PUGET SOUND INSTITUTE

UNIVERSITY of WASHINGTON

Puget Sound Institute's Study Panel on Ecosystem-based Management of Forage Fish in Puget Sound

Workshop Report and Proposed Work Plan
18 September 2013

Study Panel Members

Tessa Francis, Puget Sound Institute (Chair)
Tim Essington, University of Washington (Co-Chair)
Marc Mangel, University of California, Santa Cruz
and Puget Sound Institute (Co-Chair)
Doug Hay, Department of Fisheries and Ocean, Canada
Paul Hershberger, United States Geological Service
Dayv Lowry, Washington Department of Fish and Wildlife
Alec MacCall, NOAA – Southwest Fisheries Science Center
Ole Shelton, NOAA – Northwest Fisheries Science Center
Megsie Siple, University of Washington

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I. Executive Summary

In the Spring of 2013, the Puget Sound Institute convened a 9-member study panel ("the Study Panel") to assess the state of the science, and to recommend and conduct data analyses related to ecosystem-based management of forage fish in Puget Sound. Members include forage fish experts from across the West Coast, from universities and state and federal (including Canadian) government agencies. In August 2013, the Study Panel met for its first workshop. A day of presentations from and discussions with other regional scientists and stakeholders, followed by 3 days of discussions internal to the Study Panel, resulted in this summary and proposed research plan.

The Study Panel *agreed upon several facts* with respect to Puget Sound forage fish and, specifically, Pacific herring (a Puget Sound Partnership Dashboard Indicator):

1. Spawn deposition surveys are sufficient for estimating herring adult spawner biomass, and for describing trends in adult spawner biomass through time. However, the assumptions contained in the model that converts egg density estimates to adult biomass should be re-evaluated. The spawn deposition surveys and acoustic/trawl surveys (conducted before 2009) estimate the same abundance trends overall.
2. The major herring spawning locations are known.
3. Herring and sand lance are key prey items in the diets of several Puget Sound predators, including fish, birds and mammal.

However, *several key gaps exist* in our understanding of Puget Sound forage fish, preventing effective management. The Study Panel's work plan was developed to address these gaps (where possible), which include:

1. Status of/trends in abundance of forage fish (species other than herring)
2. Key vulnerabilities of forage fish
3. Abundance/biomass of forage fish needed to support key ecosystem predators
4. Prey base/food supply for forage fish
5. Consequences of herring age truncation
6. Partial migration by herring out of Puget Sound

The Study Panel recommended analyses that are of key importance to the recovery of Pacific herring, and achieving recovery targets established by the Puget Sound Partnership:

- Identify key vulnerabilities of herring to determine what limits their populations;

- Determine how much herring biomass – of what size, and where – is needed to sustain top predators;
- Develop a life-cycle model for use in determining how the most likely stressors affect herring populations; and
- Build a management strategy evaluation to test the effects of individual, or suites of, management actions on key stressors to herring, based upon identified key vulnerabilities and using a life-cycle model.

Several key gaps in information cannot be filled by a study panel, but rather require ongoing monitoring. The Study Panel also made recommendations for monitoring actions that are necessary for ecosystem-based management of forage fish in Puget Sound. These include:

- Collect biological samples to establish age/size composition (including of herring, to support the Vital Sign Indicator/Target).
- Conduct ichthyoplankton surveys, to provide information about early life stages, and especially for estimating abundance of sand lance.
- Conduct zooplankton surveys, to provide information about prey base for forage fish.

<u>An abbreviated list of research priorities for ecosystem-based management of forage fish</u>

1. Identify key stressors to forage fish and effective management actions to protect them

Action 1: Build life-cycle model for forage fish
Who: Ole Shelton/NOAA, Tessa Francis, UW grad student
Status: Awaiting funding for UW grad student
Completion: Spring 2014

Action 2: Identify critical stressors for forage fish, *using above life-cycle model*
Who: Essington/UW, Dayv Lowry/WDFW, Shelton/NOAA, UW grad student
Status: Awaiting funding for UW grad student
Completion: Spring 2014

Action 3: Management Strategy Evaluation: Construct operating model to determine the effects of different management actions to limit key stressors, given their effects at different life stages, *using above life-cycle model and identified critical stressors*
Who: Essington, UW postdoc
Status: Need funding for postdoc
Completion: 12 months

2. Determine abundance of (non-herring) forage fish

Action 1: Estimate forage fish abundance using predator diets
Who: Ole Shelton/NOAA, Megsie Siple/UW, Lowry/WDFW

Status: Not yet begun
Completion: ?

