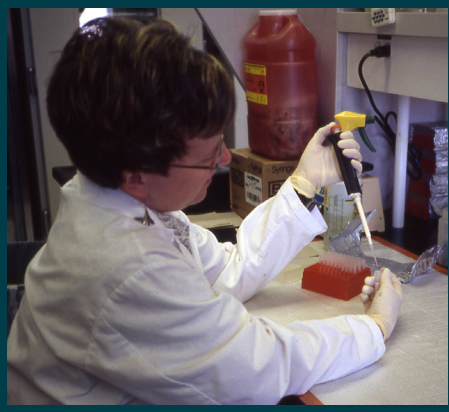
USGS Western Fisheries Research Center

Strategic Plan for Science 2015 - 2020



Excellence in Aquatic and Fisheries Science

U.S. Department of the Interior
U.S. Geological Survey

Front Cover: Left to Right

Top Row:

1. In the wet lab, Gael Kurath takes samples from a fish for a wide range of tests. Photo by USGS.

2. Mark Johnson processing a Lost River Sucker at Sucker Springs on Upper Klamath Lake. Photo by Brian Hayes, USGS.

3. Dr. Paul Hershberger working in wetlab at the Marrowstone Marine Field Station. Photo by USGS.

Bottom Row:

1. Fisheries Biologist takes a small tissue sample from a steelhead for later genetic analysis while Yakama Nation fisheries biologist, and technician collects and records biological information about the fish. Photo courtesy of Jeanette Burkhardt, Yakama Nation water shed planner.

2. Reno Field Station crew surveying for native and non-native fishes in the Independence Lake watershed.

3. Researcher preparing a sample in the lab. Photo by Debra Becker, USGS.

Western Fisheries Research Center Strategic Plan for Science 2015 - 2020

May 2015

U.S. Geological Survey
Western Fisheries Research Center
6505 NE 65th St.
Seattle, Washington 98115

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Table of Contents

Introduction 1

Vision Statement: Excellence in Aquatic and Fisheries Science 1

Science Plan Goals and Objectives 1

Background and History 2

Center-Wide Capabilities 2

Quantitative Modeling 2

Fish Pathogen Collections and Databases 3

Fish Behavior and Survival 3

Habitat Use and Evaluation 4

Physical, Environmental, and Biological Monitoring 4

Data Visualization 5

Genetics, Bioinformatics and Molecular Tools 5

Controlled Experimental Studies in Living Fish 5

Institutional Animal Care and Use Committee (IACUC) 6

Facilities – In the Laboratory and On the Landscape 6

Science Directions 10

Aquatic Animal Health 10

Drivers of Ecosystem Change 11

Restoration Ecology and Species Recovery 13

Preparing for Future Challenges 15

Recognizing Funding Challenges and Opportunities 15

Partners and Customers 16

Accountability 17

List of Images 19

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Western Fisheries Research Center
Strategic Plan for Science 2015-2020

Introduction

The Western Fisheries Research Center (WFRC) is one of 17 ecosystem-focused U.S. Geological Survey (USGS) Science Centers across the United States. It is one of only two USGS science centers that focus exclusively on fisheries science. It is recognized as a national and international resource for research on fish disease, fish passage and restoration following dam removal. Headquartered in Seattle, Washington, the WFRC is geographically dispersed in the western U.S., with four field stations in Nevada, Oregon and Washington. Our geographic diversity across ecoregions promotes research relevant to a wide variety of fish such as lampreys, sturgeons, salmonids, cyprinids and catastomids, varied fish groups such as forage fishes and desert fishes, and other aquatic organisms and communities occupying the diverse ecoregions of the western U.S.

Vision Statement: Excellence in Aquatic and Fisheries Science

Mission: The mission of the WFRC is to provide the scientific understanding and the innovative technology needed to support sound management and conservation of our nation's natural resources, with an emphasis on aquatic ecosystems, fisheries biology, and fish health. Our goal is that natural resource managers, policy makers, and the scientific community will recognize the WFRC as a premier source of objective and socially-relevant scientific information. To achieve this goal, the WFRC will maintain a highly skilled and adaptive workforce and infrastructure in order to be responsive to changing and emerging issues in aquatic ecosystems and fisheries biology. A priority for the WFRC is to provide the results of scientific research to resource managers in an effort to support informed decision making.

Science Plan Goals and Objectives

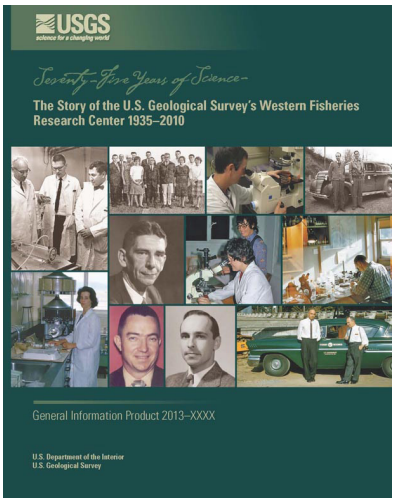
This strategic plan establishes a template for our science portfolio for the next five years. After reviewing the overarching U.S. Department of the Interior (DOI) and USGS science objectives, as well as the research priorities of our partners, we have identified the following three strategic science directions:

- Drivers of Ecosystem Change
- Aquatic Animal Health
- Restoration Ecology and Species Recovery

These directions are interrelated and often overlapping. Although this plan provides strategic direction for the next five years, clearly most of the research topics addressed within will continue into the future. The plan will be used as a road map to ensure that the WFRC is well positioned to address the next generation of science priorities.

Background and History

The WFRC originated in the early 1930s at Seattle's Montlake Laboratory within the U.S. Bureau of Fisheries and moved onto the University of Washington campus in 1934 as the Seattle Laboratory of the Fish Hatchery Disease Service. In 1940 an administrative re-organization moved the Seattle Laboratory under the U.S. Fish and Wildlife Service (FWS). The institution was renamed the Western Fish Disease Laboratory in 1950 and moved to its current location. For the next two decades the laboratory developed an international reputation for excellence in fish disease research, primarily serving hatchery managers. In the 1970s conservation legislation broadened the laboratory's mission, and it became the National Fishery Research Center. Field stations were established in Alaska, Nevada, the Columbia River Gorge, and northern Puget Sound. The Center was renamed the Northwest Biological Science Center in 1993 to emphasize a broader biological mission in the Pacific Northwest when Congress combined research laboratories from the DOI bureaus into one agency, creating the National Biological Survey. The National Biological Survey was later named the National Biological Service (NBS). In 1996 Congress moved the NBS into the USGS as its new Biological Resources Division and the Center was renamed the Western Fisheries Research Center. For more information, see the complete history of the WFRC at: http://wfrc.usgs.gov/about/history.html



The WFRC's strategic directions arise from the USGS Strategic Science Plan and Ecosystems and Environmental Health Mission Area strategic goals that are associated with the Fisheries, Aquatic, and Endangered Resources Program; the Invasive Species Program; and fish and wildlife health. These are the two mission areas from which the Center receives its appropriated funding.

Center-Wide Capabilities

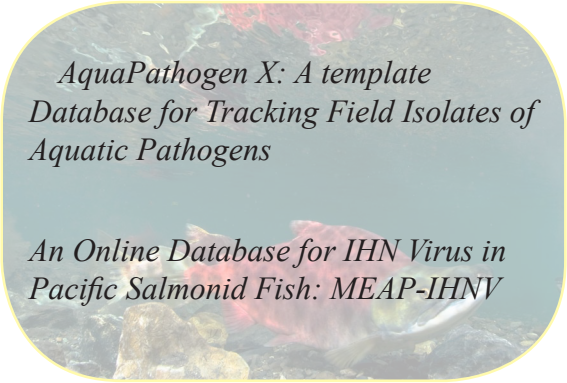
The WFRC is one of many organizations conducting fisheries research in the western U.S. However, the WFRC brings unique capabilities to fisheries research both in the field and in the laboratory.

