PUGET SOUND INSTITUTE

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Salish Sea Currents

timely, local stories about ecosystem recovery

2016-17

Special Report for PUGET SOUND POLICYMAKERS

shorebirds
native culture
forage fish
Chinook salmon
killer whales
steelhead
young salmon
harbor porpoise
emerging contaminants

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 Puget Sound Partnership and the EPA.

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Dear Salish Sea colleagues,

Anyone who has ever looked in dismay at a stack of unread papers or a crowded email inbox knows that the information age is both a blessing and a curse. No one understands this better than Puget Sound policymakers who must constantly sort through competing facts and interests. Within a region as large and complex as the Salish Sea, that can be overwhelming.

Science has always been an important tool for sorting the factual wheat from the chaff, but it too can seem daunting. Volumes upon volumes of studies look at thousands of species. Multiple threats — from climate change to water pollution and habitat loss — cry out for our attention. To be useful, science needs to be trustworthy but also accessible and relevant. That's why we produced this booklet.

This collection represents some of the past year's top science stories. It is the second in an ongoing series, and the articles represent some of the major issues facing Puget Sound recovery. We have distilled them down into an easy-to-read format that includes policy-relevant "key takeaways" and in-depth journalism for those who like a good story.

As with our previous booklet, most of these stories come out of our coverage of the 2016 Salish Sea Ecosystem Conference in Vancouver, B.C. Every two years, the SSEC brings together thousands of scientists and practitioners from the U.S. and Canada to share new and emerging research that will steer public policy for years and even decades.

In collaboration with an editorial board of leading scientists from around the region, and with support from the Environmental Protection Agency, we sent ten science writers to capture some of what rose to the top at the conference. We also surveyed the broader scientific literature for new discoveries. This is not an exhaustive collection, but it represents many critical areas of concern for decision makers.

Our understanding of the Salish Sea is constantly evolving. In some cases, we only know what we don't know. New research looks at mysterious declines in marine survival of Chinook salmon. Forage fish — a critical part of the food web — lead "secret lives" that we have only recently begun to understand. In other cases, science gives us clear answers, such as the environmental damage caused by shoreline armoring. The reporting in this booklet is meant as a guide to this evolving terrain and we hope it will be useful — and enjoyable — for all who read it.

Dr. Joel Baker
Director, Puget Sound Institute

Salish Sea Currents

CONTENTS

MASTHEAD

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INTRODUCTION

It used to seem easier to spot the polluters. There were the usual suspects — industrial pipes pumped toxic chemicals into the water; dams blocked the way for salmon; natural resources were over-harvested. Those problems still persist, but ecosystem management in Puget Sound has become increasingly complicated since the 1970s and 1980s.

Scientists now recognize that what happens on the land is intricately tied to the health of the water. We face climate change and unprecedented population growth, and scientists have identified thousands of different human-caused pressures on the ecosystem. The headlines include new threats like stormwater, emerging contaminants and widespread declines in species and habitats. Given limited resources, how can managers and policymakers make informed decisions about where to focus their recovery efforts?

That is the question driving this booklet. This is our second collection of this type, and it includes reporting on new and emerging science that we believe everyone should read. The stories are wide-ranging, but, like an ecosystem, are connected in important ways.

We start with a look at the impacts of seals and sea lions on the region's threatened Chinook populations. As many as one in five juvenile Chinook are eaten before they can migrate to open waters. That means many fewer are maturing to adulthood and returning to spawn. It also means significantly less food for the region's endangered killer whales, which depend on Chinook for about 81% of their diet.

So, are seals and sea lions the villains here, or is something else at play? Their numbers have been increasing due to federal protections, but they have always had a healthy appetite for salmon. Scientists suspect a variety of threats make the Chinook more vulnerable to what should otherwise be a normal pressure. Contaminants in the water as well as habitat loss from shoreline armoring are just two examples of threats that could be weakening Chinook, and we have several stories in this collection that intersect.

Not everything is bad news. We close out the collection with a story about the return of the harbor porpoise. Known as "the puffing pig," the harbor porpoise had all but disappeared from Puget Sound in the 1970s due to factors like gillnetting and industrial pollutants. The species is still considered to be at risk in the Salish Sea, but its population is on the rise and it is hoped that Puget Sound cleanup efforts can ensure healthy numbers in the future. It is just one reminder that we can make a difference if we understand the ecosystem's problems and their causes. Good science reporting can help to build that understanding, and we hope this collection of stories continues that tradition.

Seal vs Salmon. West End, Vancouver, BC. Photo: cesareb (CC BY-NC 2.0)

A new study shows that increased populations of seals and sea lions are eating far more of Puget Sound's threatened Chinook than previously known, potentially hampering recovery efforts for both salmon and endangered killer whales.

Study says predators may play major role in Chinook salmon declines

date: 1/25/2017 author: CHRISTOPHER DUNAGAN
web: eopugetsound.org/magazine/predators-Chinook

KEY TAKEAWAYS

- *Rising populations of seals and sea lions in Puget Sound are consuming significant numbers of Chinook salmon, potentially hampering recovery efforts and diminishing the food supply for endangered orcas.*
- *As many as one in five young Chinook are eaten before they can make it out of Puget Sound into the open ocean.*
- *Scientists estimate that seals and sea lions reduce adult Chinook returns to Puget Sound by about 162,000 fish per year. That's twice as many adult Chinook taken by Puget Sound's endangered orcas, and six times the annual commercial and recreational catches from local fishermen combined.*
- *Much of the Chinook consumption is by harbor seals, which had a bounty on their heads from 1947 to 1960. After hunting was outlawed under the 1972 Marine Mammal Protection Act, the population of Puget Sound harbor seals grew rapidly.*
- *Scientists caution that reducing the number of seals or other marine mammals is illegal and would not guarantee that more Chinook would survive to adulthood. Other factors such as pollution and habitat destruction may be weakening young salmon, making them more vulnerable.*

Seals and sea lions are taking a major bite out of the threatened Chinook salmon population in Puget Sound, and the competition for food could be having repercussions for endangered Southern Resident killer whales, according to a new study.

Seals and sea lions are eating about 1.4 million pounds of Puget Sound Chinook each year — about nine times more than they were eating in 1970, according to the report, published online this month in the Canadian Journal of Fisheries and Aquatic Sciences.

Most of these Chinook are small fish migrating to the ocean, which ultimately reduces the number of adults returning to Puget Sound. The study estimates that seals and sea lions are decreasing potential returns by about 162,000 adult Chinook each year. That's twice the number eaten by killer whales and roughly six times as many as caught in Puget Sound by tribal, commercial and recreational fishers combined.

Much of the Chinook consumption is by harbor seals, which had a bounty on their heads from 1947 to 1960. After hunting was outlawed under the 1972 Marine Mammal Protection Act, the population of Puget Sound harbor seals grew rapidly until it leveled out around 18,000 animals, according to rough estimates.

Today, the Salish Sea — including Puget Sound and the inland waters of British Columbia — is believed to have one of the highest densities of harbor seals of any place in the world, noted the study's lead author, Brandon Chasco of Oregon State University.

Meanwhile, killer whales are eating about 1.2 million pounds of Chinook in Puget Sound — a number surpassed by seals and sea lions perhaps a decade ago. The orcas consume Puget Sound Chinook — their chief source of food — mainly during summer months when they are in the inland waterway.

The new study, which is based on a variety of assumptions, raises questions about whether competition for Chinook salmon may not only impede the recovery of Chinook but also limit the orca population, said Lynne Barre, who manages the Seattle branch of NOAA's Protected Resources Division.

Barre said the study "is a step, a piece to the puzzle in understanding the complete predation and food-web picture in Puget Sound. It helps us understand the benefits of salmon recovery. If we had an increase in the abundance of Chinook," she continued, "how would that be distributed among all the predators — including us?"

Sea lion sunbathing between meals in Seattle's Eliott Bay.

Photo: Johnny Mumbles (CC BY 2.0)

YOUNG SALMON AT RISK

As Chinook runs have declined, human fishing opportunities have become more and more limited to protect the remaining fish. Total commercial and recreational catches of 400,000 Chinook in 1980 have declined to around 30,000 in marine waters in recent years, Chasco said. The new findings, which rely on previous studies by other experts, look at both biomass consumed as well as the number of fish eaten.

The biggest difference is that seals and sea lions are consuming significant numbers of small Chinook, compared to people and whales that take adult salmon. Juvenile Chinook, known as smolts, are often caught by seals as the fish leave their natal streams and migrate to the ocean. Although Chinook make up only 6.8 percent of a harbor seal's diet, about a third of that comes from eating the little smolts, according to estimates from the new study.

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Photo: Ingrid Taylar (CC BY 2.0)

Salmon leaping at the Ballard Locks. Seattle, WA.

In terms of energy content, it takes about 1,400 smolts at 9 centimeters in length to equal one four-year-old adult that is 92 centimeters long, the study says. Based on their caloric needs, each harbor seal may be eating up to five smolts a day at certain times of the year — for a total of more than 8 million smolts a year for the Puget Sound population, according to Chasco's calculations.

In 1970, harbor seals were eating about 1.1 million Chinook of all sizes, or 13 times more individual fish than killer whales. In 2015, that number had grown to 8.6 million for the seals, or 104 times the number of Chinook taken by killer whales.

If one assumes that all the smolts eaten by harbor seals are from Puget Sound hatcheries, then the study predicts that the seals are eating about 22 percent of all the smolts trying to leave Puget Sound. The 22-percent figure is recognized as an overestimate, Chasco said, because the seals are eating wild Chinook from Puget Sound and even hatchery fish from British Columbia — but those exceptions are relatively small compared to hatchery Chinook produced in Puget Sound.

"It is tricky," Chasco said. "We were asking, 'Can we even do this well enough to create estimates that we think are OK?'"

The paper is sure to generate discussion, Barre said, noting that Chasco and his fellow authors on the paper are now trying to expand those estimates to the entire West Coast.

Puget Sound Chinook were listed as threatened under the Endangered Species Act in 1999, followed by the 2005 Shared Strategy for Puget Sound, a blueprint for Chinook recovery. The plan focused on improving salmon habitat, hatchery operations and fishing regulations to restore the salmon runs.

Predation by marine mammals was not addressed in the initial recovery plans for Chinook, because people weren't aware that it was a major factor, said Laura Blackmore, who helps coordinate recovery planning for the Puget Sound Partnership.

AN EMERGING ISSUE

In 2014, an international team of researchers launched the Salish Sea Marine Survival Project, an effort to understand why so many Chinook and coho salmon and steelhead trout were dying after they left their freshwater habitats. The research is coordinated by Long Live the Kings in the U.S. and the Salmon Recovery Foundation in Canada.

Among its projects, the research team is attempting to describe the interactions between marine mammals and salmon and steelhead from the time the fish leave the streams as juveniles to the time they return as adults. Work includes "tagging" juvenile steelhead with tiny acoustic transmitters to determine how many fish leave Puget Sound and how many get eaten by various predators.

"We know the harbor seal population has increased tenfold," said Michael Schmidt, project coordinator for Long Live the Kings. "This tells you that the protections (for marine mammals) worked. Now we need to restore Puget Sound."

The near-term question, he said, is whether marine mammals are impeding salmon and steelhead recovery and possibly contributing to problems for killer whales.

"The numbers that scientists are producing are eye-opening," Schmidt said. "They compel us to make sure we are assessing this issue."

While marine mammals were not a major consideration in Chinook recovery planning in 2005, they are becoming an emerging issue, Blackmore said.

NEW STRATEGIES

Separate from recovery goals under the Endangered Species Act, the Puget Sound Partnership has spelled out targets for its Vital Signs indicators. One target calls for reversing declining Chinook runs and increasing local populations of Chinook in each region of Puget Sound. A so-called "Implementation Strategy" to meet that target could be ready as early as March, Blackmore said.

An early draft of the Implementation Strategy lists "marine mammal interactions" as an issue for Chinook recovery, but no specific actions are proposed.

"There are a number of scientific questions that we will be following up on," Blackmore said. "Food web dynamics is highlighted as an issue. It is definitely one that we are following."

Southern Resident killer whales were listed as endangered in 2005. A 2008 recovery plan developed by the National Marine Fisheries Service listed prey availability as a major threat, along with toxic chemicals, noise, disturbance from vessels and other concerns. Food competition with other marine mammals was briefly mentioned as a potential issue, but no estimates of consumption were available for seals and sea lions at the time, and no specific actions were proposed.

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Salmon-eating orcas off south shore San Juan Island, male orca K21 Cappuccino in the lead.

Photo: Andrew Reding (CC BY-NC-ND 2.0)

"We know the harbor seal population has increased tenfold."

Michael Schmidt, project coordinator Long Live the Kings

Recent studies have suggested that orca calves tend to be born during times when salmon runs are on the increase and that pregnant whales have more miscarriages when runs are down. If it can be shown that competition for food is restraining the recovery of Southern Resident killer whales, balancing the populations of fish and marine mammals could become a major issue.

At this time, controlling the seal population with lethal or nonlethal methods is not even a consideration, said Barre. Under the Marine Mammal Protection Act, such actions would be "limited and complicated," but not impossible, she said.

California sea lions have been removed from the Columbia River near Bonneville Dam, but only after problem animals were individually identified and when other means of control — such as hazing — were proven not to work for those particular animals.

While Chasco was able to estimate the current consumption of Chinook by harbor seals, California sea lions and Steller sea lions, he does not attempt to predict the outcome of any particular management action. In fact, his report cautions that no estimates were made for consumption by other known predators, including marine birds and other types of fish.

REMAINING QUESTIONS

Reducing the number of harbor seals or other marine mammals would make more fish available for other species, but that does not necessarily mean that adult Chinook would be available for killer whales or human fishers. In fact, some researchers have suggested that a significant percentage of Chinook smolts in Puget Sound are in a weakened condition — perhaps by toxic chemicals, disease or malnutrition. That could make them especially vulnerable to predation long before they return as adults.

The entire food web — a multitude of prey and predator species — must be better understood, Barre said. Another question yet to be answered is whether declines in other types of prey in Puget Sound have caused marine mammals to eat more Chinook smolts. A harbor seal's diet, after all, varies greatly but currently averages only about 7 percent Chinook. That compares to a killer whale's diet, which is believed to be 95 percent Chinook in the spring and summer and about 50 percent in the fall.

When a salmon run declines, the population effects of marine mammal predation are multiplied, assuming the animals consume the same number of fish, said Steve Jeffries, a marine mammal biologist for Washington Department of Fish and Wildlife and an author of the new report.

For example, when the runs of threatened Hood Canal summer chum were at their lowest, harbor seals were eating about 25 percent of the adult returns to Hood Canal — and that was considered a major problem, Jeffries said. But efforts to boost the summer chum population were successful. With a larger salmon run, harbor seals were able to eat the same number of fish without making a significant dent in the spawning population.

Another question yet to be answered is why the harbor seal population leveled off around the year 2000 after increasing from about 2,100 to 18,000. Jeffries said he doubts that declining Chinook runs had much to do with it, since harbor seals can easily vary their diet by switching to more plentiful fish.

Habitat for seals — such as the number of places where harbor seals can haul out to rest — may have declined, and that might affect the population, he said. In addition, visits to Puget Sound by transient killer whales — which eat seals and sea lions — are reportedly on the increase, and that could have some effect on the population of the smaller marine mammals.

Many of these questions can only be answered with more research, Chasco said, adding that the goal of the study was to identify the relative roles of known predators of Chinook salmon.

"We went out of our way not to reach beyond our findings," he said. "Is it possible in this environment that (seals and sea lions) have become the dominant predator? We didn't go that far." ■

A seagull looking for its share as a sea lion dines on salmon. Valdez, AK.

Photo: Charles Anderson (CC BY-NC 2.0)

The paper, published online in the Canadian Journal of Fisheries and Aquatic Sciences, includes 10 authors in addition to Chasco and Jeffries. They are Isaac Kaplan, Dawn Noren, Michael Ford, Bradley Hanson and Eric Ward, all of NOAA's Northwest Fisheries Science Center; Austen Thomas of Smith-Root in Vancouver, Wash.; Alejandro Acevedo-Gutiérrez of Western Washington University; Jonathan Scordino of the Makah Tribe; Scott Pearson of Washington Department of Fish and Wildlife; and Kristin Marshall of Cascade Ecology in Seattle.

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Social scientists around the Salish Sea are predicting the effects of environmental change through the lens of culturally important foods.

KEY TAKEAWAYS

- *Tribal citizens have lost millions of dollars to harmful algal blooms that have closed local fisheries, but the cultural losses are just as significant, tribes say.*
- *Quinault people speak of "clam hunger" to describe a physical, emotional and spiritual craving for a food that connects them to their native landscape and heritage.*
- *Climate change is expected to increase the number of harmful algal blooms in the future, further impacting tribal economies and culture.*
- *Social scientists are collaborating with indigenous groups to understand how increased closures of shellfish beds will affect tribal cultural and spiritual health.*
- *Studies of traditional approaches to tribal aquaculture such as clam gardens may help indigenous and non-indigenous communities alike adapt and respond to environmental challenges.*

Clam hunger

date: 8/31/2016 author: SARAH DEWEERDT topic editor: KATHARINE WELLMAN
web: eopugetsound.org/magazine/clam-hunger

> "You can't give thanks over a can of Spam."
> Swinomish Elder

The Pacific razor clam (Siliqua patula) is a meaty, six-inch bivalve common on sandy ocean beaches from California to Alaska. The clam is a cultural and economic touchstone for the Quinault Indian Nation, who co-manage a certified sustainable fishery for the mollusk with the government of Washington State.

Last year, when a toxic algal bloom closed the fishery on May 8 — a closure that lasted beyond the end of the year on many beaches — tribal citizens were left with an estimated $1.8 million less in their pockets.

But this wasn't at all the biggest loss to the tribe, which has about 2,500 citizens, just over half of whom live on the Quinault Reservation in the southwestern corner of the Olympic Peninsula. "The loss of subsistence and cultural identity cannot be estimated," says Joe Schumacker, of the Quinault Department of Fisheries.

Many Quinault people speak of "clam hunger," a physical, emotional, and spiritual craving for a food that connects them to their native landscape, their ancestors, and their very existence as a people. Clam hunger can even drive people to eat this food when scientists and resource managers tell them that toxins render it unsafe, says Kate Crosman, who studies the effect of climate change on coastal communities. "Clam hunger is something we heard a lot about in our interviews" with the Quinault, she says.

Other Coast Salish peoples in both Washington and British Columbia report a similar relationship to wild local foods from the Salish Sea. "These foods contribute not only to the physical health we have but also our spiritual and cultural health," says Larry Campbell, the historical preservation officer for the Swinomish Indian Tribal Community.

Campbell recalls attending a mussel bake on the beach with other tribal citizens, and observing the mother of one of his friends eating mussels rapidly and taking antihistamine pills as she ate — it turned out she was allergic to shellfish. Campbell asked her why should would eat the mussels if she knew they would make her sick. "Because my spirit demands it," she told him.

The paradox of clam hunger and phenomena like it — the idea that a person would eat something despite knowing that it might make them physically ill — suggests that the commonplace conception of well-being as involving mainly physical and perhaps mental health leaves something important out.

And food can help illuminate that something else — the way that health and well-being have cultural, spiritual, and intergenerational aspects as well — according to research in which social scientists are collaborating with indigenous groups throughout the Salish Sea region. In fact, these studies suggest, it will be impossible to understand and predict how climate change and other environmental challenges will affect people without this deep cultural understanding.

CULTURE AND CLIMATE

The 2015 closure of the razor clam fishery was due to a bloom of algae that produce a neurotoxin called domoic acid. "This was a phenomenal bloom in scope, intensity, and toxicity," Schumacker says.

Pacific razor clams from Pacific Beach, Grays Harbor, WA.

Photo: ConwaySuz (CC BY-NC-ND 2.0)

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2013 Swinomish Tribe clam bake.

Photo: Copyright Northwest Treaty Tribes

While domoic-acid producing algae have been scarce in nearshore waters this year, last year's bloom could be a harbinger of the future. Harmful algal blooms are expected to increase as climate change produces warmer marine waters during summer. Already, almost every marine water body of Washington State has been affected by one or more biotoxins that make shellfish unsafe to eat, says Adi Hanein of the Washington Department of Health.

The agency monitors fishery closures due to domoic acid and two other biotoxins, and in recent years has documented the toxins moving into new areas, as well as more frequent, earlier closures in some areas of the state.

Domoic acid and other biotoxins don't actually kill the clams that the Quinault and others depend on. So this research shows why simply documenting or modeling the effects of climate change on natural resources isn't enough to predict the impacts to human communities. "Harmful algal blooms may not affect the population of shellfish, but they will affect the community because of closures," Crossman says.

Yet until now, efforts to predict the effects of climate change on coastal communities have rarely taken this type of culture-focused approach. Last year, for example, a paper published in Nature Climate Change predicted that ocean acidification would have relatively modest, evenly distributed effects on people in the Pacific Northwest.

But that sort of analysis doesn't capture the real effects of environmental change on specific communities, says Melissa Poe, a social scientist with Washington Sea Grant and NOAA's Northwest Fisheries Science Center. "Some communities are more vulnerable than others, owing not just to exposure but also to non-substitutable social and cultural ties to the resources," Poe says.

By "non-substitutable," Poe and other social scientists working in this area mean that, for example, clam hunger cannot be sated by consuming chicken. Or, as one elder from the Swinomish tribe puts it, "You can't give thanks over a can of Spam."