Action 2: Estimate forage fish abundance using seabird behavior
Who: Marc Mangel/UWT and PSI
Status: Starting January 2014
Completion: May 2014

3. Determine biomass needed to support key predators
Action 1: Estimate predator needs in space and time
Who: Essington, Lowry/WDFW, Doug Hay/DFO, UW Grad student
Status: Seeking UW grad student
Completion: Summer 2014

II. Introduction

A. Aims and Scope of Study Panel and First Workshop

In March of 2013, the Puget Sound Institute formed a Study Panel to evaluate research needs for ecosystem-based management of forage fish in Puget Sound. The Study Panel was formed, under advisement of the Puget Sound Partnership's (PSP's) Science Panel, to assess the state of the science, conduct synthetic and quantitative analyses, and make recommendations related to forage fish in Puget Sound over a period of 1-2 years. This includes consideration the status and recovery of Pacific herring, the forage fish species selected by the PSP as one of its "Vital Sign" indicators of Puget Sound's health and recovery. While there may be two separate management goals at issue – recovery of Puget Sound herring, and ecosystem-based management (EBM) of forage fish generally – the two are related, and the analyses proposed in this report represent an effort to move both management issues forward.

Specifically, the Study Panel was formed in response to two research priorities identified in the PSP's 2011-2013 Biennial Science Work Plan. In addition, the Study Panel identified a third research priority that is related to the first two priorities and inherent in the goal to recover and manage forage fish in Puget Sound:

1) An evaluation of the **impacts of all stressors** on forage fish populations.
2) An evaluation of forage fish population **status and trends**.
3) An assessment of **what abundance or biomass is needed** of forage fish to sustain valued ecosystem components and species in Puget Sound?

This report is a summary of the first workshop held by the Study Panel in August 2013 at the University of Washington's Whiteley Center at Friday Harbor Labs. The goals of the first workshop were to refine the research questions, based upon initial assessment of available data and input from additional presenters during an Open Session (see below), and to develop a broad plan for studies aimed at addressing the three research priorities. This report has been drafted for the PSP Science Panel and interested parties, and contains a description of progress made at the workshop, and a Proposed Work Plan. This Work Plan is not comprehensive. It reflects analysis opportunities, gaps, and needs identified through discussions with the research and management communities and other stakeholders, and the interests/abilities of the technical team assembled. Many of the proposed projects are foundational, and set the stage for secondary analyses. Not all of the proposed analyses can be tackled simultaneously but, rather, should proceed sequentially, as resources allow.

The initial workshop was a combination of focused study and discussion by the Study Panel, and presentations and input from additional participants (see Workshop Agenda in Appendix 1, Table 1). The presentations were given by individuals who either responded to the Study Panel's open call for participation, or were selected by the Study Panel to share particular information or perspectives (see Open Session Agenda and participant list in Appendix 1, Table 2). During both the presentations and discussion following (see Open Session Notes in Appendix 2), the Study Panel noted an opportunity to advance Puget Sound forage fish research by taking a

comprehensive and integrated view of vulnerabilities and consequences that incorporates the bodies of research presented and cultivated over, in some cases, decades of dedicated research.

B. General Emergent Themes

Several general themes emerged over the course of the workshop, resulting from the presentations, from discussions among the participants immediately following the presentations, and from subsequent discussions among the Study Panel. In addition to these themes, the Proposed Work Plan (beginning on Page 8) aims to incorporate recommendations made following the Research Symposium on Forage Fish convened in September 2012 by the Northwest Straits Commission, U.S. Geological Survey, Washington Department of Fish and Wildlife, and Puget Sound Partnership, as well as guidance offered by members of the PSP Science Panel. As mentioned above, the presentations offered during the open session highlighted the opportunity for synthesis of existing information, and ecosystem-level quantitative analyses to complement existing research and monitoring projects on forage fish in Puget Sound.

