbonate is consumed, the rate of acidification increases.

At the same time, the increase in carbon dioxide also influences calcium carbonate — the material of shells. Higher acidity tends to dissolve calcium carbonate molecules into separate calcium and carbonate ions. Thereafter, the reduced concentration of carbonate ion makes this critical mineral less accessible to shell-forming animals. At low concentrations of carbonate ion, favorable chemical reactions can actually run in reverse, dissolving the shells of living creatures.

If concerns about coastal waters are running high, trends for Puget Sound and the entire Salish Sea are raising the loudest alarm bells, Feely said. That's because freshwater flowing in from rivers and streams lowers the buffering capacity even further through dilution.

In addition, excess nutrients from natural and human sources, such as runoff and sewage-treatment plants, encourage the growth of algae, which eventually die and decay, creating an oxygen deficit and even more carbon dioxide to upset the natural balance.

"We compared the changes in the open ocean right outside the Strait of Juan de Fuca to the changes in Puget Sound on a year-to-year basis," Feely said. "Puget Sound has much lower pH (higher acidity) and more rapid change because of the lower buffer capacity."

Continuing on the present course, the outcome will be increasing impairment for marine life in inland waterways — and not just for the Salish Sea but for San Francisco Bay in California and for Prince William Sound in Alaska, Feely told attendees at the ocean acidification symposium.

"Many West Coast estuaries with freshwater inputs will see these impacts," he said.

Once the buffering capacity reaches a critical threshold, the increase in acidification will occur more rapidly, Feely said, and the cascading effects on marine life will be felt throughout the ecosystem.

"We're not there yet, but we're getting near a turning point," he said. "We have to make a decision about what we are going to do. The result (for marine life) will be a function of our decisions."

EFFECTS ON FISH

As ocean acidification continues to intensify, researchers predict uncertain but profound changes in the food web, as each species adjusts to its new conditions — or eventually disappears. For shell-building creatures, the lack of carbonate ion in the water may be observed as weaker shells, assuming the animal can survive. For other animals, behavioral changes may be the most dangerous problem, although behavior can be difficult to study.

Experiments on coho salmon, for example, have shown that when they are in marine waters with low pH (higher acidity), their ability to avoid predators declines and the risk of being eaten rises dramatically.

The cause may be related to changes in blood chemistry and effects on the fish's ability to sense chemicals in the water, according to researcher Chase Williams and his colleagues at the University of Washington's Department of Environmental and Occupational Health Sciences and NOAA's Northwest Fisheries Science Center.

Specifically, the lower pH causes the fish to accumulate more bicarbonate to maintain a stable blood pH, which leads to an excretion of chloride ions, Williams said at the ocean acidification symposium.

"This is important, because the chloride concentration across the cellular membrane in the brain is critical in the signaling pathway," he said. "When you start reversing certain signals, you start altering the code."

Using special instruments, Williams' team was able to find faulty signals in the connections with the olfactory centers responsible for the sense of smell. Fish could smell the odors, but disruptions in the neural pathway altered how they reacted to smells picked up from the water. If a fish can't tell the difference between predator and prey, it probably won't last long in the real world.

Salmon also use their sense of smell for mating and finding their way back to their natal waters, Williams said, so learning how a fish responds to different pH levels could determine their chances of survival.

Changes in pH are not the only issue, he noted, because salmon face many other challenges, such as increasing temperatures and low oxygen levels, which also are influenced by climate change. Further studies are focusing on other species of salmon, and Williams is looking into how ocean acidification might affect how the fish use the Earth's magnetic field to find their way in the open ocean.

PREDICTING FUTURE DAMAGE

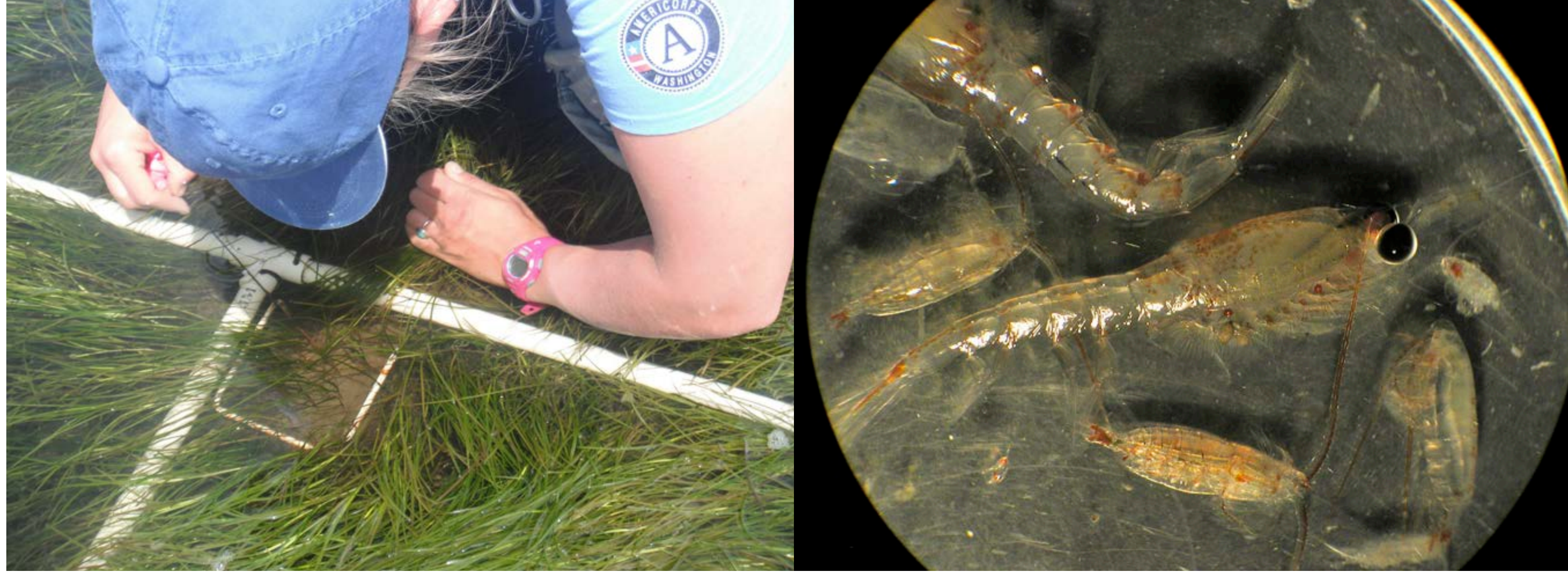
Extensive monitoring of Puget Sound waters provides a fairly up-to-date picture of water conditions, such as temperature, dissolved oxygen, acidity and so on. But these numbers alone don't describe the potential for damage that occurs to marine life when water quality gets out of whack.