For the last two years, Poe has been conducting interviews with citizens of the Squaxin Island tribe, whose ancestral territories lie in south Puget Sound. Poe and her collaborator Charlene Krise, a member of the Squaxin Island tribal council and director of the tribe's museum and library, have documented an expansive concept of health among tribal citizens that encompasses much more than physical and mental well-being. For their study participants, health depends on being able to engage in cultural practices like shellfish harvesting, and knowing that the foods from the Salish Sea they depend on are secure for future generations.

HEALTH INDICATORS

This concept of health is common among people from other Coast Salish tribes, who, like Krise, often refer to foods like seaweed, shellfish, and salmon as "medicines." "We determine health differently than other people," says Larry Campbell of the Swinomish tribe.

Campbell has been working with Jamie Donatuto, the tribe's community and environmental health analyst, to develop a set of six indigenous health indicators: community connection, resilience, education, self-determination, cultural use, and natural resources security. The indicators reflect aspects that are not often included in health assessments, yet are important to the tribe.

"Usually science is a top-down process. Scientists tell us what they've decided," Campbell says. But the project suggests an alternative approach that he argues is widely applicable: "Any indicator has got to start from the community and work your way up rather than vice versa," says Campbell.

In pilot workshops with both the Swinomish and the Tsleil-Waututh first nation in British Columbia, the indigenous health indicators proved useful in understanding how the impact of climate change and sea level rise on shellfish habitat, shorelines, and archaeological sites important to the two communities will affect community health.

Now, the Swinomish tribe is undertaking a $756,000 study, funded by the U.S. Environmental Protection Agency, to define how climate change will alter habitat for culturally important foods along the shorelines of the reservation and in turn affect the health of the tribe. An analysis has already revealed that Lone Tree Point, one of the most important fishing and shellfish gathering sites, will lose a significant portion of juvenile salmon habitat, shellfish beds, and beach seining sites over the next century.

The next step is to capture how rising sea levels and increased storm surges may put community health at risk by making the link between these findings and the indigenous health indicators, Donatuto says.

This type of interaction between the social and biophysical sciences is picking up steam around the Salish Sea. Some natural scientists are building on insights about the cultural importance of Salish Sea foods to ensure that their own studies are relevant.

For example, Jennifer Hahn, an adjunct professor at Western Washington University in Bellingham, is undertaking the first major study of seaweed contaminants in the Salish Sea in over a quarter century. In a pilot project with the SeaDoc Society, she recently measured heavy metal levels in two species of seaweed collected from 20 industrial sites and 21 seaweed harvesting beaches. Rather than seeking

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First Nations are working to restore a Russell Island clam garden rock wall in collaboration with Parks Canada.

Photo: Copyright Marco Hatch https://twitter.com/marcohatch

out "pristine" sites for comparison with the industrial ones, Hahn identified beaches, actually used now or in the past for seafood harvesting, in collaboration with tribal citizens in both British Columbia and Washington. Some beaches were ones that the first nations or tribes would like to harvest at, but were concerned about the potential of contaiminants, Hahn reports.

CLAM GARDENS

These investigations of wild Salish Sea foods can not only yield understanding of how environmental change may affect indigenous people in the region, but may also help indigenous and non-indigenous communities alike adapt and respond to environmental challenges. Some researchers say that clam gardens, which were unknown to Western science until the late 1980s but emerged at least 1,000 years ago along the present-day British Columbia coast (and may be a technology as old as 2,000 years), offer a glimpse of a more sustainable way to make productive use of the marine environment.

A clam garden is formed when people build a rock wall in the lower intertidal zone. The barrier flattens the slope of the beach to provide more habitat at the ideal tidal height for native littleneck and butter clams. According to Marco Hatch, who will move from his position as director of the Salish Sea Research Center at Northwest Indian College to become a professor at Western Washington University this fall, clam gardens can contain up to 300 butter clams per square meter. He reports that when he plunged a hand into the sediment of one clam garden beach it came up full of the bivalves. "The beach was top to bottom clams," Hatch says.

One study found that clams grow twice as fast and can reach densities up to four times as high in clam gardens compared to unmodified beaches. "That is the missing link between harvest and aquaculture," says Ralph Riccio, a shellfish biologist with the Jamestown S'Klallam tribe. "That is really cool."

Anne Salomon, a marine ecologist at Simon Fraser University who led the study comparing clam gardens to unmodified beaches, says that the structures suggest a way to achieve resilient ecosystems that can provide food to sustain a growing human population. "We have to learn how to do more with less, and I think clam gardens are a way to do that," Salomon says.

Increasingly, researchers are realizing that clam gardens aren't just about clams. The rock walls increase habitat diversity of shorelines: In some cases, they introduce rocky intertidal habitat to a sandy beach environment. Elsewhere, they create pocket beaches on top of bedrock where there was previously no soft sediment.

In turn, that diversified habitat supports more species of marine invertebrates (some of which, like sea urchins and sea cucumbers, were also sought-after foods for indigenous groups). A study in Fulford Harbor on Salt Spring Island found a greater diversity and four times the abundance of invertebrates on clam garden beaches compared to unmodified ones.

Stone fish traps were often constructed near clam garden beaches. Many also have berry patches or camas beds nearby. "This is part of a massive modification that extended from mountaintop to seafloor." Hatch says. "These systems have been fundamentally shaped by people."

That view flips the usual script that has human alterations of the landscape as a force destructive to biodiversity. And its significance becomes even greater considering that people arrived in the Salish Sea region around the end of the last Ice Age, just as a new ecosystem was taking shape in the wake of the glaciers' retreat, says Sara Breslow, program manager for the Center for Creative Conservation at the University of Washington in Seattle.

This means that the ecosystem of the Salish Sea region has coevolved, since its very beginning, with human culture. "In order to restore the natural ecosystem in the Salish Sea we have to restore the cultural management practices within that ecosystem," says Breslow. ■

[RELATED STORY NEXT PAGE]

Photo: Richard Eriksson (CC BY 2.0)

Coast Salish fish trap.

RELATED STORY

Environmental samplers may provide early detection of harmful algal blooms (HABs) in Puget Sound. This toxic algae is expected to increase as the climate changes, bringing with it new and potentially more severe outbreaks of shellfish poisonings.

Detecting harmful algal blooms

date: 7/12/2016 author: RACHAEL MUELLER
web: eopugetsound.org/articles/salish-sea-snapshots-detecting-harmful-algal-blooms

Diuretic shellfish poisoning (DSP) officially arrived in Puget Sound in 2011 in the form of a bucketful of gorgeous blue mussels. A vacationing family of four harvested the mussels, but soon after dinner the nausea kicked in, accompanied by diarrhea, vomiting and abdominal pain. It was more than just a nightmare camping trip. It marked a new chapter for harmful algal blooms (HABs), and the illnesses they cause.

DSP is just one of several types of poisoning caused by the ingestion of shellfish that contain toxic algae, and it is a relative late-comer to our waters. Both paralytic shellfish poisoning (PSP) and amnesiac shellfish poisoining (ASP) have been here since 1978 and 1990, respectively.

As their names suggest, ASP and PSP can be especially severe. Symptoms of ASP can include permanent short-term memory loss and brain damage, while PSP can cause numbness and loss of control of arms and legs and difficulty breathing. Both can be fatal. In all, there are seven types of HABs that occur in the waters of the Salish Sea.

Unlike other food-born illnesses, toxic algae can't be cooked or frozen out of food. The only way to prevent shellfish poisoning from this algae is to avoid consuming the mussels, oysters, clams and scallops that carry it. Now, new technology is being developed to forewarn and prevent contamination. Scientists at NOAA's Northwest Fisheries Science Center have developed a monitoring device that is able to identify toxins in water and send a message warning of toxic algae within three hours of detection. Dr. Stephanie Moore of NOAA described this new technology, known as the Environmental Sample Processor, at the 2016 Salish Sea Ecosystem Conference in Vancouver in April. So far, there are two of the sampling devices deployed on moorings, one in Lummi Bay and another in Samish Bay, with a new one to be installed on a mooring just north of Seattle. These instruments will provide real-time information to industry and recreational harvesters regarding HABs and the potential for toxic shellfish.

Detection of HABs may become increasingly important as the climate changes. HABs and their toxicity levels are expected to increase under warmer and more acidic seawater. That has upset the pre-1970s balance between the HABs and the HAB-nots. Scientists say we can expect to see more and increasingly severe HABs in the future, and possibly more incidences of HAB-related poisonings.

For now, scientists say, the best bets for consumers are new early detection tools and increased awareness. Health Department officials recommend checking the Washington State Department of Health website on the status of beach closures before harvesting shellfish. ■

Photo: Rachael Mueller

Monitoring devices deployed by NOAA for detecting harmful algal blooms.

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Penrose Point State Park bulkhead-removal project. Composite: Kris Symer, PSI; original photos: Kristin Williamson, South Puget Sound Salmon Enhancement Group

New numbers show progress in the state's efforts to remove shoreline armoring, but they don't tell the whole story.

Hitting a wall:
Can we fix Puget Sound's beaches?

date: 10/17/2016 author: CHRISTOPHER DUNAGAN
web: eopugetsound.org/magazine/fix-beaches

KEY TAKEAWAYS

- *More than 700 miles of Puget Sound's shoreline is armored with anti-erosion structures such as bulkheads and seawalls.*
- *That number is greater than the length of the ocean beaches in Washington and Oregon combined, and it covers more than 25% of Puget Sound's shoreline.*
- *New, comprehensive studies show that shoreline armoring is often unnecessary and causes significant harm to the environment. It lowers species diversity and causes a decline in food for juvenile salmon, marine birds and larger animals.*
- *Much of this armoring exists on private property, and agencies are working to educate property owners about the harm these structures are causing, while proposing alternative methods for erosion control.*
- *In 2015, more shoreline armoring was removed than constructed in Puget Sound, but it was a net decline of less than 1,000 feet.*

For the second year in a row, more shoreline armoring — such as rock and concrete bulkheads — has been removed than constructed in Puget Sound, according to permit statistics compiled by the Washington Department of Fish and Wildlife.

In 2015, 3,097 feet of old armoring were removed from Puget Sound, compared to 2,231 feet of new construction.

Shoreline experts have cautiously embraced the news, which comes amid new studies describing the ecological damage caused by bulkheads. Meanwhile, state and federal agencies have increased programs to assist property owners in removing unneeded structures or else replacing them with more natural erosion controls.

"We have put forth a whole lot of effort, and we have seen the needle move in the right direction," said Dave Price, restoration division manager for WDFW. "There is hope for the future, but there is still a lot of work to be done."

Price and his team have translated the challenge into a statistic as concrete as the bulkheads that line Puget Sound. Price's optimism is tempered, he says, because more than 700 miles of shoreline armoring still remain.

That number is greater than the length of the ocean beaches in Washington and Oregon combined, and it covers more than 25% of Puget Sound's winding shoreline, a collective "great wall" built by property owners to hold back erosion.

Even though the state now measures progress for armor removal in mere feet, the recent figures still mark a turning point. From 2005 to 2010, the addition of new bulkheads averaged more than a mile a year across Puget Sound, and removal was hardly a consideration. In earlier years, new walls were being built along the shoreline at an even faster pace.

Last year, new bulkhead construction totaled 0.42 mile, actually up from the all-time low of 0.29 mile the year before. But a larger amount of removal — 0.58 miles in 2015 compared to 0.45 mile in 2014 — made up the difference, continuing the net decline for two years straight.

NEW PRIORITIES

It is well understood that the benefits of removing an old bulkhead may or may not counterbalance the damage caused by building a new bulkhead of the same size. It is all a matter of location.

Restoration programs are placing the highest priority for removal on spawning areas used by forage fish, such as surf smelt and sand lance. Also high on the priority list are shorelines that supply sands and gravels for healthy beaches. These shorelines are sometimes called "feeder bluffs." Landowners may qualify for grants to remove or replace their bulkheads, especially where the environmental benefits are clear.

Megan Dethier, a research biologist at the University of Washington's Friday Harbor Laboratories, led an extensive study of armored and natural shorelines in Puget Sound. The study found that beaches containing bulkheads were generally narrower and contained less shoreline vegetation and driftwood, leading to lower species diversity and less food for juvenile salmon, marine birds and larger animals.

Dethier's study, published in April, is the first to describe the cumulative effects of bulkheads along stretches of shoreline in Puget Sound. Heavily armored areas tended to have less sand and more accumulation of coarse sediment and rocks, especially where bulkheads blocked natural erosion.

> ***"It is pretty remarkable how many bulkheads were built... just to accommodate picnic areas that seem totally unnecessary."***
>
> *Dave Price, restoration division manager WA Dept of Fish and Wildlife*

[CONTINUED NEXT PAGE]

"Some shorelines are armored right in front of bluffs that have no houses or the houses are set way back," Price said. "I see that all over the place. A little sediment coming off these hillsides can be a very good thing for fish, and I don't think they are a problem for landowners."

A major effort is now underway to help shoreline property owners understand these effects, Price said. Many people acquired outmoded bulkheads when they bought their property and are not aware of the long-term effects.

"I was on the water a couple days ago," he said during an interview in August. "It is pretty remarkable how many bulkheads were built from the 1950s to the '90s just to accommodate picnic areas that seem totally unnecessary."

At the same time, more and more people are using "soft-shore" techniques to reduce erosion where waves and currents threaten to damage their homes. Ideas include sloping a beach and anchoring logs or large rocks on the beach to absorb the wave energy. Such projects are considered less damaging to the ecosystem than hard bulkheads.

UNDERSTANDING THE NATURAL PROCESS

Cities and counties that have updated their shoreline regulations the past few years no longer allow hard bulkheads unless a significant structure, such as a house or a road, is at risk of damage within three years. These standards are derived from the Washington Department of Ecology, which plays an equal role in developing local shoreline plans.

Property owners often can save themselves the cost of building and maintaining a shoreline structure if they understand the annual erosion rate of their property, said Hugh Shipman, a coastal geologist with Ecology.

"[Erosion] rates are very slow on Puget Sound, and many properties would do just fine without bulkheads," he said. "Sometimes this requires recalibrating our personal desire to control small rates of erosion or our fear of scenarios that aren't realistic.

"Having said that, there are places where erosion needs to be considered very carefully — most commonly on some high bluffs, on landslides, and where the at-risk structure is really close to the edge."

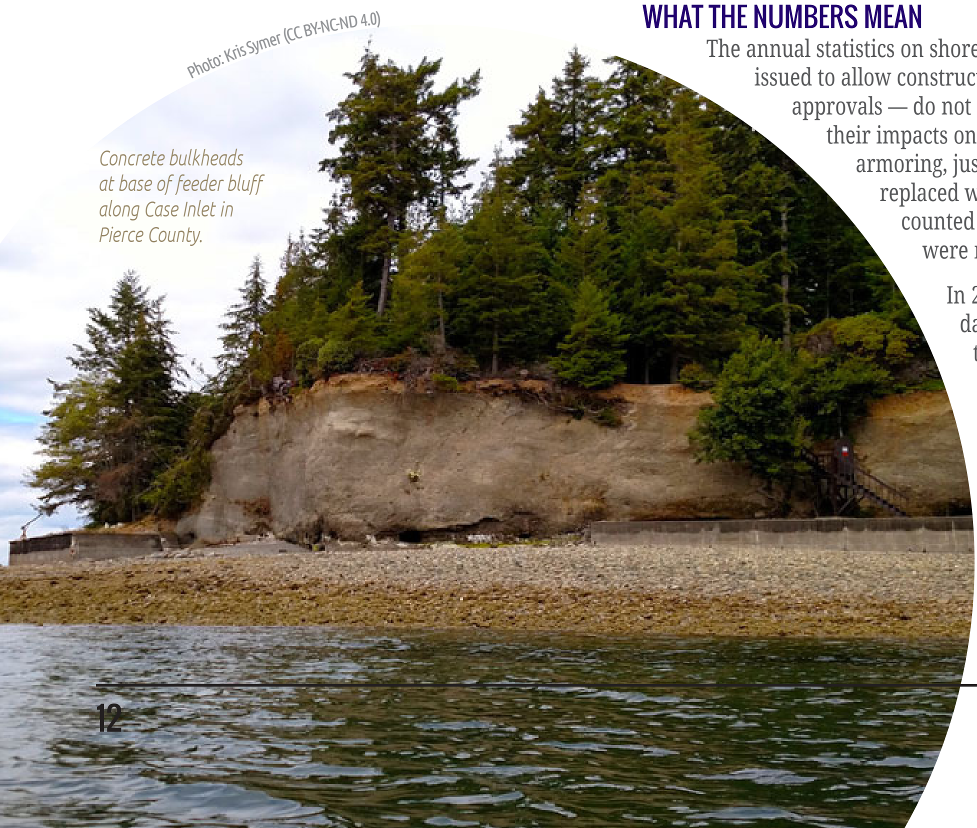
WHY NOT JUST REMOVE THE BULKHEADS?

If building a new bulkhead has undesirable effects on the Puget Sound ecosystem, then removing old bulkheads should help with the recovery effort, experts say. As part of a four-year focus on shoreline issues, the Environmental Protection Agency funded seven major beach-restoration projects involving the removal of bulkheads.

But it's not easy. And it's not cheap. In all, those projects cost about $8 million dollars between 2012 and 2016 to remove just under a mile of shoreline armoring. Such restoration projects go beyond just armor removal and are critical to Puget Sound recovery, agencies say, but they won't solve the problem on their own.

Of those seven projects, the type and amount of habitat improved with the bulkhead removal varied from project to project. By measuring habitat conditions before and after the work was done, researchers hope to describe the benefits of each project.

A more in-depth study of habitat conditions and the process of recovery will examine how quickly various species and habitat conditions return to an area after bulkhead removal and without any additional restoration efforts. The study, led by the UW's Dethier, is under way at Edgewater Beach on Eld Inlet near Olympia, where a bulkhead-removal project had been previously planned.



Concrete bulkheads at base of feeder bluff along Case Inlet in Pierce County.

WHAT THE NUMBERS MEAN

The annual statistics on shoreline armoring — which are derived from state permits issued to allow construction or repair of shoreline structures, called hydraulic project approvals — do not distinguish soft-shore projects from hard bulkheads, despite their impacts on the shoreline ecosystem. Soft-shore approaches count as new armoring, just like hard bulkheads. Likewise, when a concrete bulkhead is replaced with nothing more than logs lying on the beach, the project is counted as a "replacement" — the same as if the replacement structure were made of concrete.

In 2015, 1.8 miles of replacement structures were installed. The data do not describe how much of this work involved soft-shore techniques.

Price acknowledged that the overall restoration effort is not fully reflected in the report that shows the amount of armor added versus removed. He hopes to change the permit application so that future reports can show what appears to be a rather surprising shift from hard to soft armoring the past few years. Some projects are a combination of both types of armoring. Besides changing the application form to include more information, a clear definition of "soft armoring" is needed, he said.

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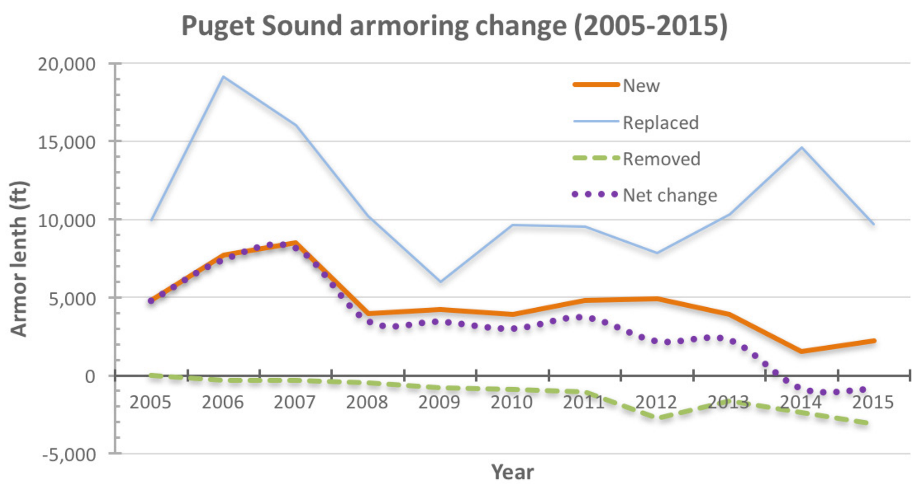

Chart: Kris Symer, PSI

The new-versus-remove statistics for shoreline armoring make up one of the "vital signs indicators" used by the Puget Sound Partnership to measure progress in restoring Puget Sound. To meet the Partnership's goal, the total amount of armoring removed must exceed the total amount of armoring constructed during the period from 2011 to 2020. That's a considerable challenge, considering that things were going in the wrong direction for the first three years, but it remains possible to make up lost ground.

Another challenge for Fish and Wildlife and the Puget Sound Partnership is to account for new armoring built without permits. Limited studies involving shoreline surveys in King, Kitsap and San Juan counties revealed numerous armoring projects completed without approval. Such projects never show up in the statistics. Even worse, many of the unpermitted projects fail to meet state or local construction standards. And even when permits are obtained, contractors may build structures longer than allowed by the permit.

Further studies have revealed that cities and counties generally place a low priority on tracking down shoreline violations and checking on compliance. Many rely on complaints from neighbors. A lack of enforcement was found to encourage further violations.

Many officials agree that a better enforcement program is needed to ensure that all waterfront property owners are treated fairly and must live with the same standards. And, despite ongoing outreach, many shoreline owners still need information about the latest scientific findings.

