SEA STAR

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ELDER MEMORIES, ANCIENT DNA AND THE FATE OF THE HERRING

WSG researcher Lorenz Hauser leads a binational, multidisciplinary investigation into the decline of the North Pacific's little big fish.

Conservation is a never-ending battle against collective amnesia. As living resources are consumed or extinguished, baselines shift. Past abundance is forgotten, and new generations adjust to a diminished new normal.

The forage fishes that are foundations of the marine food web are a case in point. In the Pacific Northwest, that means Pacific herring especially. Herring were abundant in the 19th and early 20th centuries, supporting commercial fisheries, but their populations have declined in recent years by as much as 95 percent.

Just how abundant were herring before fishing, habitat loss and other factors took their tolls; how did the fishery affect the population's diversity; and could Salish Sea and Pacific coastal ecosystems support such abundance again? To answer those questions, managers must first figure out what the original baseline was, and that itself is an open question colored with controversy. To answer it, a Washington Sea Grant-supported research team is melding insights from an unusual range of sources, from archeology to genetic analysis to traditional knowledge of tribal elders and other long-time herring harvesters.

"What got me started was the archeological findings," says team collaborator Dana Lepofsky, an archeologist at Simon Fraser University in Vancouver. In recent decades herring have spawned only sporadically at various sites in and along the Strait of Georgia. Canadian fisheries officials contended this variation was normal, because herring schools moved from one side of the strait to the other. But the archeological

Herring • continued on page 4

Pacific herring off Lopez Island. Photo by Cathleen Wilson

TO SEE A WORLD IN AN OYSTER'S SHELL

WSG Social Scientist Melissa Poe shows how shellfish are central to tribal harvesters' sense of being and belonging.

By Lauren Drakopulos, WSG Science Communications Fellow

Sense of place is something we've all experienced, a connection to a particular locale or environment. But how do we become attached to places? Do those attachments determine which places we choose to conserve? And does place-based restoration improve human well-being? That's what Melissa Poe, Washington Sea Grant's Social Scientist, and Jamie Donatuto, an Environmental Health Analyst with the Swinomish Indian tribal community, set out to discover. The goals of their project, funded by the University of Washington's Puget Sound Institute, were to evaluate sense of place as a cultural ecosystem service of Puget Sound and examine the links between shellfish harvesting, healthy marine ecosystems and human well-being.

To meet these goals, Poe and Donatuto interviewed and conducted a series of workshops with Squaxin Island and Swinomish tribal members and other residents of South Puget Sound and the Skagit River area. They looked at shoreline harvesting because, as Poe puts it, "It is a type of tangible activity that broadens how we think of cultural ecosystem services." Environmental professionals have tended to view these cultural services as nonmaterial benefits, such as recreational, spiritual and therapeutic experiences of natural environments. They usually see harvests as a provisioning activity, performed to obtain a consumable product and resulting in a net loss for the environment. But for the communities who harvest, says Poe, "The practice of shellfish harvest is not just provisioning. It has connections to other kinds of immaterial well-being."

Working in close collaboration with the tribal communities, Poe and Donatuto found that shellfish harvesting and other shoreline activities "create deep, strong and intergenerational connections to place…. People's sense of place is really integral to who they are as individuals." As one harvester told them, "Since I was two, I've lived on the water…. That's where I spent my formative years, and I think it's part of who you are when you have been raised with it."

When sense of place is considered in environmental management decisions, it's usually understood as merely an appreciation of wilderness or a scenic vista. Poe's work shows that such purely aesthetic definitions can be limiting because they neglect environmental quality. "By seeing Puget Sound primarily as a beautiful glistening body of water," she notes, "we risk not paying attention to the health of what's under the surface."

Policies that equate sense of place with scenery and seek to maximize aesthetic qualities may actually suppress rather than nurture a sense of place. Conservation approaches that define harvest activities as merely "extractive" may prevent some residents from developing a sense of place that is culturally specific and historically meaningful. As one harvester told the researchers, "I associate myself with oysters; they're a part of my identity."

This raises an important social justice issue. Because of such cultural connections, the impact of restrictive management falls more heavily on some residents than on others. Managers have traditionally accounted for this impact through substitution, a measure that assumes that as some resources become less available people can shift to other resources. But for the study's tribal participants, some shoreline resources and places were irreplaceable. "It would be that devastating," one harvester attested, "and maybe it would be even worse; if they told me I could never be by the water, it would be like the end of the world to me…. It would be probably the deepest grief I could never get over."