Quantitative Modeling

The management and conservation of fish species and their habitats relies increasingly on sophisticated statistical and quantitative modeling techniques for drawing sound inference from field or laboratory studies. Quantitative modeling is essential for assessing species risk and recovery and for predicting effects of proposed restoration and management actions. Scientists at the WFRC use and develop novel quantitative tools such as capture-recapture, occupancy,

epidemiological, and life-cycle models to investigate the ecology, population dynamics, disease dynamics, and habitat requirements of fish species throughout the western U.S. The WFRC employs a number of quantitative specialists that provide critical support to WFRC biologists and partners in the areas of statistical analysis, sampling design, and quantitative modeling. Not only does the WFRC pioneer the use of state-of-the-art sampling technology such as acoustic, radio, and PIT tag telemetry; GIS and remote sensing; and molecular biology, our quantitative scientists play a central role in developing novel quantitative techniques for analyzing data collected with these technologies.

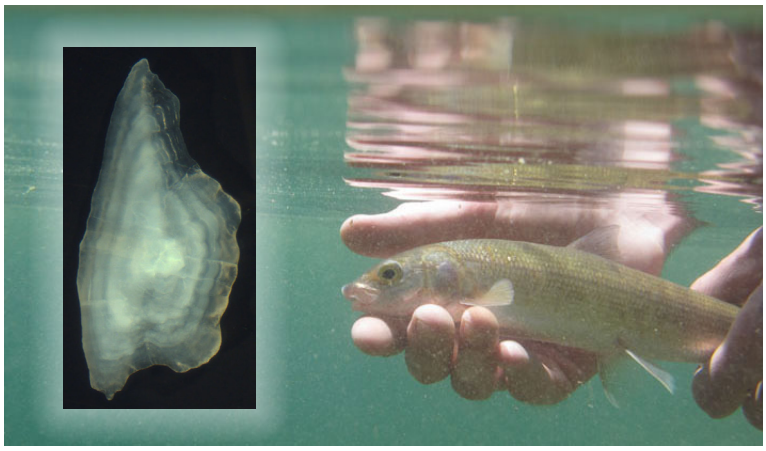
Fish Pathogen Collections and Databases



As a result of decades of research in fish health, the WFRC holds extensive collections of regional and global isolates of several viral, bacterial, and parasite pathogens of fish. Many of these collections are very broad both geographically and temporally, and include a wide diversity of pathogen types that occur both naturally and within cultured fish populations. These collections facilitate modern phylogenetic studies that provide a scientifically sound baseline for comparisons with newly emergent pathogen types. They also provide the biological material for in vivo research to study how these pathogens function and cause disease. For some of the more extensive collections databases have been assembled to provide metadata and support studies of pathogen epidemiology and evolution.

Fish Behavior and Survival

Quantifying fish behavior is often necessary to evaluate management actions or for testing questions about fish responses to biological and environmental stimuli. The WFRC has been and continues to be an innovator in field studies that measure fish migration behavior, survival, thermal selection, responses to water velocity, and fish responses to dam passage structures. For example the WFRC is a leader in using biotelemetry techniques and developing PIT tag detection arrays in streams to monitor fish movements and survival. Acoustic cameras have been used extensively to collect detailed spawning behavior of adult salmon to document movement of juvenile salmon around fish passage structures.



Controlled laboratory experiments have played a key role in evaluating fish performance and physiological response to stressors, fish behavior around fish screens, behavioral responses of prey to predators, and testing behavioral preferences to different environmental variables. Micro-chemical analysis of fish otoliths (ear bones) has been used to assess broad scale migration behavior (river mainstem versus tributaries) for small juveniles that are difficult to track by other means.

Habitat Use and Evaluation

Scientists at the WFRC are using remotely sensed data, hydrodynamic modeling, and spatially explicit habitat models to explain landscape-level patterns in fish distribution, migrations, and habitat requirements. Resource managers use these results to protect threatened and endangered fish species in systems where hydropower influences migration corridors and the availability of critical habitats. Finer scale habitat measurements by a variety of methods (including high resolution sonar for bathymetry and substrate type characterization; instrument deployments for time series of water column properties such as current speed and sediment load; and lower trophic level sampling for prey production assessment) are being used in conjunction with fine-scale measurements of fish residency and performance (habitat-specific growth and survival) across life stages to pinpoint critical habitats. Scientists at WFRC use state-of-the-art occupancy models to predict the spread of exotic species and estimate range expansion and contraction of threatened and endangered fish across a variety of ecosystems.

Physical, Environmental, and Biological Monitoring

Physical, environmental, and biological monitoring programs provide information to aid conservation management and are critical for assessing changes in ecosystem function. Long-term monitoring provides the basis for assessing landscape scale stressors that are drivers of change. Monitoring helps resource managers make informed decisions for management actions, and ensures that management actions are having their intended outcomes over longer time horizons.

Once baseline conditions are established, long-term monitoring programs can help us understand how the status of important physical, environmental, biological resources change through time and in response to management actions. The baseline and distribution data for important biota, such as aquatic invasive species, when linked to existing habitat conditions, will facilitate the research, development, and validation of decision support tools to assist managers in their decision making processes. The current lack of long-term data describing trends in ecological conditions, coupled with a poor understanding of historical baseline conditions, complicates our understanding of the ecological processes in the western U.S. As part of USGS efforts to monitor large river systems nationally, the WFRC has been

working with scientists throughout the country to establish a sound statistical monitoring framework for the long-term monitoring of large rivers in the western U.S. (currently focusing on the Columbia and Snake rivers).

Data Visualization

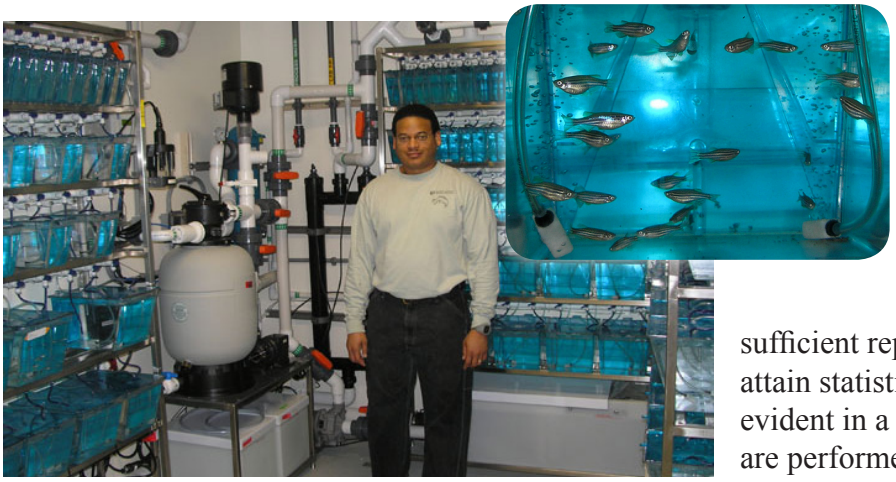
Data visualization turns rows and columns of data into maps and images that highlight patterns and correlations which provide better insights and understanding of scientific data. Scientists at the WFRC visualize data through geographic information systems that incorporate high resolution imagery and remotely sensed data as well as statistical graphs to illustrate and communicate scientific information to a broad audience.