At the most basic level, people may simply not understand the importance of shorelines to the entire Puget Sound ecosystem, said Sheida Sahandy, executive director of the Puget Sound Partnership.

"We're talking about food and nurseries for baby fish," she said. "The food chain is all messed up, from the bottom all the way up to orcas. With the privilege of living on the shore comes the stewardship of that treasure."

In some ways, Sahandy said, the issue has been framed wrong. It's not about what government makes a person do. It's about whether people desire a natural beach that works for fish and wildlife as well as humans. People have the power to decide if they want more natural conditions, she said.

"We should frame this so that people see the possibility of having a nice beach, a place where you can walk down and put your feet in," she said, adding that people who have installed soft-shore protections often rave about their easier access to the shore.

Of course, many older homes were built so close to the shore that nothing but a solid bulkhead will work, she said, and everyone recognizes that. But in many cases improvements can be made to help the environment.

Jay Manning, a member of the Partnership's governing Leadership Council and a former director of Ecology, said healthy shorelines are one of many factors in restoring salmon runs, and they may be a critical factor.

"Whatever we are doing on salmon recovery is not working right now," he said. "We need to refocus and see what levers we can turn to get recovery going in the right direction.

"We can't do much about ocean conditions (where the salmon spend much of their lives)," he said. "But where we can do better by investing money or coming up with better policies, we should do that. Many things are in our control, and we need to work with tribes and local governments."

Manning noted that shorelines are just one part of salmon habitat in Puget Sound — along with streams and water quality — and there are other important issues, such as harvest, hatcheries and dams. But the importance of shorelines to salmon growth, survival and migration must not be overlooked, he said.

"We are really determined to turn the salmon numbers to a better trajectory," Manning said, "and nearshore marine habitat is one of the most important areas to focus on." ■

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[RELATED INTERVIEW NEXT PAGE]

INTERVIEW

A new peer-reviewed study reports significant findings on the impacts of shoreline armoring in the Salish Sea.

Long-term study looks at impacts of shoreline armoring

date: 4/15/2016 author: JEFF RICE
web: eopugetsound.org/articles/conference-snapshot-lengthy-study-looks-impacts-shoreline-armoring


Megan Dethier

It's rare to hear a scientist at a major research conference take such a clear position. "No one can say any longer 'we just don't know.' We do know." Those are the words of University of Washington biologist Megan Dethier. Dethier has been leading a study into what has historically been one of the muddier topics in Puget Sound restoration — the environmental impacts of shoreline armoring.

For more than a hundred years, Puget Sound's shoreline residents have been creating seawalls and bulkheads along their beaches, armoring them almost as if they faced an imminent invasion from the sea. These concrete anti-erosion structures abound on close to a third of Puget Sound's 2500 miles of shoreline.

NEW PAPER

Dethier gave a talk at the 2016 Salish Sea Ecosystem Conference in Vancouver on the heels of her recently published paper, "Multiscale impacts of armoring on Salish Sea shorelines: Evidence for cumulative and threshold effects." The paper, published in the journal Estuarine, Coastal and Shelf Science brings together six years of studies on 65 sites from the Canadian border to the South Sound.

Much of the consensus on shoreline armoring among state and federal agencies has been that armoring is bad for the environment, and the removal of armoring has become a big priority. But this view was based largely on studies in other regions outside the Salish Sea. There were some studies locally, but few peer-reviewed papers to point to. Dethier's paper changes the landscape significantly.

"For years I served on the [state of Washington's] nearshore science team and kept saying 'how can we push for stronger regulations if we don't have good scientific data about impacts in our own environment?'" Dethier told me.

In her talk at the conference, Dethier pointed to several especially important results. The closer armoring is to the water, the larger its impact. "The lower the armoring is (on the beach), the worse it is, and now we've got some data to that effect," she said. Also among the findings:

- Armored beaches make sediment coarser and beaches steeper.
- Armoring decreases the amount of logs and sea-wrack (such as washed up seaweed) on the beach, two crucial elements for insects and invertebrates that provide food for salmon and other species.
- An armored beach can affect unarmored beaches nearby.
- Armoring diminishes and threatens habitat for forage fish.

Q & A WITH THE AUTHOR

I caught up with Dethier and asked her if she could talk a little bit more about her paper.

Salish Sea Currents: *What do you think will be the implications of this? It seems like we are in the middle of a paradigm shift for shoreline armoring right now. People are getting real evidence for effects that maybe they just assumed before.*

M.D.: I think it can only help. Whether it makes a difference is going to depend, entirely, on politicians. But at least no one can say any longer 'we just don't know.' We do know. We may not know every little detail — every stretch of shoreline is different and so trying to find patterns is very difficult — but we know that those impacts are there and we know that we need to do something about it if we want to keep all of the ecosystem functions of our beaches.

Salish Sea Currents: *How significant do you think armoring is as a negative factor in Puget Sound nearshore?*

M.D.: Oh very, very significant in many, many different ways. Forage fish spawning. Chinook migrating along shore having insects to eat [that are drawn to washed-up seaweed]... Most people don't care about the stinking seaweed, or in fact would probably rather that the stinking seaweed went away. But we know that it harbors all of these other little bugs and those bugs are eaten by birds and so forth. And one of the things I want to talk about in my Salish Sea talk is that while people don't care about stinking seaweed, there are a lot of things about beaches that people do care about, and armoring affects a lot of them. Whether it's having sand on the beach for your kids to make sand castles with, or places for forage fish to spawn or places to dig clams. All of those things can be directly or indirectly affected by armoring. ■

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Chinook salmon. Photo: DOE by Pacific Northwest National Laboratory (CC BY 2.0)

The Salish Sea Marine Survival Project has mobilized dozens of organizations in the U.S. and Canada to find an answer to one of the region's greatest mysteries. What is killing so many young salmon before they can return home to spawn? A series of talks at the 2016 Salish Sea Ecosystem Conference brought together some of the latest research.

KEY TAKEAWAYS

- *Three species of salmonids — Chinook, coho and steelhead — have experienced a mysterious ten-fold decline during the marine phase of their lifecycle.*
- *The Marine Survival Project brings together a coalition of scientists from the U.S. and Canada to solve this mystery.*
- *One pressing question is why some salmonids are in such dire straits, but pink, chum, and sockeye aren't.*
- *Other fish such as herring are also dying, while some species such as harbor seals in the region are increasing. Scientists are looking at potential connections.*
- *Scientists hope to be able to apply results of their studies to management plans in 2018.*

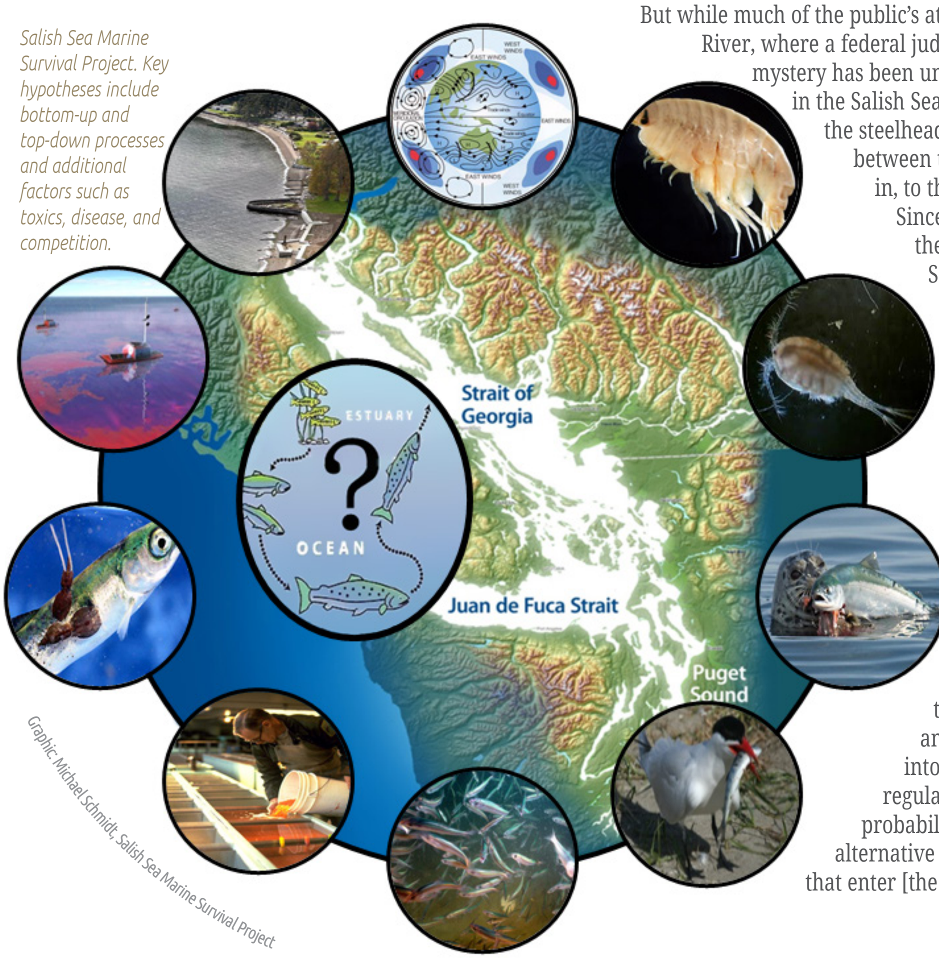
Mystery remains in deaths of young salmon

date: 6/29/2016 author: ERIC WAGNER topic editor: CHARLES A. SIMENSTAD
web: eopugetsound.org/magazine/marine-survival-project

In the 1990s, as the plight of Pacific salmon runs up and down the North American west coast rose in the public's awareness, biologists in the U.S. identified four main threats to the future of the fish. These were presented as the Four H's: there was Habitat (i.e., loss of, usually to forestry and development), Hydropower (especially the four dams on the Snake River), Harvest (too much of), and Hatcheries (i.e., competition with fish from).

While it was generally understood that not everything plaguing the five salmon species (plus steelhead) would fit neatly into one of those categories, the Four H's made a useful shorthand for a public perhaps less disposed to thrash through the complex managerial thickets of salmon recovery.

But while much of the public's attention has lately been focused on salmon runs from the Columbia River, where a federal judge just rejected—for the fifth time—a federal recovery plan, a subtler mystery has been unfolding a little farther to the north. Beginning in late 2009, scientists in the Salish Sea found that three species of its salmonids—the Chinook, the coho, and the steelhead—faced something somewhat murkier than the Four H's. Somewhere between the time they would emerge from whatever watershed they hatched in, to the time they should return to it, many more than expected were dying. Since the 1970s, all three species have experienced ten-fold declines during the marine phase of their lifecycle—the time, that is, they spend in Puget Sound in the U.S., or the Strait of Georgia in Canada.



Salish Sea Marine Survival Project. Key hypotheses include bottom-up and top-down processes and additional factors such as toxics, disease, and competition.

Graphic: Michael Schmidt, Salish Sea Marine Survival Project

The Salish Sea Marine Survival Project sprang from this revelation. The project, coordinated by two non-profit groups, the Pacific Salmon Foundation (based in Vancouver, B.C.) and Long Live the Kings (based in Seattle, Washington), seeks, as the two groups say, to leverage human and economic resources from both Canada and the U.S. to figure out why so many Chinook, coho, and steelhead are disappearing. Almost seven years later, more than forty organizations are involved in some capacity, ranging from the federal and state agencies, to academic institutions, to First Nation and Native American governments.

With the survival of juvenile salmonids in the Salish Sea, such a diversity of approaches is more than necessary—relying on the Four H's will not suffice. As such, biologists couch their key hypotheses for the salmons' decline in terms of processes: "bottom-up," "top-down," and, as a kind of catch-all, "additional." These they have parsed further into twenty-four specific hypotheses to evaluate (e.g., "Growth rates regulate survival at one or more life stages of Chinook and coho" or "The probability of being detected by predators decreases with the abundance of alternative prey"), generating a total of thirty-nine finer predictions (e.g., "Smolts that enter [the Salish Sea] during optimum food supply conditions perform better.

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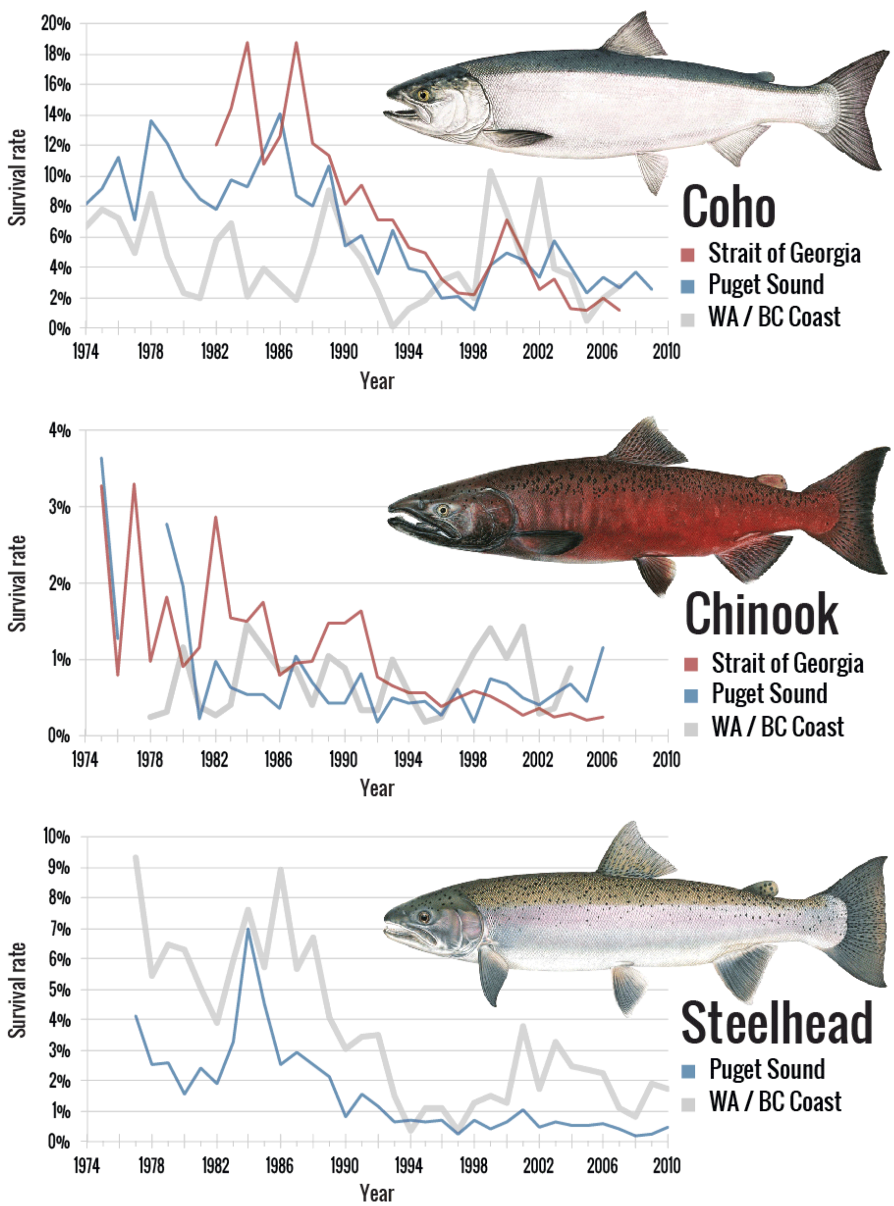
SALISH SEA
MARINE SURVIVAL PROJECT
www.marinesurvivalproject.com

Decline of salmon and steelhead: marine survival rates



Graphic: Adapted from Salish Sea Marine Survival Project by Long Live the Kings

Smolts that don't survive worse."). Some of these hypotheses and predictions address Puget Sound, and some the Strait of Georgia. But most apply to both. And as always seems to be the case with salmon, there are far more questions than answers.

Last April, at the Salish Sea Ecosystem Conference in Vancouver, B.C, researchers from several key organizations came together for a day of information sharing. From the outset, it was clear how much remains to be learned about the system. "We currently lack sufficient information regarding water and other ecosystem properties on both temporal and spatial scales appropriate to understand a number of factors," said Svein Vagle, a biologist with Fisheries and Oceans Canada (DFO). His was a sentiment oft repeated. The factors, Vagle went on, include nutrient cycling, variability in food supply, the movements of fish and their predators—knowledge gaps that comprise elements of basic natural history, in other words.

Many of the currently ongoing projects, then, are investigations that seek simply to describe parts of the Salish Sea: an analysis of phytoplankton phenology in the Strait of Georgia, for example, or observations of ecosystem processes across multiple scales in Cowichan Bay, near the southern tip of Vancouver Island. Researchers also looked to see what prey was available to juvenile salmon, and when and where it is around. There were censuses of potential predators, as well, and from that an attempt to gauge the relative risk that juvenile salmon face.

But scientists are also looking at the salmon themselves, testing ideas that might or might not explain why the fish are dying. One pressing question is why Chinook, coho, and steelhead are in such dire straits, but pink, chum, and sockeye aren't. A possible explanation, said Correigh Greene, a biologist with NOAA, is that the former three have a lengthier residence time in freshwater as smolts, among other life history variations. Similarly, Scott Hinch, a biologist from the University of British Columbia, looked at the differences in migratory behavior and pathways between sockeye and steelhead, and how that affects their respective survivals.

Further complicating matters is that juvenile salmon aren't the only creatures whose population dynamics are changing in the Salish Sea. Forage fish and some marine fish populations have gone down, as has the range of giant kelp and sea grasses. At the same time, others species are increasing: harbor seal, harbor porpoise, and white-sided dolphin numbers have all gone up. As has the human population, and with it, development. Maybe all of these are having an impact on juvenile Chinook, coho, and steelhead in some way. Maybe only some of them are. But which ones?

All of which is to say that one of the major challenges facing scientists in the Marine Survival Project will be integrating all of these somewhat disparate investigations into a cohesive management strategy that will work in this transboundary system. At present, the project is in the midst of data gathering. Dissemination of the research, as well as using the results to begin to put together a management plan, is not expected to begin until 2018.

"[Salmon decline and recovery] is a complex question," said Greene, the NOAA biologist. "There are many threads, many possible interactions." ■

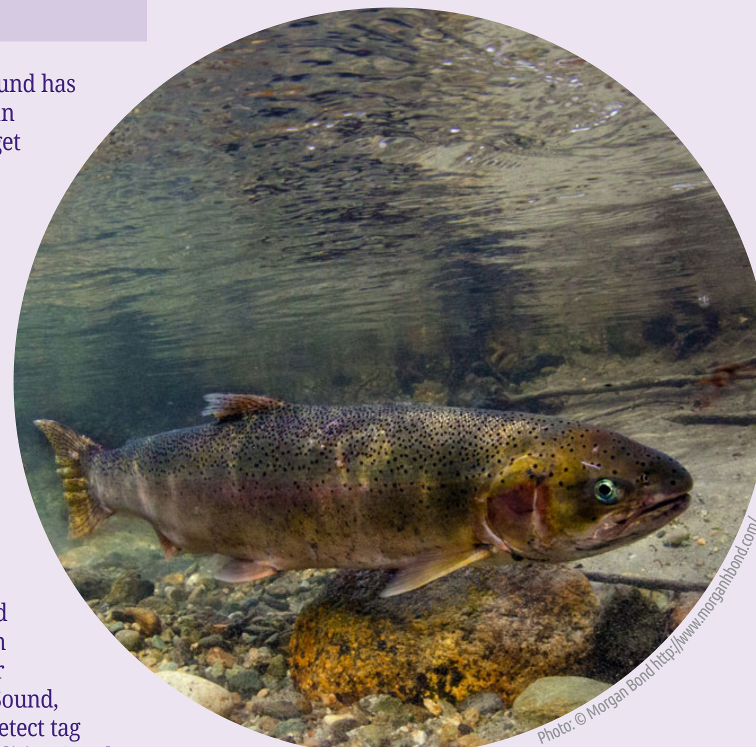
RELATED STORY

New, smaller acoustic tags will allow scientists to track steelhead migrations in Puget Sound in ways that were once impossible. Will they provide answers to the mysterious decline of these now-threatened fish?

Advances in technology help researchers evaluate threatened Puget Sound steelhead

date: 6/30/2016 author: JOSEPH M. SMITH topic editor: CHARLES A. SIMENSTAD
web: eopugetsound.org/magazine/steelhead-tech

The population size of steelhead (Oncorhynchus mykiss) in Puget Sound has decreased over the past 20 years, with current abundance at less than 4% of historical levels. The numbers are so low that steelhead in Puget Sound were listed as threatened under the Endangered Species Act in 2007. The causes of this decline are not known, but advances in technology are clearing the way for new research.



A steelhead (Oncorhynchus mykiss) in the Cascade River, WA, 2014.

A "GOOD TO GO" PASS FOR FISH

To determine when and where steelhead are dying, scientists need a way to follow individual fish on their journey from freshwater to the ocean. Electronic acoustic tags have become widely used for tracking many species of fish, but until recently, these tags were too large for steelhead. Now advances in technology have changed the game, with smaller tags that last long enough to provide useful information for scientists. These tags are surgically implanted into steelhead as they swim from the river to the ocean.

