https://doi.org/10.7289/V5/TM-NOS-NCCOS-204

Advancing Tools for Modeling, Forecasting and Managing for *Vibrio* spp. in Washington State

April 28-29 2015

Lacey, Washington

NOAA Technical Memorandum NOS NCCOS 204

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Citation for this Report

Paranjpye, R., Johnson, L., Jacobs, J., and DePaola, A. 2015. Advancing Tools for Modeling, Forecasting and Managing for Vibrio spp. in Washington State. NOAA Technical Memorandum NOS NCCOS 204. NOAA National Centers for Coastal Ocean Science, Center for Coastal Environmental Health and Biomolecular Research, Cooperative Oxford Laboratory, Oxford, MD. 27 pp. https://doi.org/10.7289/V5/TM-NOS-NCCOS-204

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NOAA Technical Memorandum NOS NCCOS 204

September 2015

United States Department of Commerce	National Oceanic and Atmospheric Administration	National Ocean Service
Penny Pritzker	**Kathryn D. Sullivan**	**Russell Callender**
Secretary	**Under Secretary of Commerce for Oceans and Atmosphere, and NOAA Administrator**	**Acting Assistant Administrator**

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EXECUTIVE SUMMARY

Shellfish aquaculture generates $185 million USD annually in the State of Washington dispersed among small farmers, tribal entities and large companies. Demand for half-shell product from the region is high, as are the number of *Vibrio*-related illnesses associated with consumption of raw shellfish. The vast majority of *Vibrio*-related illnesses in Washington State are associated with a single species, *Vibrio parahaemolyticus* (*Vp*). The intent of this workshop was to bring together tribal and non-tribal industry representatives, Federal subject matter experts, State Shellfish Control Authorities, and academic researchers to explore new tools to improve harvest and post-harvest strategies and practices to reduce the risk of illness.

Nearly 60 individuals convened on April 28th and 29th, 2015 at the Lacey Center near Olympia, Washington to discuss *Vp* related issues, prioritize needs and outline a plan to move forward. The workshop began with an introduction to NOAA's Ecological Forecasting Roadmap, a cross-line-office effort within NOAA designed to coordinate efforts in the provision of guidance models and forecasting tools for environmental applications.

The first day of the workshop opened with a plenary talk focused on what is already known about the ecology of *Vp* in the Pacific Northwest (PNW). This was followed by a panel session geared towards reviewing the current *Vp* control plan in Washington State, the FDA *Vp* risk assessment, and efforts underway to update and regionalize the risk assessment for the State. The second panel session consisted of industry representatives and tribal co-managers who were asked to provide a short overview of their harvest practices and respond to a series of questions designed to assess research, monitoring, and modeling needs for *Vp* control. The afternoon concluded with the third and final panel session of the day, which focused on the modeling and forecasting tools being developed and their potential application to *Vibrio* spp. issues in Washington. In all, the plenary and panel sessions served to provide a foundation for further discussion of research, monitoring and modeling needs of the State Shellfish Control Authorities and the shellfish industry to reduce *Vp*-associated illness.

The remainder of the workshop focused on facilitated discussions designed to identify the research, monitoring, and modeling needs that are specific to the industry and State Shellfish Control Authorities. Day Two continued on this theme and focused on identifying commonalities, prioritizing needs, and determining which entities were most appropriate for addressing each need.

From a monitoring standpoint, supply chain monitoring for *Vp* levels and temperature was assigned the highest priority. This is due to a lack of information on how *Vp* levels fluctuate under typical industry practices through the entire supply chain continuum from harvester to consumption. This knowledge could be used to improve risk assessment models as well as reduce the likelihood that more risky product reaches consumers. Increased sampling of areas with low risk of *Vp* was also identified as a need. The identification of areas for cool water storage for holding post-harvest stock was noted as a high priority, although more research is needed to determine if holding shellstock in cool water can be used to reduce the likelihood of *Vp* illnesses.

Modeling needs were equally weighted between the development of models to predict *Vp* levels after intertidal exposure and those predicting purge rates of *Vp* in oysters after re-submergence. The former reflects a need to refine the FDA risk growth models at elevated temperatures experienced by oysters during intertidal exposure that may relate more to solar irradiance and other factors than air temperature alone. The latter would assist growers in determining length of time needed to purge *Vp* from oysters at various water temperatures to reduce to background levels or lower for added safety. Combined, the outputs of the intertidal growth model could serve as inputs for the proposed purge model, which could predict time needed to reach targeted reductions for re-harvest.