Genetics, Bioinformatics and Molecular Tools

One of the hallmarks of contemporary biology is the increasing use of genetic, bioinformatic and molecular tools to address questions that previously could not be answered until recently. At the WFRC, these tools are being applied to questions involving both ecology and aquatic animal health. Current projects at the WFRC using high-throughput sequencing and bioinformatic approaches include identification of invasive species; analysis of hybridization of rainbow and cutthroat trout; studies on the recolonization of salmonids following dam removal; profiling the fish immune response to infections; analysis of the effects of climate change on fish health; tracking the evolution of fish pathogens; finding the determinants of genetic resistance to disease; and the discovery of novel or non-culturable fish pathogens.

Controlled Experimental Studies in Living Fish

Hypotheses derived from laboratory results or field observations can be tested under controlled experimental conditions using living fish in the WFRC wet labs. This capability is used extensively to define factors that influence fish biology, fish behavior, fish genetics, disease resistance, infection processes, pathogen virulence, and transmission of pathogens. The wet labs in Seattle and at the MMFS facilitate in vivo research using freshwater or seawater, with temperature control. Flexible tank formats accommodate a wide variety of experimental designs and allow sufficient replication within treatments to attain statistical significance that might not be evident in a smaller wet lab facility. Studies are performed on a wide range of regionally

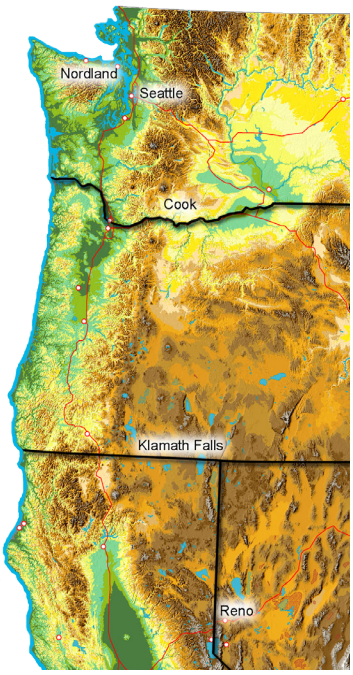


and globally important fish species at various life stages. For infectious disease research the collective experience at the Center includes well-established challenge models for several different pathogens, effectively re-creating the diseases that cause significant ecological and economic burden in fish populations.

Institutional Animal Care and Use Committee (IACUC)

The welfare of laboratory animals used in research, including finfish, has received increasing attention by granting agencies, peer-reviewed journals and the general public. For many years scientists at universities and other laboratories working with higher vertebrate species have been required to have proposed animal research reviewed and approved by an Institutional Animal Care and Use Committee (IACUC). Scientists have begun to find that many granting agencies and peer-reviewed journals now require that research involving fish must also be approved by an IACUC. To increase the standard of laboratory animal care and to be able to provide such assurances, the WFRC has hired a Veterinary Medical Officer to supervise the overall care of laboratory animals and has formed a WFRC IACUC that meets the national guidelines established by the U.S. Public Health Service/Office of Laboratory Animal Welfare. The WFRC IACUC meets regularly to perform inspections of the facility and to review and approve all protocols for research involving vertebrate animals conducted by federal scientists at the WFRC.

In addition to the IACUC, the WFRC has established an Institutional Biosafety Committee (IBC) to establish, review, and revise guidelines for facilities, work practices, and equipment for research involving biohazardous agents and recombinant DNA. This committee also provides annual training as required and meets regularly to review protocols and to provide assurances for grant proposals requiring IBC approval for research with recombinant molecules or biohazardous agents.



Facilities – In the Laboratory and On the Landscape

Our WFRC scientists work from five locations in three western states.

Headquarters, Seattle, WA
6505 NE 65th St., Seattle, WA 98115

The Center's Headquarters and Seattle Laboratory are located at Sand Point near the shores of Lake Washington. The campus was completed in 1994 and is a state-of-the-art research facility for work on fish health and aquatic ecology that includes over 16,000 square feet of laboratory space. The facility sustains a 9,000 square foot wet laboratory supplied with pathogen-free, temperature-controlled fresh water from Lake Washington. The wet laboratory effluent is treated and then sent to nearby Magnuson Park where

it is used to maintain the park's wetlands before returning to the lake. The facilities dry lab (21,664 sf) houses scientist offices and research laboratories and shared scientific equipment. Within the dry lab is a restricted access Biosafety Level 3 laboratory for research on exotic fish pathogens. All research performed at the Seattle laboratory meets National Institutes of Health guidelines for the institutional use and care of animals. The Center is also equipped with an artificial stream building (3,500 sf) that house six experimental streams for fish habitat research.

Investigations cover both basic and applied research aimed at providing scientific information relevant to the needs of federal, tribal, state, and local natural resource managers. Research at the Seattle laboratory is primarily devoted to the following areas of focus:

- Virology
- Bacteriology
- Immunology
- Histology
- Molecular biology/genetics
- Nearshore ecology and marine resource inventories
- Fish pathogen ecology, epidemiology, and evolution
- Ecosystem responses to dam removal and ecosystem restoration
- Evolutionary and conservation implications of genetic introgression between fish species
- Studies associated with describing and understanding life history variability of salmonids and other fish species with economic or conservation importance

On campus is a Visiting Scientist Quarter (VSQ) consisting of a dormitory space and a separate apartment. The VSQ makes it possible for scientists from other countries to come to the WFRC to conduct collaborative research.

Marrowstone Marine Field Station (MMFS)
616 Marrowstone Point Rd., Nordland, WA 98358

The Marrowstone Marine Field Station consists of a 5.2 acre campus, located on the northeast point of Marrowstone Island, Puget Sound, WA. The campus contains three large wet laboratory buildings (approximately 2,500 sq. ft. each), a dry laboratory building with offices, guest quarters, and several smaller structures that are used for facilities operations. Research at the facility addresses marine ecosystem health concerns, with particular emphasis on infectious and parasitic diseases that affect wild marine and anadromous fishes. The Marrowstone facility maintains capabilities that are unique within

the USGS, including the provision of treated seawater (400 gpm) to experimental laboratories and the efficacious treatment of tank effluent, thereby enabling the safe and responsible biocontainment of endemic pathogens. Because of these unique attributes, researchers at the facility have developed extremely valuable colonies of Specific Pathogen-Free marine fishes. The facility routinely hosts visiting international scientists who collaborate on experiments that can only be performed using the unique resources of this facility. Research at the Marrowstone facility is primarily devoted to the following areas of focus:

- Ecology of diseases in populations of wild marine and anadromous fishes
- Forecasting and mitigating disease impacts to wild marine fishes
- Provision of infection and disease information that is incorporated into population abundance and recruitment forecasts
- Understanding factors that predispose populations of wild marine fishes to diseases

Columbia River Research Laboratory (CRRL)
5501-A Cook-Underwood Road, Cook, WA 98605

The CRRL conducts research on a variety of topics related to the conservation and management of fish species, habitats, landscape scale stressors, and other aquatic resources throughout the Columbia River Basin and across the western U.S. Since its inception the CRRL has conducted a multitude of studies in the Columbia River Basin that provide the scientific basis for the operation of the Federal Columbia River Power System to benefit endangered and threatened juvenile Pacific salmon and steelhead; the management of native and introduced fish predators; the management of white sturgeon; and other important management issues. The Scientists at CRRL have provided leadership in science by conducting studies in large river systems and with biotelemetry, creating innovations that are transferable to areas beyond the Columbia River Basin such as the Sacramento Bay Delta and the Mekong River. Pacific salmon are the subject of many studies at CRRL, but projects examine other species, such as bull trout, cutthroat trout, lamprey, rainbow trout, sturgeon, benthic invertebrates, plankton, invasive species, native and introduced resident fishes. Research objectives include addressing the physical, environmental, and biological effects of hydropower generation as well as other landscape scale stressors, and assessing the restoration efforts intended to mitigate the effects of development within the Columbia River Basin. The scientific and technical expertise at the CRRL ranges from telemetry studies of

movement, behaviors and fish physiology to the modeling of aquatic community dynamics. Research at the CRRL laboratory includes the following:

- Biotelemetry
- Fish behavior
- Restoration evaluation
- Large river monitoring
- Controlled laboratory experiments
- Understanding ecosystem food webs and their response to stressors
- Predictive, spatial, and ecological modeling
- Invasive species monitoring and response
- Numerical modeling of population parameters

Klamath Falls Field Station (KFFS)
2795 Anderson Ave., Suite 106, Klamath Falls, OR 97603

The KFFS has facilities and resources for investigations into the life history, population dynamics, and behavioral ecology of fishes in lentic and lotic habitats within the basin. The field station features a PIT tag engineering team that constructs and deploys custom state-of-the-art PIT tag detection systems for a wide array of fish movement and survival related research. The KFFS research program currently emphasizes work on two endangered lake suckers (Lost River and shortnose suckers) in Upper Klamath Lake, Oregon, and Clear Lake Reservoir, California, as well as a number of projects with salmonids (Chinook and coho salmon, bull trout) in the upper and lower parts of the Basin. The Klamath River Basin and its water resources have been dramatically altered from their historical state as a result of human development, resulting in numerous challenges for resource managers. Research at the KFFS helps managers make informed decisions about resource use in this complex environment. Research at the KFFS is primarily devoted to the following:

• Describing ecology of endangered suckers
• Mark-recapture studies and analyses
• PIT tag detection technology
• Evaluating the effects of land and water management on behavior and survival of endangered fish
• Effects of eutrophication on endemic fishes
• Biotelemetry
• Predictive and ecological modeling

Reno Field Station (RFS)
1340 Financial Blvd., Suite 161, Reno, NV 89502

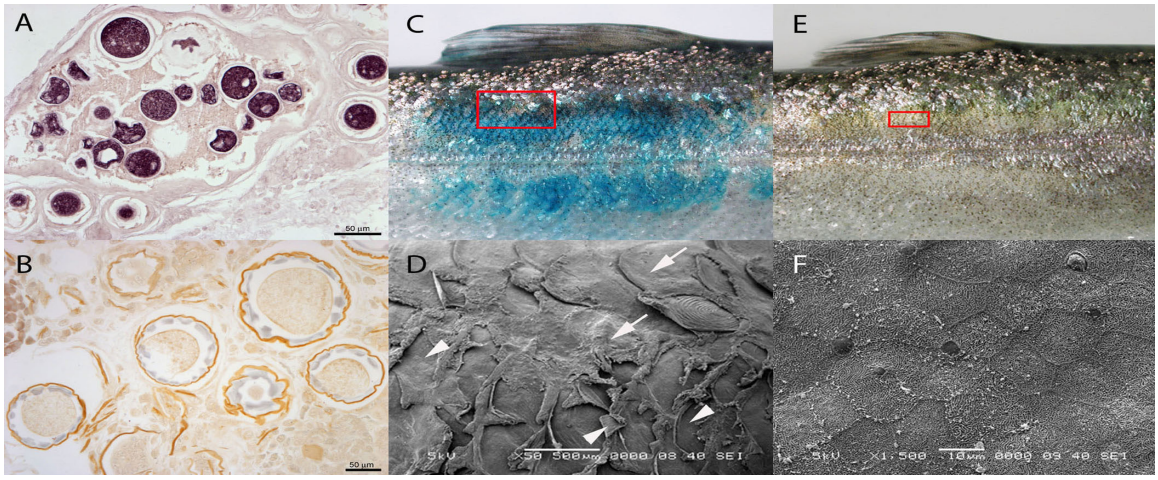
The RFS was established with the goal of protection, preservation, and recovery of ESA listed and sensitive fishes of the western U.S. Located in Reno, Nevada, the Station is within 400 miles of half of the Nation's ESA listed endangered fishes. The RFS's expertise is in field research and analysis of fish population viability. Reno biologists determine the influence of water manipulation, habitat modification, and non-indigenous fish introduction on native fish populations. Research at the RFS is primarily devoted to the following:

- Population dynamics, basic life history, interspecific interactions between native and introduced species
- Status and trends of threatened and endangered fishes
- Research in systems ranging from large lakes to desert spring systems.
- Habitat restoration and invasive species control

Science Directions

Aquatic Animal Health

Infectious and non-infectious diseases are increasingly recognized as important components of the health of all aquatic and terrestrial ecosystems, affecting both population dynamics and ecosystem function. While diseases in humans, terrestrial animals and captive aquatic animals are relatively easily observed and studied, impacts among populations of free-ranging fishes often go unobserved and are difficult to study. In addition, natural populations of fish are threatened by novel emerging diseases due to anthropogenic factors such as increased commercial aquaculture and global trade. These factors may introduce exotic pathogens or stressors such as alteration of habitats, global climate change, and introduction of contaminants that act synergistically with endemic diseases in aquatic animals.



The WFRC research in this area will improve our understanding of the ecology of infectious diseases among natural populations of freshwater and marine fishes, as well as provide tools and predictive capabilities to aid in management of these important resources. Priorities include:

- Expand understanding of the molecular basis of pathogenesis for a range of viral, bacterial, protozoan, and fungal pathogens
- Improve knowledge about the role of multiple anthropogenic stressors that can alter the severity of disease and affect the immune response
- Better understand the impacts of exotic pathogens introduced by sources such as ballast water, commercial aquaculture, and trade in ornamental fish
- Increase efforts to understand essential elements of the epidemiology of important aquatic animal diseases, including transmission of pathogens between wild and cultured fish
- Enhance understanding of factors affecting the emergence of new diseases of aquatic animals
- Develop and adapt epidemiological models to define both local and landscape-scale transmission patterns of important fish pathogens
- Contribute science-based data for development and assessment of management strategies for control of diseases in aquatic ecosystems

These science directions implement components of the USGS Strategic Science Plans for both the Ecosystems and Environmental Health Mission Areas and address important needs for other Mission Areas as well. They reflect strategic shifts in program emphases from hatchery-reared to wild fish, increasing attention to ecosystem processes, and our need to better understand the effects of multiple environmental stressors, such as global climate change and contaminants, on the health of aquatic animal populations. Results from this research are directly useful to partners in state, tribal and federal agencies as well as the private sector.

Drivers of Ecosystem Change

Ecosystems and the benefits that they provide are continually changing in response to physical, environmental, and biological conditions. Identifying and understanding human and naturally induced stresses to ecosystems at multiple spatial and temporal scales is needed. These changes are often related to human land use practices. In the western U.S., practices such as dam construction, channelization of waterways, invasive species, agriculture, mining, and urbanization have resulted in changes to habitat and water quality, decreased resilience

to landscape-level stressors such as climate change, and altered ecosystem structure and function. On a global scale, recent projections for the upcoming century point to rapid alterations of climate that will affect water temperatures, sea level rise, seasonal flows, and result in changes to fish and wildlife habitats and migratory patterns. Natural resource managers and research scientists will increasingly be called upon to develop and use tools and knowledge necessary to predict the trends in valued ecosystem resources in the face of potential change. The WFRC has the expertise to provide the fundamental and applied science support to inform management about many aquatic resources.