Each tag is cylinder-shaped and a little larger than a large pill such as a cold capsule. Each has a battery and sends out a uniquely coded high frequency sound (69 or 180 kHz), well above human hearing. In order to detect the tags in the water, researchers put out underwater listening stations (also called receivers) throughout the river, Puget Sound, and the ocean. These listening stations have microphones that can detect tag transmissions from over five football fields away (depending on conditions). When a tagged fish gets within the range of the listening station it decodes the transmission and records the unique identification of the fish and the date and time that it was detected. The listening stations can be deployed in a line, which forms a gate, so that when a tagged fish swims by that location it will be recorded. This is similar to having a Good To Go pass in your car and then crossing the SR-520 toll bridge in Seattle. These gates are set up at specific checkpoints in the system, such as the mouth of a river, narrow portions of Puget Sound such as Admiralty Inlet, and across the Strait of Juan de Fuca (which is the last checkpoint before heading to the Pacific Ocean).

This technology allows researchers to ask questions such as: What percentage of the tagged fish make it to the ocean? Is there a difference in survival between hatchery and wild steelhead? Are there difference in survival among populations from different rivers or points of entry to Puget Sound? ■

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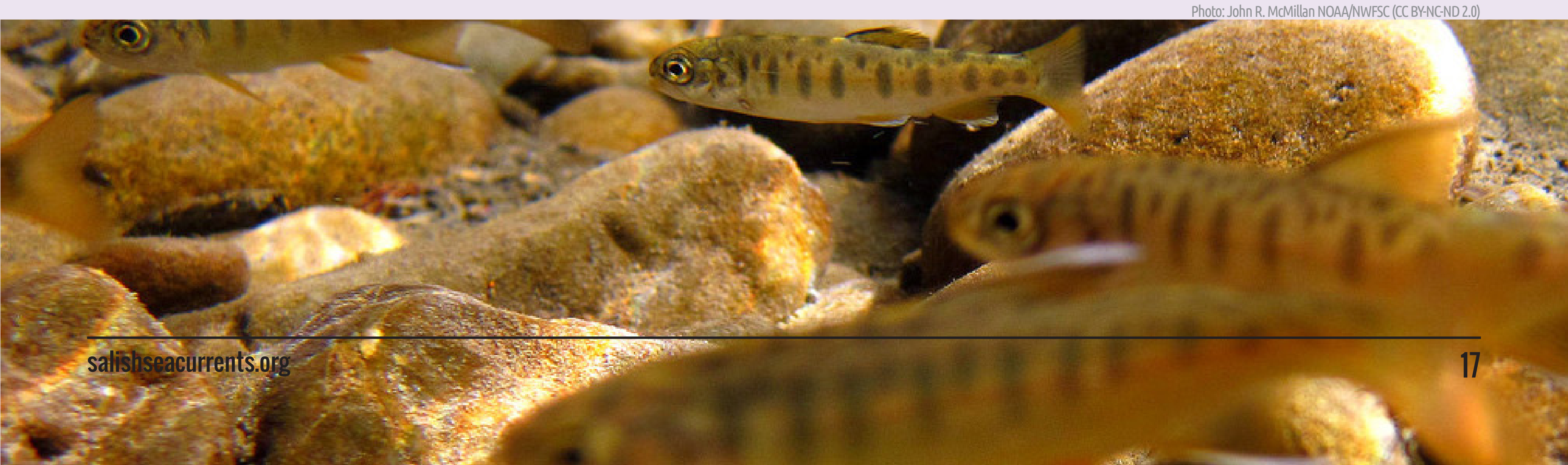
Juvenile steelhead.

Photo: John R. McMillan NOAA/NWFSC (CC BY-NC-ND 2.0)



J51 and her two offspring (2015). Photo : NOAA Fisheries, Vancouver Aquarium

New techniques for studying orcas have been credited with breakthroughs in reproductive and developmental research. Drones and hormone-sniffing dogs are helping scientists connect declines in food supply with low birth rates and poor health.

KEY TAKEAWAYS

- *About 65% of pregnancies among endangered Southern Resident Killer Whales result in miscarriages, an unusually high rate for mammals.*
- *A third of these miscarriages take place in late stages of pregnancy which is especially dangerous to the mother.*
- *Scientists are using new methods to track these pregnancies such as aerial drones and hormone-sniffing dogs.*
- *Resulting studies show that the high number of miscarriages is related to low food supply due to declines in Chinook salmon. Leaner orcas are more susceptible to the effects of toxic chemicals such as PCBs, which can cause miscarriages.*
- *A variety of experts are working together to develop a health assessment for each of the 80+ orcas in the three Southern Resident pods.*

Killer whale miscarriages linked to low food supply

date: 7/20/2016 author: CHRISTOPHER DUNAGAN topic editor: JOE GAYDOS
web: eopugetsound.org/magazine/orca-miscarriages

Pregnancy is an uphill battle for fish-eating killer whales of the Salish Sea, according to new hormonal studies, which show a high miscarriage rate among expectant orca moms.

In addition to the new and intriguing hormonal studies, researchers taking photos from unmanned aircraft have been able to monitor changing body conditions of the killer whales — including females as they progress through pregnancy.

Among the Southern Residents of the Salish Sea, about 65 percent of the pregnancies are ending early with miscarriages, according to research led by Sam Wasser, director of the Center for Conservation Biology at the University of Washington. And of those miscarriages, nearly one-third take place during the last stage of pregnancy.

That's an awfully high level for mammals — especially orcas, which carry their unborn offspring for 17 or 18 months, Wasser said during a presentation at the Salish Sea Ecosystem Conference in April. "Late abortions are very rare in mammals, because they are dangerous for the animal."

Just how dangerous was revealed in December 2014, when an 18-year-old Southern Resident orca named "Rhapsody" was found dead off Vancouver Island with a late-term fetus still in her uterus. An examination confirmed that the decomposing fetus became lodged in her body. That likely led to a septicemia, a severe bacterial infection that probably led to her death.

Killer whale advocates were shocked at Rhapsody's death, which came near the beginning of her reproductive life. It was a loss for the entire Southern Resident community, because this young female had the potential to add several babies to the dwindling population, listed as endangered under the Endangered Species Act.

Rhapsody, designated J32, had been pregnant at least twice before, but those pregnancies ended in miscarriages, according to Wasser, who learned to identify pregnant females by studying hormone levels in their feces. One question will forever remain unanswered: Would Rhapsody and her offspring still be alive if environmental conditions in the Salish Sea had been better?

J32, an 18-year-old female named "Rhapsody," died in December 2014 with an unborn calf lodged in her body. Pregnant killer whales face serious challenges in bearing offspring, especially when salmon runs are low.

Photo: Marcie Callewaert

Before Wasser's studies, nobody had a reliable way to tell when an orca was pregnant, so miscarriages generally went undetected. Long-time researchers, such as Ken Balcomb of the Center for Whale Research, have reported on females that appeared to be pregnant by noting their increasing girth, but such observations come months into the pregnancy. Now, Wasser says hormones can reveal the stage of pregnancy as well as stresses affecting the whales.

Meanwhile, a separate team of researchers working with small unmanned aircraft, commonly called drones, are reporting that they can detect pregnancies by taking high-resolution photographs to measure body length and width to within an inch or two. Without disturbing the whales, the

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researchers can identify subtle changes in the animals, including signs of poor health, according to Canadian researcher Lance Barrett-Lennard of Vancouver Aquarium speaking at the Salish Sea conference.

Together, the hormonal and drone studies, along with other research, are confirming what marine mammal scientists have been suggesting for years: When food is adequate during pregnancy, female orcas are more likely to carry their unborn calves to term, thus adding to the population. But when food is scarce, some babies are never born or else die within days of birth.

"We've moved toward some great sophisticated technology," said Lynne Barre, who heads NOAA's Protected Resources Division in Seattle and oversees recovery efforts for the endangered Southern Residents. "These great technologies combined can tell us more than any one method can ... such as when and where food limitations might be affecting their health and reproduction."

As much as death has been linked to a lack of salmon among the killer whales, birth is connected to times of improved salmon runs. During last year's so-called "baby boom," an unprecedented nine calves were born between December 2014 and January 2016, following an upturn in Chinook numbers along the West Coast. All but one of these baby-boom calves are believed to be still alive.

Photo: Kelley Balcomb-Bartok

Tucker, a Labrador retriever mix, has a keen ability to track down killer whale feces, which contains trace levels of hormones and toxic chemicals. Researchers can tell a great deal from these fecal samples.

HORMONAL LINKS TO HEALTH

The findings by Wasser and his associates are the result of testing hundreds of fecal samples, which were collected by following killer whales in a boat. Tucker, a black Labrador retriever mix, has become a celebrity for his keen ability to sniff out whale scat on the water and direct the boat to the correct spot using subtle movements of his head and body.

From the fecal samples located by Tucker, DNA can be extracted to identify individual whales. Then, by testing various excreted hormones, the researchers can determine a whale's level of stress, nutritional condition, metabolic rate and reproductive status.

For example, when progesterone levels are high, one can conclude that the female is pregnant, Wasser said. Testosterone, which increases slowly during pregnancy, can be used to determine the stage of fetal growth.

Wasser's study involved fecal samples from nearly three dozen pregnant females from 2007 through 2014. About a quarter of all the pregnancies resulted in a late-term miscarriage or else a birth in which the calf died before being noticed by human observers.

Reasons for the high rate of miscarriages were explored by looking at other hormones excreted by the pregnant females. They include thyroid hormone, which controls metabolism, and glucocorticoids, which rapidly boost glucose levels to help an animal confront various challenges, ranging from hunger to confrontation with an enemy.

For most orcas, thyroid hormones decline when food is scarce, slowing their metabolism and conserving their energy reserves. When food is abundant, the thyroid hormones keep the body in a highly functioning state.

When the whales return to the Salish Sea each spring, fecal samples for most orcas show a relatively high level of thyroid hormone, which means the whales must have been finding food in the ocean. It is likely that they were intercepting Chinook salmon returning to the Columbia River, Wasser said.

The story is somewhat different for a portion of the pregnant females coming into the Salish Sea, he noted. That group arrives with low thyroid hormone levels, and these are the ones most likely to have a late-term miscarriage. For some reason, they were not finding enough food to keep themselves and their unborn calves at highly functioning levels.

Generally for all the whales coming back to the Salish Sea, their high thyroid levels begin to drop upon their arrival, meaning they are not finding enough food. Many years ago, the whales may have been able to hunt for large runs of early-spawning spring Chinook, but those runs have declined drastically over the years. Now, the whales are often forced to wait for later runs of Chinook to the Fraser River and northern Puget Sound before they get enough to eat. Chinook salmon are listed as threatened under the Endangered Species Act.

Pregnant females who come into the Salish Sea with low thyroid levels are in trouble, Wasser said. Their fetus needs adequate thyroid hormones for proper brain growth, but the expectant moms are not getting enough food to provide for them.

"They don't arrive in good condition, and they don't ever catch up," Wasser said.

TOXIC CHEMICAL EFFECTS

Compounding the problem for killer whales, especially pregnant females, are polychlorinated biphenyls (PCBs) and other toxic chemicals embedded in their blubber, according to studies by Wasser's colleague Jessica Lundin, now with NOAA. The whales use this stored fat as an emergency energy supply. When a pregnant female cannot find enough fish, she begins to burn her fat supplies, releasing PCBs into her bloodstream. One of the many effects of PCBs is to depress thyroid hormones.

"A pregnant female is feeding for two," Wasser said. "She is running out of food and dumping toxins. Her fetus desperately needs thyroid hormone for brain growth, but it's not there."

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> *"A pregnant female is feeding for two. She is running out of food..."*
>
> *Sam Wasser*
> *UW Center for Conservation Biology*

Ultimately, the fetus may not survive, and the ordeal also takes a heavy toll on the mother, who may not have enough energy reserves to make it through the winter.

The internal survival strategy is far more favorable for the males and those females that aren't pregnant. Without the burden of a growing fetus, their thyroid glands adjust to the available food supply and aid in building up fat reserves for the winter.

When it comes to PCBs and other contaminants, males accumulate toxic chemicals for a lifetime. Although PCBs have been shown to have multiple hormonal effects on mammals, the precise effects on the killer whales have not yet been identified. Still, blubber samples taken from the Southern Residents show toxic levels high enough to create immune and reproductive problems, based on toxic studies of seals, otters and mink.

Like males, females accumulate toxic chemicals throughout their lives — with one critical exception. When a female becomes pregnant, she begins transferring contaminants to her unborn fetus. If the baby survives, the lactating mother will transfer even more toxics through her fat-rich milk, often leaving the calf with a higher concentration of PCBs than the mom.

Wasser and his associates spent considerable time developing and testing procedures for collecting and measuring toxic chemicals in killer whale feces. The result is that chemical concentrations obtained from fecal samples are fairly consistent with those obtained from blubber samples. And hundreds of fecal samples can be obtained without disturbing the animals, whereas getting a blubber sample requires moving in close to the whales and firing a dart that takes out a bit of their skin.

Photo: NOAA Fisheries

John Durban, left, pilots a small hexacopter into the hands of Holly Fearnbach. The two biologists, both with NOAA's Southwest Fisheries Science Center, use the remote-controlled aircraft to capture detailed images of killer whales.

AERIAL PHOTOGRAMMETRY

Killer whales are literally shaped by how much food they eat, according to Barrett-Lennard, a longtime research scientist currently involved in the new drone program. When salmon are abundant and a young whale can get enough to eat, it will grow to become a larger adult, he explained. Those who grow up during a food shortage turn out to be smaller animals, he added, referring to a report by Holly Fearnbach of NOAA's Southwest Fisheries Science Center.

The idea of carefully measuring each killer whale to assess its health and monitor its growth began to take hold a decade ago among whale researchers. In 2008, a group of scientists took to the air in a chartered helicopter to take photographs for measuring the length and girth of Southern Residents. The research team was led by John Durban, who worked for the Center for Whale Research at the time.

The researchers took more than 2,800 useable images during 10 flights over the whales. At 1,000 feet over the animals, measurements were accurate within about 1.5 inches. Besides length, measurements included breadth and head width — breadth measured at the front base of the dorsal fin and head width measured just behind the cranium. Using photos as a measuring tool is called photogrammetry.

One whale, a 23-year-old female, had the thinnest head of all the adult females. Researchers on a research boat also said she appeared to be in poor condition. The day that her measurements were taken from the helicopter was the last day she was ever seen.

From that study, the scientists concluded that aerial photos could be used not only to monitor the growth of whales but to assess their health throughout life. By chance, small, quiet and lightweight drones were coming on the market to do what helicopters could do, but at a fraction of the cost.

Now, the researchers use a remote-controlled aircraft with six horizontal blades, called a hexacopter, which is paired up with a high-resolution camera. Photos are taken from about 100 feet — high enough that the whales never even know they are being watched. Final measurements are taken at 20 points along the length of each whale.

"We now have a quantitative measure of how the whales are changing over time, as they advance through different ages and reproductive conditions," said Durban, who now works in NOAA's Southwest Fisheries Science Center and teams up with Barrett-Lennard and Fearnbach to conduct the photogrammetry studies.

"Sam (Wasser) can detect pregnancies from fecal hormones, and we can detect pregnancies reliably from the air," Durban said. "Together, these two approaches provide a lot of (analytical) power."

By photographing pregnant females over time at SeaWorld in California, the researchers in the Salish Sea are now able to estimate the stage of pregnancy once the orca moms begin showing, which is a few months into gestation. When a pregnant female gets smaller in the midsection, it generally means she has given birth or had a miscarriage.

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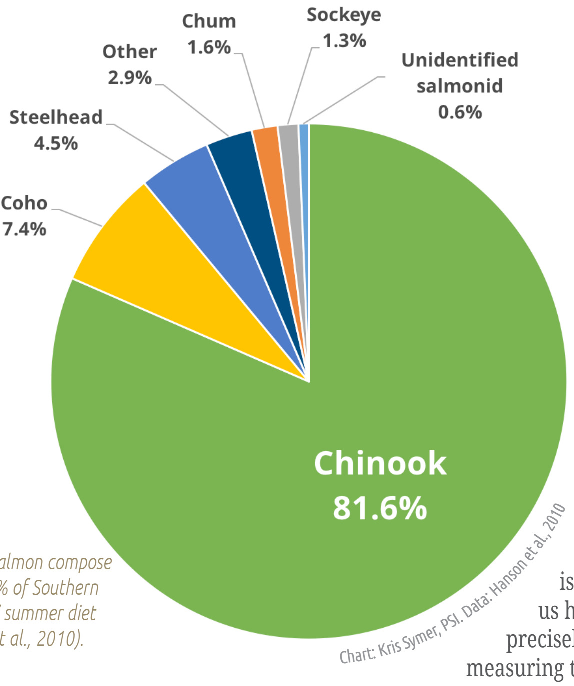

Chinook salmon compose nearly 82% of Southern Residents' summer diet (Hanson et al., 2010).

Last September, the team was able to use the hexacopter to photograph every living orca within the Southern Resident community. In May, 34 whales that were in the San Juan Islands at the time were caught on film. Another round of photos is scheduled for September.

"The analysis is still underway," Durban said, "but we will be able to look at how the whales are doing from year to year and season to season."

Similar work is being done on the Northern Resident orcas of British Columbia, which also depend on Chinook salmon for the majority of their diet.

When salmon are in decent numbers, the whales take on weight. One youngster shown in photographs over a two-year period had nearly caught up in length to his older siblings.

"Each individual has a different shape," Durban said. "The question is how those individuals change over time. The whales are going to tell us how they relate to the salmon runs. We might not be able to measure precisely the number of fish that are available to the whales, but we are measuring the results."

Consequently, natural resource managers may begin to understand which salmon runs are most important at key times to the whales and focus efforts on protecting and restoring those particular runs.

One goal is to create a body index, or score, based on the condition of each whale. A declining score, on average, could indicate that the whales are in trouble. How that might translate into management actions is something to be explored.

NEXT STEPS

A variety of experts involved in killer whale studies are working together to develop a health assessment for each of the 80+ orcas in the three Southern Resident pods. Sharing information as soon as it is available could help researchers understand their medical problems and possibly allow for intervention and treatment at some future date.

Since adequate food availability seems to be a key issue, one group of researchers is studying all the known predators that eat salmon — including seals and sea lions — to learn how the whales are affected, said Barre. The effects on orcas from hatchery operations, salmon fishing and habitat are all under investigation, she added.

Many of the new findings will be included in a five-year status report on the Southern Residents, Barre said. The report also will re-examine the risk of extinction and consider whether actions proposed to help the whales have been carried out. The report is expected by the end of this year.

Next year, long-awaited decisions about whether and how to expand "critical habitat" for the killer whales should be released for public review, Barre said. Designated habitat currently covers much of the Salish Sea but not the outer coast, even though researchers have learned that the whales spend much of their time in the ocean.

Beyond the question of where the whales travel and where they find food in the ocean, the determination of critical habitat must account for other issues, such as effects of the designation on the economy, military needs for national security and tribal interests.

One thing is becoming more certain as time goes on, experts agree. The fate of the Southern Residents is closely tied to the abundance of salmon. As salmon runs decline, the whales spend less and less time in large social groups. Instead, they break up into smaller family groups and travel farther in search for food. That can affect behaviors, from mating to caring for young ones in the population.

Despite a similar preference for Chinook salmon, Northern Resident killer whales of British Columbia have somewhat different population characteristics. A Northern Resident female, for example, will bear an average of one additional calf over her lifetime compared to Southern Residents.

Many would agree that Chinook salmon are the key to the future. "If you want to fix the system," Wasser says, "you need to bring the food back." ■

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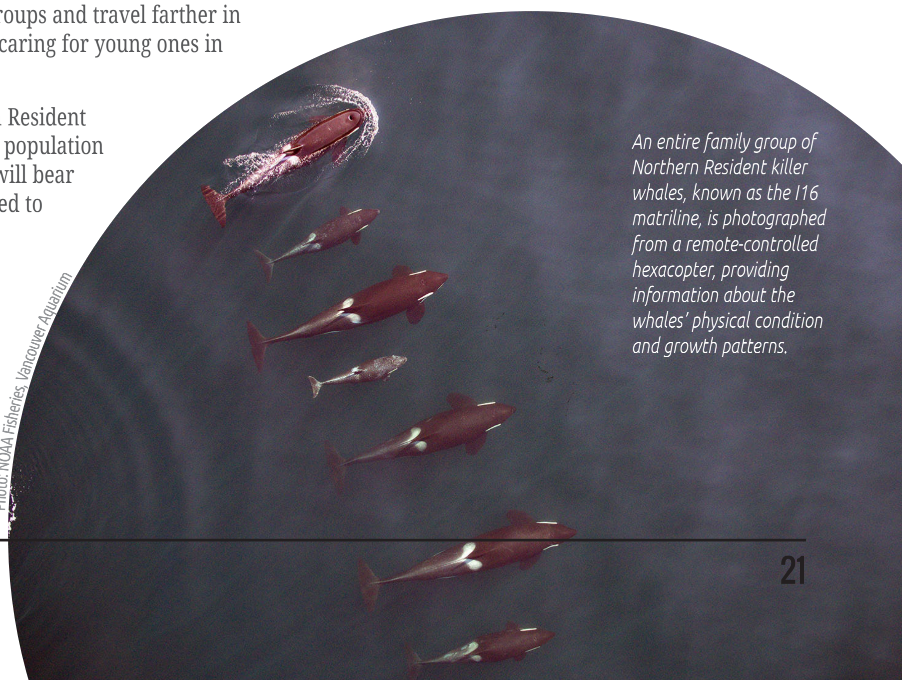

An entire family group of Northern Resident killer whales, known as the I16 matriline, is photographed from a remote-controlled hexacopter, providing information about the whales' physical condition and growth patterns.