Further reading: Poe M, Donatuto J, Satterfield T (2016) "Sense of place": human well being considerations for ecological restoration in Puget Sound. *Coastal Management Journal* 44(5).

FISH KILLS AND VANISHING RAZOR CLAMS ALARM THE QUINAULT

By Lauren Drakopulos, WSG Science Communications Fellow

Fishermen and tribal elders join in WSG's investigation of devastating coastal hypoxia.

Abundant razor clam beds extend south from the mouth of the Quinault River, which runs through the heart of the Quinault Indian Nation. Quinault life centers on the surrounding natural resources, and razor clams have been a mainstay of Quinault cultural identity for millennia. With their ready access to the clam beds, the Quinault would harvest and dry the clams to trade along the Columbia River and elsewhere around the region, where they were highly prized by tribes that didn't enjoy the same access to them.

In the last few years, tribal elders have observed highly localized fish kills caused by hypoxia (low oxygen levels). Hypoxia events have occurred with alarming frequency all along the Pacific Northwest coastline. They are associated with upwelling, the movement of cold dense water from the ocean floor toward the surface and coastline. Upwelling brings important nutrients, nourishing algal plankton and boosting biological productivity along this coast. But it's a double-edged sword — when those algae die, sink and decompose, they cause even more oxygen depletion in the already dense, salty, oxygen-poor lower depths.

Even more concerning, the fish kills coincided with low razor-clam densities on tribal beaches, leading the Quinault to wonder if there might be a relationship between the two. Ervin "Joe" Schumacker, a Marine Resources Scientist in the Quinault Department of Fisheries, is working in partnership with tribal elders, managers and the local fishing community on a Washington Sea Grant-funded project to better understand the relationship between hypoxia and razor clam health.

In addition to their cultural value, razor clams are a significant food and economic resource for the Quinault. They are an excellent protein source and provide work through both commercial digs and value-added production at the Quinault Pride Seafood Plant in Taholah. Further, one of the beaches where the clams are dug is the only beach in Washington that is solely managed by a tribal entity. Other tribal beaches are co-managed with the state.

The range of species killed by the hypoxia reflects a local geography that compounds the impact. "Point Grenville Beach was inundated with dead fish of all kinds," explains Schumacker. "There were species galore, bottom-dwelling demersal fishes, crabs, pelagic fishes. Those pelagic fish, in this case anchovy, are so mobile they can generally escape these events, but they had gotten trapped in a natural cove and couldn't escape the hypoxia." Other marine fishes have been observed swimming up the Quinault River, trying to get to better oxygenated waters.

Understanding the hypoxia and, perhaps, protecting the clams holds personal significance for Schumacker, who grew up making family trips to the West Coast to dig razor clams and went on to graduate from the University of Washington's School of Aquatic and Fishery and Sciences. Schumacker has since spent 17 years working with the Quinault community. Beyond the goals of improving water quality and razor clam health, he sees this project as a chance to build connections between fishermen and other tribal members and the wider research community. "The project is really trying to do some relationship work," he notes. "Fishing boats [which deployed data-collection instruments] were key to the collaborative process. Tribal fisherman really wanted to help."

Getting the blessing of tribal leaders was also key to the project's success. The history of the Quinault people and their deep knowledge of the area are key research components. Elders, leaders and managers have shared their traditional ecological knowledge, which is critical to understanding how the ecosystem functioned in the past and how razor clam populations have been affected. The elders did not recall ever seeing anything like the fish kills and other changes. "Nothing sparks in my mind about it," one elder told Schumacker.

Research is still underway, although a poor crabbing season (likely caused by natural cycles but potentially exacerbated by hypoxia) kept many partner boats from fishing this year, providing fewer opportunities to collect data. Still, Schumacker is optimistic about the research — the first Sea Grant-funded project on Quinault territory — dedicated to an issue of surpassing local importance.

Joe Schumacker, Marine Resources Scientist with the Quinault Indian Nation.

Herring • continued from p.1

Lorenz Hauser, Associate Professor, University of Washington School of Aquatic and Fishery Sciences.

record belies that: "Thousands of herring bones, appear throughout the middens", says Lepofsky, indicating they were harvested year after year throughout the region.

Indeed, herring bones are prevalent in 95 of 171 archeological sites sampled, common in most of the others, and absent from only two — indicating a huge role for the little fish in traditional diets. But researchers missed the evidence until recently, explains UW population geneticist Lorenz Hauser, who analyzed the midden samples. The herring bones were so small they slipped through the screens used to sift the samples. That may have led those earlier researchers to underestimate the dietary importance of herring relative to salmon and other fishes.