Finally, tools were addressed that could be imbedded into existing resources, or new modeling approaches to assist the industry with scenario analysis. The greatest need was again addressing purging rates, but in the form of an easy to use calculator. Following close behind was spatially explicit sea surface temperature and air temperature products readily available to growers for specific locations.

The results of this workshop are being used to formulate work plans and specific objectives for the remainder of 2015 and beyond. The participants will remain in contact through e-mail updates of progress, and future workshops to further refine strategies to reduce illness risk in the Pacific Northwest (PNW) and maintain the strong reputation of the region for quality oysters.

INTRODUCTION

Bacteria belonging to *Vibrio* spp. occur naturally in our coastal areas around the globe. However, certain species and strains are capable of causing human illness. In the United States, one species, *Vibrio parahaemolyticus* is responsible for the majority of the estimated 80,000 illnesses a year. While normally presenting as self-limiting gastroenteritis, its strong association with consumption of raw oysters is a concern both for human health and the sustainability of a growing half-shell industry.

Washington State is the largest shellfish producing regions in the country, and also has the highest *Vp* illness burden. Many factors make the region unique, such as low average summer water temperatures, deep estuaries, and large tidal ranges that can leave oysters exposed to the warming rays of the sun for extended periods. There are also differences in harvest practices among oyster growers in the region. Much of the harvest is conducted at low tide when oysters are exposed. Other methods are employed such as long lining where oysters are suspended on lines or tumbling where oysters are grown in bags that are flipped with the tide to produce shorter, deeper oyster growth. These practices may have different effects on the ultimate *Vp* levels in oysters.

Because of the historic occurrence of illness, Washington State has developed a control plan in accordance with the National Shellfish Sanitation Program (NSSP) that aims to reduce the likelihood of illnesses during periods when *Vp* illnesses are reasonably likely to occur. The end goal is to keep illnesses below 1 per 100,000 oysters consumed. Closure of growing areas due to illnesses can create financial hardship, particularly on smaller operations that only have harvest sites in the affected area. In addition, shellfish recalls that commonly occur in addition to closing the area to harvest erodes consumer confidence and likely influence sales.

In recent years, significant progress has been made in predicting the concentration of *Vibrio* spp. in the environment (water) and in oysters. Groundbreaking efforts by the Food and Drug Administration (FDA) in the mid 2000's provided a complete risk assessment framework for evaluating risk of illness from time of harvest through consumption. While still the best tool available for states to use, there are recognized limitations and data gaps. These are apparent in the PNW in several areas where there are differences in relationships between temperature and salinity, with *Vp* abundance at harvest, post-harvest growth in intertidal regions, and serving size among others. With the exception of an intertidal module for the PNW, the risk assessment was developed as a "one size fits all", national tool out of necessity and lack of regionally specific data. However, 10 years have passed since its publication, and new tools and data are available to begin to address these gaps. FDA and NOAA have recently developed a partnership to work with states to provide the environmental data, modeling tools, and *Vibrio* expertise to regionalize and update risk assessments.

In the midst of this effort lies a new breed of predictive tool for environmental conditions. Satellite technology is ever improving, and coastal ocean models are available for nearly every coastal water body. Combined with weather and climate models, the capability exists to accurately forecast many of the major drivers for growth of *Vibrio* spp. Recently, NOAA and partners have capitalized on these resources to provide regionally based forecasts for *Vibrio* concentrations, and conditions suitable for growth of *Vibrio* spp. and proliferation in many regions around the country. However, understanding regional needs, resources and variations in harvest practices and environmental drivers is key to the development of useful tools. The purpose of this workshop was to engage the industry and the State in the pursuit of new tools and technology that may reduce the burden of risk for Washington oyster growers.

MEETING OBJECTIVES

1. Participants gain a shared understanding of:

    a. The unique characteristics of the shellfish industry in WA state;

    b. Tribal and other shellfish industry operations in WA State: data and information needed to improve resource/harvest management operations, and tools and development efforts that would be most useful for operations;

    c. Existing tools and techniques for risk assessment of *Vibrio* spp. and resource management;

    d. Information from the academic, state and federal research community on the current state of scientific modeling and management of risk of *Vibrio* spp. (including current assumptions and limitations) and/or development of new tools and techniques for risk assessment and harvest management.

2. Participants develop a prioritized list of research, monitoring, and modeling needs and shared understanding of next steps.