Western Sandpiper at Nisqually National Wildlife Refuge. Photo: Jon. D. Anderson

It turns out that a gooey substance known as biofilm is a big deal for Salish Sea shorebirds, providing critical food for some species. But could a proposed port expansion in Vancouver threaten this slimy resource?

Salish Sea “slime” vital for shorebirds

date: 6/1/2016 author: ERIC WAGNER topic editor: JOE GAYDOS
web: eopugetsound.org/magazine/biofilm

KEY TAKEAWAYS

- *A slimy substance known as biofilm is an important source of food for shorebirds.*
- *Scientists worry that a proposed port expansion in Vancouver, B.C. could disrupt the amount of biofilm for migrating birds in the Salish Sea.*
- *To complete its expansion, the port will need to add fill to Roberts Bank, one of the most important stopover sites for migrating birds in Canada. Ecologists say this could affect the water’s temperature, salinity and currents, which could reduce available biofilm.*
- *Researchers are studying the potential impacts on the Western Sandpiper, for which biofilm accounts for more than 60% of its total diet.*
- *About 120,000 sandpipers visit the area and eat more than 20,000 metric tons of biofilm per tidal cycle.*

If you have ever been to an estuary in the Salish Sea, then you’re probably familiar with the scuzzy green stuff that sits atop the mud when the tide is out. And when it got all over your shoes, you may have even referred to it by one of several less-than-flattering nicknames: scum, slime, snot.

The scum/slime/snot is actually a living assemblage called biofilm: a dense layer of diatoms, primarily, along with organic detritus and sediment, all of which is held together by the microbes’ sticky cells to form what biologists refer to as a mucilaginous matrix. Biofilm was known to be a food source for benthic invertebrates, as well as a few species of fish, but only recently have scientists begun to understand better just how central a role it plays in the lives of migrating shorebirds. And this knowledge could have significant implications for development projects proposed in sensitive estuaries.

NEW STUDIES

That shorebirds might depend on biofilm for food was not suspected until recently. Earlier diet studies found high sediment loads in the guts of some species, but that was assumed to be an artifact of their ceaseless probing for worms and other invertebrates. But in 2008, a group led by Tomohiro Kuwae, an ecologist with the Port and Airport Research Group in Japan, decided to take a closer look. Using video recordings, stable isotope analysis, and stomach contents, Kuwae and his colleagues showed that several shorebirds frequently graze on biofilm, scooping it up with their tongues and gulping it down. In 2012, Kuwae co-authored a paper in Ecology Letters that described for the first time the direct link from biofilm to one species, the Western Sandpiper, estimating that biofilm accounted for up to 59% of its total diet, or roughly 50% of its energy budget.

Other studies have since elaborated on the relationship between shorebirds and biofilm all over the world. But the relationship in the Salish Sea, and Roberts Bank in particular, was the focus of one project described at the recent Salish Sea Ecosystem Conference, in Vancouver, Canada.

Roberts Bank sits roughly twenty miles south of Vancouver. Along with Sturgeon Bank and Boundary Bay, it is part of the massive, ecologically productive Fraser River delta. As such, Roberts Bank is one of the most important stopover sites for migrating birds in Canada, hosting millions of shorebirds, ducks and geese during the fall and spring migrations. (In 2004, BirdLife International designated the Fraser Estuary-Boundary Bay system an Important Bird Area.)

But humans can be drawn to estuaries just as the birds are, and Roberts Bank is the site of one of the largest ports in Canada. In their present configuration, at the end of a four-kilometer-long causeway, the port’s two terminals have the capacity to support 3.1 million twenty-foot equivalency units, or TEUs.

> **“Ecologists worry that the water’s temperature, salinity, and currents could be affected.”**

Western Sandpiper feeding at Storey’s Beach, Port Hardy, BC.

Photo: Nicole Beaulac

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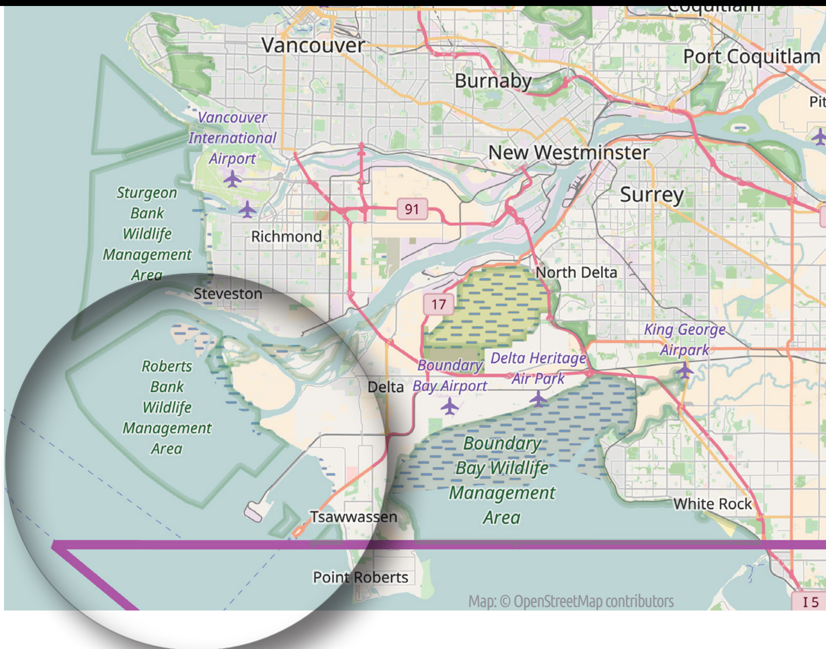

Roberts Bank Wildlife Management Area is located south of Vancouver, BC and northwest of Point Roberts, WA.

(Each TEU is roughly the size of a standard shipping container.) The Port of Vancouver is looking to build a third terminal at Roberts Bank, which would help increase the port's capacity by an additional 2.4 million TEUs. The Roberts Bank port is also Canada's largest coal export terminal, handling more than 33 metric tons of coal per year.

How much the port's proposed expansion might affect migrating shorebirds isn't clear, but it was a question that James Rourke, a senior biologist with Hemmera, an environmental consulting firm, tried to answer. Rourke was part of an interdisciplinary team of scientists, including biologists, hydrogeologists and spatial modelers.

As Kuwae had before, Rourke and his team focused on Roberts Bank's most abundant visitor, the Western Sandpiper. Although historically the estuary could support sporadic peaks of as many as 500,000 Western Sandpipers in a day, that number now usually falls between 120,000 – 180,000. Still, it represents between 14% - 21% of the flyway population, and sometimes up to 64%.

Earlier work suggested that biofilm made up more than 60% of the Western Sandpiper's diet. To estimate how much biofilm Western sandpipers ate at different levels of attendance during their spring migration, Rourke first had to determine how extensive biofilm coverage was. He found it was spread over more than three square kilometers of intertidal habitat.

Next, Rourke checked to see how Western Sandpipers used the mudflats, and how tightly their presence was tied to the presence of biofilm. To do this, he set up a series of transects to walk at low tide. Western sandpipers will defecate about every two minutes, so he simply documented whether or not their droppings were present. Then the tide would come in and wash the poop away. At the next low tide, the birds would return to feed and poop, and Rourke would walk his transects again. From this, Rourke found that Western Sandpiper spent most of their time in spots where biofilm was. (A similar 2015 study in PLOS ONE showed that biofilm was present in up to 53% of Western Sandpiper droppings.)

Photo: Gord McKenna (CC BY-NC-ND 2.0)

DeltaPort, Roberts Bank 2008. Exposed tidal flats just west of the container berth.

Finally, Rourke tried to determine whether biofilm at present levels is a limiting resource for the sandpipers. Biofilm can regenerate about every nine days, he said. If sandpiper populations were moving through at a great clip, was it possible for them to eat all the biofilm, forcing them to replace its nutrients with other foods? He concluded that, at its existing capacity, there was enough biofilm to support more than 1.3 million shorebirds. (The largest single-day count in the past twenty-four years was 1.1 million shorebirds.)

Although he didn't dwell on it, Rourke's work was done as part of an environmental assessment for the proposed port expansion. In the end, it would seem to suggest that life will go on more or less as usual for Western Sandpipers and the other shorebirds of Roberts Bank. But how might the port's expansion affect biofilm, and the 120,000 sandpipers that eat more than 20,000 metric tons of it per tidal cycle? The question concerns ecologists. To complete the new terminal, the port will need to add fill to more of Roberts Bank, and ecologists worry that the water's temperature, salinity, and currents could be affected. Biofilm is so abundant at Roberts Bank in part because it benefits from nutrient and freshwater input from the Fraser River during the spring. And one map showed that most of the biofilm is found north of the port; south of the port, there was considerably less, although the reason for this is uncertain.

Photo: B.C. Ministry of Transportation and Infrastructure (CC BY-NC-ND 2.0)

Deltaport is Port Metro Vancouver's largest container terminal.

In the end, it might be the questions Rourke was not asked to ask that are the most pressing. Are microscopic diatoms enough to stop a major port expansion, one the port estimates will bring nearly 1,000 jobs and contribute nearly $1.2 billion to Canada's economy? Should they be? These are, of course, much more difficult questions to answer. ■

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2016 Salish Sea Ecosystem Conference

RELATED STORY

Sand lance in parts of British Columbia are ingesting small pieces of plastic that may be passed through the food web.

Plastics in fish may also affect seabirds

date: 6/17/2016 author: DALANA DAILEY
web: eopugetsound.org/magazine/plastics-fish

The Pacific sand lance (Ammodytes hexapterus) is a slender fish that buries itself into sediment and feeds primarily on copepods. A study led by Dr. Douglas Bertram at Canada's Institute of Ocean Sciences analyzed the intestinal contents of 20 sand lance collected from Sidney Channel between 2013 and 2015. Of those fish, 85% had ingested plastic filaments. The average length of these filaments was 2.14 millimeters and there were 1 to 63 pieces found per fish. Bertram presented the findings at the 2016 Salish Sea Ecosystem Conference last spring in Vancouver, B.C.

The plastic filaments found in the sand lance were small enough that they did not directly kill the fish. However, the prevalence of ingested plastic is a problem for a number of reasons. In some cases, plastic filaments can entangle organs or become too large to pass. They can also lower the amount of nutritious food a fish reaps from its efforts.

Rhinoceros Auklet carrying sand lance. Photo: Peter Hodum

High amounts of plastic ingestion by fish could also affect birds due to what is known as bioaccumulation. Many types of plastic can leach toxic chemicals. If large amounts of toxic filaments are ingested, these chemicals can get incorporated into fish muscle tissue. The amount absorbed would likely be too small to kill or overtly harm fish. However, if a particular species of bird gets much of its diet from these tainted fish, the concentration of toxic elements will be magnified.

Several species of seabirds, including rhinocerous auklets and marbeled murrelets regularly feed on sand lance. The Sidney Channel collection site is designated as an Important Bird Area by Birdlife International.

The source of the plastic found in the fish was unclear. Such microplastics — synthetic polymers less than 5 millimeters in size — are found ocean-wide, but Bertram suspects that there may also be a local source that accounts for the high levels in sand lance. It is also not known if sand lance are ingesting the plastic directly, mistaking it for food such as copepods or other zooplankton. ■

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2016 Salish Sea Ecosystem Conference

Schooling forage fish. Roche Harbor, WA. Photo: Ingrid Taylar (CC BY 2.0)

Some of the most important fish in the Salish Sea food web are also the most mysterious. Researchers have only begun to understand how many there are, where they go, and how we can preserve their populations for the future. A University of Washington researcher describes how scientists are looking into the problem.

The secret lives of forage fish:
Where do they go when we aren't looking?

date: 8/18/2016 author: MARGARET SIPLE topic editor: TESSA FRANCIS
web: eopugetsound.org/magazine/secret-forage

KEY TAKEAWAYS

- *Forage fish provide critical food for many species ranging from salmon to seabirds, but scientists know relatively little about them.*
- *Spawning grounds for several species of forage fish in Puget Sound are still being identified, and their habits in the marine waters of the Salish Sea remain largely unknown.*
- *Uncertainty about the ecology and life history of forage fish could make it difficult for managers to adequately protect them.*
- *Scientists are tracking forage fish through beach surveys, acoustical tags and even archaeological records in the hope of learning more.*
- *Scientists are learning that Pacific herring spend time in unexpected places, indicating a need to protect additional habitat.*

To understand the importance of forage fish, imagine the Salish Sea without seabirds. Imagine it without salmon or orcas or seals and sea lions. You might also toss out its rockfish, cod or halibut. In fact, consider the ecosystem as you know it. Scientists have identified forage fish — small, schooling fish that provide much needed food (forage) for all of these species and more — as an indicator of the health of the open-water food web in the Salish Sea.

These fish include commonly known species such as herring and anchovies, as well as less familiar ones like surf smelt and sand lance. All are considered critical, but until recently, many of them were not even on the map — literally. Key spawning grounds for several species of forage fish in Puget Sound are still being identified, and their habits in the marine waters of the Salish Sea remain largely unknown. These gaps prompted scientists to gather last spring for several sessions at the 2016 Salish Sea Ecosystem Conference in Vancouver. This article brings together some of the conference findings, and examines a central question puzzling researchers: Where do forage fish go, anyway?

SPAWNING GROUNDS

Many forage fish have one feature that gives us a small window into their secret lives: they return to shore to spawn.

In Puget Sound, the most is known about Pacific herring. This is partly due to their economic importance to the fishing industry, but also because of their spawning habits and the size of their eggs. Herring spawn from late winter through early summer in shallow habitats just off shore. They lay sticky eggs the size of dried quinoa or couscous grains on fronds of submerged algae, seagrass, and almost any other structure to which they can adhere. Their eggs are large enough that the biologists who manage herring can pull up the vegetation and visually estimate egg abundance. That provides some insight into how many herring are laying those eggs.

> **"Knowing where they spend time is a first step towards defining and ultimately protecting their critical habitats."**
>
> *Marty Liedtke, research scientist US Geological Survey*

Other species like surf smelt pose more of a challenge. They spawn year-round (although there are noticeable peaks in the summer in North Puget Sound and winter in South Puget Sound), and lay tiny eggs — about the size of FDR's eye on the U.S. dime — in the gravel, rocks and sands of the intertidal zone. Sand lance spawn on beaches too, where their eggs become coated in fine sand, rendering them barely visible. After these tiny eggs incubate for several weeks, herring, smelt and sand lance larvae emerge and spend some time in the (relatively) safe, shallow waters close to shore. After this nursery period, they disappear into the depths. That's when the mystery broadens.


Surf smelt collected as part of a study of rhinoceros auklet diet and forage fish on the outer coast and inland waters of Washington.

SURF SMELT

To find out where surf smelt go when they aren't spawning, Theresa "Marty" Liedtke, research scientist at the US Geological Survey (USGS) used the power of sound. Liedtke and her team

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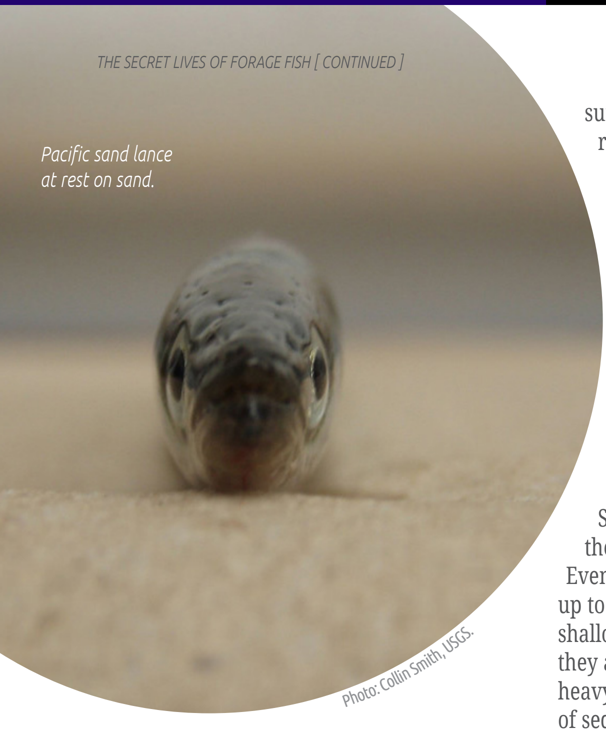

Pacific sand lance at rest on sand.

Photo: Collin Smith, USGS.

surgically implanted acoustic tags in 35 smelt at Ross Point in Sinclair Inlet after winter spawning. Acoustic receivers set around the area indicated that tagged surf smelt stayed inside the inlet, with only a few moving to Port Orchard about 1.2 miles away. In a separate project, Phillip Dionne and Dayv Lowry, research scientists at the Washington Department of Fish and Wildlife (WDFW) noticed that smelt whose fins were clipped for a genetic study often reappeared in Hood Canal where they were first captured, several days later. To learn more, their team also conducted a smelt tagging study, using injectable elastomers (called "Visible Implant Elastomers" or VIEs) to tag roughly 9,000 fish over 15 months. Seventy of these fish were recaptured, some up to nine months after they were tagged. Their results confirmed what Liedtke had found: tagged smelt tend to stay within the same bay where they were tagged. However, tagging studies so far have also only covered movement during the spawning season, says Liedtke, and more data are needed to find out where they go during the rest of the year. "These data are lacking for all the forage fish species in Puget Sound."

SAND LANCE

Sand lance are masters of avoiding detection. In addition to burying their miniscule eggs in the sand, they are skinny enough to slip through the mesh nets that are typically used to catch other forage species. Even with the right kind of net, the chances of finding them in open water are slim — sand lance spend up to six months of the year completely buried under the sand. If scientists are lucky, they can find them in shallow water on beaches, where they can be dug up with a shovel at low tide and counted. Often, however, they are under several meters of water. To find them in deeper water, scientists use a Van Veen grab — a heavy, awkward, crane-operated piece of machinery designed to sample sediments — to pull up a heavy block of sediment, and with it the wiggling bodies of sand lance. Matt Baker, Science Director at the North Pacific Research Board and affiliate faculty member at Friday Harbor Labs (FHL), has been working with students at FHL who have spent the last two years surveying sand lance in the San Juan Islands. They have been building a long-term survey dataset on sand lance diet, foraging patterns, and habitat preference. Gary Greene, a geologist who also works with FHL, has identified fields of sand "waves" where sand lance are likely to be buried.* Baker's team visits these fields to sample with the Van Veen grab. Baker and his students found that over the course of a single winter, the body condition of the fish they collect declines steadily, suggesting that they remain buried in the sand, dormant or nearly-dormant, through the whole winter. Research by Cliff Robinson at the University of Victoria using trawl data and oceanographic information has suggested that sand lance bury themselves in coarse sediments and emerge during the day to feed in well-mixed waters on the edges of sand banks. The picture that is emerging from these separate studies is that when they are not spawning, sand lance are either swimming in deep, offshore waters or burrowing snugly in the sand.

"...sand lance spend up to six months of the year completely buried under the sand."

According to previous research by Clifford Robinson, sand lance bury themselves at sites with unique oceanographic and sedimentary properties, and forage in the water column nearby.

HERRING

Herring, on the other hand, appear to be a little more adventuresome.

Doug Hay, a former research scientist for Canada's Department of Fisheries and Oceans (DFO), may have some clues as to where herring go when they're not spawning. He found herring accidentally while sampling for eulachon, another forage fish species. With the help of some anglers on the Fraser River, he observed herring swimming in a salt wedge — a deep layer of salty water that extends back up the river in highly-stratified estuaries. For a prey species, a river plume is "nice — the low visibility protects them from predators, and there are a lot of things to eat." Hay found "dozens" of adult herring, their stomachs filled with baby pink salmon, lurking in the depths of the Fraser, much farther up river than most ecologists thought herring could go. The gonads of these herring indicated that they hadn't spawned yet, and the only other population in the close vicinity that hadn't yet spawned was the Cherry Point population. For this reason, Hay suspects that the fish they found in the salt wedge belong to the Cherry Point stock — a "stocklet" which has declined from ~10,000 tons in 1972 to an average of only 800 tons (approximately 6.4 million fish). This indicates that herring might be spending time rearing in places where ecologists — and predators — might not even look for them. If this is the case, managers need to conserve this secret refuge, and attempt to find others, in order to protect the plummeting Cherry Point stock.

Pacific herring are small forage fish that fit in the palm of your hand.

Photo: Margaret Siple

Another way to answer questions about behavior and habits in forage fish is to look for their larvae. Forage fish larvae are sensitive; herring larvae use up their yolk sac in the first week of their life, and after that they depend on ocean currents to bring them to areas with microplankton and low predation in order to survive (Penttilla 2007). Almost nothing is known about the distribution of Puget Sound herring, sand lance, or surf smelt during this critical stage. Juvenile forage fish can be found in the water column for a few months after spawning. Alicia Godersky, a master's student at the University of Washington's School of Aquatic and Fishery Sciences, is studying the larval distribution of herring and sand lance in Puget Sound. Using information collected by scientists from The National Marine Fisheries Service (NMFS), the Washington tribes, and several research groups at the University of Washington, Godersky found that the presence or absence of larvae depended on the season and location of sampling. In some places (like Hood Canal) she found no sand lance at all. It turns out that larvae, like adults, are patchily distributed — but Godersky has a window into a part of the life

[CONTINUED NEXT PAGE]

Juvenile sand lance (top) and surf smelt (bottom). Bainbridge Island, WA. Scale in inches

Photo: David Ayers/USGS

cycle scientists know very little about. These larval surveys are essential for understanding the challenges that forage fish face during this crucial stage in their life cycle, when they are probably the most sensitive to oceanographic conditions. The surveys also provide additional information about where young forage fish go once they leave the beach where they hatched, says Godersky.

