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Session 1: Climate Change

Restoration strategies to increase salmon resilience to climate change

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Climate change will affect many aspects of Pacific salmon habitat including flow regimes, water temperature, ocean productivity, land cover, pathogens, food webs, and water quality. However, anticipated habitat changes and salmon life histories vary greatly across the geographic range of salmon, so salmon populations are not all equally susceptible to climate change. Moreover, causes of habitat degradation vary among rivers, so options for conserving robust salmon populations must be evaluated in the context of each watershed and population's sensitivity to climate change. Both of these factors—the relative susceptibility of populations to future climate, and the likely impacts of management strategies in different areas—are key for prioritizing actions aimed at protecting and restoring salmon under a changing climate. This study addresses two questions that must be answered to develop effective salmon conservation strategies across their range. First, which salmon populations or meta-populations are most sensitive (or, conversely, most resilient) to climate change? And second, what management strategies and conservation actions will most benefit salmon populations under alternative climate futures?

We address the first question by ranking population sensitivity to climate change based on current and historical salmon population status for abundance, productivity, spatial structure and diversity, the effects of habitat degradation, and climate change scenarios for in stream flow and water temperature. We are first conducting a pilot study on populations in the Columbia River basin, using existing data from landscape and population analyses conducted in the contexts of salmon recovery planning and the Federal Columbia River Power System Biological Opinion. Once we have developed the ranking methodology, we will then expand the analysis to the full range of salmon using correlated but coarser resolution data sets for the three key ranking criteria -- predicted climate change effects, salmon population status, and current habitat degradation. We address the second question

using salmon population modeling to evaluate the likely outcome of alternative restoration strategies combined with shifting habitat conditions due to climate change. These analyses will be conducted on a limited number of watersheds and salmon species spread across latitudinal range of salmon (Sacramento River to Yukon River). Outcomes of these analyses will identify region-specific restoration strategies that are most likely increase salmon resilience to climate change.

Predicting effects of climate change on freshwater stages of Columbia River salmon

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Climate affects organisms through an intricate web of ecological interactions and evolutionary responses, all mediated by local habitats. We have explored some of these interactions and population-specific environmental sensitivities in Columbia River salmon. Because of the complex life history of salmon, each life stage confronts different environmental challenges. Recognizing this complexity, we have focused on identifying life-stage-specific and population-specific responses of Columbia River spring/summer Chinook and sockeye salmon to variation in climate. Using a unique 18-year PIT-tag study of 13 Snake River Chinook populations, we identified strong but complex effects of variation in temperature and flow on juvenile growth and survival. At low fish densities, temperature correlated positively with parr length, but higher fish densities reduced or reversed this relationship. All of the 13 populations studied exhibited this pattern. Populations differed, however, in the sensitivity of parr-to-smolt survival to environmental conditions. Fall flow was the most important environmental predictor of survival for most populations, but summer temperature was highly significant in some cases, especially at lower elevations. We linked these patterns in survival with hydrological projections of climate change in these streams, and used life-cycle models to evaluate potential consequences of climate change for population viability. Scenarios of climate change produced declines in abundance and increases in extinction risk in all populations, but the relative risks among populations depended on the climate change scenario. Shifting our focus to the adult stage, we explored the history of upstream migration timing in sockeye salmon. Sockeye salmon now enter the lower Columbia River 10 days earlier, on average, than they did in the 1930s. Based on a model of the potential effects of river temperature on migration survival and a simulation of historical selection pressure, we argue that this change reflects both evolutionary and plastic

responses to rising river temperatures. We conclude that climate change can have both positive and negative effects on salmon, but the net effects depend, in part, on the responses of other species to environmental change. Salmon will adapt to climate change, but the limits to adaptation are unknown. Ultimately, the extent of climate change will determine which life history types remain viable in the Columbia River basin.

Canaries in the sea: Monitoring physiological status of fish in the context of environmental conditions

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The status of fish populations is generally monitored in terms of number of individuals and characteristics such as body size, age of maturity and genetic diversity. These characteristics generally reflect how fish are adapting to environmental change over long periods of time. However, more in-depth analyses of the physiological status of individual fish in the context of environmental variables can yield valuable information on the quality of the habitat and future life history decisions. To this end, we have developed and validated a variety of endocrine and molecular tools to monitor growth, reproduction, and stress in salmonid fish that may be useful for a variety of marine fish species. A combination of laboratory and field studies have shown that plasma levels of a growth factor (IGF I) can be used as a growth index in juvenile salmon. Levels of sex steroids have been used to identify individuals that are maturing as much as 12 months before spawning, well in advance of obvious changes in gonad morphology or size. This information has been used to determine precisely when salmon are initiating maturation in a given year so that we can better understand what environmental factors may be influencing this critical life history decision. We have also taken a targeted gene approach to identify transcripts for reproductive genes that are altered in response to environmentally relevant concentrations of estrogenic chemicals, and could be incorporated into current programs that monitor juvenile salmon for exposure to environmental estrogens. Aims of current and future work are to develop more comprehensive molecular markers of cell growth, cell death, and reproductive status that can be used on tissue biopsies to assess physiological status of salmon in relation to environmental variables in field studies.

Tempo and mode: possible effects of climate change on variability in ocean environments and salmon survival.

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Many climate change studies have explored the likely physical and biological effects of rising temperatures on salmon runs and a variety of other species. Less attention has been paid to another likely effect of climate change: increasing variability. We are starting to see evidence of changing patterns of inter-annual variability in ocean environments. Given the sensitivity of salmon populations to ocean conditions, we would expect to see accompanying changes in patterns of salmon survival. We use 10-year moving standard deviations to look for changes in variability in major ocean climate indices and in salmon populations from Alaska to California. Patterns vary widely, but there is a strong indication of increased variability in large-scale climate indices such as the PDO. Many, but not all, salmon populations also show increasing variability in escapements. Climate-driven patterns in salmon can be difficult to identify as they are confounded by other anthropogenic factors including harvest, hatchery practices, and habitat alterations. If environmental variability is, indeed, increasing we would expect to see it in freshwater as well as marine environments. This would challenge salmon populations' ability to respond and places increasing importance on maintaining genetic and life-history diversity in salmon runs. Population viability models often include variability, based on historical observations, as a risk factor. Increasing variability would increase risk to salmon populations and should be accounted for in assessing viability.

Climate Impacts on Harmful Algal Blooms in Puget Sound

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The influence of weather and climate variations on harmful algal blooms of *Alexandrium* in Puget Sound is investigated using observations of shellfish toxicity from

1957 to 2007. *Alexandrium* produce potent neurotoxins called paralytic shellfish toxins (PSTs) that accumulate in filter-feeding shellfish and threaten human health. We use concentrations of PSTs in shellfish tissues as a proxy to describe *Alexandrium* bloom dynamics and examine the influence of climate on daily, interannual, and interdecadal timescales. A combination of low streamflow, weak surface winds, and small tidal variability appears to precede sound-wide PST events. This combination of environmental conditions typically occurs in early fall following seasonal warming of sea surface temperatures over the summer. On longer timescales, shellfish toxicity co-varies with warm phases of the Pacific Decadal Oscillation (PDO) and the window of optimal growth conditions for *Alexandrium* as determined by sea surface temperatures exceeding 13°C. However, no robust relationship exists with warm phases of the El Niño Southern Oscillation (ENSO). This is because warm winter temperature anomalies during warm ENSO events do not persist for long enough to overlap with the annual time period that shellfish accumulate PSTs in Puget Sound, which is typically from July through November. In contrast, warm winter temperature anomalies during warm phases of the PDO persist for 4 to 5 seasons or more with re-emergence the following year. By extrapolating mechanisms leading to shellfish toxicity on smaller and more localized scales, we predict that rising water temperatures associated with the regional impacts of anthropogenic global warming may promote earlier and longer lasting PST events in Puget Sound in the future.