Our research priorities are focused around a number of direct and indirect drivers of ecosystem change, including climate change, aquatic invasive species, and in-water infrastructure such as dams, levee systems, water diversions, and stream-road crossings. These drivers affect fundamental processes that occur across ecosystems. To address these drivers, we will need to continue to improve our understanding and predictions of changes in hydrological processes, droughts, floods, water availability, and sea level rise under changing environments and how they will affect our aquatic resources.

Priorities include:

- Improve understanding of how aquatic resources are impacted by climate change and land use changes
- Develop adaptation strategies for aquatic species to mitigate the effects of climate change
- Advance our understanding of food web dynamics in freshwater and marine ecosystems
- Examine what enables a species to invade and how it subsequently affects ecosystem structure
- Improve fish passage at hydropower facilities and areas that limit aquatic organism passage
- Determine the effects of ecological flows related to aquatic resources
- Expand our understanding of how climate and anthropogenic changes across landscapes have altered trophic cascades, macro and micro nutrient transfer, and ultimately the health and survival of target species
- Provide science to support natural resource managers in vulnerability assessments, structured decision making, and adaptation planning

These science directions implement components of the USGS Strategic Science Plans for the Ecosystems, Climate, and Land Use Change Mission Areas, as well as addressing needs in other Mission Areas, such as Environmental Health. The strategic shift in WFRC priorities will require multidisciplinary approaches that

link the biotic and abiotic components of an ecosystem, emphasizing the need to leverage and expand partnerships that advance our research priorities. Additionally, our strategic plan includes a shift toward building more predictive capacity and decision support tools. Priorities align with the needs of partners within the DOI agencies (e.g. Landscape Conservation Cooperatives and the Climate Science Centers) and natural resource managers. Although much of the WFRC's research is focused on the western U.S., the expertise and tools developed at WFRC are nationally and even globally applicable to analogous situations in other ecoregions or biomes. Our science can extend outside of our geographic focal areas. We provide decision makers with the proper data, technical assistance, and tools needed to make decisions and develop actions that anticipate changes, reduce risks, and promote resiliency in aquatic natural resources.

Restoration Ecology and Species Recovery

Due to the unique combination of evolution, climate, topography, and historical patterns of human habitation, the Pacific Northwest and Intermountain West contain abundant natural resources that our society values greatly. Natural resources sustain significant economic and ecological values that sometimes come into conflict, resulting in ecosystems that, now or in the future, function in ways different from historical or societal preferences. For example, marine coastal areas of Puget Sound are highly diverse and productive ecosystems valued for commercial and recreational fish and shellfish production, providing habitat for numerous wildlife species, recreation, aesthetics, commercial shipping and infrastructure. As a result of large habitat loss and modifications such as diking and shoreline armoring, some of these valued resources have been diminished, consequently economically important species have been negatively affected. Realization of these values often requires management intervention, and management activities frequently combine with natural processes to create new conditions.

Natural resource managers are often tasked with reversing or changing current ecosystem processes to re-establish historical or preferred patterns. These efforts vary in focus and include broad-scale bio-physical processes, such as treatments for aquatic invasive species controls. The efforts can also focus on individual species that have legal protection or significant economic value, for example restoration projects focused on several species or subspecies of Pacific salmon. The USGS has a role in ensuring that the efforts of natural

resource managers are informed with the latest and most relevant science. Restoration ecology provides the scientific foundation for management efforts to change processes necessary for an ecosystem to function consistent with societal values. Science driven support of habitat restoration and species recovery contributes towards conservation, restoration, and sustainability of biological diversity. The USGS invests significant human capital in restoration ecology and in studies related to species recovery to address societal, and more specifically natural resource managers', scientific information needs.

The WFRC conducts research that elucidates how landscape level stressors like climate, land use, and water availability affect culturally, ecologically, and economically important species and ecosystems. This information is vital for informing decisions involved with restoration ecology and species recovery, by increasing the effectiveness of restoration programs. The WFRC conducts multifaceted research related to the restoration of ecosystems and the recovery of imperiled species. All of our research projects involve addressing one or more of the following science priorities within the domains of restoration ecology and species recovery.

Priorities include:

- Continue to develop tools, technologies, and capacities to inform the selection of priority restoration projects that mitigate habitat loss, reassert habitat connectivity, and foster the recovery of imperiled species
- Better understand how we can use science to track trends in key drivers that influence ecosystem integrity and the ultimate effectiveness of management actions once habitat restoration or species protection programs have been implemented
- Estimate and predict the level of ecosystem services achieved from restoring habitat and how positive changes may be undermined by future climate change
- Better understand how the basic biological needs of a species interact with population limiting factors at all stages of the organism's life cycle. Once identified, determine how data can best be applied towards addressing species recovery efforts
- Identify what factors are affecting changes to critical habitat requirements of a target species, what life stages are affected, and how we can use information about these drivers to forecast species recovery trends
- Advance our understanding of how species recovery efforts and trends will be affected by climate change

These science directions implement components of the USGS Strategic Science Plans for both the Ecosystems and Climate and Land Use Change Mission Areas. This direction aligns well with partners within the DOI agencies (e.g. Landscape Conservation Cooperatives and the Climate Science Centers) and other natural resource managers. Further development of partnerships between science agencies and natural resource managers responsible for developing effective restoration plans and meeting recovery goals will be important under this science direction as we collaborate to develop tools and research projects.

Preparing for Future Challenges

Several regional, national, and global trends or challenges are evident that will profoundly affect aquatic ecosystems and thus future research at the WFRC. Among these are an increasing human population making greater demands on both natural resources and available funding for research; greater concentrations and novel types of toxics and contaminants entering into aquatic systems; continued loss and alteration of freshwater and estuarine habitat; introduction of non-native species and exotic pathogens; changing temperatures and increased weather extremes due to climate change; changes in trophic interactions due to overharvesting; and increasing water use conflicts. All of these factors will alter or stress aquatic ecosystems and the health of animals dependent upon them. Although restoration and recovery efforts will help to mitigate the effects in some areas, we expect that in the future a greater number of aquatic species and habitats could be adversely affected and generate a correspondingly greater need for research. In addition, many of these aforementioned challenges will act synergistically, making it increasingly important for the WFRC to partner with other USGS Centers and colleagues in various disciplines in order to conduct the more integrated and inter-disciplinary research needed to address these challenges.

Recognizing Funding Challenges and Opportunities

Although this is a Strategic Plan for Science, challenges that come with limited funding affect the implementation in meeting science goals, as well as the extent that we can assist partners and provide technical assistance. Finding effective and efficient ways to partner and conduct research will be critical to implementing our plan. Current challenges include the ratio of appropriated to reimbursable dollars, high overhead rates, underfunded scientists, and increasing competition/ cross-over from private contractors and other agencies. The increasing need for interdisciplinary collaborations to better understand the complex natural ecosystems will call on us to find effective ways to respond readily to meet the needs of natural resource partners. The WFRC must maintain a flexible program in a deliberate, effective way to ensure our responsiveness, versatility, and continued

success in addressing the ever-changing needs of natural resource managers. We seek to extend our funding options/alternatives to allow us to readily partner and meet emerging science needs as they arise.

In addition to better understanding our funding alternatives for meeting our science goals, an effort to communicate our capabilities and funding programs will encourage partner to choose WFRC in addressing their science needs.