Now, thanks to a team of scientists focused on biological effects, red flags can be raised to signal serious problems for certain organisms when water-quality measurements reach dangerous thresholds. The team is led by Nina Bednaršek, senior scientist at the Southern California Coastal Water Research Project, who presented the latest threshold findings during the ocean acidification symposium.

Bednaršek and colleagues used pteropods, a group of sea snails, to identify dangerous thresholds. These tiny animals are an important food source for many marine species, and they have been studied extensively for their sensitivity to ocean acidification. Specifically, their shells, which are made of calcium carbonate, do not grow properly in waters with low carbonate ion concentrations — so water chemistry becomes a life-or-death matter.

Besides a low concentration of carbonate ion, the time of exposure in corrosive waters can affect the severity of damage. Both ion concentration and the duration of exposure are used to estimate thresholds beyond which pteropod growth and survival will be impaired. For example, pteropod eggs may fail to develop in water low in carbonate ion — even when the exposure is for just two days. On the other hand, pteropod adults are likely to survive longer in the same water, perhaps because their shells are already complete. Studies have identified threshold levels for mild and severe shell dissolution, as well as other negative biological responses.

Published thresholds — which include bothe the magnitude and duration of stressful conditions — have been derived through a consensus of a dozen or more experts familiar with ocean acidification effects on specific species. Besides pteropods, thresholds have been developed — but not yet reported — for echinoderms, such as sea stars and sea urchins. Thresholds for Dungeness crabs are under development.



Left: A researcher monitors eelgrass characteristics of height, density, percent cover, flowering shoots, and biomass at the Padilla Bay Reserve. PHOTO: ELLIOT BANKO, ECOLOGY (HTTPS://FLIC.KR/P/GD3CRN) **Right: Krill and copepods under a microscope.** PHOTO: JEFF NAPP, NOAA/NMFS/AFSC (HTTPS://FLIC.KR/P/JSK2PD)

When combined with real-time temperature and chemical data gathered from monitoring buoys and other sources, one can get an understanding of the type of damage taking place over time. Bednaršek said conditions in Puget Sound often reach harmful levels for all stages of pteropods, especially in Hood Canal, South Sound and Whidbey Basin.

One can also combine predictive models with biological thresholds to anticipate problems for specific species. For example, the Salish Sea Model, under development by the Washington Department of Ecology, is designed to predict water chemistry based on a number of factors — including the amount of nutrients from natural and human sources coming into Puget Sound.

Based on that modeling, excess nutrients — such as nitrogen from sewage-treatment plants — may contribute to water conditions that can cause thresholds to be exceeded for pteropods and larval Dungeness crabs in parts of Puget Sound.

Thresholds for Dungeness crabs and other commercial species could be used in the future to help estimate economic losses from ocean acidification, whether caused by nutrient loading or atmospheric deposition.

A different kind of predictive model discussed at the symposium, called LiveOcean, is designed to produce daily forecasts of underwater conditions likely to occur over the coming three days. Similar to a weather forecast, the model uses up-to-date information on currents and other physical and chemical properties to predict changes in water conditions in the Salish Sea and along the coast.

LiveOcean can predict when and where pH will dip to dangerous levels, the potential course of toxic algal blooms, and likely pathways for incursions of aquatic invasive species, such as European green crabs, according to UW oceanographer Parker MacCready, who led the effort to develop the model.

One of its most important applications — and the initial motivation for building the model — is to help shellfish growers avoid harmful waters when planting oyster seed and operating oyster hatcheries, MacCready explained.

Oceanographer Samantha Siedlecki reported on an analysis that looked out to the year 2100, showing that many ocean conditions along the West Coast are likely to become more severe — more harmful to sea life — than predicted by global models.

The analysis, which involved numerous collaborators, considered how local factors — such as coastal currents, upwelling and biological activity — tend to "amplify" projections developed at a global scale, said Siedlecki, a former UW research scientist now based at the University of Connecticut.

While the new analysis showed a rate of acidification fairly consistent with global models, levels of temperature and carbon dioxide are projected to be adversely higher in the year 2100 — much higher in some areas. Likewise, beneficial oxygen and carbonate ion concentrations are predicted to be lower than global projections would suggest, and the amount of time that dangerous low-oxygen levels are present could double by 2100 in several coastal areas.

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Chinook salmon (Oncorhynchus tshawytscha) swimming upstream. PHOTO: INGRID TAYLAR (CC BY-NC 2.0) HTTPS://FLIC.KR/P/DMBYRE

Volunteer Vernon Brisley surveys a bull kelp bed near Ebey's Landing on Whidbey Island as part of the Island County MRC regional monitoring project. PHOTO: RICH YUKUBOUSKY