Session 2: Research HiLights I

Multivariate characterization of anadromous and resident *O. mykiss*: three dam scenarios

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Fish isolated behind major dams in the Northwest United States have undergone differentiation for 80+ years. As these dams are removed or bypassed, resident rainbow trout (O. *mykiss*) upstream will be exposed to anadromous populations of *O. mykiss* (steelhead). How rainbow trout will interact with steelhead is an important question to consider in conservation and management circles. Precise characterization of both gene pools is paramount prior to dam removal/bypass to follow the interaction of the two life history types.

I present an overview of our studies of O. mykiss in six river systems in the Columbia River and Puget Sound basins (including Icicle Creek, Wenatchee River; White Salmon River; Little Sandy River; Lewis River; Green River; and Elwha River). Results for three dam sites are provided. To describe the level and patterns of differentiation of gene pools above and below dams, we are using 15 microsatellite loci, two major histocompatibility loci, and morphological characteristics (body shape and coloration patterns). These results can be used to understand rates of character differentiation and adaptation, to monitor population recolonization, and to recognize/conserve not only critical populations but also unrecognized "gems" in river restoration projects.

The Role of the Columbia River Estuary in Salmon Recovery

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In 1999 NOAA Fisheries organized a team of researchers to review the status of knowledge about the estuarine ecology of Columbia River salmon and the potential role of the estuary in salmon population decline and recovery. The results of this review, summarized in the Salmon at River's End (SARE) report, hypothesized that historic habitat losses had (1) reduced rearing opportunities for salmon; (2) simplified salmon life history diversity; and (3) reduced the contribution of wetland and other macrophytic plants to estuarine food webs, potentially decreasing the estuary's capacity to support juvenile salmon. From 2002-2007 we conducted new studies to investigate salmon distribution and habitat use in the estuary and to evaluate the SARE hypotheses. Our results confirm that salmon rearing opportunities in the lower estuary have decreased substantially during the last century, while hatchery programs, watershed modifications, and other changes likely have simplified historical patterns of estuarine migration and residency by juvenile Chinook salmon. Nonetheless, we have documented significant variation in Chinook salmon life histories, longer-than-expected estuarine residence times (even among some upper basin stocks), and strong selection by salmon for carbon sources that are linked to wetlands and other shallow estuarine habitats. Genetic analyses revealed that all Columbia River ESUs (Evolutionarily Significant Units) are capable of expressing estuarine-resident life histories, although the patterns of estuarine habitat use may vary among genetic stock groups. The estuary's role as a nursery ground for stocks throughout the basin suggests that restorative actions above Bonneville Dam alone will not be sufficient to meet salmon recovery goals or to ensure population resilience in a changing environment. However, restoration needs throughout the upper estuary (Rkm 100 to Bonneville Dam), where wetland and floodplain habitat losses are extensive and stock-specific habitat use has not been investigated, remain poorly understood. An important question for future ecosystem management is whether hydrological and other changes have caused the ecosystem to cross an ecological threshold that could resist future estuary restoration and salmon recovery efforts.

A novel approach for estimating the ages of cetaceans using blubber fatty acid compositions of biopsy samples

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Information on the age distributions of cetacean populations is important in assessing their status and long-term viability. Current methods of ageing cetaceans rely either on limited longitudinal sighting studies of individual animals from the birth year or on post-mortem procedures to extract tissues suitable for age determination. Here, we describe a method for estimating the ages of live, free-ranging eastern North Pacific killer whales, as well as humpback whales from the Northwest Atlantic and Southeast Alaska, using low-impact biopsy sampling techniques. Specifically, shallow outer-blubber samples were obtained from known-age whales and analyzed for lipid class and fatty acid (FA) compositions. Individual short-, branched-, and odd-chain FAs correlated better with age for transient and resident killer whales of both sexes than did wax/sterol esters but these single parameter relationships were population specific, moderately scattered and varied with long-term diet. We found that, independent of whale age, diet and ecotype, the ages of individual animals could be predicted with good precision ($\sigma = \pm 3.8$ years) using a simple, multi-linear equation model derived from the combination of two specific FA ratios. For humpback whales, four multilinear FA-age models were developed, using exact known-age animals or exact age plus minimum known-age whales from two distinct populations. Each of these empirical models was based on a linear combination of FA ratios (two specific FA ratios per model) rather than their individual FA compositions and each appeared to be largely independent of sex, diet and nutritional status. Although the precision of these models was somewhat variable, our findings suggest that it should be possible to estimate the age of an individual humpback whale with better than decadal resolution using this approach. Based on these findings, it is our intention to explore the possibility of using this novel approach to estimate the ages of other species of cetaceans and pinnipeds, particularly for remote populations that have not been continuously observed.

How noise exposure affects the vocal behavior of Southern Resident killer whales

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Marine mammals use sound for foraging, breeding, predator avoidance, and coordinating group movement. Noise exposure has the potential to interfere with the reception and use of these sounds. Killer whales produce a variety of acoustic signals including echolocation clicks to detect prey and calls for communicative functions. Call production and exchange is believed to function to coordinate movement among group members when individuals are dispersed and foraging. The inland waters of Washington state and British Columbia are important summer and fall foraging areas for Southern Resident killer whales where a variety of vessels and other sources of anthropogenic noise are also prevalent. Vessel noise can mask or cover up the calls that killer whales produce because the frequency range of noise emitted from nearby vessels overlaps with the frequency range of killer whale calls. Individuals may compensate for background noise by changing their signal's amplitude, duration, repetition rate, and/or frequency. Such vocal compensation is often interpreted as an anti-masking strategy for high background noise levels. The goal of this study was to investigate call amplitude compensation (the Lombard effect) in these killer whales to elucidate how they might compensate for changing levels of background noise in the marine environment and how vessel numbers contribute to noise exposure in this population. Additionally, behavioral data observed at the surface were also collected to determine how the use of different acoustic signals corresponded with group activity states. This information is useful to infer events such as foraging using remote acoustic monitoring and also to determine how noise exposure might affect the activity states of the whales. Data were collected in waters surrounding the San Juan Islands during the summer months using a calibrated recording system. We used multiple hydrophones to determine the range at which calls were produced and then calculated call source levels and background noise levels in the 1-40 kHz band. Call source levels were positively correlated with background noise levels and the slope of the fitted linear regression line indicated that whales increased their call amplitude by 1 dB for every dB increase in background noise levels. Motorized vessels within 1000 m of the recording device explained 45% of the variation in background noise levels. The upper range of background noise levels corresponded to approximately 45 nearby vessels. Sound production patterns compared by behavioral states illustrated that calling rates as well as the presence of fast and slow clicks were significantly higher when whales were foraging compared to when they were travelling. These results indicate that not only echolocation clicks but also communicative signals are particularly important to foraging whales that are faced with the challenge of hearing these signals in anthropogenic noise.

Home range size and patterns of space use by lingcod, copper rockfish and quillback rockfish in Puget Sound in relation to diel and tidal cycles

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For marine fishes the estimation of home range size has received attention recently because of its application to the design of marine reserves. How individuals use space may also be important to the management of the species or for understanding behavioral processes like optimal foraging or territoriality. We used an acoustic tracking system (VRAP) to examine patterns in home range size and movement behavior for three demersal fishes in Puget Sound: lingcod *Ophiodon elongatus*, copper rockfish *Sebastes caurinus* and quillback rockfish *S. maliger*. Data were collected over eight weeks in the summer of 2006.

Home ranges were relatively small (~1500 to 2500 m2) and did not differ among species. However, lingcod had larger home ranges during the day than at night. Movement in all three species was in some way related to diel and tidal cycles, although individuals within species differed, and there was no general pattern. For example, about half of the lingcod used particular portions of their home ranges only during the day and on the flood tide. However, other individuals did so on the ebb tide. Some copper rockfish moved to specific areas of their home range on the day ebb tide, while others did so on the night flood tide and others showed no pattern. Similar results were seen for quillback rockfish. The individual variation in movement behavior is the most interesting aspect of the results. Failure to incorporate this variation into ecological models ignores the individual level variability upon which natural selection operates.