Our focused discussions began with consideration and refinement of the three primary research questions. We identified areas of overlap among the questions and, as a result, several of the proposed analyses support multiple research questions, and are "foundational" to other focused projects. For example, we plan to construct a generalized forage fish life-history model that will not only be used to explore the effects of multiple stressors that affect particular life history stages at a population level, but will also serve as the modeling framework for a larger effort. In addition, we propose to conduct an assessment of the sensitivity/vulnerability of predators to changes in forage fish population that not only will inform questions about ecosystem needs for forage fish, but also can be used to assess the broad changes in the abundance and distribution of forage fish species for which we have no direct measurements of abundance.

Some of the key points that emerged from the discussion following the open session include:

- The Study Panel aims to take advantage of and synthesize available data as much as possible;
- We aim to address the multiple potential vulnerabilities of forage fish (e.g., to loss of shoreline habitat, diseases, contaminants, fishing, etc.) simultaneously, in a common framework;
- We aim to address PSP's herring "Vital Sign" recovery target;
- We aim to inform long-term monitoring strategies with an emphasis on scientific questions.

III. Research Priorities

Over the course of the 5-day workshop, the Study Panel assessed what information is known, and what gaps in information exist, related to ecosystem-based management of forage fish and recovery of Pacific herring. Below is our summary of (1) what is known; (2) what gaps in information remain; and (3) analyses or long-term monitoring programs proposed by the Study Panel to address those gaps.

A. What is known

i. Adult herring spawner biomass (ongoing), growth, survival, age structure

Although the Study Panel agreed that the assumptions contained within the model used to estimate adult herring spawner biomass (the Vital Sign indicator) from egg deposition surveys should be re-evaluated, egg deposition surveys are a standard and acceptable method used to estimate spawner biomass. Owing to the cancellation of acoustic trawl surveys in 2009, however, no current information on growth, survival or age structure exists. Without these important pieces of information, attributing cause to trends in the future will be difficult.

- *See Monitoring Recommendation #1*

ii. Trends in adult herring spawner biomass

Based on the egg deposition surveys, and the acoustic trawl surveys (conducted until 2009), many herring sub-populations are in decline. The acoustic trawl surveys and the egg deposition surveys describe the same trends in adult spawner biomass.

- *See Research Project #14: Demographic structure of Pacific herring (Clupea pallasii) in Puget Sound*

iii. Herring age truncation

Through 2009 (when the acoustic trawl surveys ended), most herring sub-populations showed evidence of age truncation (loss of older age classes). This is a West Coast-wide phenomenon; however, it has yet to be documented and the consequences of this pattern for population dynamics have not yet been explored.

iv. Herring spawning locations

While the Study Panel acknowledged that likely not all spawning sites have been identified, there is good reason to believe the major spawning sites, the sites that likely contribute most of the stock biomass, have been identified.

v. The role of forage fish in predator diets

While not perfect, there is good information on which forage fish species are consumed and in what amounts across a wide range of predators (birds, mammals, fish). There is opportunity for a synthesis of this information across predators and a meaningful analyses of the role of predation in abundance trends.

B. Gaps in Information

i. Status of/trends in abundance of forage fish (species other than herring)

Assessing status and trends requires a reference point and, in fact, multiple reference points are needed to reflect the multiple dimensions of status and trends: age structure, size structure, spatial and temporal variability, organizational scale (population, meta-population unit, community).

There is a need for some rules of thumb (akin to the "1/3 for the birds" rule[1]) and simple indicators of stock status, e.g., the fraction of suitable spawning habitat used annually.

Biological indicators, e.g., seal scats, seabird foraging, piscivorous fish stomach contents, nest success of seabirds, etc., might augment direct sampling of forage fish abundance by providing information on predator responses to fluctuating forage fish abundance.

There is presently no monitoring of early life stages of forage fish, though this life stage may (a) be the most vulnerable and a driver of population dynamics; and (b) sampling the early life stage may be the best way to directly assess abundance for some species (e.g., sand lance).

- *#8 Let the predators speak for themselves – An analysis of predator diets*
- *#10 Seabirds as samplers*
- *Monitoring Recommendation #2*

[1] Cury PM, et al. 2011. Global Seabird Response to Forage Fish Depletion – One-Third for the Birds. *Science* 334(6063): 1703-1706.

ii. Key vulnerabilities of forage fish

Both management aims addressed herein (recovery of herring and EBM of forage fish) require an understanding of what limits forage fish populations. For example, at present, while there are many hypothesized drivers of herring declines, there is little agreement on the primary cause and, therefore, the best management or policy actions for recovery. Likewise, there is very limited information about key vulnerabilities of other forage fish species. There is a need to assess the impacts of multiple, and interacting, stressors on forage fish in a common framework. Where critical stressor interaction effects are unknown, conservative estimates may be generated based on general physiology and life history characteristics.