WORKSHOP ORGANIZATION

The workshop was structured in a manner to first bring participants to a common state of knowledge about the issues, management framework, harvest practices, and modeling tools. This was accomplished through a series of plenary presentations and panels on day one. Following the presentations, participants were divided with growers in one group, resource managers in the other, and modelers dispersed between both groups. Each group was asked to respond to a series of questions designed to ascertain needs. During day two, all participants convened to discuss and prioritize research, monitoring and modeling needs. This list is the major outcome of the workshop and will serve to direct these tasks for the next several years, funding dependent.

PLENARY PRESENTATION SUMMARIES

<u>Introduction</u>

NOAA Ecological Forecasting Roadmap (Allison Allen, NOAA, NOS)

Allison Allen provided a brief introduction to NOAA's Ecological Forecasting Roadmap (EFR). The Roadmap is an effort within NOAA to organize and coordinate the delivery of accurate and efficient forecast products for biological organisms and processes. Four areas were chosen for initial development based on maturity and utility of forecast products: harmful algal blooms, species distribution, hypoxia, and pathogens. While the effort is national in scope, the approach is largely based on regionally specific, stakeholder driven products. Those forecast products found to be of greatest utility and accuracy are further developed as "operational" products, or maintained and delivered without fail by NOAA. For pathogens, initial efforts have focused entirely on *Vibrio* spp. in coastal waters and shellfish. The first step in the process is learning the needs and requirements of the intended users of the forecasts. The goals of this workshop are to explore and document those needs, and begin to chart a path forward.

Ecology of *Vibrio parahaemolyticus* (*Vp*) in the Pacific Northwest (Rohinee Paranjype, NOAA, NWFSC)

Vibrio parahaemolyticus (Vp) is a Gram-negative bacterium naturally present in marine and estuarine environments worldwide. While the majority of environmental strains are innocuous members of the marine microbiota, small subpopulations are opportunistic pathogens of humans. Currently potentially virulent strains are commonly differentiated from avirulent strains by the presence of the thermostable direct (TDH) and *tdh*-related (TRH) hemolysin. Acute gastroenteritis is the most common manifestation of illness and is often associated with the consumption of raw or undercooked oysters, which can bioaccumulate the bacteria through filter feeding.

Reports of increasing illnesses due to *Vibrio* spp. in temperate regions have been linked to global warming and subsequent increases in water temperature. In the U.S., illnesses due to *Vibrio* spp. increased 3-fold over the 15 years from 1996-2012 with the majority of increase attributed to *Vp*. The first major *Vp*-related outbreaks in the Pacific Northwest (PNW) occurred in 1997-1998, and this *Vibrio* species continues to be the major species of concern in the PNW. Managing and assessing the risk of *Vp*-related illness from consumption of oysters has been particularly challenging in this region since current risk assessment methods based primarily on water temperature at time of harvest and the concentrations of total *tl+* and *tdh+ Vp* in oysters have not proved to be effective in predicting illnesses, and consequently result in underestimation of illnesses.

Vp is a genetically and serotypically diverse species. Outbreaks prior to 1996 were geographically isolated and associated with a diversity of serotypes. Since 1996, the majority of illnesses worldwide have been attributed to a new serotype (O3:K6 and its serovariants) that originated in Southeast Asia. The *Vp* O3:K6 serotype and its related serovariants, referred to as the pandemic complex, have been responsible for two outbreaks in the U.S. (e.g. Texas and New

York, 1998). However illnesses in the PNW have been associated with strains that are genetically and serotypically distinct (O4:K12 and variants) from the pandemic complex. Studies conducted in the PNW indicate that *Vp* strains related to the pandemic complex are present in the PNW environment, but have not been responsible for the illnesses. Multiple serotypes, including 04:K12 have been implicated in illnesses from oysters harvested in the PNW.

Numerous studies in different geographic locations have been conducted to assess the correlation of abiotic (temperature, salinity, nutrients, dissolved oxygen, turbidity, etc.) and biotic (chlorophyll, plankton, phytoplankton, etc.) parameters. In most locations, temperature is correlated with the concentrations of total *Vp*, with the influence of the other abiotic factors such as salinity, dissolved oxygen and nutrients varying depending on geographic location. However studies conducted in the PNW suggest that the environmental drivers that affect populations of *Vp* in this region are complex. Seasonality appears to be the key parameter in predicting trends in *Vp* density while temperature and nutrients have a marginal effect. Additional studies incorporating oceanographic modeling are needed to provide additional insight into conditions that impact *Vp* concentrations in this region.

<u>Session I – Current Management and Risk Assessment in Washington</u>

This plenary session was designed to provide participants with: 1) a basic understanding of the shellfish associated illnesses occurring in Washington State, 2) control plans in place to minimize risk, 3) how the FDA risk assessment works and its limitations, and 4) current efforts to improve the risk assessment in the region.