Local knowledge holders confirm that importance, and changes in the herring's abundance; many of them can be heard at the highly informative *pacificherring.org*. "They've seen huge declines in their lifetimes," says Lepofsky, but they remember when the herring were plentiful and consistent. She also notes, "People said that the migratory herring were skinny, and the residents were fatter and shorter." Place names such as Teeshoshum — "milky waters from herring spawn" — reflect this past abundance. Native families guarded and managed their own spawning grounds, harvesting roe where it was particularly thick and using eelgrass, kelp and hemlock boughs anchored in the water as collectors.

By contrast, the industrial roe fishery took a more destructive approach, slicing the gravid fish open for eggs to be sold in Japan. Fisheries officials have baseline data for the last decades of industrial fishing, from the 1960s in Canada and the 1970s in Washington. "But for us, what's more interesting is what the levels were before that fishery," says Hauser. To fill in that picture, his graduate student, Eleni Petrou, is interviewing traditional harvesters in Washington about the plenitude they once knew. Not all are tribal members; Petrou located eight older Euro-American fishermen in the San Juan Islands for whom herring was a staple catch. "They used to smoke it, eat it fresh and salt it in barrels," she explains. "It was a very common food back in the day."

The fishermen's recollections show "a typical shifting baseline phenomenon," says Hauser. "In every generation, mid-career fishermen see the baseline as too depleted and just give up. But the next generation starts from there." The fishermen's testimony suggests that abundance has decreased by about 80 percent since 1930 around the San Juans, with the steepest losses occurring in the 1960s and 1980s.

Hauser and his colleagues aren't only concerned with herring abundance. They're using ancient and current genetic data to map the diversity and distribution of regional herring stocks and determine how they've changed over time and under fishing pressure.

This effort to open a new window on the fish's past has required several technical innovations. Most studies of ancient genetics use mitochondrial DNA, which is prevalent and accessible but does not reveal herring population differentiation. Nuclear DNA would reveal that differentiation but is less common, and no one had successfully extracted it from ancient herring. Dongya Yang, another collaborator at Simon Fraser University, managed to extract usable nuclear DNA from the tiny bones, opening a new window on the fish's past.

Petrou, whose training is actually in population genetics, meanwhile tried

Herring • continued on back page

DRAWING THE LI

At the Yakama Tribe's innovative experi

On the east side of Cle Elum, Washington, between Interstate 90 and the Yakima River, sits a tribal salmon-rearing facility that encapsulates the past and present of hatchery management in the Pacific Northwest. Now, thanks both to foresight that was controversial in its time and to Washington Sea Grant-sponsored research that looks beyond its time, this unique salmon hatchery may also chart a future for the region's prize fish.

The Cle Elum Supplementation and Research Facility, operated by the Yakama Nation's Yakama Klickitat Fisheries Program, was approved in 1982 under the Northwest Power Act. Its original mission was a common one for hatcheries, to produce more salmon (spring Chinook, in this case) that would swim out to sea, mature and return for fishermen to catch. The original plan was to use returning hatchery-bred fish as broodstock for the next generation, maintaining a population genetically segregated from wild fish.

By the time the facility opened in 1997, however, fisheries thinking had diverged from this approach. Scientists feared that genetically segregated populations would lose diversity and fail to adapt, as wild fish must, to changing conditions. "Worse than that," recalls Yakama Fisheries Research Manager Dave Fast, "when one hatchery was short of brood eggs it would just transfer them from another" — removing the stock further yet from its wild roots.

The Cle Elum facility instead adopted an "integrated" approach — using wild broodstock to produce hatchery fish matching the river's natural population as closely as possible. As a research facility, it inves-

NE IN SALMON GENETICS

mental hatchery, WSG researchers show what a difference a wild broodstock can make.

tigated differences between the natural environment and hatcheries as well as genetic changes in the two stocks. But some scientists thought they were missing an opportunity. "A perceived weakness of the integrated program was that we were inadequately monitoring genetic change," says Craig Busack, a NOAA Fisheries Senior Fish Biologist who was assigned to the Yakama Klickitat project as a Washington Department of Fish and Wildlife (WDFW) employee in the 1990s. A scientific review panel suggested that integrated and segregated lines be reared under identical conditions and the genetic outcomes be compared.

That idea met initial resistance from hatchery operators. Raising segregated lines was and remains controversial; critics warned that the "domesticated" fish thus produced could breed with and weaken wild stocks. "It was assumed that the integrated approach was the better way to go," recalls Busack.