It is important to acknowledge and assess the effects of stressors on multiple life stages. These effects may be lethal or sub-lethal, the latter resulting in complex physiological or population-level responses. A life history model is the natural framework for assessing effects of stressors on forage fish, and this model would be useful in other applications.

- *#7 Scenarios of effects of multiple stressors on forage fish*
- *#1 Management Strategy Evaluation of stressors for forage fish*
- *#5 An integral projection model for the dynamics of viral hemorrhagic septicemia (VHS) in Pacific herring*
- *#6 "Pick your poison" -- Contaminant loads and fishery management*
- *#12 Historical habitat effects on Puget Sound herring*
- *#13 Are herring habitat limited? Spatial variation in herring egg mortality*

iii. Abundance/biomass of forage fish needed to support key ecosystem predators

Humans also need forage fish species, but not all forage species interact with the non-human food web with the same intensity, and therefore those sets of species should be treated separately. Thus, "ecosystem needs" is qualified by "for key ecosystem species," which are those predators that are priorities for humans.

In assessing ecosystem (predator) needs for forage fish, attention should be paid to how those needs vary over space and time, and particularly to seasonal variation.

- *#2 Biomass is not enough: Predator needs across dimensions of prey size and distribution*

- *#3 Forage fish in space*

- *#4 Reference points for ecosystem-based management*

iv. Prey base/food supply for forage fish

Critical to herring recovery and EBM of forage fish generally is understanding the dynamics of forage fish prey base, zooplankton. The lack of a long-term monitoring program focused on describing the abundance and community structure, and its spatial and temporal variation, of Puget Sound zooplankton creates a challenge for ecosystem management and recovery broadly speaking, and for forage fish specifically.

- *Monitoring Recommendation #3*

v. Consequences of herring age truncation

While it is acknowledged that herring have experienced age truncation (loss of older age classes) across the West Coast herring stocks, the phenomenon has yet to be documented, and the consequences of this pattern for population dynamics have not yet been explored.

- *#11 A large-scale biological indicator of ecosystem state: Bayesian analysis of inter-decadal changes in northeastern Pacific herring mortality rates*

vi. Partial migration by herring out of Puget Sound

One challenge to our understanding of what limits Puget Sound herring populations, to our ability to quantify predator needs for forage fish in Puget Sound, and to food web models that include herring is that we do not know the extent to which, or conditions under which Puget Sound migrate out of the Sound as adults before returning again to spawn. We cannot, therefore, predict when that migration is aborted or only partially attempted.

- *#9 Partial migration in herring: Proximate and ultimate mechanisms*

IV. Proposed Work Plan

The following proposed projects are organized into several stages of "shovel readiness": Need Additional Resources to Begin, Ready to Begin, In Progress, and Complete.

Stage: ***Need Additional Resources to Begin***

1. Management Strategy Evaluation of Indicators (Lead co-authors: Tim Essington and post-doc TBD)

We will build an operating model based on a hypothesized list of stressors to forage fish, e.g. human population growth, climate, contaminants, diseases, habitat, exploitation, mixture of resident and migrant populations. We will then ask what portfolio of stressors are the most effective indicators of forage fish stock status, and for what driver of population dynamics. This will essentially be an age-structured meta-population / spatially structured model, for herring, sandlance and smelt. This model can be used as a foundational framework for future analyses that consider consequences of human activities on forage species, and to test management and sampling strategies. The model can also be used to ask whether the consequences of existing stressors can reasonably be detected based on current monitoring programs, while identifying new monitoring strategies to improve the ability to detect these consequences.

2. "Biomass is Not Enough": Predator needs across dimensions of prey size and distribution (Lead authors: Tim Essington, Dayv Lowry, Doug Hay and UW Graduate Student TBD)

Biomass density is one important dimension for assessing predator needs, but there are other dimensions of forage populations that are also important for sustaining predators. One hypothesis is that for the forage fish guild to meet the needs of all predators, one needs to pursue restoration or protection effects that maintain: stock diversity (providing variation in space and time when juvenile fish are available for predation, while also providing portfolio benefits), age / size diversity (to provide the right type of prey across a range of predators), and species diversity (so that alternative species are available if one is undergoing a period of low productivity). There are likely other dimensions. This work will summarize predator needs across these dimensions (e.g., size of forage fish consumed), and also calculate time series of availability of prey across slices of these dimensions (e.g., the abundance of small, medium, and large-sized herring).