Overview of Illness Occurrence and Regulations in Washington State (Laura Johnson, Washington State Department of Health)

Laura Wigand Johnson provided an overview of the number of illnesses reported in 2014, the state's newly adopted control plan, and the state's environmental monitoring program for *Vibrio parahaemolyticus* (*Vp*). In 2014 there were a total of 76 *Vp*-associated laboratory confirmed or epidemiologically associated illnesses potentially implicating commercially harvested Washington molluscan shellfish. Of those 76 illnesses, 26 were single-source illnesses with complete trace back to one growing area in Washington. 50 were multi-source illnesses with incomplete trace back, either due to the consumption of oysters from multiple areas or the inability to determine the precise source of the oysters during the illness investigation. Of these illnesses 18 were traced back to only growing areas in Washington and 32 were traced back to growing areas in Washington, other states, and Canada. Additionally, there were three illnesses due to the consumption of shucked meats. Shucked meats are not included in WAC 246-282-006 (*Vibrio* Control Plan) so illnesses resulting from the consumption of shucked meats are not attributed to a growing area to determine time of harvest to temperature control reductions and closures. There were also 18 illnesses traced to commercially harvested product, but the illness investigation revealed post-harvest abuse issues either in the transport and handling of the product or at the retail level. An additional seven illnesses were reported with no trace back information. Many of these individuals were either unsure of the source of the oysters (such as a purchase from Craigslist), were not cooperative in completing the epidemiological interview, or denied any exposure to shellfish or water. Non-commercial illnesses included two from clams, two from Dungeness crab, eight from oysters, and one from salmon. The total number of illnesses reported from oyster consumption was within the range of illnesses reported from 2010-2013 of 70-90 illnesses per year.

The Department of Health (DOH) proposed to revise the state's control plan rule in 2013 to the State Board of Health. DOH sought this avenue due to the steady number of illness reports and reactive nature of the existing control plan. Occurrences of sporadic Vibriosis illnesses are prevalent in the warmer months and the control plan addressed the risk of illness by reducing time of harvest to temperature control requirements in the summer months and closing areas based on illnesses. This approach led to many late season closures (August and September) and missed an opportunity to prevent illnesses during the peak illness months (July and August). *Vp* is a highly temperature-dependent bacterium and illnesses primarily occur during the summer months. Since *Vp* does not grow significantly at or below 50 degrees Fahrenheit it is important to cool oysters to this temperature to reduce the opportunity for post-harvest growth. There are also conditions in the environment when water temperatures allow *Vp* growth to levels that can cause illness. In these scenarios, post-harvest controls are unable to prevent illness and suspending harvest is the only known measure to prevent these illnesses. The control plan adopted by the State Board of Health in March focuses on preventing illnesses by triggering time reductions and closures based on environmental conditions. The new plan also aligns the state's control plan with NSSP requirements, as the NSSP requirements have been revised since the last revision to the state control plan in 2009.

To develop the new control plan DOH convened a *Vp* Advisory Committee (*Vp*AC). This committee met nearly monthly for two years to develop the concept and rule language for the new plan. DOH worked closely with the Northwest Indian Fisheries Commission, Point No Point Treaty Council, individual tribes, the Pacific Coast Shellfish Growers Association, small and large shellfish businesses representing all shellfish license types operating in Puget Sound and in coastal areas, local health jurisdictions, Sea Grant, FDA, and NOAA to develop this rule. The main changes to the rule are shown in Table 1 below.

Table 1. Main Changes in Control Plan Rule

Component	Previous Version	Adopted Version
Shellfish production data	No requirements	Requirement to report
Growing area categories	Geographic area (coastal and inland)	Risk level (historic illness trend)
Time of harvest	Temperature control (placing oysters in temperature control)	Cooling (reaching and maintaining 50^{0} F)
Time reduction	Two sporadic illnesses (1 hr reduction)	Air temperature threshold (2 hr reduction) or Harvest temperature threshold (4 hr reduction)
Closure	Four sporadic illnesses	Harvest temperature threshold
Closure period	Remainder of control plan months	24 hours

These changes to the rule were intended to reduce the opportunity for post-harvest growth, reduce growth during exposure when mid-day low tides occur during heat waves in the summer months, limit harvest when post-harvest mitigation may not be sufficient to reduce the likelihood of illnesses, and target the most stringent controls during the months when the majority of illnesses occur.