Session 3: Ecosystem Research

Quantitative approaches for identifying species interactions and resilience in marine ecosystems

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Scientists and policy makers often rely on models to improve their understanding of marine ecosystems and effectively manage fisheries resources. Mechanistic models (e.g., ATLANTIS, EcoSim) utilize functional relationships and empirical data on diets in an attempt to recreate food web dynamics. In systems where information on diet and functional relationships is missing, or they change over time as environmental conditions change, the development of mechanistic ecosystem models typically proves challenging and requires assumptions that are difficult to validate with data. Over the past decade, however, quantitative ecologists have been developing and applying an alternative approach to ecosystem modeling. This statistical method is based on modeling time series of species abundances produced by biological interactions and the physical-chemical environment rather than modeling the underlying mechanisms themselves. By using a set of multivariate auto-regressive (MAR) equations as an approximation to nonlinear, stochastic community dynamics, one can estimate the strength of interaction among various species and compare them to the relative effects of environmental drivers (e.g., temperature, contaminants) in structuring the ecosystem. This allows for the identification of important (i.e. "keystone") species toward which management efforts might be concentrated. Furthermore, various stability properties can be calculated and used to assess ecosystem resilience to environmental and anthropogenic disturbances. We will discuss how we have applied MAR models to freshwater ecosystems and how we are advancing their development and application in the Puget Sound and California Current ecosystems.

An ecosystem-scale assessment of abundance, life history and genetic diversity of steelhead (*Oncorhynchus mykiss*) in Hood Canal, Washington.

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In 2006, we initiated an ecosystem-scale hatchery experiment in the Hood Canal to determine the effects of steelhead (*Oncorhynchus mykiss*) hatchery programs on ESA-listed natural populations. The study involves monitoring abundance, genetics and life history diversity in three supplemented and four non-supplemented natural populations before, during, and after hatchery fish begin spawning in any of the streams. This presentation reports preliminary data from the 'pre-supplementation' phase of the project to characterize the 'natural' condition of Hood Canal *O. mykiss* populations.

Flow and temperature and geologic profiles of Hood Canal streams vary widely. Eastside lowland streams (Big Beef Creek, Dewatto River, Tahuya River) are typified by lower flows (particularly in the summer) higher temperatures and a decreasing flow through the winter and spring. Western streams draining the Olympic mountains (Little Quilcene, Dosewallips, Duckabush, Hamma Hamma, and Skokomish) are steeper, colder, have increasing spring flows associated with glacial or snow melt run-off, and all but one (Skokomish) have barriers to anadromous fish migration.

Adult abundance (based on redd surveys) is strongly positively correlated with stream length (R2 = 0.87), but not mean flow (R2 = 0.24) or annual cumulative temperature units (R2 = 0.01). Abundance has been fairly stable in all streams over the past 15 years. Streams without barriers to anadromous migration support adult populations that are approximately twice as dense (# redds per mile) as populations with anadromous barriers that support rainbow trout populations above and below the barriers. Otolith microchemistry data suggest that juvenile *O. mykiss* in non-barrier streams were spawned almost exclusively by anadromous (i.e., steelhead) females, whereas significant proportions of parr from the anadromous-accessible reaches of the barrier streams (Hamma Hamma, Duckabush, and Dosewallips) were spawned by resident (i.e., rainbow trout females).
Analyses of microsatellite DNA data show significant genetic differentiation between east side and west side populations. The Hamma Hamma River also shows further differentiation from other west side populations. Resident and anadromous *O. mykiss* within the same river were genetically more similar to each other than to samples of the same life history type from different rivers.

Despite the large variation in watershed characteristics and habitat quality throughout the Hood Canal, all populations appear to be in a depressed state (fewer than 8 redds per km). Early marine survival estimates obtained through acoustic telemetry monitoring suggest that mortality during the first two to three weeks after seawater entry may be a common factor limiting the productivity of steelhead populations throughout Hood Canal.

Ecosystem Services Provided by the Nearshore in Puget Sound: An Analysis of Change

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In principle, the framework of ecosystem services (benefits people obtain from ecosystems) can inform ecosystem approaches to managing coupled social-ecological

systems such as Puget Sound. However, the transition from theory to practice is challenging. Making ecosystem services a useful concept to Puget Sound ecosystem management requires basic research on how services vary across the region and how they might be affected by alternative management schemes. We examine a diverse suite of ecosystem services that are derived from nearshore marine habitats across the Puget Sound region and model how changes in the nearshore are likely to affect the flows of those services. First, we will outline the scope of our program, summarizing the range of services within our purview and the ways in which we are modeling them. Then, we will discuss model results from some key services (e.g. the provisioning of seafood and carbon sequestration by eelgrass). Throughout we will emphasize three key themes: 1) the utility of modeling change in ecosystem services under alternative management scenarios, rather than tallying static ecosystem services and their values, 2) the importance of incorporating spatially-explicit information into ecosystem-service modeling, and 3) the benefit of close interdisciplinary collaboration between economists and ecologists undertaking ecosystem services work.

A descriptive example of applying vulnerability evaluation criteria to California nearshore species

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In light of ongoing crises in fisheries and marine ecosystem management, a growing body of literature has highlighted the need for biologists and resource managers to develop and apply methodologies that are capable of identifying species or populations at greater risk of overexploitation and extirpation. One increasingly popular approach is a productivity and susceptibility analysis (PSA), originally developed for Australian prawn fisheries, in which the vulnerability of a given stock is based on a combination of the estimated or perceived productivity of the stock plotted against the susceptibility to overfishing. This presentation provides an example of this type of analysis developed for the 19 species included in the California Nearshore Fishery Management Plan (NFMP). The methodology is based on a version of the PSA approach being developed by the NOAA Fisheries Vulnerability Evaluation Working Group (VEWG), which is currently in the process of preparing draft technical guidance for conducting vulnerability assessments for species managed under Fishery Management Plans implemented by the regional Fishery Management Councils.

Results of this case study in particular indicate that the more vulnerable species in the NFMP include China, copper, quillback and blue rockfishes, of which only the latter has been evaluated in a formal stock assessment. More importantly, we suggest that additional and more rigorous analysis of these or of other species managed by either (or both) the State of California and the Pacific Fishery Management Council, may aid managers and stakeholders in setting research and assessment priorities, considering management alternatives and strategies, developing or revising species assemblages for multispecies management systems, and evaluating how precautionary catch limits should be based.

A regional effort to select environmental indicators for the Puget Sound

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The Puget Sound Partnership (PSP) is developing an Action Agenda to serve as a roadmap for restoring and maintaining the health of Puget Sound. To evaluate progress towards their goals, NOAA led a regional effort to identify a robust, integrated, set of environmental indicators to characterize and communicate information about six components of the Puget Sound ecosystem (species and food webs, habitat and processes, water quality, water quantity, human health, and human well being). Developing quantified outcomes and performance standards for environmental indicators takes several years, so, to meet the short timeline for developing the Action Agenda, a tiered two-phase process was developed to inform policies and management actions both immediately (Phase 1) and in the longer term (Phase 2). The objectives of the Phase 1 indicator's project were to develop a consistent set of criteria and framework for evaluating environmental indicators, to create conceptual models that define key structures and functions of the Puget Sound ecosystem, and to then select the most suitable "recommended available indicators" from a list of existing indicators. Additional work will be necessary in Phase 2 to develop new indicators.