3. "Forage Fish in Space" (Lead author: Tim Essington)

Available evidence suggests that pelagic food web structure varies considerably across the main basins of Puget Sound. Available data could be compiled to create distinct food web models (e.g., via an Ecopath-like structure) for each basin to flag data gaps, highlight clear differences, and compare and contrast predator sensitivities to forage fish density.

4. "Reference Points for Ecosystem-based Management" (Lead authors: Tim Essington, Tessa Francis)

A synthesis of maximum or mean observed herring (or total forage fish) density across multiple

ecosystems could be used to find good biophysical predictors of each of these metrics (e.g., total shelf area, primary productivity, etc.). These could be compared to metrics derived from presumed trophic level and trophic transfer efficiencies. This will also include a re-examination of the existing herring target.

5. An integral projection model for the dynamics of viral hemorrhagic septicemia (VHS) in Pacific herring (Lead authors: Megsie Siple, Paul Hershberger, Tim Essington)

Viral hemorrhagic septicemia virus (VHSV) is a pathogen that typically occurs endemically among coastal marine fishes in the NE Pacific; however, resulting disease (VHS) epizootics and associated fish kills periodically occur in populations of Pacific herring and other forage fishes. Host susceptibility is likely a function of continuous variables that influence infection pressure, including fish age, water temperature, prior exposure history, fish behavior, and exposure level / duration. The response of a population to VHSV depends on transmission kinetics, frequency of epizootics, and consequences of infection. We will develop an integral projection model for VHS dynamics in Puget Sound herring, starting with epizooticological parameters that have been determined from lab experiments. This model will answer key questions about the sensitivity of the Puget Sound herring population to assumptions about disease parameters (mode, rate, and consequence of transmission) and population biology (growth, survival, and reproductive rates). We will use sensitivity analyses to ask, under what disease and life history parameterizations does VHS have a substantial population-level effect?

6. Pick Your Poison -- Contaminant Loads and Fishery Management (Lead author: Alec MacCall)

The presence of contaminants in forage fish such as herring may impair reproduction or survival both of these fish and their predators, but also reduces the value of these fish as commodities in the human economy. In a system where fishery management may be reluctant to address issues of contaminants and forage directly (as is often the case), it is possible that market forces may nonetheless result in a de-facto allocation of forage fish production. This study would use the models of the previous papers to determine how the regulatory threshold for human effects of contaminants in herring (e.g. used for aquaculture*) may interact with the threshold for deleterious effects on the population and predators. Given the continuing presence of contaminants, the spectrum of trade-offs will help determine if there are circumstances that produce a self-regulatory system as opposed to a system requiring strong management intervention. Results may suggest need for experimental work to support model "tuning."

*The study may be less relevant to Puget Sound, where there are strong existing limitations on use of herring for aquaculture.

Stage: ***Ready to Begin***

7. Scenarios of effects of multiple stressors on forage fish (Lead authors: Tim Essington,

Dayv Lowry, Ole Shelton, UW Graduate Student TBD)

The first step of this work will be to develop a generalized life cycle model so that the importance of threats in individual life stages, as manifest at the population level, can be explored. This work will also provide the foundation for (1) a gap analysis of key threats by life stage, and (2) a modeling framework for a larger effort to simulate multiple meta-population components and multiple forage fish species. The identified threats will be incorporated into the life-cycle model to assess the potential impacts on population of each threat, allowing for comparison of the relative importance of each threat. The results of the first step, identifying potential threats for each life stage, will be produced into a technical report for management purposes.

8. Let The Predators Speak for Themselves – An Analysis of Predators Diets (Lead co-authors: Ole Shelton, Megsie Siple and Dayv Lowry)

The abundance of forage fish species is notoriously difficult to quantify directly via surveys. Fortunately, these small fish species play a vital role as prey for many other fish, bird, and mammal species that we can readily observe. Therefore these predator species provide the possibility that we can use the predators as indirect samplers of forage fish in Puget Sound. From the predator's perspective we can ask: what are the most important forage species in Puget Sound? We will compile an inventory of current available information about what is known about predator exploitation of forage fishes in Puget Sound. We will include analysis of how predator use varies across years, by season, and among Puget Sound regions. We will also perform a scoring of predator vulnerability based on behavior, life history, and degree of dependence on forage species. We will also explicitly enumerate gaps in available predator information and highlight areas that could benefit from additional study.