WHAT CAN WE LEARN FROM HISTORY?

Hints about forage fish movement might be found in archaeological records and genetic information. Robert Kopperl, an archaeologist with Steven W. Carothers & Associates (SWCA) Environmental Consultants, studies Native American middens — large piles of ancient food waste discarded by some of Washington's first residents. At Burton Acres Park on Vashon Island in Central Puget Sound, he found a shell midden with thousands of herring bones underneath, from up to 1000 years ago. “The prootic bone is my favorite — it is dense compared to the rest of the skull so it sticks around when the central orb erodes,” he enthuses, “there are two per individual so it's a convenient way to count how many herring there were.” He found between 4,000 and 6,000 herring in the Burton Acres midden, and he anticipates finding more at other sites in south Puget Sound. The herring bones will be sent to Dr. Dongya Yang's lab at Simon Fraser University for extraction of ancient DNA. Using bones from different sites in South Puget Sound and comparing with genetic data from today's herring, Kopperl and Yang should be able to figure out whether certain genetic groups (like Cherry Point) were always present, or whether they are relatively new to the Sound.

THE RISKS OF UNCERTAINTY

Uncertainty about the ecology and life history of forage fish could make it difficult for managers to adequately protect them. Daniel Okamoto, a postdoctoral researcher at Simon Fraser University, has developed a model that shows that herring populations in BC may seem more stable than they really are when they're surveyed on a broad scale, causing managers to allow fishing pressure that puts local subpopulations at risk of overfishing. This finding is corroborated by Ashleen Benson (Adjunct Professor at Simon Fraser University) and Jaclyn Cleary (Biologist at DFO), whose model explores the effects of fishing on herring subpopulations with different rates of movement between them. Benson and her coauthors found that mischaracterizing the amount of movement can put local subpopulations or regional populations at risk of depletion. This shows that herring movement is something managers have to consider in order to sustain fisheries for herring and the predators that depend on them.

There are also places in Washington where knowing about herring movement might help managers protect them. Doug Hay jokes, “As we all know, herring don't swim past the 49th parallel.” Cherry Point herring are surveyed and managed by WDFW, but the adults can easily swim north past the border into Canadian waters, where the herring fishery is managed by DFO. If the WDFW scientists knew where Cherry Point herring spent their time, they might collaborate with managers in Canada to protect adults that are crossing over. Knowing about trends in other forage fish like surf smelt and sand lance will help WDFW determine which spawning beaches are more important, or whether the recreational fishery for surf smelt needs to be more carefully regulated. The solution of these mysteries could improve management and mitigate risk.

THE STATE OF THE SCIENCE

The talks at this year's Salish Sea Ecosystem Conference highlighted some critical gaps in our understanding of forage fish ecology in the region. Although scientists have some idea of the population status of herring and have likely located all of the possible spawning beaches — largely because the commercial fisheries targeting herring make them a valuable commodity — sand lance and surf smelt remain largely uncounted and difficult to locate, and surveys will be misleading if they miss crucial life stages or subpopulations. Says Liedtke, “knowing where they spend time is a first step towards defining and ultimately protecting their critical habitats.” Larval surveys may be the one way to accurately estimate their numbers. For other forage species, information about trends in abundance could be a life-saver when it comes to managing them. These recent discoveries, and the mysteries that remain to be solved, show that basic biological knowledge about forage species can help us manage shorelines and protect the people and ecosystems that rely on these fish. ■

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Two transient orcas in Hood Canal, WA. Photo: Minette Layne (CC-BY-NC-2.0)

Researchers are proposing a shift in thinking about how some of the region's most damaging pollutants enter Puget Sound species like herring, salmon and orcas.

New theory rethinks spread of PCBs and other toxics in Puget Sound

date: 5/18/2016 author: CHRISTOPHER DUNAGAN topic editor: ANDY JAMES
web: eopugetsound.org/magazine/pcb-theory

KEY TAKEAWAYS

- *For years, scientists have assumed that high concentration of PCBs in Puget Sound species come mainly from contaminated mud on the seafloor. The story may be more complicated.*
- *Although animals in Puget Sound have comparatively high amounts of PCBs in their bodies, concentrations in the seafloor are not as high as in some other regions. This suggests that significant amounts of toxic chemicals are coming from other sources.*
- *Scientists theorize that toxic-laden particles may be picked up by bacteria and plankton before reaching the bottom. These compounds are then ingested by fish and passed through the food web.*
- *These top-down contaminants could come from stormwater, sewage effluent, air pollution and industrial discharge, among other sources.*
- *Scientists say the key to breaking the cycle of toxics in the food web is to locate and shut off the sources of pollution before they reach Puget Sound.*

Researchers at WDFW remove Pacific herring from a gill net.

Recent findings about how toxic chemicals creep into the food web, causing harm to species from herring and salmon to killer whales, could strengthen commitments to control pollution pouring into Puget Sound.

Researchers with the Washington Department of Fish and Wildlife (WDFW) and other agencies have been tracking toxic chemicals — including polychlorinated biphenyls (PCBs) — as they move from smaller to larger animals in Puget Sound. In doing so, the researchers confronted a perplexing problem.

Compared to other waterways, Puget Sound seems to have a considerably higher level of PCBs in its living creatures. However, the concentration at the seafloor in its sediments is comparatively low.

Jim West and Sandie O'Neill of WDFW say the difference may lie with the beginning of the food web, where harmful chemicals first enter the waterway. If borne out, their findings could result in a shift in thinking about the biological transfer of contaminants.

"There is something unique about Puget Sound," O'Neill says. "We have always said Puget Sound is a PCB hotspot. What gets in the sound stays in the sound."

ENTERING THE FOOD WEB

PCBs and many other pollutants have properties that make them more like oil than water. They are called "hydrophobic," meaning repelled by water. Rather than dissolving, these chemicals tend to quickly attach to particles of sediment, dead organic material or tiny organisms, which get swept along in water until they reach Puget Sound. This is part of why PCBs often persist in the environment, and it has led to major Superfund cleanups in Seattle's Duwamish and Tacoma's Thea Foss waterways.

> "We have always said Puget Sound is a PCB hotspot. What gets in the Sound stays in the Sound."
>
> Sandie O'Neill, research scientist
> WA Department of Fish and Wildlife

A long-standing assumption has been that these particles, along with their PCB hitchhikers, settle to the bottom fairly quickly, polluting the sediments. From there, the chemicals get picked up by invertebrates and other bottom-dwellers. Fish then eat the contaminated organisms or their eggs, moving the contaminants up the food web — or so the old story goes.

But West and his associates found something wrong with this standard picture, based on the concentration of contaminants. Their ideas have been turning this picture upside down.

"When you look at the concentrations in herring and the concentrations in the sediments, something does not line up," West said. "The predictions are way off. We think there is a different mechanism."

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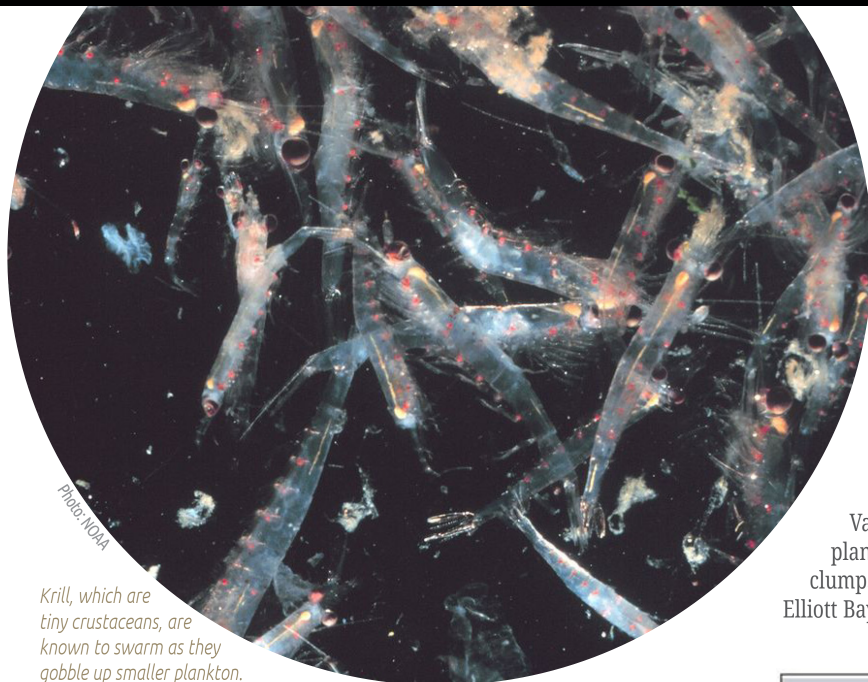

Photo: NOAA

Krill, which are tiny crustaceans, are known to swarm as they gobble up smaller plankton.

West suspects that when these toxic-laden particles get into Puget Sound, many never reach the bottom. Instead, the particles get picked up by bacteria or plankton, which are then consumed by higher organisms, including fish.

"A lot of particles in seawater are living things," West said during a slideshow presentation at the 2016 Salish Sea Ecosystem Conference. "They are very attractive to hydrophobic molecules (such as PCBs)."

In fact, he noted, bacteria are so numerous in Puget Sound that their total surface area may account for up to 80 percent of the biosurface of all living things in the waterway. PCBs are likely to glom onto bacteria before they sink to the bottom.

"Once you get PCBs into a bacteria or phytoplankton, they are very reluctant to come out of that matrix," West said.

Vast numbers of krill, which are tiny shrimplike crustaceans, devour bacteria and plankton that have picked up contaminants along the way. Krill also can break apart clumps of organic material, according to West, who has explored the idea in Seattle's Elliott Bay.

"The depth of the bay allows for the development of a really robust population of zooplankton," he said. "Krill hang out at the bottom during the day (to avoid predators), then come up to feed at night. Krill are not only consuming PCB-laden particles, they are also physically breaking up the remaining particles and reducing their sinking rate."

Smaller particles are more easily swept along in the currents, allowing more tiny animals to nibble on bits of PCB-laced matter.

Sources of contamination in Elliott Bay are not fully understood, but they include stormwater, sewage effluent and industrial discharges along the Seattle waterfront, as well as pollutants washed downstream from the industrialized Duwamish River. Sediments buried on the bottom of the river can be dislodged by strong currents, working their way into the predators and prey living in open waters — the pelagic food web, West said.

Transfer of contaminants through this food web can be complicated. But depth can help explain why a greater percentage of hydrophobic compounds never reach the bottom of Puget Sound, compared to other major waterways. In fact, the average depth of Puget Sound is 205 feet, far exceeding that of Chesapeake Bay (22 feet) and central San Francisco Bay (44 feet). The deepest spot in Puget Sound is about 900 feet, and Elliott Bay reaches 600 feet deep on its outer perimeter.

PCBs, which were banned in the 1970s, break down very slowly. As much as they refuse to dissolve in water, they love to work their way into the lipids, or fat tissue, found in living things. Once PCBs check in, they don't check out. They remain in fatty tissue, working their way up the food web in higher and higher concentrations, a process known as biomagnification.

Even when PCBs reach the top of the marine food web, where killer whales are the apex predator, their destructive behavior is not over. When animals die, their tissues are broken down by scavengers and bacteria, allowing PCBs to recycle back through the food web again and again. Adding to the overall contamination are historic PCBs still washing off the land along with very low levels allowed in some paints and dyes.

And that can explain why Puget Sound killer whales continue to carry some of the highest burdens of PCBs found anywhere in the world. Together PCBs and other long-lasting compounds found in Puget Sound can alter metabolism, behavior, immune response and

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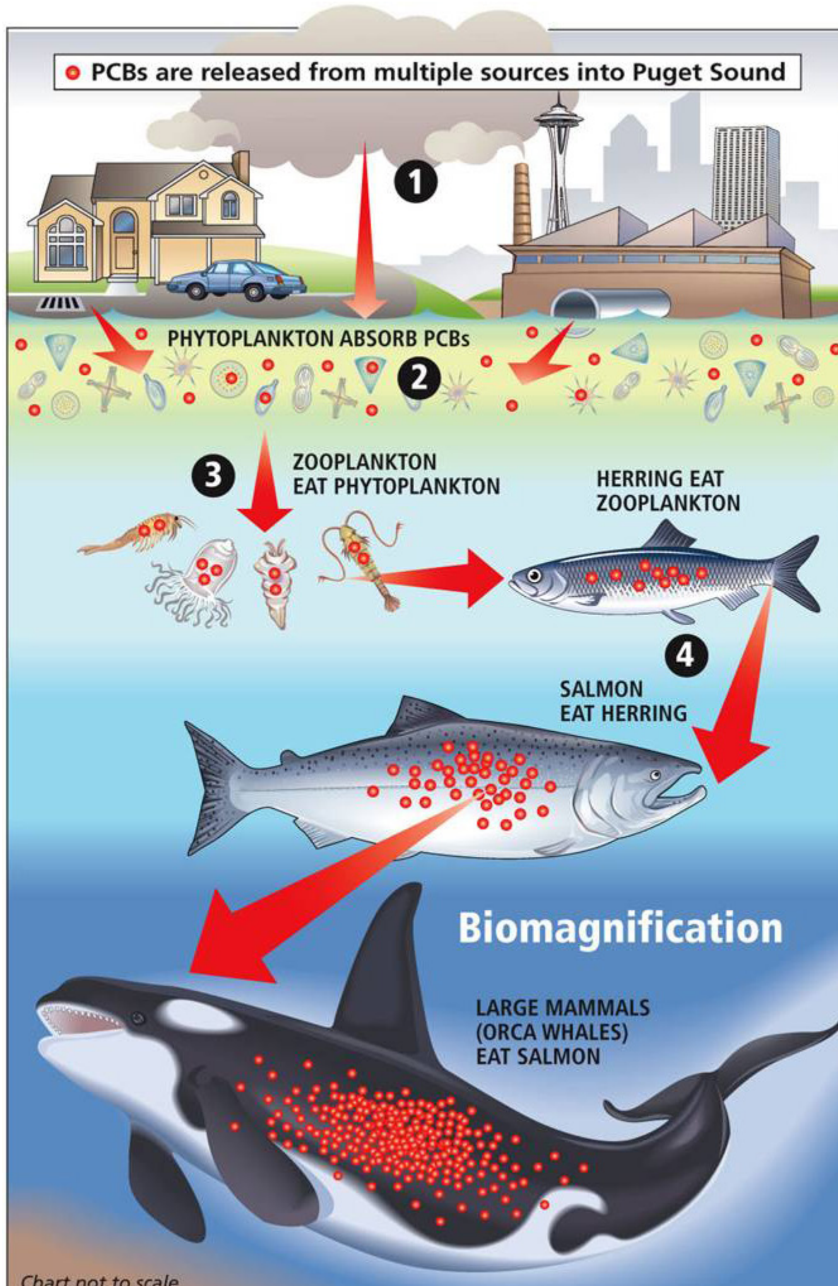

Diagram showing PCB biomagnification in the Puget Sound food web. Image: Copyright Seattle Post-Intelligencer

reproductive capability of fish, birds and marine mammals — effectively degrading the health of the entire ecosystem.

Stefanie Karney (left) and Laurie Niewolny (WDFW) processing juvenile Chinook salmon at the WDFW Marine Resources Laboratory, Olympia, WA.

Photo: WDFW

TOXIC LEVELS IN YOUNG FISH

As with humans exposed to toxic chemicals, the greatest risk to fish comes during their formative stages of development. For salmon, that includes the period when juvenile fish leave the streams and migrate along the shoreline.

Levels of contaminants found in many Puget Sound Chinook are high enough to cause serious health problems, including slower growth, reduced immunity to disease and altered hormone levels, according to Andrea Carey, a WDFW researcher who, alongside O'Neill, has studied toxic levels in young Chinook salmon.

Juvenile Chinook from five river systems were tested for a variety of toxic compounds, including PCBs, often used in electrical devices and building materials; polybrominated diphenyl ethers (PBDEs), used as flame retardants; and DDT, used to control insects. To measure changes as the fish grew, juvenile Chinook were collected in three locations at different times: first, just outside their home rivers, then along the marine shoreline and later in open waters of Puget Sound.

As the researchers expected, fish entering Puget Sound from the more urbanized areas experienced higher toxic levels than fish from more rural streams. For example, salmon from the Green/Duwamish River near Seattle and the Snohomish River near Everett picked up more pollutants than those in the Skagit River in northern Puget Sound or the Nisqually in South Puget Sound.

As the Chinook continued to grow and accumulate pollutants in offshore areas of Puget Sound, the researchers found that contaminant concentrations in the fish for PCBs, PBDEs and DDT became more and more alike. Levels were below the high concentrations found in fish from urban streams but above the levels of fish from rural streams.

This suggests that pollution is not limited to nearshore areas but is distributed across the prey base throughout the open waters of Puget Sound, Carey said.

Other studies have found that plankton and small schooling fish caught in offshore areas of Puget Sound are indeed contaminated with PCBs and DDT.

The findings may support the notion that pollutants are being dispersed well beyond the urban areas and are still spreading through the pelagic food web.

TOXIC EFFECTS

The levels of pollutants found in juvenile Chinook from urban bays and offshore areas were high enough to cause serious problems or even death for the young fish. In total, about one-third of all the fish sampled in Puget Sound had contaminant levels known to cause adverse effects. This bleak picture comes about from an evaluation of a relatively small number of pollutants, compared to thousands of chemicals working their way into Puget Sound, all with their own effects. In addition, the impacts of multiple chemicals on metabolic, hormonal, immune or reproductive systems are not well understood.

Photo: WDFW

Richard Henderson (Skagit River System Cooperative) closing up a beach seine to sample for juvenile Chinook in the Skagit River delta.

The key to breaking the cycle of toxics in the food web is to locate and shut off the sources of pollution before the dangerous chemicals ever reach Puget Sound, O'Neill said. Typical pathways include stormwater, sewage and industrial discharges, sediments from streams and deposition from air pollution.

Millions of dollars have been invested in the physical structure of streams, such as protecting buffers, restoring floodplains and side channels, and adding woody debris. Recently, extra attention is being paid to streamflows, with efforts to reduce damaging floods in winter as well as dangerous low flows in summer.

But none of it is enough when PCBs and other toxic chemicals remain embedded in the food web, with more pollutants being added all the time, O'Neill said.

"When you look at habitat, it is important to look at all the different attributes," she said. "We tend to focus on the physical and the hydrological, but we should not ignore the chemical — including the water quality." ■

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[RELATED STORY NEXT PAGE]

Many of Puget Sound's Chinook salmon spend their entire lives in local waters and don't migrate to the open ocean. These fish tend to collect more contaminants in their bodies because of the sound's relatively high levels of pollution.

RELATED STORY

Photo: WDFW

Chinook salmon (Oncorhynchus tshawytscha).

Contaminants higher in resident "blackmouth" Chinook

date: 6/17/2016 author: CHRISTOPHER DUNAGAN
web: eopugetsound.org/magazine/pcb-blackmouth

When Washington Department of Fish and Wildlife scientist Sandie O'Neill began studying toxic contaminants in fish 26 years ago, many people wondered why Chinook salmon from Puget Sound were so heavily contaminated with PCBs. Everyone knew that the urban bays of Puget Sound were hotspots for harmful chemicals, but didn't the migrating salmon put on most of their growth in the ocean, far from the polluted bays?

The answer was found by looking at individual fish. Some Chinook caught in Puget Sound were heavily contaminated with PCBs, while others showed relatively low levels. The level of variation appeared to be far greater than for most waterways around the world.

Further studies by O'Neil and others revealed that nearly one-third of the adult Chinook caught in local waters had lived their entire lives in Puget Sound. Those were the ones most heavily contaminated.

In contrast, Chinook that migrated out of Puget Sound still carried the chemicals they acquired from their early days. But by the time they returned, the chemical concentrations were far lower, because of the cleaner foods they had consumed in the ocean.

Puget Sound Chinook — both residents and ocean migrants — are listed as "threatened" under the Endangered Species Act. So far, efforts to rebuild the Chinook population — such as reducing the harvest, rebuilding the habitat and altering hatchery programs — have failed to reverse the downward spiral.

Chinook that live out their entire lives in Puget Sound are known as "resident Chinook" or "blackmouth," a nickname derived from their dark gums. Some fish hatcheries release their Chinook later than normal to increase the blackmouth population and provide for winter sport fisheries.

Studies suggest that in years with colder temperatures more of the wild Chinook will become resident. Also Chinook that remain in their home rivers for a year, instead of moving right into Puget Sound, tend to be larger, which also makes them more likely to become resident.

"If you are big enough, you might want to stay [in Puget Sound]," O'Neill noted.

Photo: Jim West, WDFW

Sandie O'Neill sorting the catch during a bottom trawl survey.

In general, South Puget Sound seems to produce more resident Chinook than areas to the north.

Studies of fish implanted with acoustic transmitters have shown that resident Chinook tend to stay more or less in their home areas, rather than moving widely about Puget Sound, according to O'Neill. It would then follow that fish from more contaminated areas, such as Central Puget Sound, would have higher levels of toxic chemicals. A study now underway will examine this idea by testing fish from a half dozen different areas to measure their toxic levels.