Partners and Customers

For more than five decades the WFRC has worked with partners to provide research findings to managers of aquatic resources, primarily in the western U.S. These partners form a network of clients, colleagues, co-investigators, and customers. Our partners include numerous clients in other DOI agencies such as the FWS, Reclamation, and the National Park Service. The Center also has partners in other federal agencies, state agencies, universities, tribal governments, and non-government organizations such as The Nature Conservancy and the Lower Columbia River Estuary Partnership.

The WFRC brings specialized expertise, broad research capabilities, and an unbiased approach to conducting science and reporting research results to its many partners. In addition to working on DOI priority research questions, the WFRC conducts research to support partner agencies and other customers. Our partners bring natural resource problems; management perspective and relevance; and questions that challenge our research scientists. The WFRC's partners use the results of our research to benefit natural resource management in the Pacific Northwest and beyond.

The nature of our partnerships varies widely. In some cases they are formalized through mechanisms such as contracts, cooperative agreements, interagency agreements, or memoranda, but they can also be informal. In-kind contributions toward research; collaboration on publications and workshops; and service on graduate student committees are some of the ways these informal partnerships are formed. The WFRC has important collaborations with universities, fisheries partnerships, and community groups that provide significant contributions to its research programs. WFRC scientists conduct collaborative research projects with the University of Washington (UW) faculty. Through our participation in UW programs the Center acquires post-docs, graduate, and undergraduate students that work side-by-side with, and are mentored by, our scientists.

Scientists from the WFRC routinely collaborate with foreign colleagues on a variety of research and technical assistance efforts. A listing of the WFRC's current activities can be summarized in several broad areas:

- Serve as subject matter experts on international scientific panels
- Investigations of genetics and conservation biology of fishes
- Investigations of biogeography and phylogeny of disease-causing microbes
- Investigations of drivers of ecosystem change and resilience
- Investigations of fish response to disturbance and restoration
- Involvement of scientists in development of collaborative research programs and tools
- Provide opportunities for training of specific techniques for visiting scientists or during visits to foreign nations
- Provide technical assistance to partners

Accountability

Accountability can be measured in multiple ways in terms of scientific contributions and public participation. The WFRC has a prolific group of scientists; on average, the WFRC publishes 77 peer-reviewed journal articles, book chapters, reports and other publications annually. The majority of WFRC publications are in the public domain. Additionally, WFRC scientists and managers sit on a wide variety of local, regional and national science committees and boards ranging from city planning groups to landscape conservation cooperatives. These committees and boards keep the WFRC aligned with internal strategic priorities as well as those of our partners on the regional and national scale. The WFRC will begin producing an annual report in 2015 outlining our accomplishments and how they align with our strategic direction as well as with the USGS, Department of Interior and other partners.

Outreach

The WFRC recognizes our responsibility to communicate science findings to a broad audience. As a USGS science center, the WFRC's mission is to provide impartial information in a timely, relevant, and usable format. Maintaining the high quality of our science and communicating it effectively is critical for meeting the needs of agencies, tribes, and partners. The diversity of our scientific expertise allows us to carry out large-scale, multi-disciplinary investigations and provide impartial scientific information to

resource managers, planners, and other customers. The importance of communicating science findings to the society at large makes it essential to share scientific findings with non-science agencies, agency staff, and the general public.

The WFRC strives to focus its outreach efforts on building a unified understanding of the Center's mission and capabilities, creating visibility, promoting the WFRC scientific expertise, and developing partnerships. Through this process, outreach enables the Center to increase the level of trust and assistance to the various entities it serves. Concentrating on developing stewardship and public understanding leads to an increase in public appreciation.

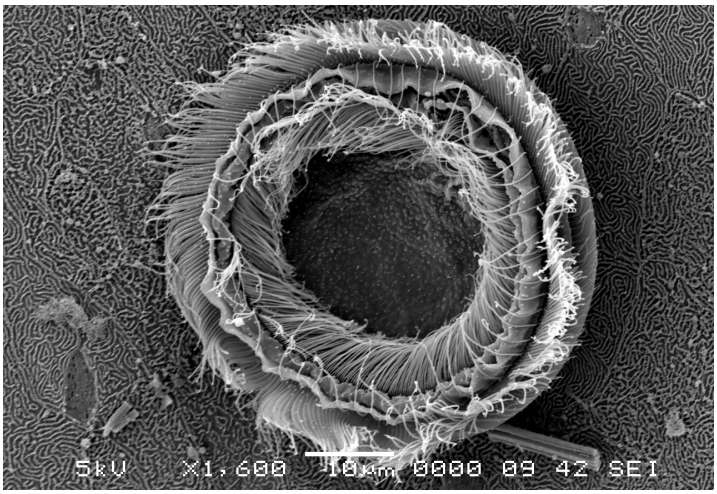
Center strategies for enhanced visibility and coordination include developing relationships with appropriate Program and Regional Coordinators, partners, and congressional staff; arranging site visits to facilitate an understanding of WFRC science and capabilities; demonstrating leadership in organizing and conducting technical meetings, workshops and symposia; preparing informative briefing materials (USGS fact sheets, information sheets, newsletters, congressional briefing materials, and Annual Science Briefs); and developing information transfer and outreach programs (e.g., website, responses to information requests, educational events); engaging in social media (e.g., twitter, Facebook, and Google+), and continued publishing of science products in peer reviewed journals, cooperator publications, and USGS series.

List of Images

Page 2

Image 1. Cover of Western Fisheries Research Center Strategic Plan. Photo by USGS.

Image 2. Mark Johnson, fishery biologist using handheld computer to download PIT data off one of several remote PIT tag detection stations at shoreline spawning areas on the eastern shore of Upper Klamath Lake. Photo by Todd Perry, USGS.



Scanning electron micrograph of a ciliated protozoan, *Trichodina* sp., on the skin of a juvenile Chinook salmon. Trichodinids are ectocommensals and attach to fish while feeding on waterborne particles and bacteria, as well as detritus and particles from the fish surface. Photo by Carla Conway, USGS.

Page 3

Otolith (inset) chemistry and tagging shed light on the migration patterns of mountain whitefish like the one pictured. Photo by USGS.

Page 4

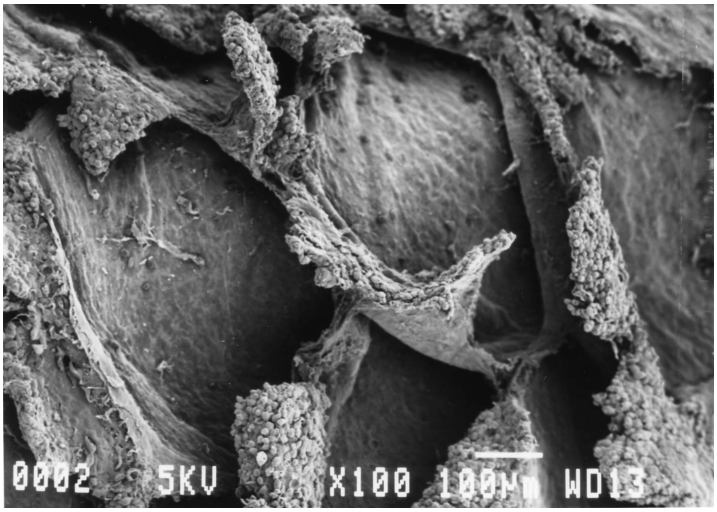
Image 1. Reno Field Station crew surveying for native and non-native fishes in the Independence Lake watershed.

Image 2. Jill Hardiman, fishery biologist collecting samples for invertebrate surveys, Klickitat River. Specifically doing an early detection survey for New Zealand mudsnail. The mudsnails are not present in this river, but this was the first quantitative sampling effort to establish a baseline probablistic effort for this species. The surveys were done in conjunction with outreach efforts on invasive species by the Underwood Conservation District. Photo by Amy Puls, USGS.