9. Partial Migration in Herring: Proximate and Ultimate Mechanism (Lead co-authors: Marc Mangel, Alec MacCall, and Doug Hay)

We will use behavioral models to understand the environmental conditions under which herring populations will exhibit partial migration. In this case we will use state dependent behavioral theory, implemented by stochastic dynamic programming, to characterize the interaction of environment and physiology in determining migration. Mangel has applied these methods extensively to salmon and steelhead and his collaborators at the University of Bergen (where he is an adjunct Professor of Theoretical Ecology) to herring.

10. Seabirds as Samplers (Lead author: Marc Mangel)

Seabirds are natural samplers of the ecosystem. We will build behavioral models, once again using state dependent life history theory, to make inferences about the abundance of fish from the observed behavior of seabirds. We will work with Tom Good, Peter Hodum, and Scott Pearson on this project to be sure that data and models are linked appropriately.

11. A large-scale biological indicator of ecosystem state: Bayesian analysis of inter-decadal changes in northeastern Pacific herring mortality rates (Lead authors: Megsie Siple, Ole

Shelton, Alec MacCall, Tessa Francis)

An important consideration for the sustainability and management of herring is determining if similar biological processes (e.g. survival) are acting at distinct herring spawning locations. One consequence of a decline in herring survival should be an observed is changes in the herring age structure. On a coast-wide scale, age truncation has been observed in many herring populations from California to Alaska, but the effects of this shift in age structure have not been systematically explored. Within Puget Sound, age-specific survival of herring should vary to some degree but it is important to understand if subpopulations have similar survival characteristics and if these characteristics show trends over time. We will use a Bayesian life-history model to explicitly estimate the degree of similarity in growth and survivorship among subpopulations using available WDFW egg deposition surveys and age structure data. We hope to mesh our results from Puget Sound with similar information from San Francisco and British Columbia to provide a coast-wide perspective on changes in herring age-structure and the potential consequences for populations. Results from this study will inform both the degree of life history variation of herring and inform overall assessments of herring population trends in Puget Sound. This project complements previous work examining synchrony among the biomass time-series of Puget Sound herring stocks (see "Demographic structure of Pacific herring (*Clupea pallasii*) in Puget Sound" below).

Stage: ***In Progress***

12. Historical Habitat Effects on Puget Sound Herring (Lead co-authors: Ole Shelton and Tessa Francis)

Nearshore beach and vegetated habitats are utilized as spawning habitat for many forage fishes. One of the least understood aspects of Puget Sound forage fish biology is how changes to nearshore habitats may affect the productivity and sustainability of these forage fish populations. We are using habitat and herring spawning information collected during WDFW spawning surveys (1972-2012) to ask if available vegetated habitat has systematically changed over the past 40 years and if any of these change in available habitat have affected the location and intensity of herring spawning events. Going forward, we hope to incorporate additional habitat information about shoreline development and the presence of marine contaminants and ask if these factors are linked to temporal changes in herring spawning. We will develop our methods for one or two populations initially with an eye toward expanding our work to all Puget Sound herring populations over the next few years.

13. Are Herring Habitat Limited? Spatial Variation in Herring Egg Mortality (Lead co-authors: Tessa Francis and Ole Shelton)

Eelgrass is a key substrate used by Pacific herring for spawning in the nearshore habitats of Puget Sound. Herring lay their eggs on a variety of substrates, including other species of seaweed and even rock and gravel in some locations. However, because some patches of eelgrass are shrinking, it has been hypothesized that recovery of Puget Sound herring is linked to

increasing eelgrass abundance. We are testing this hypothesis by measuring herring use of eelgrass and other substrates around Puget Sound and measuring egg mortality rates on each substrate type to determine whether eelgrass provides the highest quality spawning substrate for herring.