For Phase 1, a hierarchical decision tree was selected for evaluating individual indicators that grouped selection criteria into five evaluation questions: Is the indicator conceptually valid? Do data exist? Can the indicator be feasibly implemented? Are the statistical properties understood and sufficient? Does the indicator fulfill management and reporting needs? Additionally, two frameworks were identified that collectively assist with identifying the suite of indicators necessary to track the health of the Puget Sound ecosystem, one that reflect properties of a functioning ecosystem, plus one that attempts to address causal mechanisms underlying ecosystem function. EPA's list of Essential Ecological Attributes was used to

assess and report on ecological conditions. A Driver-Pressure-State-Impact-Response (DPSIR) causal chain framework was used to define the causal links or relationships between ecosystem attributes we can measure and aspects of the ecosystem that have high relevance to humans. A DPSIR framework was also chosen as the common framework to develop several component-based conceptual models.

Based on these criteria/ framework and conceptual models, a non-prioritized list of indicators was selected for further consideration by the Partnership. The use of the selected indicators will depend upon the specific assessment questions and strategies put forward by the Partnership and their intended uses. The provisional indicators serve as a tangible starting point for dialogue between policy and science, placeholders until final indicators are identified. The final suite of indicators to be selected in Phase 2 will draw from the pre-approved provisional indicator list and new indicators that will be developed using the criteria/framework and conceptual models from Phase 1. The final suite of indicators should include state and impact indicators that inform us about the seriousness of the problems and response and pressure indicators that tell us how best to fix them.

Session 4: Rapid Fire I

Molecular correlates of olfactory imprinting in Pacific salmon

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Pacific salmon are well known for their extraordinary homing migrations from oceanic feeding grounds back to their river of origin to spawn. These migrations are governed by olfactory discrimination of homestream odors that juvenile salmon learn (imprint to) prior to their seaward migrations. Successful homing requires that salmon experience homing cues during sensitive periods for imprinting. Our previous studies have suggested that during imprinting, the peripheral olfactory system is sensitized to specific homestream odorants. In our program we are hoping to exploit this sensitization to develop cellular or molecular markers that are correlated with olfactory imprinting to identifying important developmental periods and environmental influences important for successful imprinting. As part of this sensitization process, we have shown that specific olfactory receptors are upregulated in response to odorant exposure. Specifically, we are studying expression of a candidate odorant receptor for L – arginine, a potent salmon odorant, during the process of imprinting. Using a combination of molecular, physiological, and behavioral assessments, we have demonstrated

that salmon exposed to L-arginine during appropriate developmental stages demonstrated long-term memory formation for this imprinting odorant ($P \leq 0.05$; two-sample t-test). Treatment groups that successfully imprinted, as evidenced by adult behavior, also demonstrated increased expression (relative to arginine-naïve fish) of the putative arginine receptor mRNA in the olfactory epithelium. Our results suggest that early odorant exposure may affect olfactory receptor expression throughout the life of a salmon and these receptors may provide a molecular marker for imprinting success. Ultimately, we hope to use these markers to aid in developing management and land-use practices that ensure successful imprinting and will minimize straying by hatchery and wild fish.
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Voucher specimen collections for deep-water corals and marine fishes

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We are developing an initial species inventory of deep-sea corals off the NE Pacific coastline as a necessary first step to understanding more about the ecology and distribution of deep-water corals. To facilitate species identification we are creating a DNA sequence repository in collaboration with Fisheries and Oceans Canada and NOAA's Alaska Fisheries Science Center. All DNA sequences will be linked to verified morphological identifications to create a West Coast repository of coral species found in this area. This repository will serve not only as an essential resource for coral researchers and other stakeholders, but also as a foundation for future research efforts at the NWFSC aimed at understanding the biogeography and ecology of coral species in these deep-sea communities. Two genes from each specimen will be sequenced: COI for submission to the DNA Barcode of Life, and mitochondrial MutS. This sequence information will allow us to make a preliminary ID based on genetics, and thereby group like individuals to reduce the number of individuals needed to send to morphological taxonomists already overwhelmed with their workloads.

Our preliminary results indicate that specimens recovered opportunistically from trawl surveys are of sufficient quality to give clean genetic sequences. Initial shipboard identifications are made by volunteers given minimal training in identification of corals, so it is critically important that reference material supplied to them be clear and accurate. Our sequencing and identification efforts will help provide the most up-to-date information regarding the genera and species likely to be found off the NE Pacific coastline. We have already demonstrated instances where initial shipboard identifications were accurate, as well

as those where initial species designations were inaccurate or of insufficient detail. The combination of MutS sequences, which are species-specific for many octocorals but is not found in hexacorals, plus COI which is found in all coral species, should yield sufficient power for identifying all taxa present in our regional waters.

I will also briefly describe our collaboration with the University of Washington Fish Collection to develop a marine fish species voucher archive linked to molecular genetic data for species identification. As with the corals, the COI data we generate for these vouchers are submitted to the Barcode of Life.

Evaluating the Microbial Composition of the Sea Surface Microlayer and Killer Whale Breath.

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The sea surface microlayer (SML) is the interface between the atmosphere and ocean, and it is a distinct aquatic environment. The SML is enriched in dissolved organic matter, lipids, and microbial communities compared to underlying pelagic seawater. Cetaceans such as killer whales intersect the SML when breathing, offering a route for respiratory exposure. This study evaluated the microbial composition of SML in waters inhabited by endangered Southern Resident killer whales (SRKW) and the exhaled breath of proximal individual killer whales over a three-year period during summer and fall. SML and exhaled breath were cultured on selective media, and bacterial and fungal isolates were taxonomically classified to at least the genus. Bacterial isolates from exhaled breath were ribotyped and tested for resistance against a panel of eight antibiotics. Human pathogens, such as *Clostridium perfringens* and *Pseudomonas aeruginosa*, were isolated from SML, and antibiotic-resistant *Salmonella enterica* Heidelberg and *Vibrio alginolyticus* were isolated from exhaled breath. Multidimensional scaling identified similarities between microbial composition and geography, suggesting potential spatial influences. This study demonstrates that evaluation of SML and exhaled breath offers an opportunity to monitor killer whale health in the context of environmental influences.

Reproductive parasitism of lithodid crabs by snailfishes off the western U.S.

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The FRAM Division has conducted annual bottom-trawl surveys along the West Coast since 1998. Though the primary mission of the surveys is to collect data for the management of groundfish resources, the surveys are also a highly effective means of conducting other scientific research, from addressing basic life-history questions to more advanced research such as helping to establish genetic databases for deep-sea corals. These projects often feature collaborations with other government agencies and universities, resulting in thesis dissertations, technical memoranda, and peer-reviewed papers. Here we present some results on reproductive parasitism by snailfishes of lithodid crabs.

Snailfish (Family Liparidae) are probably the most broadly distributed family of marine fishes, occurring in temperate and cold ocean waters from intertidal to depths below 7700 m. Some snailfishes of the genus *Careproctus* have the unique reproductive strategy of depositing their eggs in the branchial chambers of large lithodid crabs, probably via an ovipositor. The relationship has been described as parasitic, with effects on crabs ranging from no obvious damage to major gill compression and necrosis of half (an entire side) of the gills. Records of carcinophily consist of observations of eggs (and/or larvae) in crabs, but generally the fish involved are unidentified because the eggs have no distinguishing features, and snailfish are too similar in morphology to allow identification of embryos. West Coast U.S. occurrences have been reported.

We initiated a pilot study during the 2007 NWFSC groundfish trawl survey to collect data on the presence of snailfish eggs in the branchial chambers of crabs captured in the survey trawls, to identify adult snailfishes collected on the survey, to use genetic methods to match eggs to adults, and to initiate further studies of carcinophily. In 2007, we included a non-lithodid group of crabs with potential commercial value, tanner crabs of the genus *Chionoecetes*, but 807 crabs were checked for the presence of snailfish eggs and none were found. Snailfish eggs were found in four different lithodid species in 2007 and five different species in 2008. At least seven different species of snailfish in three genera were collected during the 2007 survey, including one (*Paraliparis pectoralis*) that is rare in collections. Visual analysis of the egg masses suggests there are at least two different liparid species depositing their eggs in crabs. The most common species collected was *C. melanurus*.