Page 5

Image 1. Viruses are very small. Researchers use fish cells grown in plastic flasks to detect the presence of fish viruses by observing the changes in the infected cells. Photo by Gael Kurath, USGS.

Image 2. George Sanders, veterinarian in zebrafish laboratory at the Western Fisheries Research Center. Enlargement of zebrafish in tank (upper right). Photo by Gael Kurath, USGS.



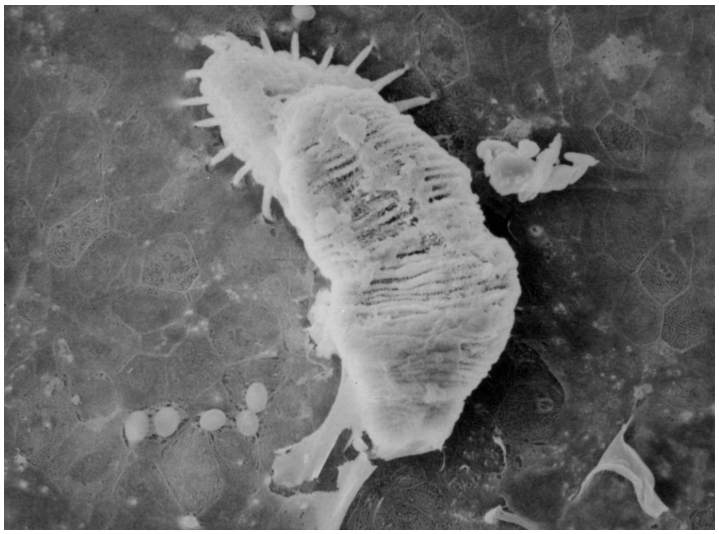
Scanning electron micrograph of a recent skin injury to a juvenile Chinook salmon showing torn epidermis, scale loss and empty scale pockets. On non-injured skin, epidermal tissue covers the scales and is important in preventing the entry and establishment of pathogens. Photo by Carla Conway, USGS.

Page 6

Image 1. Biological technician Doug McKenney and graduate student Daniel Hernandez prepare to add virus to replicate tanks of juvenile Chinook salmon for an

experiment comparing the virulence of five strains of the fish virus infectious hematopoietic necrosis virus. Photo by Gael Kurath, USGS.

Image 2. Map showing location of WFRC facilities. Original image proved by EROS - USGS.



Scanning electron micrograph of an ectoparasitic fluke, *Gyrodactylus* sp. on goldfish skin. Note the hooks along the margin of the attachment organ. Photo by Diane Elliott, USGS.

Page 7

Image 1. Susceptibility testing of fish species to exotic or invasive viruses by injection in the aquatic biosafety level three (BSL-3) laboratory, a high level quarantine facility designed to conduct in vivo and in vitro studies with aquatic pathogens of veterinary significance. Scientist in photo: Evi Emmenegger, supervisor of the aquatic BSL-3 laboratory. Upper left: Experimental infection of a juvenile fish by injection of virus controls the dose of virus delivered to each fish. Photos by USGS.

Image 2. Adult cutthroat trout infected with Cutthroat Trout Virus show no sign of disease. Photo by David Leer, Oregon State University.

Page 8

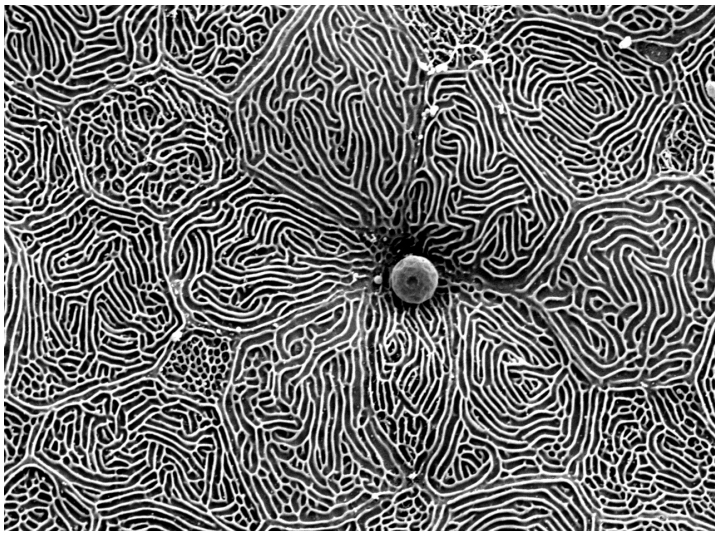
Image 1. Dr. Paul Hershberger performing a necropsy on wild rockfish collected from the Salish Sea. Photo by USGS.

Image 2. Deploying a DIDSON acoustic camera to observe chum salmon spawning behavior. Photo by USGS.

Page 9

Image 1. Mark Johnson, fishery biologist with a female Lost River Sucker from Sucker Springs on Upper Klamath Lake. Photo by Todd Perry, USGS.

Image 2. Installation of two 20’ PIT tag antennas across the Wood River in Klamath County, Oregon. Antennas are used to monitor movements of Lost River and shortnose suckers and Redband trout throughout the Klamath Basin. Photo by Brian Hayes, USGS.

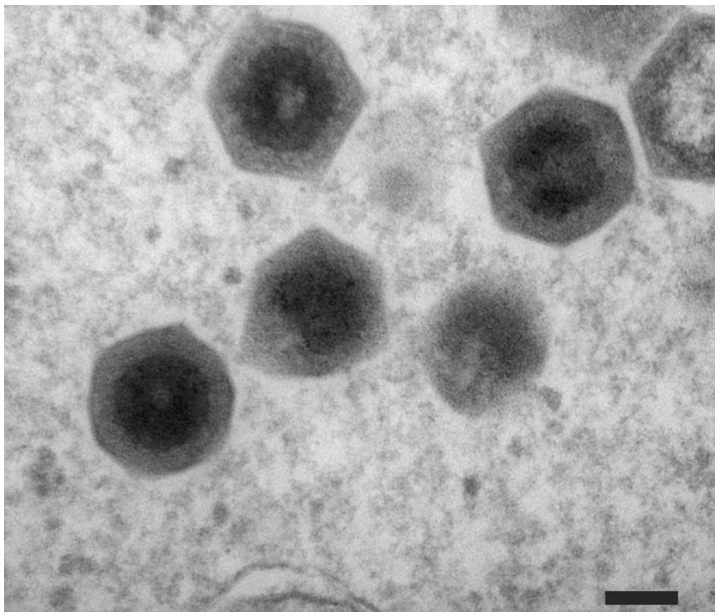


Individual epithelial cells on the skin of a juvenile Chinook salmon have finger-print-like microridges, which help mucus adhere to the surface. A mucous cell seen in the center of the photo is discharging mucus. Scanning electron micrograph by Carla Conway, USGS.

Page 10

Image 1. A volunteer releases a tagged Lahontan cutthroat trout. Photo by Danielle Johnson, USGS.

Image 2. Figures 1A and B. Histological sections of Pacific herring heart (A) and red-spotted newt skeletal muscle (B) after CISH staining. (A) Dark purple specific DNA staining identifies the *Ichthyophonus* parasite. (B) No specific DNA staining in a parasite previously identified as *Ichthyophonus*.