Stage: ***Complete***

14. Demographic structure of Pacific herring (*Clupea pallasii*) in Puget Sound
(Co-authors: Megsie Siple and Tessa Francis)

Small-scale genetic and demographic diversity can stabilize populations on a larger scale. However, subpopulations of pelagic fish species can be difficult to distinguish. Here, we examine demographic diversity in 21 stocks of Pacific herring (*Clupea pallasii*) in Puget Sound, WA using a multivariate auto-regressive state-space (MARSS) model. Herring populations associated with individual spawning beaches are asynchronous but share a common negative growth rate across the Puget Sound basin. We use survey data from both acoustic trawls and subtidal egg deposition surveys to estimate growth trends. We find that both survey techniques observe the same underlying processes, and egg surveys on beaches are a more accurate estimator of total spawning biomass. We use states obtained from MARSS analysis to measure portfolio effects in Puget Sound herring, and find that the Puget Sound population as a whole is stabilized by the presence of several separate spawning subpopulations. We estimate the effects of local environmental conditions on spawning beaches and regional conditions on a basin-wide scale. Winter upwelling and Pacific Decadal Oscillation (PDO) do not explain variation in stock biomass, but may, instead, affect recruitment. The absence of correlation between spawning beach conditions and total spawning biomass suggests that environmental factors affecting juvenile herring may not be manifested in year-to-year fluctuations in adult spawning biomass.

V. Monitoring Recommendations

The Study Panel noted that an effective monitoring program for forage fish will be built around specific scientific questions, and thus will be comprised of science-based data collection. Our proposed work plan aims to answer key questions, given available data. However, we also noted data gaps that limit the scope and approach of our investigations. For example, there is only limited information available to assess status and trends of forage fish (Table 1). In addition, information on spatial and temporal variation in forage fish abundance, and time series relating predator demographic rates to forage fish availability, are missing and would provide direct empirical evidence for the assessment of predator needs. Furthermore, conclusive evidence about Puget Sound herring migration would contribute to the assessment of key vulnerabilities for herring in Puget Sound.

In addition, the Study Panel identified the following data and/or survey strategies that would be important to support ecosystem-based management of forage fish generally, and in particular would allow for the use of sophisticated time-series methods:

1. Age/size composition (especially of herring, to support the Vital Sign Indicator/Target)
2. Ichthyoplankton surveys (to provide information, such as mortality rates, about early life stages, and especially for estimating abundance of sand lance)
3. Zooplankton surveys (to provide information about prey base for forage fish)

Last, the Study Panel noted the following opportunities for improving the method for estimating herring spawner abundance currently used by WDFW:

- Revisit the width of beaches with either isobaths or remotely operated vehicles (ROVs);
- Measure age structure with thoughtfully-selected spot sampling (e.g. at north, central, and south points in the Sound);
- Collect information on size-specific fecundity (rather than using a number determined in 1972-77);
- Conduct a comprehensive assessment of egg mortality, including the effects of density dependence, predators, PAHs and UV radiation (also see paper #13 “Are herring habitat limited? Spatial variation in egg mortality” in progress);
- Investigate the simultaneous application of genetics and microchemistry to determine site fidelity/infidelity.

VI. Caveats

Given the limited size of the panel, some aspects of ecosystem-based management of Puget Sound forage fish are not explicitly addressed in this proposed work plan. For example,

while we intend to include climate variables as covariates in our models, we do not propose any climate-specific projects here. In addition, while it is not within the scope of our present work, members of the study panel discussed different approaches including community-based monitoring of forage fish, perhaps building upon traditional knowledge of Native American fishing practices as a potential avenue for development, but we do not propose a specific project here.

Table 1. Data Available for the Assessment of Forage Fish Status and Trends (in progress)

Type of Information Available			Herring	Sand Lance	Smelt	Other Species
Direct Measurement						
	Occurrence		X	Sparse	Moderate	Sparse
	Biomass or Density		X			
	Age and/or Size Structure		Some		Sparse	
	Disease Prevalence or Severity		?			
	Pollution/Contamination		Some			
Indirect Measurement						
	Predator Diet		X	X	X	Sparse
	Predator Reproductive Success		?	?		
	Other?					
Associated Habitat Metrics						
	Potential Spawning Habitat		X	X	X	Some
	Oceanic Environment					
		Growth potential				
		Other?				