But raising and comparing parallel stocks could test that assumption and quantify the benefits of using wild broodstock. The Cle Elum hatchery's multiple-raceway design and location just above Roza Dam, where workers could count and separate the fish, made it uniquely suited to conduct such experiments. Its operators agreed to undertake the expanded mission.

Kerry Naish, a WSG-supported evolutionary geneticist at University of Washington's School of Aquatic and Fishery Sciences (SAFS), had just the genetic tools and just the graduate researcher, Charlie Waters, to carry out the experiment. Nearly a decade earlier, Ken Warheit — supervisor of WDFW's Fish Health and Genetics Programs and collaborator on the Cle Elum project — had more limited tools with which to compare the two broodstocks. In the intervening years, he noted that genetic technology had progressed "even further than we imagined." Then Naish and her SAFS colleague Jim Seeb mapped the Chinook salmon genome,[1] and another of Naish's graduate students, Marine Brieuc, identified markers for an important fitness trait.[2] Waters used these tools to track genetic divergence over four generations in integrated and segregated lines bred from the same wild population at Cle Elum.[3]

The results were striking — divergence from the source stock was minimal in the integrated line. But it was rapid and pronounced in the segregated line and largely due to genetic drift (random loss of genetic diversity). Still supported by WSG, Waters is now working to determine which fitness traits are most susceptible to genetic change, and to what degree using natural broodstock can prevent it. He notes that teasing out such comparisons would be extremely difficult or impossible using lines drawn from different stocks in different hatcheries. "You'd have so many confounding factors — different histories, population sizes, environments," he explains. "Cle Elum is a unique opportunity because the two lines were derived from the same wild population."

Some confounding factors intrude even at Cle Elum, despite the common base stock and shared environment. Because the hatchery is also dedicated to producing fit fish for harvest, its integrated line is much larger than its segregated line, making the latter more susceptible to genetic drift. Still, says Waters, after accounting for that difference, the integrated line shows more diversity than could be explained by its greater size.

What does all this mean to salmon production? Despite the genetic differences, "We've seen no significant difference in survival between the integrated and segregated stocks," says WDFW's Warheit. "I would expect it will be a longer time before we see differences. We really have no idea how long it will take. This is all set up as a big experiment."

Charlie Waters, UW graduate researcher.

1 Siple MC (2013) A code of many colors: the salmon genome revealed. *Sea Star*, Autumn:4-5.

2 Brieuc MSO, Ono K, Drinan DP, Naish KA (2015) Integration of random forest with population based outlier analyses provides insight on the genomic basis and evolution of run timing in Chinook salmon (*Oncorhynchus tshawytscha*). *Molecular Ecology* 24:2729-2746.

3 Waters CD, Hard JJ, Brieuc MSO et al. (2015). Effectiveness of managed gene flow in reducing genetic divergence associated with captive breeding. *Evolutionary Applications* 8:956–971.

RISING SEAS AND A PLAN TO DEAL WITH CLIMATE CHANGE

WSG's Ian Miller helps the Jamestown S'Klallam Tribe lead the way in climate planning.

Many native tribes in Washington are acutely exposed to the effects of climate change. From the Swinomish Reservation on Skagit Bay to Port Gamble on the Hood Canal and LaPush on the Olympic Peninsula, tribal members live on river deltas and low-lying shores unprotected from storm surges and rising seas. Ocean warming and acidification threaten the fish and shellfish species that are central to their diets, incomes and traditions.

Almost nowhere is the risk more apparent than along Sequim Bay, whose shore the Jamestown S'Klallam Tribe hugs like an overhanging cedar tree. A map that WSG Coastal Hazards Specialist Ian Miller prepared for the tribe shows vividly[1] how predicted sea level rise will inundate that shoreline. Under severe climate scenarios, the rising sea will reach far up Jimmycomelately Creek and sever State Highway 101, Jamestown's essential link with the outside world. Coastal flooding will threaten the tribe's natural resources lab, wastewater tanks and, ironically, its planning offices.

Large cities around the world are numb and helpless in the face of such threats. But the S'Klallams have a long history of taking control of their future. In 1874, after living for thousands of years along what's now called the Strait of Juan de Fuca, they were loath to be relocated with other groups by the U.S. government to a reservation at the bottom of the Hood Canal. Instead, several families pooled funds to buy 210 acres near Dungeness, the seed of today's S'Klallam communities. They then fought for official recognition as a tribe, which the government denied because they would not relocate, and finally won it in 1981.