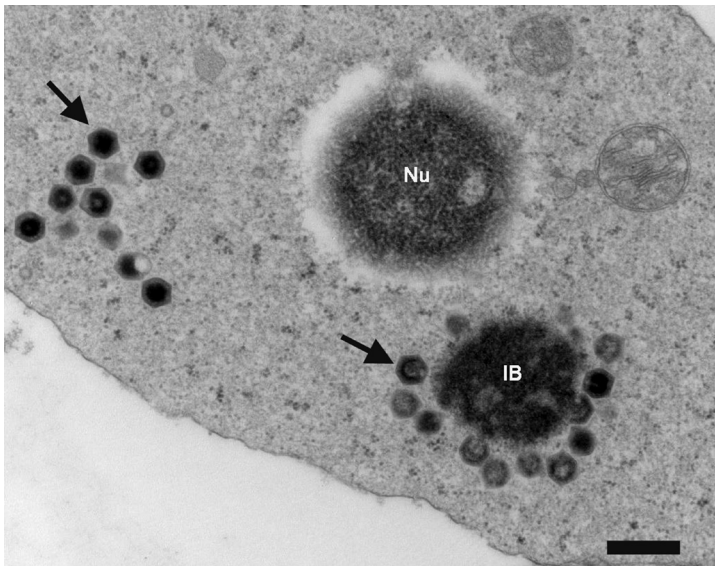
Higher magnification transmission electron micrograph of erythrocytic necrosis virus particles in the cytoplasm of a Pacific herring erythrocyte. Scale bar=500 nm. Photo by James Driver, University of Montana for USGS.

Figures 1C to F. Juvenile Chinook salmon exposed to 0.1 % fast green FCF following descaling injury. (C) Descaling site 6 hours after injury, showing blue-green stained areas of scale loss and epidermal injury. Unstained areas have intact epidermis. (D) Scanning electron micrograph (SEM) of descaled area delimited by box in (C), showing empty scale pockets and epidermal disruption (white arrowheads) and areas of intact epidermis covering scales (white arrows). (E) Descaling site 24 hours after injury, showing scale loss but no fast green staining. (F) SEM of descaled area delimited by box in (E), showing individual epithelial cells that have migrated to cover the injury site. Photos by Carly Conway, USGS.

Page 11

Image 1. A recently arrived steelhead trout virus is killing thousands of juveniles like the one pictured in the waters of coastal Washington. Photo by Rachel Breyta.

Image 2. Greg George, USGS walks a section of the Wapato reach, the focus of recent hydrodynamic studies on the Yakima River. Photo by USGS.



An erythrocytic necrosis virus inclusion body (IB) surrounded by virus particles (arrows) in the cytoplasm of an erythrocyte in blood sampled from a Pacific herring. The nucleus (Nu) of the infected cell is also visible. Scale bar=100 nm. Transmission electron micrograph by James Driver, University of Montana for USGS.

Page 12

Image 1. Scientists at WFRC are conducting multidisciplinary studies on the Elwha River to understand the outcomes of dam removal and ecosystem recovery. Photo by USGS.

Image 2. Detroit Dam on the North Fork Santiam River, a major tributary of the Willamette River, poses a challenge to

juvenile fish on their journey to sea. Photo by Philip Haner, USGS.

Page 13

Image 1. Negative effects of shoreline armoring include reduced beach width, accelerated sediment scour, and restricted beach nourishment. Photo by USGS.

Image 2. USGS researchers survey forage fish spawning to determine preferred spawning habitat. Photo by USGS.

Page 14

Image 1. Small herring spawning event in Puget Sound, evidenced by the presence of 'white water', caused by mass release of spawning products into the water. Lower left: Naturally-deposited herring eggs attached to submerged macrophytes. Coiled embryos are evident inside the eggs. Lower right: Herring juvenile 103 days post-hatch. Larval metamorphosis to juveniles is complete. Photo by USGS.

Image 2. Collin Smith, fishery biologist and Ryan Tomka, biological technician collecting phytoplankton samples to assess carbon and nitrogen ratios in the food web within central Puget Sound to evaluate the effects of urbanization on the nearshore ecosystem. Photo by Lisa Gee, USGS.

Page 15

Image 1. Graduate student Daniel Hernandez, from the University of Washington School of Aquatic and Fishery Sciences, measures virus for a Chinook salmon infection experiment in the WFRC wetlab. Photo by USGS.

Image 2. USGS research ecologist Jeff Duda takes habitat measurements on the Elwha River, Washington. Photo by USGS.

Page 16

Image 1. Boats along the bank of the Mekong River and fish at a local market at Luang Prabang, Laos. Photos provided by John Beeman and Matthew Andersen, USGS.

Image 2. Retrieving a lampara net while sampling nearshore fish habitats, Nisqually River delta. Photo by Mike Hayes, USGS. Upper left: Karl Stenberg tossing the lead line and preparing to set a lampara net, Nisqually River delta. Photo by Walker Duval, Nisqually River Foundation.

Page 17

Image 1. Graduate student Michelle Penaranda, from the University of Washington Pathobiology program, nets sockeye salmon for an experiment in the WFRC wetlab. Photo by Gael Kurath, USGS.

Image 2. Fish health principle investigators, students, post-docs, and technicians from different research groups work together as a fish processing team on days when large numbers of fish require sampling. They are collecting multiple tissues from each fish for testing virus infection and host immune response. Photo by Gael Kurath, USGS.

Page 18

Image 1. Photo Crims Island, by USGS.

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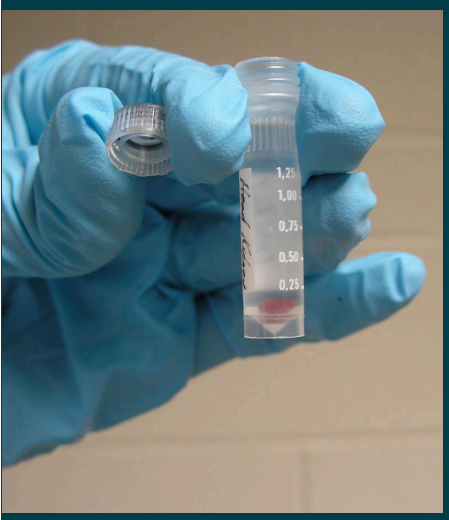

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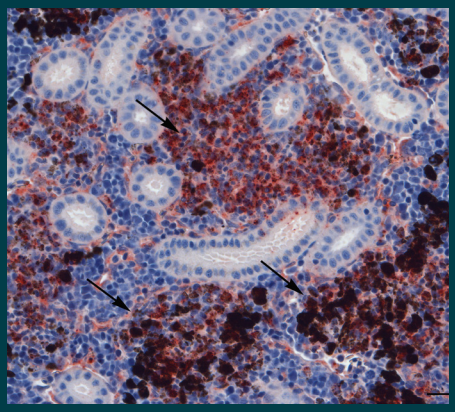

Back Cover: Left to Right

Top Row:

1. Small tissue sample in a storage tube. Photo by Gael Kurath, USGS.

2. Former graduate students Michele Penaranda and Andrew Wargo, University of Washington, in the wetlab at the WFRC, Seattle, WA. Photo by Gael Kurath.

3. Jake Gregg, fishery biologist working at the microscope, Marrowstone Marine Field Station. Photo by USGS.

Bottom Row:

1. Researcher releasing female chum salmon. Photo by USGS.

2. Sunrise on the Columbia River. Photo by Glen Holmberg.

3. Immunohistochemical detection of *Renibacterium salmoninarum* bacterial antigen (red color at arrows) in a 5 µm-thick section of Chinook salmon kidney. This species of bacteria is the causative agent of bacterial kidney disease (BKD), which is a serious disease of both wild and farmed salmonids. Photo by Carla Conway, USGS.