Appendix 1: Study Panel Workshop Agenda

Table 1. Study Panel Agenda, 25-29 August 2013

Sunday, August 25		
1300	Arrival	
1400	Group Meeting	meet & greet, discuss sessions, set strategy for the week
1700	Adjourn to dinner in Friday Harbor	
Monday, August 26		
0830	Group Meeting	preview of presentations
1030-1530	Presentations	
1530-1600	Break	
1600-1730	Group Meeting	presentations debrief, brainstorm
1730	Adjourn to dinner in Friday Harbor	
Tuesday, August 27		
0830	Group Meeting	general discussion
0900-1030	Break-out session 1	led by session chairs
1030-1200	Break-out session 2	led by session chairs
1200-1300	Lunch	
1300-1430	Break-out session 3	led by session chairs
1430-1600	Break-out session 4	led by session chairs
1600-1615	Break	
1615-1730	Group Discussion	wrap-up, share ideas
1730	Adjourn to dinner in Friday Harbor	
Wednesday, August 28		
0830	Group Meeting	general discussion
0900-1200	Breakout/working sessions	
1200-1300	Lunch	
1300-1600	Breakout/working sessions	
1600-1615	Break	
1615-1730	Group Discussion	wrap-up, share ideas
1730	Adjourn to dinner in Friday Harbor	
Thursday, August 29		
0830	Group Meeting	next steps, timelines, milestones
1100	Check-out time	
1135	Ferry to Anacortes	
1415	Ferry to Anacortes	

Table 2. First Workshop: Open Session Presentations

Presenter	Presentation Title
Kurt Stick, WDFW	Estimation of Herring Abundance in Puget Sound
Casimir Rice, NOAA NWFSC	Puget Sound's Nearshore Pelagic Food Web
Iris Kemp, UW SAFS	Zooplankton in Puget Sound
Russel Barsh, Kwiaht	What do Juvenile Chinook Eat?
Fred Felleman, NW Consultant	Cherry Point's Pickled Herring
Tom Good, NOAA NWFSC	Patterns in Seabird Diet and Persistent Organic Pollutants in Puget Sound Forage Fish
Chris Harvey, NOAA NWFSC	Update on Ecopath with Ecosim Modeling of Puget Sound: Planktivorous Fishes
Dave Beauchamp, UW	Life Beyond the Spawning Grounds: Distribution and Food Web Relations of Forage Fishes in Puget Sound
Eric Eisenhardt, Whale Museum	Some Observations of Forage Fish in the Salish Sea
Jim West, WDFW	Toxic Contaminants in Puget Sound's Pelagic Food Web

Additional Attendees

Joel Baker, PSI
Alan Chapman, Lummi Tribe
Caroline Gibson, NW Straits Commission
Lauren Kuehne, UW SAFS
Dan Penttila, Private Consultant
Megsie Siple, UW SAFS

Appendix 2. Discussion Notes from Initial Workshop Open Session

Open Session – post-session conversation

- Important to remember to consider degradation of spawning habitat as driver of forage fish population decline
    - Armoring
    - Vegetation (herring)
    - Shellfish aquaculture
- Other important stressors to consider:
    - PAHs
    - UV-enhanced toxicity by PAHs as a measure of lethality
        - Especially for spring-spawning of Cherry Point herring
- Concern of above should be extended, especially summer-spawning surf smelt, spawning on gravel
- Surf smelt & sandlance eggs could be used in lab experiments
- Habitat restoration should include water quality/quantity
- PSNERP ignores water quality
- Coal terminals are also an important potential threat
    - No EISs have been done
- Herring spawning has declined across Salish Sea but near historic highs some places on Vancouver Island
- Offshore trawling may have effects. There are very few net fisheries in Puget Sound.
    - There is some forage fish bycatch in the beam trawl of shrimp fishery
- What is the framework for considering all these different threats on forage fish?
- We're missing some connections, between habitat/eggs; harbor seals/adult herring
- What's the connection between Casey's CPUE and egg deposition data?
    - We need comprehensive basic monitoring across life stages and dominant environmental gradients
- Hatchery salmon data are available, could that be useful
- What about the idea that juvenile salmon are forage fish?
- There are a lot of data/samples in the freezer, basic biological questions that can be answered
- Could we quantify total available habitat? Depth, water quality, shoreline length, vegetation
- What about carrying capacity? Could we quantify carrying capacity?
- What about an analysis of growth potential/available consumption potential by basin: increases in gelatinous zooplankton (competitors), plus temp/O2 gradients that vary by basin, prey availability
- Some really good oceanographers who make good collaborators
- What temperature data are available?
    - Race Rocks
    - PSAMP
    - Individual counties