In 2007 the tribe began planning to assess its climate risks. Jamestown S'Klallam wasn't the first Washington tribe to take that step; the Swinomish Tribe issued a proclamation promising climate action that same year and completed its ambitious "Climate Adaptation Plan" in 2010.[2] But Jamestown was the first community on the Olympic Peninsula to step up, and its "Climate Vulnerability Assessment and Adaptation Plan" has helped inspire similar efforts for the Port Gamble S'Klallam tribe and, under Clallam County leadership, the entire North Olympic coast.

Byron Rot, then the Jamestown S'Klallam Habitat Program Manager, supervised the climate assessment. Environmental Planning Manager Hansi Halls obtained EPA support funds, then took over supervision when Rot left Jamestown. The tribe turned to Sascha Petersen of the Austin-based consultancy Adaptation International to conduct the assessment and he in turn enlisted Ian Miller. Port Angeles-based Miller, an oceanographer and geomorphologist who had already written a climate assessment for the Olympic Coast National Marine Sanctuary, was the natural choice for the scientific aspects —"the right guy in the right location," as Rot puts it. Miller and WSG Coastal Management Specialist Nicole Faghin also helped a team of University of Washington graduate students create a social marketing plan for the project.

Together, the student team convened a two-day workshop to ask tribal representatives what *their* concerns were. "We got direction from the tribal council, elders, subsistence fishermen and executive staff so we could do some reality checking on what we were doing," explains Halls, "to make sure it wasn't what *we* thought was important." The representatives' answers were sometimes surprising. "There was more emphasis than I would have given to the transportation corridor, but it made sense, looking through a broader lens."

The S'Klallams rated Highway 101 as a "high priority" for protection, as well as the tribal water supply and 7 Cedars Casino and Resort, a main employer and revenue source. But they rated several natural resources even higher: salmon, shellfish, waters uncontaminated by harmful algal blooms and the cedar bark "withes" they harvest each spring to weave traditional baskets, a skill imparted to Jamestown children as a cultural touchstone. Already, says Elaine Grinnell, an elder on the panel, the window when the withes are moist and supple enough to be peeled from the trees is narrowing and coming earlier. "It used to not start until June, in some places not until the Fourth of July," she says. "Now you start in May, and it dries out faster."

Grinnell has seen other changes in the bay where she harvests shellfish. The offshore sandbar has moved east a mile or more, and what was firm sandy bottom is now deep "sucky mud" that nearly drowned her young grandson. The cockles still do well, the clams less so. "That's probably the river," she acknowledges — but warmer, wetter springs can mean more floods washing down silt.

"We succeeded because we had a lot of engagement with tribal elders," says Miller. "We needed that, not just for community buy-in but for the cultural history they carry." Outside experts like him don't remember the days before sucky mud, when the cedar withes were still fresh in July.

1 Jamestown S'Klallam Tribe (accessed Nov. 1, 2016), Blyn sea level rise (high severity), *jamestowntribe.org/programs/nrs/nrs_climchg.htm*

2 Swinomish Tribe (accessed Nov. 1, 2016) Swinomish climate change initiative, *swinomish.org/climate_change/climate_main.html*

FIELD NOTES

WSG is proud to present "North Pacific Marine Life" by Ray Troll, the Caravaggio of Ketchikan, on its 2017 calendar. Troll's whimsical but scientifically rigorous depictions of the creatures of the North Pacific have delighted everyone from young children to trained biologists. Reproduced in every medium, from books and T-shirts to 3-D posters, they have introduced thousands of fans worldwide to the weirdness and wonder of the aquatic world. Though he's based in Alaska, Troll is a longtime friend of the University of Washington who has collaborated with the Burke Museum and School of Aquatic and Fishery Sciences. He will be WSG's featured artist for the next four years. To order a calendar go to *wsg.washington.edu/2017-calendar-request-form.*

Staff Social Scientist **Melissa Poe** is part of an interdisciplinary research collaborative that has received a prestigious $1.5 million Coupled Natural and Human Systems grant from the National Science Foundation. Their project, "The Dynamics of Adaptation to Climate-Driven Variability in California Current Fisheries and Fishing Communities," will examine the ecological, economic and social impacts as fishermen move across fisheries and target different species in response to environmental changes. Melissa will lead the social science component, working with NOAA colleagues. They'll survey 3,000 fishing permit holders and interview fishermen all along the West Coast about such close-to-the-heart questions as the importance of fishing to their identities and quality of life, and how they deal with economic, environmental and management shocks.