Females collected had ovarian eggs ranging from undeveloped to 4.9 mm in size, suggesting that spawning may be protracted, even if periodic. Genetic analysis of egg masses and tissue samples taken from adult snailfish to identify which species laid the eggs is underway and results will be presented if available. Information on the relative frequency of occurrence of parasitism will be presented as well. This work will both help clarify the natural history of two groups of species distributed worldwide: snailfishes and lithodid crabs, and, we hope, lead to clarification of the evolution of this unique behavior.

A summary of acoustic tagging programs for migratory and resident Chinook salmon in Puget Sound.

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Like many other stocks throughout the Pacific Northwest, Puget Sound Chinook salmon have now declined to the point that they are listed as Threatened under the Endangered Species Act. An increased understanding of their residence time, origins, migration pathways, predator/prey interactions, and habitat use is needed to help reverse this trend. We are currently using acoustic telemetry to help fill this information void. Currently there are over 20 organizations deploying more than 900 tags and over 200 receivers in every Puget Sound basin and coincident with this is an international monitoring effort (POST project) using the same technology from California to Alaska. This presentation is a summary of the Chinook portion of this collaborative effort initiated over the last three years and an overview of the upcoming research plans.

To date, we have focused on two types of Chinook salmon present in Puget Sound; ocean-type, which follow the traditional life-cycle model and residents (blackmouth) that spend their entire life in Puget Sound. We hypothesized that the ocean-type fish (based on run timing and size) would rapidly exit Puget Sound. However, many were still present in the winter months following tagging. In turn, we assumed that the resident-type salmonids would have a high probability of remaining in Puget Sound. We have detected over 75% of these fish on at least one receiver. Over 25% were detected up to a month after release; most from receivers adjacent to the capture/release locations. Five fish released around Central Puget Sound were detected moving around the same area 1-5 months later. Another two fish spent 2 and 5 months, respectively, traveling between central and South Puget Sound and

were detected on all receivers in between. All of these findings seem to indicate that Puget Sound fish are on the move. There are different scales of movement including a surprising amount of rapid short-term long distance movement. There are also movement patterns within smaller geographic areas ("movers" and "sitters"). We are planning on continuing this research and examining these fish movement patterns for correlations with tides, diel patterns, water quality, predator/prey interactions and other possible environmental predictors.

This united approach will give a clearer picture of the status of Puget Sound Chinook salmon including ocean-bound smolt and resident (blackmouth) behavior and survival in both the estuarine and nearshore environments and contribute to a greater ecosystem level of understanding. This in turn will help direct future fisheries management decisions surrounding recovery and help focus future protection and restoration efforts.

Residence time of juvenile Chinook salmon in the Columbia River estuary

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The importance of estuarine habitat to juvenile Chinook salmon has been documented in many estuaries of the Pacific Northwest. However, estuarine habitat use in the Columbia River, historically one of the largest producers of Chinook salmon, is underrepresented in the literature. Conventional sampling methods can indicate presence/absence, but more comprehensive techniques must be used to measure behavioral characteristics, such as residency.

A combination of passive integrated transponder (PIT) tags, PIT tag detection arrays, and acrylic paint was used to conduct a mark-recapture study in emergent marsh habitat in the Columbia River estuary. Five hundred seventy-four and 864 subyearling Chinook salmon were PIT tagged in 2006 and 2008, respectively. Three hundred twenty-four subyearling Chinook salmon were marked with acrylic paint in 2006. All target (PIT-tagged and marked) fish were released within the emergent wetland habitat. Target fish were actively recaptured using seine nets. In 2008, PIT-tagged fish were also passively monitored with two PIT detection arrays. Over 400 individual target fish were recaptured during the two years of the study. Residence times were greater than expected, given the tidal nature of the emergent wetland. Thirty-seven percent of recaptured fish resided for 7 or more days and 5% resided for 3 weeks or longer. Active recapture of target fish using seine nets provided individual

growth rate information in addition to residence time. Instantaneous growth rates of PIT-tagged fish in 2006 and 2008 were 0.67 and 0.60 mm/d, respectively.

An unexpected benefit of the study was active and passive recovery of subyearling Chinook salmon that were PIT tagged above Bonneville Dam. These fish demonstrated significant estuarine habitat use and their growth rates were analogous to growth rates of fish collected and tagged locally.

This study verifies that subyearling Chinook salmon are dependent on estuarine habitat in the Columbia River for rearing and growth. However, the availability of estuarine habitat has been greatly reduced by diking and filling of wetlands. Restoration needs to occur so that populations of Chinook salmon, like those in the ESA-listed Lower Columbia River ESU, are able to increase.

Toxic Contaminants and Juvenile Salmonids in the Lower Columbia River and Estuary

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As part of the Lower Columbia Estuary Partnership's Ecosystem Monitoring Program, we measured concentrations of contaminants in the Lower Columbia River and Estuary (LCR&E) environment and in outmigrant juvenile salmon to evaluate the potential risks of toxics to the productivity of ESA-listed Columbia River salmon stocks. Contaminant levels were determined in juvenile Chinook salmon, water, and sediment samples from six sites in the LCR&E, from Bonneville to the estuary mouth. Salmon from upper, middle, and lower Columbia stocks were feeding and rearing in the LCR&E, and were exposed to PCBs, DDTs, PBDEs and PAHs via their diet, with especially high concentrations of contaminants in stomach contents of fish from the Portland/Vancouver area. Contaminant levels in bodies and stomach contents of some fish were above thresholds for effects on salmon health, such as delayed mortality, poor growth, and reduced disease resistance. Salmon from the Portland sites also showed signs of exposure to estrogenic compounds. Moreover, concentrations of copper and organophosphate pesticides in the water column were at levels that could interfere with olfaction in salmon at some sites. Field data are being used in bioaccumulation and

population models to better understand pathways of exposure for salmon, and potential impacts on stock recovery.

Pacific salmon on the brink of ocean entry: new insight from the Columbia River estuary

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Anadromous Pacific salmon spend part of their life cycle in fresh water and part in salt water. However, the specific details of how juvenile salmon make the transition from freshwater to marine environments—a time of potentially high mortality--remains poorly understood. We have been sampling juvenile salmon and the larger estuarine fish community in the lower Columbia River estuary to address this issue and characterize salmon immediately before ocean entry. We have observed variation in both juvenile salmon and the estuarine fish community, associated with variation in physical forcing. These biological changes, in turn, likely influence juvenile salmon's vulnerability to predators and therefore influence predation rates. Insight provided by this study allows us to look backwards to comprehend how salmon may have functioned in the unaltered Columbia River system, but also to look forward to predict how they may respond to further changes in climate.

Evaluating ecological and economic impacts of individual quotas for the groundfish trawl fleet

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In November, the Pacific Fisheries Management Council decided to begin implementing an individual quota system for the West Coast groundfish trawl fleet. Under the individual quota system, each vessel will now have dedicated access to a portion of the quota for groundfish, such as rockfish and flatfish. This is a radical departure from the traditional competitive "race to fish". The modeling work presented here investigates the ecological and economic effects of this new management regime. I use an integrated ecosystem model of the US West Coast (Atlantis) to simulate the abundance of target fish species and other biological groups. I simulate fleet dynamics for the 12 major groundfish fleets, with each fleet choosing fishing locations that maximize net revenue. Net revenue includes landed value of the catch, minus the cost of quota and fixed and variable costs. I

explicitly include the penalty that fishers expect if they exceed their quota. The main findings are: 1) Even with crude spatial resolution, under the individual quota scenario the simulated fleets show some improved targeting behavior, avoiding overfished rockfish species and aiding recovery of these stocks. 2) The penalty fishermen expect for exceeding quota has a large effect on fleet behavior. This points to the importance of monitoring and enforcement.