DOH conducts extensive environmental monitoring for *Vp* from June through September each year. Oysters are collected for tissue samples and analyzed using a real-time PCR assay for *tlh*, *tdh*, and *trh* at the Public Health Lab. In addition, salinity and air, water and tissue temperature are recorded at each sampling site. At each site a USB data logger is also deployed to monitor temperatures. In 2014 DOH collected 270 environmental samples from June to September. The samples were collected from a total of 24 growing areas. Of those growing areas, 15 were sampled weekly from June-September and 2 were sampled bi-weekly from July-August. The remaining 7 growing areas were sampled as part of illness investigations or to expand the state's pulsed field gel electrophoresis (PFGE) library.

DOH is now working to train the industry and prepare to implement the new rule on May 1, 2015. DOH is also finalizing a near real-time data sensor network using cellular data loggers to aid DOH and the industry in implementing the new rule. The sensors will be deployed throughout Puget Sound and the outer coast and the data will be available through NANOOS. DOH is committed to reviewing the effectiveness of the rule annually and revising the new rule as necessary. Given the unique nature of the new rule, DOH expects that revisions will be necessary to clarify and improve effectiveness of the rule's preventive approach.

Overview of Washington State's *Vp* Risk Assessment (Hilary Browning, Washington State Department of Health)

Hilary Browning provided an overview to the work she did in 2013 - 2014 to develop a *Vp* risk assessment for Washington State. This effort involved developing a conceptual model of the harvest practices unique to Washington State and gathering data that could be used as input in each stage of harvesting and processing chain. Hilary provided examples of data that the Washington Department of Health collected in order to support this risk assessment, including information on serving sizes, oyster weights and cooling rates of oysters in tubs. Finally she gave a summary of what the risk assessment has been able to accomplish and where more work may need to be done to make this assessment useful as a regulatory tool.

Current FDA *Vp* Risk Assessment and Vision for Updating and Regionalization (Angelo DePaola, FDA)

Andy DePaola provided a review of the FDA *Vp* Risk Assessment including the framework, features, assumptions and limitations. He also presented his vision for updating and regionalizing *Vp* risk assessments using stakeholder generated local data. FDA and NOAA collaboration activities and plans regarding EFR were summarized. The goal of this collaboration is to blend FDA risk models with NOAA capabilities to widely monitor, analyze and forecast environmental conditions that affect *Vp* risk and to continuously deliver current information and analysis with multiple media. Proposed web-based forecasting systems could potentially accommodate risk calculator tools for evaluating risk or for scenario analysis or risk reduction options. These capabilities are urgently needed by State Shellfish Control Authorities and industry to better inform their risk evaluations and analyze mitigation scenarios.

Session II – Overview of Washington Shellfish Industry

Industry practices surrounding the harvest and distribution of shellfish differ regionally around the United States. Understanding these practices is critical for developing useful and equitable strategies and tools to reduce risk of illness. In this session, industry representatives were asked to provide a brief overview of their operation and participate in a facilitated Q and A discussion designed to begin the process of identifying needs.

Adam James (Hama Hama Oyster Co.)

Adam James provided a brief overview of his operation, Hama Hama Oyster Co., on the Hood Canal. While some product is sourced from the South Sound and Straight, most is grown locally on the family farm. Harvesting is conducted at low tide and thus the primary concern for Adam is that the oysters are exposed to heat when the tide is out. Methods for keeping oysters cool during intertidal exposure would be of great utility. The company has learned not to harvest oysters for the half shell when water temperature is high. Oysters harvested when temperatures are high are sold for consumption after cooking only. Another option would be to not harvest unless the water temperature is below 63° F.

Bill Dewey (Taylor Shellfish)

Taylor Shellfish, the largest shellfish grower in Washington State, manages 11,000 acres of tideland in Washington State and sells 22,000,000 oysters per year for raw consumption to restaurants and oyster bars. Sales have increased 600-700% since 1999.

Oyster production includes both clusters and singles. The market has seen a shift to more single oysters. Oysters are harvested at low tide, which is during the day in summer and at night during winter months. Oysters are iced within the hour of harvest and processed under refrigerated conditions to keep them cold during shucking and handling. All personnel, including truck drivers, are trained on proper handling techniques. All oysters are transported in refrigerated trucks.

Taylor also has farms in British Columbia where levels of total *Vp* in oysters cannot exceed 100/g. At this location, oysters are grown on trays and the trays are lowered down until they are immersed in cold water prior to harvesting. The company is experimenting with a number of new and innovative methods for oyster growing and harvesting.