Comparing the levels of various toxic chemicals in fish tissue could be a good indicator of where the fish come from. On a larger scale, O'Neill has discovered an interesting difference between California and Washington fish, beginning with herring — a central figure in the pelagic food web and an important source of nutrition for larger fish, birds and marine mammals.

Herring caught in California tend to have higher levels of the pesticide DDT than Puget Sound herring but lower levels of PCBs. So the ratio of PCBs to DDT can be used as a type of geographic marker.

Because Chinook are eating herring, their PCB/DDT ratio is about the same as the fish they are eating, both for California Chinook and for resident Chinook in Puget Sound.

It might be expected that Southern Resident killer whales, which are frequently seen throughout the Salish Sea, would have a PCB/DDT signal similar to the Chinook salmon that dominate their diet. But there is a distinct difference among the three pods of orcas.

J pod seems to be eating more fish with the Puget Sound signal," O'Neill said. "But K and L pods seem to be more in line with the California signal."

Those findings might have surprised experts several years ago, but more recent observations — including satellite-tracking studies — have shown that all three pods move into the Pacific Ocean at various times during the winter. While J pod spends more time within the Salish Sea, K and L pods venture down the coast to the Columbia River on the Washington-Oregon border and sometimes travel as far south as Monterey Bay, Calif.

Although the PCB/DDT ratio tends to be passed from prey to predator, the concentration of toxic chemicals increases from herring to salmon to killer whales, because of biomagnification resulting from the tight hold by hydrophobic compounds embedded in their fatty tissues. ■

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Fluoxetine hydrochloride. Photo: Meg (CC BY-NC-ND 2.0)

Drugs like Prozac and cocaine have been showing up in the region's salmon. But these are just some of the potentially thousands of different man-made chemicals that escape into the Salish Sea every day, from pharmaceuticals to industrial compounds. Now the race is on to identify which ones pose the greatest dangers.

Concerns rise over rogue chemicals in the environment

date: 11/9/2016 author: CHRISTOPHER DUNAGAN topic editor: JOEL BAKER AND ANDY JAMES
web: eopugetsound.org/magazine/rogue-chemicals

KEY TAKEAWAYS

- *There are 85,000 synthetic chemicals on the market. On any given day, thousands of them — from pharmaceuticals to industrial compounds — flow into Puget Sound.*
- *Many of these compounds are biologically active in humans and other animals, posing a variety of health problems.*
- *Scientists are trying to decide which compounds are the most dangerous and should get the most scrutiny.*
- *Even minute amounts of some chemicals can disrupt normal hormone functions in both humans and wildlife.*
- *A rise in man-made chemicals being produced and escaping into the environment over the past 50 years has been accompanied by increasing health problems in the human population.*

Rogue chemicals are everywhere that researchers look — from seagull eggs in the Arctic, to trout in high mountain lakes, to blue whales far out in the Pacific Ocean, along with virtually every animal studied in Puget Sound.

Many of these chemicals are found in vanishingly small traces, in the parts per trillion, but they are always nearby, available for uptake into living things and providing a reminder of the 85,000 synthetic chemicals on the market. On any given day, thousands of them flow into local waters.

In some cases, their impacts have been well studied. Harmful effects of PCBs — polychlorinated biphenyls — were identified before they were banned in the 1970s. But thousands of other compounds are now catching the attention of scientists. With growing alarm, they are discovering that many of these compounds are biologically active in humans and other animals, posing a variety of health problems.

Among the chemicals of emerging concern are certain pesticides, medicines, cosmetics, soaps, plastics, household products and industrial solvents. Gaining increasing attention is a group of mysterious and difficult-to-study compounds that play havoc with the body's own internal chemistry.

Consider these findings:

- Even though many toxic flame retardants have been banned or phased out, residents of the Puget Sound region are retaining these chemicals in their blood, causing potential health effects that remain largely unknown.
- Compounds that mimic female hormones are continually discharged from wastewater treatment plants into Puget Sound, where some chemicals could be shifting reproductive timing in salmon and flatfish, potentially reducing their reproductive success.
- Human anti-depressant drugs have been found in salmon and other fish at levels that could be changing their behavior and perhaps their ability to escape predators or find food.
- Anti-depressants also have been found to alter the day-night cycles of amphipods, tiny shrimplike creatures that play a key role in the food web. These drugs can cause them to swim to the surface during the day, a time when they should be hiding out in deep water to escape predators.

As research continues, biologists and toxicologists in Puget Sound and across the country are trying to decide which compounds should get the most scrutiny, given limited research dollars.

Chemicals that have been identified in Puget Sound were discussed during special sessions at the 2016 Salish Sea Ecosystem Conference last April in Vancouver, B.C., where scientists considered the latest findings — including effects on humans and sea life.

NEW STUDIES OF FLAME RETARDANTS

One group of toxic chemicals, polybrominated diphenyl ethers, or PBDEs, was commonly used to reduce the risk of fire in a variety of household products. Many PBDEs have been banned or phased out, but they are still found at varying levels in nearly every creature on Earth.

Water sample.

Photo: USDA NRCS

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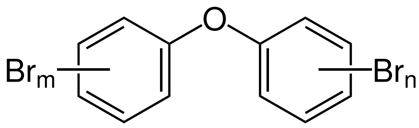

Chemical structure of PBDEs

A study discussed at the conference involved 113 workers in commercial fishing, electronic recycling and general office occupations. All had measurable levels of PBDEs in their blood, although most of the levels were low, according to Irv Schultz, a research scientist at Battelle's Pacific Northwest National Laboratory.

A record of their dietary choices showed that people who ate the most fish — more than five servings per week — had the highest levels of PBDEs. Electronic equipment recyclers, who generally consumed less seafood, had the next highest levels of PBDEs, followed by general office workers. Dust from electronic recycling sites also contained notable levels of PBDEs, particularly the chemical formulations used in electronic equipment.

EFFECTS ON BRAIN CELLS

Other findings, consistent with studies elsewhere, suggest that PBDEs may be disguising themselves as thyroxin and related thyroid hormones, which exert control over a multitude of body functions. Chemicals that mimic hormones or block their action can set off a sequence of reactions in the endocrine system, thus they are known as endocrine disrupting compounds, or EDCs.

What's an EDC?
Chemicals that mimic hormones or block their action can set off a sequence of reactions in the endocrine system are known as endocrine disrupting compounds, or EDCs.

Although the biological actions of PBDEs are not well understood, research on animals suggests that they may reduce thyroid hormone levels in the blood, which can result in abnormal brain and nerve development. In humans, low thyroid levels during fetal development are linked to mental impairment, while both low or high thyroid levels seem to alter brain development through childhood.

Levels of PBDEs found in humans and animals in the Puget Sound region may not be a major issue for adult age groups, Schultz said. But increasing attention is being focused on long-term effects resulting from exposure during early development. In mice, for example, even relative low-dose exposure at critical times can result in deficits in learning, memory and sensory development, a condition that grows worse with age.

In a competitive world of prey and predators, brain impairment from chemical exposure can increase the risk that an animal will be eaten or be unable to find its next meal, either one with deadly results, experts say.

Other studies have shown that PBDEs may be passed from mother to child during pregnancy, the most formative stage of life. Children also pick up more contaminants than adults, both through breast milk and through hand-to-mouth exposure to household dust.

PBDEs often escape into the environment by attaching to dust particles. Also, when clothing and other fabrics are washed, the compounds can pass from the wash water into a sewer, through a sewage treatment plant and out into marine waters.

Raw sewage flows into the Tacoma Central Wastewater Treatment Plant.

Photo: Kris Symer (CC BY-NC-ND 4.0)

Not surprisingly, this has consequences for many Puget Sound species in addition to humans. A long-term study of harbor seals in the Salish Sea showed that their PBDE levels doubled every three years from 1984 to 2003, but have leveled off or declined since then. Because seals are high-level predators, they incorporate PBDEs from numerous species of fish as well invertebrates, providing an "integrated contaminant signal" for the entire Salish Sea food web, according to the study's lead author, Peter Ross of Vancouver Aquarium, who was with Canada's Department of Fisheries and Oceans at the time of the study.

At the Salish Sea conference, Laurie Niewolny of the Washington Department of Fish and Wildlife reported that PBDEs had declined in four different Puget Sound herring stocks from 1998 through 2013. In contrast, the trend for English sole, a bottom fish, was an increase in some areas and a decrease in others.

The general decline in PBDE levels likely resulted from regulatory and voluntary efforts to ban the chemicals, starting with the more toxic forms. Still, the complex chemistry of these compounds can complicate longtime effects on the food web. For example, less-toxic forms of PBDEs, which were manufactured in far greater quantities, have been found to break down in sunlight or during metabolic processes to create more toxic, longer-lasting forms.

THE PHARMACEUTICAL FRONT

While biological activity turned out to be an unexpected side effect of flame retardants, altering biological activity is the sole purpose of many man-made drugs. The trouble with pharmaceuticals is that some of them escape into the environment — often in tiny amounts through wastewater — where they can disrupt the endocrine systems of non-target species.

A widely reported problem in both fresh and marine waters is the number of male fish with female characteristics, such as oocytes in the male reproductive organs. Oocytes are the precursor cells that develop into an egg. This so-called "feminization" of male fish is believed to result from exposure to female hormones during critical stages of early development.

Synthetic estrogens, used in human birth-control pills, can be found in waterways where they have been discharged with treated sewage after passing through a woman's body. Other synthetic compounds — including bisphenol-A, a chemical used in plastics, have been found to mimic the effects of estrogen.

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Birth-control pills.

Photo: UC Irvine (CC BY-NC-ND 2.0)

Laboratory studies suggest that reproductive success is often reduced among these "intersex fish" — males with female reproductive characteristics. Besides the formation of oocytes, intersex fish may have reduced numbers of sperm or sperm of poor quality. Some defects, such as deformed or missing sperm ducts, can render them sterile.

An experiment conducted in Ontario, Canada, took the investigation into feminization to a new level by studying fish populations in near-pristine lake devoid of pollution. For three years, researchers applied synthetic estrogen to the lake to maintain a concentration equivalent to what might be found near the outfall of a sewage treatment plant.

After the second year of treatment, the entire population of fathead minnows in the lake had collapsed due to reproductive failure, according to lead researcher Karen Kidd of the University of New Brunswick. A nearby lake, left untreated, showed no significant problems.

Fathead minnows, a short-lived species, were nearly extinct in the experimental lake at the end of three years, although the population of a longer-lived species of minnows, called pearl dace, was able to survive. Still, all the male fish in the lake — including adult trout — were effectively "feminized," as revealed by their unnatural ability to produce vitellogenin, a protein that helps eggs develop. Vitellogenin, which the liver produces in response to estrogen, is not found in males under normal conditions.

Since vitellogenin is normally produced only in females, finding this protein in males is now considered a reliable test for the presence of estrogens or structurally related compounds.

In a study of 16 sites around Puget Sound, a research team led by Lyndal Johnson of NOAA's Northwest Fisheries Science Center found vitellogenin in male English sole at 10 of the sites. The highest percentage of affected fish — 47 percent of those sampled — was at the north end of Seattle's Elliott Bay. At other Elliott Bay sites, male fish with vitellogenin ranged from 12 to 38 percent.

Outside of Elliott Bay, the highest percentage of male fish with vitellogenin were found in Tacoma's Thea Foss Waterway, with 22 percent, followed by Port Gardner near Everett, 19 percent; Central Puget Sound near Blake Island, 17 percent; Port Susan in northern Puget Sound, 7 percent; and Bremerton's Sinclair Inlet, 6 percent.

Out of nearly 3,000 English sole examined, only two intersex fish were found — one male with female characteristics and one female with male characteristics. But the study may have revealed another major issue of concern. In places like Elliott Bay where the percentage of males with vitellogenin was high, the females seemed to have an altered reproductive cycle. Instead of releasing their eggs in the normal February-to-March time period, these females delayed their releases until April or May. This kind of delay could lead to egg fertilization during a time when environmental conditions are less conducive to survival, according to the report.

Louisa Harding, who recently received her doctoral degree from the UW, worked with experts in multiple labs in the Puget Sound region to examine how estrogen and estrogen-like compounds affect the pituitary gland in juvenile coho salmon. The pituitary, a pea-sized body at the base of the brain, is sometimes called the "master gland" for its role in regulating all sorts of hormones.

"The pituitary acts like an operator," Harding said. "Phone calls that come into the brain get diverted to all the different target tissues."

Harding discovered that early exposure to synthetic estrogen altered the release of key hormones involved in sexual maturation in coho. At the same time, changes were observed in proteins related to an internal circadian clock, which regulates the timing of hormonal activity and ultimately reproduction.

Tests using effluent from select sewage treatment plants in the Puget Sound region revealed similar endocrine-disrupting effects on the pituitary. Since coho are migrating into saltwater during a critical stage of sexual development, her study and others raise obvious questions about how urban waters may impair salmon reproduction.

Juvenile Chinook salmon.

Photo: Roger Tabor/USFWS (CC BY 2.0)

ANTI-DEPRESSANTS UNLEASHED

If anti-depressants, such as Zoloft and Prozac, can reduce anxiety and alter people's behavior, what happens when fish and other marine species are exposed to these chemicals, commonly found in sewage effluent?

Both Zoloft (generic name sertraline) and Prozac (generic name fluoxetine) act in a precise way to block the uptake of serotonin in nerve cells, which affects how the brain sends and receives messages. Thus these drugs are known as selective serotonin reuptake inhibitors, or SSRIs. They are often found in sewage effluent at relatively low levels.

In a study of 150 compounds tested from three urban bays in Puget Sound, researchers discovered

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Prozac (or its equivalent) at detectible levels in both juvenile Chinook salmon and sculpins, according to Jim Meador, a researcher with NOAA's Northwest Fisheries Science Center. Zoloft (or its equivalent) was found in Chinook salmon.

Working together, along with a similar compound called norfluoxetine, it seems likely that these chemicals can accumulate in the brains of fish at a high enough level to have an effect, Meador said. Based on other studies, these antidepressants could slow the reaction time of predatory fish and inhibit their ability to capture prey, with potential consequences for their survival, he noted.

Some researchers dispute that the levels of antidepressants found in the environment are high enough to change the behavior of fish, but even lower levels could produce effects that are difficult to measure. Studies will go on, but it could take decades before researchers describe the full effects of a drug on thousands of organisms in Puget Sound.

In amphipods, for example, antidepressants may exert a powerful influence on their daily rhythmic behaviors. Many of these tiny shrimplike crustaceans swim up to surface waters at night to feast on plankton. During the day, they descend into the dark depths to escape predators.

But exposure to antidepressants like Zoloft and Prozac can cause amphipods to swim faster and head into perilous surface waters even during daylight hours, according to several studies of the phenomenon. These effects can be triggered through internal photoreceptors and complex biochemical pathways with drug concentrations found in typical urban waterways.

Because antidepressants are so readily found in marine waters, they could be affecting a multitude of creatures and perhaps the entire food web. Increasing research is being focused on how these drugs may affect the many biological functions influenced by serotonin, the neurotransmitter that helps regulate reproduction, metabolism, immune function, behavior and cycles of life.

> **"It simply is not reasonable to assume a chemical is safe until proven otherwise."**
>
> *EDC-2: The Endocrine Society's Second Scientific Statement on Endocrine-Disrupting Chemicals (2015)*

GROWING AILMENTS

A rise in man-made chemicals being produced and escaping into the environment over the past 50 years has been accompanied by increasing health problems in the human population. Growing ailments include thyroid deficiency, type II diabetes, obesity, early-onset of puberty in girls, reduced sperm count in men, and increased breast, prostate and testicular cancers. Also notable are an apparent increase in neurodevelopmental disorders, such as autism and attention deficit disorder.

While evidence is growing, many of the apparent connections between endocrine disrupting compounds and human disorders have not been fully explained. For that reason, researchers around the world are working to better understand how modern chemicals become entangled in biological processes.

Because some hormones can affect multiple systems and even feedback to maintain their own levels, some EDCs may trigger biological effects at both low doses and high doses, yet they seem to have little effect at midlevel doses. Toxicologists can no longer rely on the idea that higher doses will yield greater biological effects. They've also learned to avoid old assumptions about "threshold doses" — the level below which no effects are seen.

As if the issue were not complex enough, one of the great challenges of the future is to study the ongoing effects of multiple chemicals working together, according to The Endocrine Society, a group of researchers, medical doctors and educators who published a 150-page "scientific statement" on EDCs last year. In real life, humans and other affected species are not exposed to just one compound at a time.

"It simply is not reasonable to assume a chemical is safe until proven otherwise," states the report. "Clearly, not all chemicals are EDCs, but substantial information needs to be provided before inclusion of a new compound in a food storage product, a water bottle, or a household product."

That goes for replacement compounds as well, the paper says. An example is bisphenol S, which was pushed into production when experts found that bisphenol A, used in plastics, could act like estrogen, causing potential adverse effects during early development. The U.S. Food and Drug Administration banned the use of BPA in baby bottles.

Plastic water bottles.

Photo: Keoni Cabral (CC BY 2.0)

"The BPA substitute, bisphenol S, is now shown to have endocrine-disrupting activity on par with BPA in experimental studies," according to The Endocrine Society document — although much controversy remains over the effects of BPA at normal exposure levels. Some states have taken action to ban BPA beyond the federal prohibition involving baby bottles.

Because the health effects of so many chemicals are yet unknown, various groups of researchers and medical professionals have called for increased studies into the effects of endocrine disrupting compounds. Some have even offered suggestions about setting priorities for analyzing the effects of the 85,000 chemicals on the market.

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> *"The idea was that if you didn't die, then in a few days you would be fully recovered."*
>
> *Irv Schultz, research scientist*
> *Pacific Northwest National Laboratory*

Pharmaceuticals, which have been tested in human drug trials, should raise alarms when found in significant levels in the environment, experts say. One approach is to identify concentrations of drugs in marine waters likely to have biological effects on fish. The approach uses existing human studies and conversion factors, such as a drug's ability to accumulate in fish tissue.

SETTING PRIORITIES

In 2015, a group of scientists from various agencies in the Puget Sound region developed a "prioritization framework" to help guide future studies into contaminants of concern in Puget Sound [Editor's note: our parent group the Puget Sound Institute was also involved with creating this framework]. Priorities should focus on chemicals that are most likely to cause harm. That involves an assessment of the levels of a contaminant found in local waters as well as the chemical's known effects on marine life, the group said.

Monitoring also can be important when a biological effect is observed but the cause has not been identified, according to the report published by the Puget Sound Ecosystem Monitoring Program.

This report will be valuable as funding agencies decide which studies involving chemical exposures should come first, said Sandie O'Neill, a biologist with the Washington Department of Fish and Wildlife and a member of the committee.

Since 2008, a combined program of the EPA, the National Institutes of Health and the Food and Drug Administration has been using a high-tech system, involving robots and cell cultures, to rapidly screen 10,000 chemicals for biological effects. The project, still being refined, is called Toxicology Testing for the 21st Century, or Tox21. The program promises to identify the most dangerous compounds for further testing.

More broadly, in June of this year, President Obama signed into law an update to the Toxic Substances Control Act, now called the Frank R. Lautenberg Chemical Safety for the 21st Century Act. Under the revised law, a new chemical must be approved as safe by the Environmental Protection Agency before it can go on the market. Chemicals already on the market must undergo an evaluation to determine if they pose a high or low risk to people and the environment. High-risk chemicals will go through more extensive evaluations to determine which ones pose an "unreasonable risk." Evaluations must take into account vulnerable populations with no consideration of cost. Formal actions by the EPA, including bans and restrictions, may consider costs and replacement chemicals.

The new law sets out deadlines — including a requirement to have 10 risk evaluations underway by Dec. 22. ■

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NOT JUST CANCER

As recently as the mid-1900s, it was generally believed that if a person exposed to a chemical didn't get sick, then no harm was done, said Irv Schultz, a research scientist with Battelle's Pacific Northwest National Laboratory. Chemically induced illness was considered a short-term problem.

"We can see how naïve that is," Schultz said, "but the idea was that if you didn't die, then in a few days you would be fully recovered."

That thinking changed over time as medical experts came to realize that exposure to certain chemicals greatly increased the risk of cancer, a disease that often begins in the hidden recesses of the body and may not emerge for years.

"The disease could be going on for five, 10 or 20 years before someone tells you that you have only a few months to live," Schultz noted.

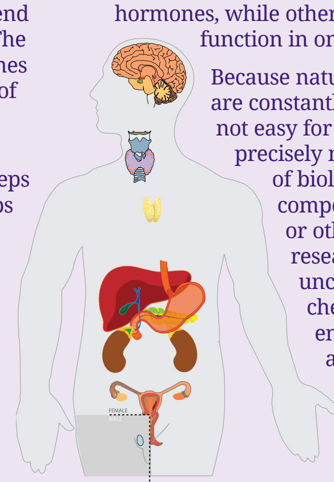
Today, as cancer research continues, there are new concerns. Scientists are exploring the subtle effects of man-made chemicals on growth and development, brain function, immune response and reproductive success. In some cases, even small chemical concentrations can trigger a sequence of hormonal responses, which can be difficult to measure yet have profound consequences for the individuals affected — and sometimes their offspring.

In living creatures, some of the most important biological functions depend on an internal communications network that uses natural chemicals — hormones — to send messages from one organ to another. The orchestrated release of various hormones helps to maintain an intricate balance of bodily functions.

The endocrine system, which includes hormone-releasing organs, not only keeps the body working smoothly, it also helps regulate growth, reproductive cycles, perception and emotions, among other things.