Congratulations to **Kevin Decker**, WSG's Aberdeen-based Marine Outreach Specialist and resident economist, who received his doctorate in environmental science from the University of Idaho in August. His discipline-crossing dissertation explores the economic and environmental value of preserving and restoring the native Palouse Prairie, 99 percent of which

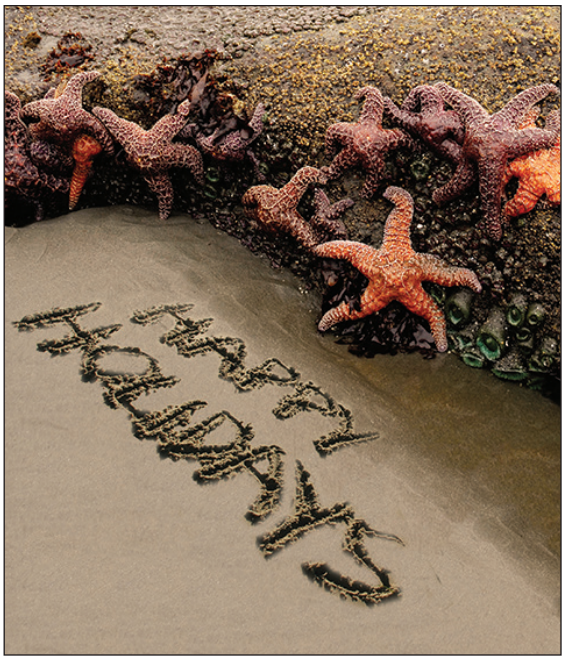
has been lost to agriculture and development. The research has already yielded a publication for Decker. The paper, titled "Estimating willingness to pay for a threatened species within a threatened ecosystem," focuses on the giant Palouse earthworm and will appear in the *Journal of Environmental Management.*

In other news that attracted media attention, fellow Marine Water Quality Specialist **Teri King** scooped NASA and everyone else in July. Teri was driving along the Hood Canal to a SoundToxins training session when she was startled by the sight of an unusual algal bloom erupting offshore. "I knew in my gut what was causing it when I saw it," she says. But she took a sample to confirm that the bloom was indeed coccolithophores, single-celled algae whose calcium carbonate plates reflect sunlight, turning water a tropical turquoise color. Soon after, NASA satellite spotters noticed the glow and inquired of Washington Department of Ecology staff, who asked Teri, "What's this?" Media across the state followed. The good news: unlike other algae Teri tracks, coccolithophores are generally harmless. They may actually slow marine warming and acidification by blocking sunlight and boosting reflective albedo.

WSG's Crab Team — 100 volunteers trained by Marine Water Quality Specialist **Jeff Adams** and UW colleagues to monitor for invasive European green crab — made big news at the end of August. Volunteers on San Juan Island caught the first green crab ever found in Washington's inland waters (additional crab were found in Padilla Bay in September). Local, national and international media leapt on the story, alerting beachgoers, residents and maritime workers to watch for the crab. More eyes are always good; early detection is the best defense against infestations.

Boating Program Specialist **Aaron Barnett** added a new feature to the Port Townsend Wooden Boat Festival this year. Terry Durfee, operator of a WSG-sponsored free mobile pumpout service, removed 1,000 gallons of raw sewage from festival boat owners' onboard biffies. Aaron hopes to make the free pumpouts a regular feature at the annual festival.

Season's Greetings
FROM WASHINGTON SEA GRANT



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Herring • continued from p.4

to analyze samples from contemporary spawning herring but encountered frequent contamination with sperm DNA. So she devised a bleaching technique that removed contamination but left the target genes intact.

Armed with these tools, the researchers are assembling and analyzing data spanning a thousand years, and Hauser hopes to parse 2,000-year-old genomes. Recent advances in genetic techniques make this much more feasible. "Now we can look at 30,000 markers in the genome, whereas before we could look at 10 or 12," he says. They've identified markers associated with traits such as spawning early or late and favoring colder or warmer water; checking those markers in the ancient DNA will show how population boundaries have changed.

This work has conservation implications. Genetic analysis can identify populations that should be separately managed and protected, as salmon runs are. Considering Puget Sound, Hauser says, "Even in this very small water body, three populations are genetically differentiated and thus identifiable in ancient material." Sustaining diverse populations ensures against environmental change, just as diversification protects an investment portfolio from market volatility. Hauser, Petrou and their colleagues are creating tools to do that for the Pacific Northwest's little big fish.