Specific Comments:

- In Washington the average serving size is 3 oysters/person. Since this varies regionally, it is important to factor it in for risk assessment.
- Modeling for total *Vibrio* spp. may not be the best predictor for illness in WA State.

- Effective post-harvest process that leaves the oyster alive would be a great solution.
- Growers need to find the cooler waters so that they can containerize the products.

Tamara Gage (Tribal perspective, Port Gamble Tribe)

In Washington State, tribes have harvest rights to 50% of the naturally occurring shellfish. Shellfish is harvested both on public and private land. Harvesters are not employees but are tribal members who harvest shellfish that is sold to provide income for the families of the tribe. Oysters are harvested as the tide is exposed. All harvesters follow strict requirements and must pass a test to ensure that they know the rules to be used until the oysters are sold. Oyster harvest is highly regulated during the summer, but for many members this is their only source of income. Harvesters rely on buyers to handle the oysters properly after purchase.

Q&A Session

What are your main concerns regarding Vp?

The main concerns voiced among growers were related to issues with data needs, post-harvest strategies, and enforcement. The need for accurate summer production data was noted as critical for estimating risk per serving as was the need for more reliable virulence markers for *Vp* to better evaluate the potential for illness. Because of the lack of reliable markers, management must rely on total *Vp* as the best surrogate. Industry representatives were also frustrated with the lack of reliable post-harvest technology that eliminates *Vp*, but leaves the oyster alive. Finally, it was noted that most harvesters follow the regulations, but it is difficult to change behaviors or enforce regulations on those who do not.

How do the growers/co-managers respond to Vp illnesses?

Many growers are extremely proactive in managing *Vp* risk and illness. It begins with cooperation with DOH in implementation of *Vp* control plans and training workers to follow new requirements. In addition, there is much cooperation with DOH to evaluate what practices might be leading to single source illnesses when they occur. Beyond working with DOH, many growers constantly evaluate their individual practices and processes to implement strategies to reduce risk and shorten harvest periods. This risk reduction strategy also includes working with customers to inform them of the risk of consuming raw product, and handling prior to consumption.

How can forecasting help you manage your Vp risk? What tools do you need?

The panel identified a variety of tools during this initial deliberation. Precise information on tides and use of the data to plan harvesting to minimize risk was noted, as was the implementation of buoy systems in growing areas for real time temperature and salinity data as is being implemented by NANOOS in 2015. Forecasting *Vp* itself would be most useful if the models were capable of identifying conditions where the presence of virulent strains are most likely. In addition to levels at harvest, tools predicting doubling time or growth during inter-tidal exposure, and purge times for *Vp* in oysters to return to background levels after re-submergence were suggested. Finally, models capable of identifying locations of consistently cool water for purging and wet storage would be of great value.

Session III – *Vibrio* forecasting and observational networks

Over the past decade, much progress has been made in our ability to observe and model environmental parameters. Because of these advances and established relationships between certain parameters and growth of *Vibrio spp.*, modeling and forecasting its abundance and distribution is now a reality. In this session, the current state of forecasting efforts within NOAA and FDA were discussed as well as existing hydrodynamic models for Puget Sound and available observational networks.

NOAA/FDA *Vibrio* forecasting (John Jacobs, NOAA/National Ocean Service)

John Jacobs provided an overview of joint NOAA and FDA efforts geared towards providing short term forecast products for *Vibrio* spp. for the shellfish industry and state resource and public health managers. Through the EFR (see opening presentation summary), NOAA has embarked on an effort to harness existing NOAA infrastructure (i.e.; observational platforms, ecosystem models, operational framework) for application to ecological issues. One focus area has been the distribution and concentration of these bacteria in surface waters and oysters. The latter has been explored through a partnership with FDA, where NOAA is using output of environmental variables from operational hydrodynamic models throughout the country to force FDA algorithms for growth of *Vibrio* spp. in oyster and post-harvest. The result is a spatially explicit graphical forecast system that predicts total *Vp* at time of harvest, and each hour post-harvest up to 48 hours in advance. Other tools have also been developed to demonstrate doubling time of *Vp* in oysters each hour post-harvest up to seven days in advance. A demonstration of the latter was provided for Puget Sound. The goal of this presentation was to demonstrate the potential for application of predictive tools to the PNW and how this process is working in other regions of the country. Along with FDA and state partners, NOAA is interested in helping to validate and improve risk assessment models for each region, and hosting operational forecast products that are deemed to be beneficial to the industry and community.