Assessing institutional designs for managing water supplies across the Puget Sound

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Understanding the laws, policies, and organizational structures needed to successfully implement complex habitat management activities is critical for the recovery of pacific salmon in the Northwest. This project investigates formal and informal water supply control measures that have been implemented to support salmon recovery in the Puget Sound Basin. A census of efforts to manage freshwater flows across eighteen Puget Sound Water Resource Inventory Areas (WRIAs) is provided. This information is compared against a set of social science design principles that have been presented as necessary for the successful management of common pool resources such as water and fish. Results from the study highlight institutional designs that are associated with the effective implementation of water supply control measures and establishes whether hypothesized institutional design principles explain the success of efforts to manage freshwater supplies to support salmon recovery across Puget Sound. By identifying effective institutional designs, data from this research may assist managers in developing new flow control programs to support salmon recovery. This project augments existing social science research related to salmon recovery and offers a novel application of institutional analysis and common pool resource theory to integrated water and fisheries management scenarios.

Restoration of salmon habitat in tidal wetland habitats: an example from the Grays River tributary of the lower Columbia River

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Degraded wetland systems with impaired hydraulic connections have resulted in suboptimal habitat opportunity for salmonids and other native flora and fauna in the Pacific Northwest. Reconnection of these systems to tidal fluctuations restores connectivity and

material exchange between wetland and riverine or estuarine environments. We developed and tested a series of monitoring metrics designed to evaluate and compare physical and biological responses of hydraulic reconnection, and then tested the metrics at various field sites. As an example, in the Grays River tidal freshwater system, we measured hydrologic changes due to removal of tide gates from diked pastureland, and determined subsequent time series of abundance and size frequency of salmonids in the restoring marshes. Dike breaching caused an immediate return of full semidiurnal tidal fluctuations to the pastureland. We found that juvenile salmonids quickly expanded into this newly available habitat and utilized prey items presumably produced within the marshes. There was differential habitat utilization by species, with chum and coho salmon exhibiting higher abundances in restoration sites compared with Chinook salmon. There was also differential use by life-history stage. All chum were fry that migrated rapidly through the system. Chinook were a mixture of fry and fingerling-sized animals that were present from March to at least July. The coho population was composed of fry, fingerling, and yearling fish also present from March to at least July. Based on size and the timing of hatchery releases, we conclude most Chinook, chum, and coho sampled in restored and reference sites were progeny from wild spawners. Restoration of tidal wetlands in the lower Columbia River and estuary is likely to improve overall ecosystem connectivity, reduce habitat fragmentation, and increase resilience of varied salmon stocks to anthropologic and climatic perturbations.

Improved Flatfish Health Following Remediation of a Superfund Site

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Eagle Harbor in Puget Sound became a Superfund site in 1987 due to high sediment concentrations of polycyclic aromatic hydrocarbons (PAHs) released chronically from a nearby creosoting facility. Early studies with English sole from this site (1983-86) demonstrated high prevalences (up to ~80%) of toxicopathic liver lesions, including neoplasms. These lesions have been strongly and consistently associated with PAH exposure in multiple field studies, and have been induced in the laboratory injections of a PAH-rich fraction extracted from Eagle Harbor sediment. Further studies (1986-88) incorporated biochemical biomarkers of PAH exposure and effect, including hepatic CYP1A expression, biliary fluorescent aromatic compounds (FACs), and DNA adducts in liver. Prior to site remediation, hepatic lesion prevalences and biomarker values in these species from Eagle

Harbor were among the highest in Puget Sound. In 1993 and 1994, a primary cap of clean sediment was placed over 54 acres of the most contaminated portions of Eagle Harbor, with a secondary cap added between November 2000 and February 2002, in order to sequester PAH-contaminated sediments. Lesion prevalences and biomarker values just before capping were reduced compared to historical data, consistent with closure of the creosoting facility closure in 1988, and subsequent shore-based source controls. Data on liver lesion risk, hepatic CYP1A, and biliary FACs from fish collected immediately after and at regular intervals up to ~2 years after primary sediment capping were highly variable relative to pre-capping values. However, over the entire monitoring period (up to 142 months) since cap initiation, but particularly after ~3 years, there was an overall, significantly decreasing trend in risk for hepatic lesions in English sole, and for biliary FACs and hepatic DNA adducts. In particular, the risk of hepatic lesion occurrence in English sole has been consistently low (> 0.20) compared to lesion risk at cap initiation (1.0), from ~4 years after sediment cap placement through April 2005; results of liver lesion occurrence through May 2007 continue to show very low prevalences. These results show that the sediment capping process has been effective in ameliorating PAH exposure and associated biological effects in resident flatfish species, and that longer term monitoring of pollutant responses in biological resources, such as resident fish, is necessary and far superior to monitoring of only sediment contaminants in order to demonstrate the efficacy of this type of contaminant remediation.

Session 5: Research HiLights II

Hatchery induced life history variation in Columbia River Chinook salmon

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In teleost fish measurement of the androgen 11-ketotestosterone (11-KT) in blood provides a reliable physiological indicator of the initiation of male maturation (a.k.a. puberty). Over the past decade we have used this endocrine tool to reveal that approximately 10-50% (depending on population and brood year) of the male fish released from several Columbia River Chinook salmon hatchery programs mature precociously at age-2 (commonly referred to as minijacks) rather than the more typical age 3-5 for this species. Instead of migrating to the ocean for long-term rearing and growth, minijacks remain in headwater streams or undertake a short-term migration downstream, turn around, and attempt

to migrate back upstream to complete the maturation process a few months later. Rates of minijack production in wild stocks are difficult to quantify, but believed to be less than 5%. Age of maturation in salmon is influenced by genetic, biotic, and abiotic factors including energy stores, size and/or growth rate at specific times of year. Studies in salmonids have shown that maturation for each age class is physiologically initiated approximately 10-12 months prior to spermiation and growth rate during this period significantly influences the physiological "decision" to mature in a given year. Growth profiles of hatchery fish are not well matched to that of wild fish, suggesting that rearing practices are a key component of the altered life-history pattern. Changes in the life-history composition of salmon populations are undesirable in conservation and production hatcheries, potentially resulting in loss of returning anadromous adults, biased gender ratios, and negative genetic and ecological impacts on native species. Laboratory and production scale experiments aimed at more closely matching growth profiles of wild fish have met with mixed success in that growth regimes that suppress early maturity often produce smaller fish at release. Release of smaller smolts typically results in lower rates of survival to adulthood. Future studies are aimed at reconciling the population scale trade-offs between short-term survival advantages of large phenotype at release and potential long-term survival disadvantages of genotype alterations of fish in hatchery programs.

The promise and pitfalls of using climate data in fish stock assessment

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Concurrent declines in demersal fish stock abundances and shifts in long term average environmental conditions in the Pacific have been well documented. However, changes in abundance of fish stocks are largely attributed to fishing impacts, rather than environmental conditions. High variability around stock-recruitment curves indicates environmental or other factors, in addition to stock size, probably affect early life history survival and subsequent recruitment to fisheries. Thus, management advice that ignores environmental forcing of recruitment, the effects of which are exacerbated by fishing pressure, may cause stocks to be over- or under-harvested. The efficacy of including environmental impacts on recruitment in management models needs to be evaluated to move single species stock assessment methods towards taking account of ecosystem considerations. Simulation testing is used to determine the statistical power of currently-used stock assessment methods to correctly identify long term decadal scale environmental forcing of recruitment. Three alternative stock assessment

methods are evaluated: 1) fit the population dynamics model treating the annual recruitments as estimable parameters and then estimating the parameters of a Beverton-Holt stock recruitment relationship using the estimates of spawning biomass and recruitment (M0), 2) apply the stock assessment including the fit of a Beverton-Holt stock-recruitment relationship ignoring the environmental data and the possibility of temporal auto-correlation in recruitment (MSR) and, 3) conduct the stock assessment, but integrate the environmental data (but not temporal autocorrelation in recruitment) into the assessment (MSRE). Simulation results are based on three generalized life histories: a long-lived unproductive rockfish, a moderately long-lived and productive flatfish, and a moderately long-lived and productive hake with highly variable recruitment. The ability of the stock assessment methods to balance type I and type II error rates suggests that methods M0 and MSR tend to produce lower total error rates for the rockfish and flatfish life histories; these methods are those used most commonly in practice. In this study, the promise of integrating environmental data directly into stock assessments is outweighed by the pitfall of high type I error rates for the rockfish and flatfish life histories, suggesting that the conventional means of avoiding spurious correlation are not sufficient when using method MSRE. The method MSRE produced the lowest total error rate for the hake life history. Type II error can be minimized if catch and index data are available for at least the same period as the environmental index, in this study 50 years. The proportion of failures was highest for hake life history, with the fastest dynamics, and lowest for the rockfish life history, with the slowest dynamics.