Some man-made compounds are known to mimic natural hormones, while others block their activity. Chemicals that have such effects are called endocrine disrupting compounds, or EDCs. When EDCs increase or decrease hormonal activity, the result can be developmental problems, reproductive failure, immune suppression or cognitive difficulties.

Foreign chemicals enter the body when people eat contaminated food, breathe contaminated air or come into direct contact with chemicals. Some mimic the body's hormones, while others block hormonal function in one way or another.



Because natural hormone levels are constantly changing, it is not easy for researchers to precisely measure the effects of biologically active compounds on humans or other animals. Still, researchers continue to uncover the ways that chemicals can disrupt the endocrine systems of animals throughout the Puget Sound region.

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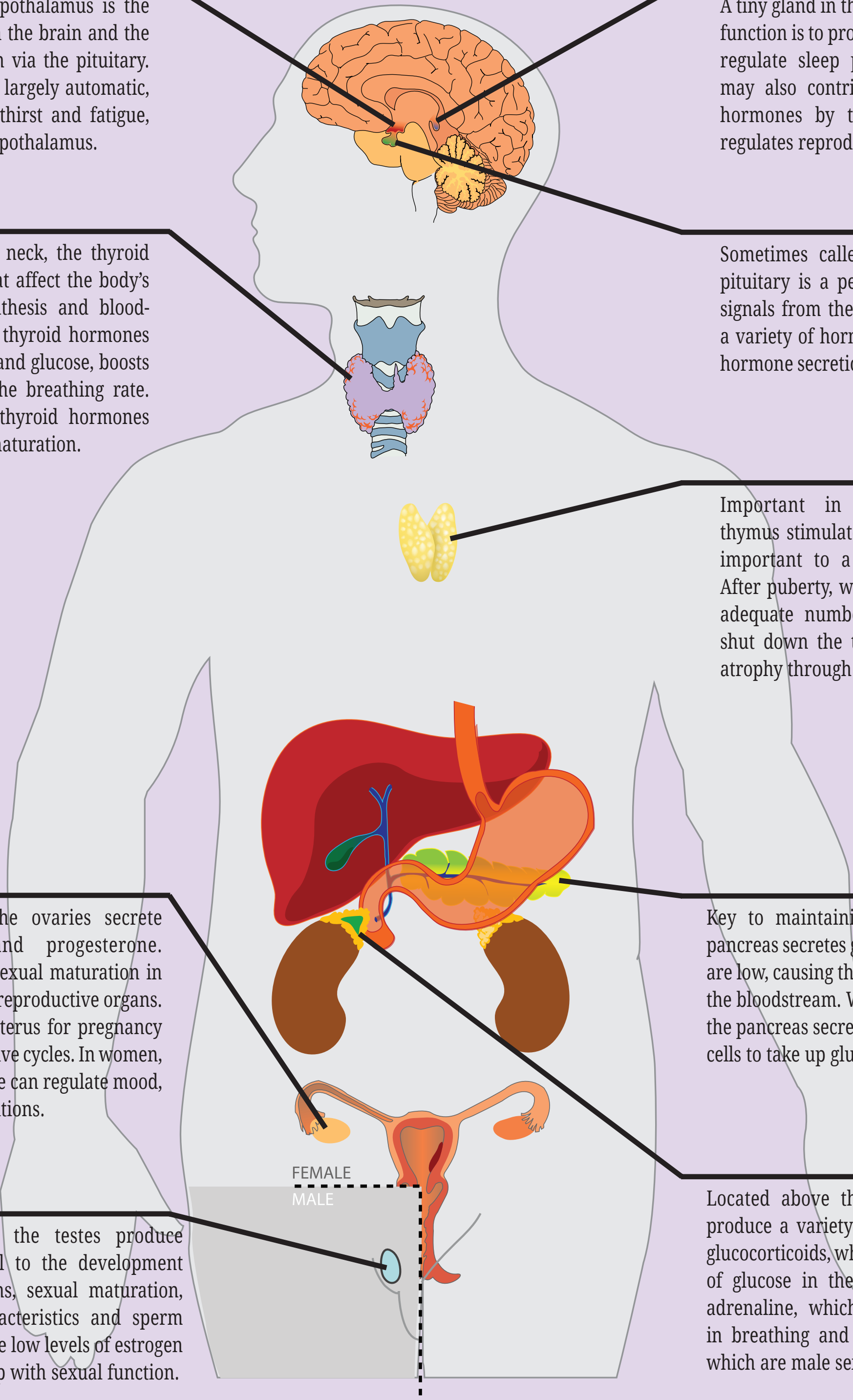
HUMAN ENDOCRINE SYSTEM

Organs involved in the endocrine system produce the hormones that regulate a multitude of biological processes from conception to death. That includes growth, brain development and function, metabolism and reproduction, all acting in concert with each other.



HYPOTHALAMUS

A part of the brain, the hypothalamus is the primary connection between the brain and the rest of the endocrine system via the pituitary. Metabolic processes that are largely automatic, such as body temperature, thirst and fatigue, are regulated through the hypothalamus.

THYROID GLAND

Located at the front of the neck, the thyroid gland releases hormones that affect the body's metabolic rate, protein synthesis and blood-calcium levels. A release of thyroid hormones increases the burning of fat and glucose, boosts the heart beat and raises the breathing rate. During fetal development, thyroid hormones play a critical role in brain maturation.

OVARIES

Besides producing eggs, the ovaries secrete estrogen, testosterone and progesterone. Estrogen is responsible for sexual maturation in females and maintenance of reproductive organs. Progesterone prepares the uterus for pregnancy and helps regulate reproductive cycles. In women, small amounts of testosterone can regulate mood, bone growth and other conditions.

TESTES

Besides producing sperm, the testes produce mainly testosterone, critical to the development of male reproductive organs, sexual maturation, maintenance of male characteristics and sperm production. Men also produce low levels of estrogen and progesterone, which help with sexual function.

PINEAL GLAND

A tiny gland in the brain, the pineal's primary function is to produce melatonin, which helps regulate sleep patterns. The pineal gland may also contribute to the release of sex hormones by the pituitary gland, which regulates reproduction.

PITUITARY GLAND

Sometimes called the "master gland," the pituitary is a pea-sized structure that takes signals from the hypothalamus and releases a variety of hormones, which in turn trigger hormone secretion in other endocrine glands.

THYMUS GLAND

Important in early development, the thymus stimulates the production of T cells, important to a body's immune response. After puberty, when T cells have reached an adequate number, sex hormones begin to shut down the thymus, which continues to atrophy through adult life.

PANCREAS

Key to maintaining blood-sugar levels, the pancreas secretes glucagon when glucose levels are low, causing the liver to release glucose into the bloodstream. When glucose levels are high, the pancreas secretes insulin, which signals the cells to take up glucose from the bloodstream.

ADRENAL GLANDS

Located above the kidneys, adrenal glands produce a variety of hormones. They include glucocorticoids, which stimulate the production of glucose in the liver among other things; adrenaline, which triggers a rapid increase in breathing and heart rate; and androgens, which are male sex hormones.

Harbor Porpoise (Phocoena phocoena), Bellingham Bay, WA. Photo: Andrew Reding (CC BY-NC-ND 2.0)

After an almost complete collapse in the 1970s, harbor porpoise populations in Puget Sound have rebounded. Scientists are celebrating the recovery of the species sometimes known as the "puffing pig."

The return of the pig

date: 10/13/2016 author: ERIC WAGNER topic editor: JOE GAYDOS
web: eopugetsound.org/magazine/harbor-porpoise

KEY TAKEAWAYS

- *Harbor porpoise were once common in Puget Sound, but all but disappeared from the region in the 1970s.*
- *Causes of the decline were largely attributed to gill nets and pollution.*
- *Harbor porpoise populations began to return in the 1990s, and their numbers in Puget Sound are now thought to exceed 500.*
- *The species may have benefitted from tightening of fishing regulations and shorter fishing seasons, although pollution remains a concern.*
- *Harbor porpoise are the smallest of the 22 cetaceans found south of Admiralty Inlet.*

Early in September of 2005, Dave Anderson and Laurie Shuster were out kayaking in Puget Sound, near Olympia, when they saw a small, gray, blunt-nosed something-or-other swimming off in the distance. It was some kind of dolphin, they figured, but Anderson wasn't sure of the species. When he got home, his guidebook was pretty straightforward. Small, gray, blunt nose: harbor porpoise.

Anderson at the time was going back to school at Evergreen State College, studying to be a marine biologist. (He had been a computer programmer for years up until then.) The observation stayed on his mind, and months later, when he took a course on marine mammals he mentioned that he had seen a harbor porpoise.

"Are you sure it was a harbor porpoise?," the instructor, John Calambokidis asked him. Calambokidis, who was also the founder of the Cascadia Research Collective, was skeptical. "There aren't any harbor porpoises in south Puget Sound."

But Anderson was certain that was what he had seen. Later, more reports started to come in of harbor porpoise sightings. The years passed, the sightings piled up, the evidence was becoming irrefutable: after an almost forty-year absence, the harbor porpoise was returning to Puget Sound.

THE PUFFING PIG

As cetaceans go, the harbor porpoise is fairly nondescript. Its back is dark gray, gradually lightening towards a white belly. Adults may grow up to six feet in length and weigh more than fifty kilograms, or about 120 lbs. (They are usually five feet long and weigh 100 lbs.) They eat cephalopods and forage fish, mostly—smelt, sand lance, herring. They can dive more than two hundred meters deep, but are most often found closer the water's surface. On the surface they breathe frequently, in loud snorts and grunts. In New England and southeastern Canada, fishers call harbor porpoises the "puffing pig," presumably out of affection. ("Porpoise" comes from the Latin word porcus, or pig.)

Harbor porpoises live all over the world, from Greenland in the North Atlantic to Florida, and from northern Europe to the waters off west Africa. Along the west coast of North America, they occur from Chukchi Sea to southern California. As a species, they are generally non-migratory; NOAA Fisheries currently recognizes six different management stocks along the U.S. West Coast, according to a 2016 Washington Department of Fish and Wildlife (WDFW) report.

> **"Back in the 1940s, they were thought to be the most common cetacean in Washington."**
> *Dave Anderson, marine biologist*

In Puget Sound south of Admiralty Inlet, the harbor porpoise is the smallest of the twenty-two species of cetaceans found. Until fairly recently, it was also one of, if not the, rarest. This wasn't always so. "Back in the 1940s, they were thought to be the most common cetacean in Washington," Anderson says. But then they started to disappear. The decline was likely due to two main causes. After the end of World War II, there was a sharp increase in commercial fishing in Puget Sound. With the proliferation of gillnets, bottom set nets, and trawls, harbor porpoises were often caught and drowned.

Second, Puget Sound became increasingly polluted, as industries flourished along its shores and in its watersheds. As top predators, harbor porpoises may have suffered as heavy metals and pesticides accumulated in their bodies, weakening their immune systems and reducing their reproductive success. By the early 1970s, they were almost never seen south of Hood Canal, and only infrequently elsewhere.

Photo: Imtiaz Ahmed (CC BY-NC-ND 2.0)


Jack, the baby Harbour Porpoise, at the Vancouver Aquarium.

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A 6-year-old killer whale from L pod, known as L-73, chases a Dall's porpoise, 1992.

Photo: Debbie Dorand / Center for Whale Research

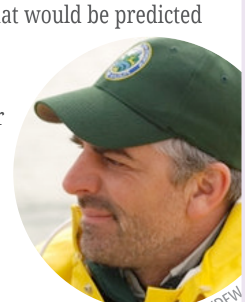
AERIAL SURVEYS

Because harbor porpoises were almost never seen, biologists more or less stopped looking for them. For twenty years, a sporadic sighting or two might trickle in, but these were not thought indicative of any larger trends.

Then, in the early 1990s, a biologist named Joe Evenson took over the WDFW's aerial surveys of marine bird populations. The surveys covered the whole of Puget Sound, from South Puget Sound north to Washington Sound near the U.S.-Canada border, and out to Cape Flattery, in the Strait of Juan de Fuca. Although Evenson's putative focus was sea ducks, he had experience doing marine mammal counts from years before, with Cascadia. "I thought, Why not also count mammals?" Evenson says. So he did.

Aerial surveys for birds aren't the same as those dedicated to marine mammals — the planes tend to fly lower, and biologists restrict their observations to narrower bands on either side of the plane — but Evenson and his colleagues counted whatever marine mammals they happened across. Some of those mammals were harbor porpoises. Not many at first, but a gradually growing number as the years went on.

Evenson would offer the dataset to John Calambokidis around the time Anderson was finishing his thesis at Evergreen. Calambokidis asked Anderson to analyze the numbers. When Anderson did, he found that harbor porpoises were increasing in inland Puget Sound at rates beyond what would be predicted from reproduction alone. "The porpoises are coming from somewhere," Anderson says, "but we don't know where."



Joe Evenson, WDFW

Still, they are coming. The population is increasing by over eight percent per year in both the Strait of Juan de Fuca and Washington Sound. And from 2000 through 2014, the annual growth rate in south Puget Sound was a whopping 36.8%.

BUCKING THE TRENDS

No one knows precisely why the harbor porpoise's fortunes seem to have changed. "Fishing regulations have tightened significantly, and the seasons have shortened," says Evenson. "So bycatch isn't as big of a problem, although pollution is still a concern."

The harbor porpoise's increase also stands opposed to region-wide trends in seabirds and other marine mammals, whose populations are largely either declining or just holding steady. (This is especially true with the Dall's porpoise, which had moved into Puget Sound in the absence of the harbor porpoise, and has since declined as the harbor porpoise came back.)

As for precisely how many porpoises are in Puget Sound now, Anderson is circumspect. "I try to avoid pushing out abundance numbers," he says, "but I feel comfortable saying 'many hundreds,' probably in the 500s category." He thinks there might be about four hundred porpoises in south Puget Sound alone.

Both Anderson and Evenson will continue with their surveys and documentation efforts, in spite of a profound lack of funding. After all, in a time when ecological recovery stories are uncommon, the return of a cetacean, even a small, gray snub-nosed one, should be celebrated. "I've found myself as a guest at a wedding on Vashon Island, and people were asking about the porpoise that swam by earlier in the day," Anderson says. "People are interested, and we need to take time to help them learn more about these interesting animals that are returning to part of their traditional home range." ■

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RELATED STORY

Resident killer whales sometimes attack porpoises but never eat them

date: 4/14/2016 author: CHRISTOPHER DUNAGAN
web: eopugetsound.org/magazine/ssec16-attack

They're not playing with their food — because Southern Resident killer whales eat fish, not porpoises.

So there must be another reason why fish-eating orcas stalk, attack and sometimes kill harbor porpoises and Dall's porpoises, both marine mammals, according to researcher Deborah Giles, who has opened an investigation into this seemingly odd behavior.

"It looks like they are having fun," Giles said of the killer whales, describing the "mugging" behavior Wednesday during the Salish Sea Ecosystem Conference in Vancouver, B.C. "It's like if you were in a pool with your friends and trying to keep a ball above water, but you can't use your hands."

Giles, of the Center for Whale Research on San Juan Island, has discovered that the chasing and killing of porpoises has gone on since the first methodical observations of killer whales in the Salish Sea. She has looked at reports going back to the 1970s and is still gathering information from both expert and amateur whale watchers.

This kind of "play" does not happen often. So far, Giles has collected 41 reports of this type of attack, including 11 confirmed deaths, over the past 40 years. When the age of the attacking whales can be determined, they are often juveniles going after young porpoises.

"They may surf with them, carry them around on their pec(toral) fins and generally exhaust them to death," she noted. Teeth marks are sometimes seen on the carcasses of recovered porpoises, caused by the whales holding them in their mouths, but bites are not taken out.

Orcas in L pod, the largest of the three Southern Resident pods, have been implicated in many of these incidents in the historical records, she noted. Since 2005, however, it appears that members of J pod have been taking part in an increasing number of attacks.

Giles calls it "Phocoenacide" (pronounced Foe-seen-a-side) — the killing of porpoises. That covers the scientific grouping (genus) for harbor porpoise, Phocoena, as well as for Dall's porpoise, Phocoenoides.

Why the orcas may be doing this is open to speculation, but Giles hopes to get answers by collecting more historical reports and by asking observers for any new reports of this practice. She put out a plea at the conference for anyone to contact her at giles@whaleresearch.com.

The population of harbor porpoises in the Salish Sea has been increasing, with some estimates of growth at well over 10 percent per year.

Could the fish-eating whales be sensing a growing competition for food from these porpoises, which also eat a lot of fish?

Not likely, says Giles, because porpoises generally eat forage fish, such as herring, while the diet of orcas is made up almost entirely of Chinook salmon. In fact, the young harbor porpoises that are most often attacked are not much bigger than the largest Chinook salmon that the whales are consuming in Puget Sound, she said.

Her speculation is that the attacks on porpoises may be a training exercise for the young fish-eating whales. Transient killer whales, which actually feed on harbor porpoises, are known to wound the animals, chase them, then toss them around before eating them.

"In my mind, it is kind of a teaching thing," Giles said in answer to a question, "or it might just be fun. We need more data."

The Southern Resident killer whales are listed as endangered under the Endangered Species Act. Despite efforts to protect them, a major reason why their numbers have failed to recover appears to be a lack of salmon.

It seems unlikely that these whales would begin to eat harbor porpoises, since their ancestors probably ate fish for thousands of years, Giles said. But if they were to alter their diet, she would like to have a record of their behavior leading up to that moment. ■

FOR MORE INFORMATION

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Sunrise at Seal Rock Campground. Brinnon, WA.

Right, back cover: Map of the Salish Sea & Surrounding Basin, Stefan Freelan, WWU, 2009.

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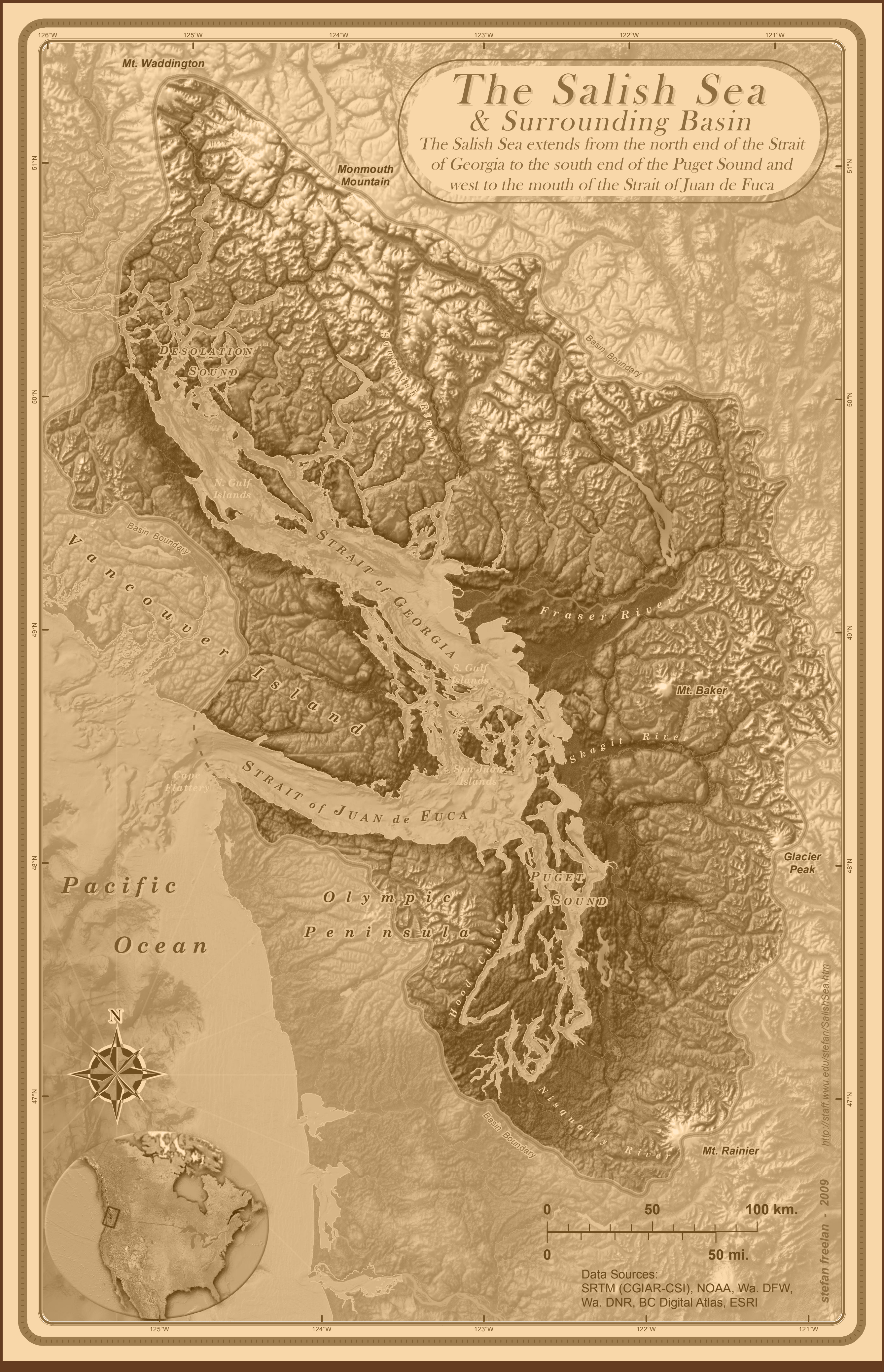

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