Overview of (FVCOM-ICM) Salish Sea Model and its Application to Intertidal Nearshore Environment (Tarang Khangaonkar, PNNL)

Tarang Khangaonkar provided an introduction to the *Salish Sea Model* at the workshop. The Pacific Northwest National Laboratory (PNNL) has developed a predictive ocean-modeling tool for coastal estuarine research, restoration planning, water-quality management, and assessment of climate change effects. This work is a collaborative effort between PNNL, the Washington State Department of Ecology, and the U.S. Environmental Protection Agency (EPA). The hydrodynamic component of the model is based on the unstructured grid FVCOM model and the water quality component uses CE-QUAL-ICM kinetics developed through the Chesapeake Bay restoration efforts. Tarang explained that this combination of tools is particularly suited for addressing the biogeochemistry and water quality issues affecting the near shore intertidal regions of Puget Sound within the greater Salish Sea. The model currently includes 99 wastewater outfalls, and 64 rivers and streams from watershed runoff. It has successfully reproduced the fjordal circulation, flushing and estuarine exchange with the Pacific Ocean. The model also simulates annual biogeochemical cycles of algae growth and die-off and nutrient uptake and dissolved oxygen. Of particular relevance to the issue of *Vibrio* spp. is the ability of the model to accurately resolve the conditions within the intertidal flats and marsh regions, simulate circulation in complex multiple tidal channels, wetting and drying of tide flats, and sediment transport. The Salish Sea model has been used extensively by water quality management agencies to design near-shore restoration actions and address waste-load allocation issues. Tarang provided several examples of projects around the Salish Sea shoreline that were developed through the use of Salish Sea Model as a part of feasibility and design. Sediment digenesis and carbonate chemistry modules are currently being added to the model in connection with hypoxia and ocean acidification concerns. Tarang concluded by stating that with site-specific improvements to the model for shellfish growing areas, the Salish Sea Model could be a valuable tool for simulating and forecasting environmental conditions for management of the *Vibrio* spp. issue in Washington.

Modeling Puget Sound and the Washington Coastal Ocean Using ROMS (Parker MacCready, University of Washington)

Parker MacCready presented some examples of modeling activity from the UW Coastal Modeling Group (http://faculty.washington.edu/pmacc/cmg/cmg.html). These are numerical simulations of marine water currents and properties (salt, temperature, nitrate, phytoplankton, zooplankton, detritus, and oxygen) designed to reproduce past time periods as accurately as possible. They rely on realistic bathymetry and forcing from USGS rivers, larger ocean models, and atmospheric weather forecasts. Because of the realistic forcing they may be compared directly with observations, allowing in-depth validation of what works and what does not. In general such models do fairly well with currents, salt and temperature, and less well with biogeochemical properties. Dr. MacCready showed results from particle tracking experiments in a Puget Sound model designed to mimic fecal coliform. He also showed a preview of a new model called LiveOcean, which will make daily forecasts of properties related to Ocean Acidification in Washington coastal waters. He concluded with a slide about the 19-year cycle of lunar declination, which, in Puget Sound, will lead to summertime lower low water being 0.5 m deeper than it is this year. The increased sun exposure may increase risk of *Vibrio* spp. at that time.

NANOOS: Tools for Accessing Ocean and Coastal Data for the Northwest (Amy Sprenger, University of Washington Applied Physics Lab)

Amy Sprenger provided an introduction to the U.S. Integrated Ocean Observing System (IOOS) highlighting the Regional Associations' contribution. Regional associations provide increased observations, distinctive knowledge, and critical technological abilities, and apply these towards the development of products to meet regional and local needs. The Pacific Northwest Regional Association of IOOS is NANOOS – the Northwest Association of Networked Ocean Observing Systems – works to create and sustain a comprehensive coastal ocean observing system for the Northwest. NANOOS integrates data from over 38 data providers including state, tribal, federal and Canadian agencies, private institutions, industry, non-profits and academic institutions. The data from these many partners is delivered via the NANOOS Visualization System (NVS), an online data portal found at: http://nvs.nanoos.org. NVS provides real-time and near real-time observations, model and forecast data, and remote sensing overlays from over 190 assets in the Pacific Northwest. Many of these assets provide data important for monitoring and managing *Vibrio* spp., including real-time water temperature, air temperature data and forecasts, and tide and weather forecasts.

SUMMARIES FROM BREAKOUT SESSIONS

Breakout Session 1: IDENTIFICATION OF NEEDS.

The goal of this session was to generate input on the data and information needed to improve resource and harvest management operations. Participants were separated into two groups, shellfish growers and tribal co-managers, and health policy managers, with the academics and modelers distributed between both groups. The responses from the groups were prioritized and separated into four areas: monitoring, modeling, tools and information and research needs on day 2.