Acoustics: an advanced remote sensing technology in fisheries surveys

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The oceans provide a virtually boundless habitat for ten's of thousands of marine species ranging from microbes, to phytoplankton, to zooplankton, and all the way up to marine mammals - the highest level in the marine food chain. The dynamic distribution of the biomass and/or abundance of these organisms provide the spatial and temporal signatures of the ocean ecosystem and is of crucial importance to human existence. In reality, the oceans, however, are grossly under-sampled. To understand the temporal and spatial variations in the distribution of these marine species, we need to sample as much ocean volume and extract as much information as possible. Conventional pump and net samplers can provide discrete

information on biomass, size distribution, patchiness, and time evolution of marine animals, but these sampling methods are time consuming and inefficient. To sample the oceans more efficiently, acoustic technology has evolved significantly from the simple analog, single-channel, and single-frequency systems to the much more sophisticated digital, multi-channel, and/or multi-frequency systems. With advances in acoustic techniques, the efficiency and accuracy of oceanographic-biological surveys have been substantially improved. In this presentation, a review of several major advances in sonar techniques over the past few decades is given, and its applications to and impact on fisheries surveys are emphasized. Examples of the Integrated Acoustic and Trawl Survey of Pacific hake (*Merluccius productus*) are presented to demonstrate how to extract biological information (abundance and biomass) from the recorded acoustic echograms.

Ecosystem dynamics in the Northern California Current: effects on juvenile salmon

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The Estuarine and Ocean Ecology Program has been studying the early life history of juvenile salmon in the coastal environment of the Northern California Current (NCC) for over a decade now, examining physical and biological processes underlying variations in early marine survival. This has involved an extensive field program (3 or more broadscale cruises a year) that has sampled the environmental conditions that salmon inhabit, along with the prey field and abundances of ecologically-related competitors and predators. The NCC ecosystem has undergone dramatic changes during the period encompassed by our study, including several regime shifts, one of the strongest El Niños ever recorded, a strong La Niña, years with pronounced subarctic water influence, and anomalous upwelling conditions, providing a natural experiment to test the effects of the ocean on salmon marine survival. Our analyses of the collected data have led to a better understanding of the distribution, migration routes and speeds, growth, condition, feeding and health of juvenile salmon in the coastal marine environment. We have developed maps of preferred habitats for both Chinook and coho salmon based on multiple physical parameters. Species and stock-specific migration behaviors have been elucidated through recovery of tagged fish and also genetic techniques. Growth variability has been examined through scale and otolith analysis. Feeding ecology has been studied through direct diet analysis, parasites, and the use of stable

isotopes. The health of juvenile salmon has been studied through examination of pathogen and parasite infections. Concurrent with our salmon sampling, we have examined the prey field of these juveniles at higher spatial and temporal scales to monitor changes in the ocean environment that may affect salmon. We also have been monitoring the abundance and feeding habits of potential piscine and avian predators and examining their spatial overlap with juvenile salmon. A related component has examined the abundance and ecology of several forage fishes that are important prey of juvenile salmon in their juvenile stage and potential competitors as adults.

In recent years, we have incorporated our field observations into biophysical models of the environment and food web in the NCC, using these models to test hypotheses about abiotic and biotic control on salmon survival. We have been using these models to examine the effects of climate and ecosystem change on salmon, providing managers with some leading indicators of potential recruitment trends in salmon populations.

The enigma of *Vibrio parahaemolyticus* outbreaks in the Pacific Northwest

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Members of the genus Vibrio are ubiquitous in the marine environment, especially in coastal waters. These bacteria accumulate in shellfish such as oysters through filter feeding and are the leading cause of seafood-related bacterial infections reported in the U.S. *Vibrio parahaemolyticus* is commonly acquired by consumption of undercooked or raw shellfish and is responsible for the majority of these infections, primarily manifested as a self-limiting gastroenteritis.

In the past decade, there has been a significant increase in *V. parahaemolyticus*-related gastroenteritis from the consumption of raw oysters harvested in the Pacific Northwest, possibly attributable to increases in water temperature. Such illnesses/outbreaks pose a threat to public health and result in severe economic losses to the shellfish growers. Increases in Vibrio populations due to changes in climatic conditions have been previously reported but the ecology of these bacteria and their interactions with the aquatic environment are not clearly understood.

The Washington State Department of Health currently monitors oysters, from selected growing areas that have previously been associated with *V. parahaemolyticus*-related illness, from May to September of each year with a mandate to close harvesting if concentrations of potentially pathogenic (tdh+) *V. parahaemolyticus* exceed action levels of 50 bacteria per

gram of oyster meat. However rarely have these levels been reached for the past few years, and there has been little or no correlation between the concentrations of tdh+ *V. parahaemolyticus* in oysters harvested from growing areas associated with illnesses.

We are presently investigating the influence of environmental variables on concentrations of potentially pathogenic and avirulent strains of *V. parahaemolyticus* in oysters as well as in water and plankton, focusing on harvest areas with historically higher incidences of the bacteria. In addition we are examining the association of *V. parahaemolyticus* with co-isolated phytoplankton and zooplankton species. Through this work, we hope to gain a better understanding of environmental conditions that promote proliferation of these bacteria, which may assist in the improvement of risk assessment strategies and mitigation tools to prevent disease outbreaks.

Session 6: RapidFire II

Acoustic Tracking of Hatchery-Reared Lingcod in Puget Sound

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Lingcod are being developed as a model species to test hypotheses about stock enhancement. This research addresses stock enhancement issues concerning egg collection, rearing, and release strategies, and will expand in the future to include assessments of ecological interactions and genetic impacts. This work may also provide insight into the behavior and ecology of wild juveniles, which can be elusive and for which minimal field data exist. In 2008, eggs were collected from the wild and reared at the Manchester Research Station. Forty-eight telemetry-tagged, hatchery-reared subyearlings were released into South Puget Sound in November 2008 and are being tracked with an array of stationary acoustic receivers and a mobile boat-mounted receiver. This talk will present some preliminary data from the mobile tracking work that aims to document movement, habitat associations, and possible eventual recruitment to adult habitat. This project is a collaboration with the Washington Department of Fish and Wildlife, the Northwest Indian Fisheries Commission, the Washington SCUBA Alliance, and the Puget Sound Recreational Fishery Enhancement Committee.

Early marine survival and behavior of Steelhead (*Oncorhynchus mykiss*) smolts through Hood Canal and the Strait of Juan de Fuca

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The depressed status of Puget Sound steelhead trout (*Oncorhynchus mykiss*) populations contrasts with the healthier condition of those along the Washington Coast and suggests that substantial smolt mortality occurs during the migration through Puget Sound to the Pacific Ocean. Acoustic telemetry transmitters and stationary receivers were used to investigate survival, migration timing, and migratory behavior of 159 steelhead smolts in 2006 and 187 smolts in 2007 from four Hood Canal (part of Puget Sound) streams and one stream flowing into the Strait of Juan de Fuca. Estimated population-specific survival rates for wild and hatchery smolts from river mouths to the northern end of Hood Canal (28.1 to 75.4 km) ranged from 67% to 85% in 2006, and from 64% to 84% in 2007. Survival was much lower from the north end of Hood Canal to the Strait of Juan de Fuca (135 km) in 2006 (23% to 49%), and could not be reliably measured in 2007. Travel rates through Hood Canal (8 – 10 km·d-1) were significantly lower than those estimated as the fish migrated through northern Puget Sound and the Strait of Juan de Fuca (26 - 28 km·d-1), while the mortality rates per unit distance travelled were very similar in the two segments. The high daily mortality rates estimated during the early marine phase of the steelhead life cycle (2.7%·d-1) suggest that mortality rates decrease substantially after steelhead enter the Pacific Ocean.

Pesticides as a limiting factor for salmon recovery in the western U.S.

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Pesticides pose a complex threat to the biological integrity of aquatic ecosystems. In the western United States, widespread pesticide use has contaminated surface waters that provide habitat for endangered salmon and steelhead. These keystone species depend on the productivity of rivers, lakes, and estuaries to provide food for juvenile growth, a key determinant of subsequent marine survival. Because pesticides can be toxic to many non-target taxa (e.g., primary producers and macroinvertebrates), they can have adverse but still poorly understood impacts on salmon populations via indirect trophic cascades. In addition to food web effects, this presentation will also review recent Center research on the toxicity

of pesticide mixtures, interactions between pesticides and non-chemical stressors (e.g., stream temperatures), and links between the health of individual salmon and the productivity of wild populations.

Super-crunching multi-species monitoring data

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Multivariate autoregressive (MAR) modeling is a form of multivariate analysis that uses time series data from multiple species along with physical factors to infer inter-species interactions, the dominant environmental drivers and the system stability and resilience. MAR modeling is well-grounded on theory concerning population and community dynamics. Using estimated MAR models, comparative properties of communities, such as resistance to disturbance, resilience, and return time after disturbance, are easily calculated in terms of the stability properties of the matrix of species interaction strengths. This framework has been used successfully to understand the dynamics of various freshwater plankton communities. We are extending this statistical framework in order to apply it to the analysis of marine community data and to estimate the impacts of physical, biological, and anthropogenic drivers on marine ecosystems. I will introduce the ecosystem modeling tools we have developed based on MAR and give snapshots of a variety of ecosystem analyses where we are using these tools.

Effects of temperature change on demersal fishes in the California Current: a bioenergetics approach.

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Diverse fish assemblages such as West Coast groundfish should feature a wide range of biological and ecological responses to temperature change. This is borne out by bioenergetics modeling: when temperatures were varied around historic annual means, three groundfish species (yelloweye rockfish, sablefish, spiny dogfish) responded with different intensities across several key variables (age-1 mass, age at 50% maturity, and prey consumption). Translating such results to a field setting is a challenge: temperature change may directly affect fish bioenergetics, cause range shifts related to behavioral thermoregulation, or produce complex ecological interactions, all of which can affect fish

populations and influence management decisions. Future research priorities are to quantify temperature sensitivity among species and anticipate temperature-mediated changes in populations and diverse communities.

Rebuilding depleted west coast groundfish species: management actions and early results

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The Sustainable Fisheries Act of 1996 established a new mandate for NOAA Fisheries Service to identify and rebuild depleted fish stocks under its jurisdiction. Since 1996, seven rockfish and two other groundfish stocks that inhabit waters off Washington, Oregon, and California have been declared "overfished". In response to these declarations, a variety of measures have been implemented in an effort to rebuild the depleted stocks to target biomass levels. These responses have included dramatic reductions in Optimum Yields, new restrictions on gear usage, designation of closed areas, and the development of a comprehensive, scientific observer program. The two non-rockfish species that were listed as "overfished" have since been declared "rebuilt" and two of the rockfish stocks are expected to reach target biomass levels within the next few years. For some rockfish species, however, rebuilding is expected to take more than 60 years. Assessments were conducted during 2007 for all of the depleted rockfish species, as well as several others. The progress toward rebuilding will be evaluated through examination of biomass trends reported in these assessments.

Known unknowns now known: the fish heart as a target for the long-term impacts of oil spills

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Studies following the Exxon Valdez oil spill in Prince William Sound showed that the early life history stages of fish are highly sensitive to lingering trace crude oil contamination. Pink salmon exposed to oiled gravel as embryos showed significantly reduced juvenile to

adult marine survival in tagging studies. Using zebrafish, we have cracked into the black box of the mechanisms underlying this delayed mortality. Studies with weathered crude oil and the most abundant types of crude oil-derived polycyclic aromatic hydrocarbons (PAHs) showed that tricyclic PAHs acutely disrupt cardiac function in developing fish embryos. The well known links between cardiac form and function during development, and the relationship between the shape of the fish heart, cardiac output, and maximum swimming speed suggest that early disruption of heart function will have long-lasting physiological impacts on oil-exposed fish embryos. Consistent with this, zebrafish exposed to sublethal levels of crude oil as embryos were found to have reduced swimming performance as adults in spite of identical condition factor. These findings suggests a hypothetical basis for the development of biomarkers relating to cardiac performance, such as cardiac natriuretic peptides secreted in response to hemodynamic stress, that in conjunction with biomarkers of exposure such as cytochrome P4501A or levels of fluorescent aromatic compounds in bile, may provide a more sensitive and efficient means for assessing oil spill impacts on fisheries resources.

Using PIT-Tag technologies to investigate adult salmonid straying in the Lower Columbia River

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Accurate estimates of adult salmonid survival rates are critical for meeting hydrosystem performance standards established by NOAA Fisheries Biological Opinions. Straying and adult fallback rates are key components in adjusting adult survival estimates. Previous methods to estimate straying have been limited. Fish Ecology Division researchers proposed to evaluate the feasibility of using PIT-tag systems to estimate straying in large tributaries.

A prototype PIT-tag system was installed near McDonald Ferry on the John Day River in September 2007. This site is located in the lower reach of the river (around RM 20) and is below all of the major spawning tributaries. The detection system consists of six antennas installed as two arrays into the thalweg portion of the river. By installing two antenna arrays, researchers can infer travel direction and increase the overall tag-detection efficiency of the PIT-tag system.

Since 27 September 2007, the detection system has been operating continuously to monitor migrating PIT-tagged adult salmonids. Through December 2008, we have detected 227 PIT-tagged adult salmonids and 37 juveniles. The majority of the adults, (~85%) have been steelhead. Steelhead appear to be actively migrating over longer periods of time and at different times than had previously been thought while the native Spring Chinook migration pattern has followed the expected springtime-only migration pattern. We will continue to monitor the river in 2009 and 2010 to see if the first year's patterns were unique or reflect the normal migration patterns for this river.

Of the 196 steelhead detected, 71 were straying fish that originated outside of the John Day River Basin. Most (56) of the straying steelhead were fish transported from Lower Granite Dam. These were detected in the fish ladders at Bonneville Dam between July 2007 and October 2008 when ~3,300 other similarly transported fish were also detected. This would suggest an overall straying rate of ~2%; however, certain release locations within this larger group yielded higher rates.

We know the number of tagged fish that the PIT-tag system has detected, but we do not know how many it has not detected. Therefore, in September 2008, we started an evaluation to determine the detection efficiency of the PIT-tag system using test fish double-tagged with PIT and radio tags. We set up two radiotelemetry antenna arrays below and two above the PIT-tag antennas to monitor the double-tagged fish. Due to a strong native run and permit complications, we were able to double tag only seven fish (four hatchery and three wild fish). The PIT-tag system has detected all five double-tagged steelhead that have passed the antennas. The other two fish are still below the PIT-tag antennas. We plan to start tagging more fish later in January.