Questions for breakout session 1:

1) What data and information do you need to improve resource/harvest management operations (shellfish growers and tribal co-managers) and risk assessment (health policy managers)?

2) What types of tools and research efforts would be most useful for your commercial growing (shellfish growers and tribal co-managers) operations, and managing public health risk?

3) Are there any data that are particularly useful in improving the precision and accuracy of *Vp* risk modeling?

4) What research related to *Vp* would be most useful for your commercial shellfish operations (shellfish growers and tribal co-managers) and vibrio risk assessment (health policy managers)?

Responses from shellfish growers and tribal co-managers

The growers and tribal co-managers identified sampling of the product prior to shipment as their highest priority in the area of monitoring. Another concern was a need for more frequent environmental sampling. The growers stressed that sampling the product at the time of harvest would be more informative for risk assessment rather than the “worst case scenario” when the product is sampled after exposure to high temperatures. More frequent sampling also raises the need for access to companies/institutions for additional laboratory analysis of the product. The group would also benefit from having information on areas of cooler water to re-submerge/relay oysters. In addition, expansions of areas where environmental parameters are monitored, as well as monitoring in less risky areas were also identified as needs.

Tools, information and research needs identified included consistency in sampling methods, knowledge about the oyster condition indices and genetics, confidentiality of landing data, relationship between harvest practices and illnesses from specific locations, knowledge about environmental factors leading to presence of *Vp* strains associated with illness and precise and accurate testing for virulent strains. Of high priority was a method to effectively depurate oysters of Vp without killing the animal.

Responses from health policy managers

From a monitoring perspective, health policy managers identified 7-day temperature forecasts near shore and in sediments and seasonal forecasts as priorities. This group also identified several parameters that would be useful as inputs into a model. These included air, water and tissue temperature, solar radiation, doubling time of Vp, concentration at time of harvest, relationship between oyster temperature and sediment temperature, oyster production numbers and information about intertidal exposure on Vp concentrations.

Research and information needs included identification of consistently cool areas for wet storage, relationship of Vp with abiotic and biotic parameters (salinity, chlorophyll etc), estimation of the purge rate of oysters, growth rate of Vp, identification of virulence markers in PNW strains, concentrations of both total and pathogenic Vp at harvest, differences in Vp concentrations between oyster species as well as identifications of habitats/locations where Vp cells overwinter.

Day 2, Breakout Session II: PRIORITIZATION.

The information provided by participants on Day One was summarized and presented back to the whole group on the morning of Day Two. Needs were sorted into four categories (monitoring, modeling, tools and information and research needs), distilled to capture similar ideas and concepts, and participants were asked to prioritize needs through a voting process. Following prioritization (Table 2), participants were engaged in a facilitated discussion to begin to address next steps in meeting the highest ranking needs, and to decide who would be most suited to accomplishing the task (Table 3). The list below does not commit any agency or individual to completion of the task, as there are dependencies on many of the items. However it does provide a roadmap of what could be accomplished and those most likely to have the capability or authority to complete the task. Because of time limitations, this process was not completed for all categories.

From a monitoring perspective, sampling of the supply chain was the top priority identified to determine how well the risk assessment framework works through to consumption (Table 2). While the need was clear, the capacity of FDA and the industry to conduct this sampling is not. In the short term, discussions with ISSC and identification of resources will be required. A pilot study approach to gain some information may also be beneficial (Table 3).

Similarly, more frequent environmental sampling and monitoring of areas not typically associated with illness were identified as a need. Again, limitations due to resources and lab capacity were noted as critical dependencies. The WDOH already conducts an intensive sampling for *Vp* in Washington during the growing season, does not have the capacity to do additional sampling, and there are few labs in the area that have the analytical capability to process samples. Monitoring of oyster tissue temperature at time of harvest was also noted as a need. This information is collected by WDOH during routine sampling, and could be conducted by the growers and tribal co-managers as well.

Identification of consistently cool waters near growing areas for re-submergence was a high priority among growers in order to safely store and purge the product. While included in monitoring needs, it was noted by the modelers that the information could be readily obtained through hind-cast runs of either the ROMS or FVCOM models that already exist. This request can be accomplished without the collection of new data, and should be of relatively low cost.

Of the other modeling needs, the highest priority as ranked by the participants was the development of intertidal temperature and *Vibrio* abundance models. It is recognized that air temperature alone may not fully account for temperature elevation and *Vibrio* growth during intertidal exposure, and better estimates would improve risk assessment. Since the workshop, WDOH and NOAA have planned a sampling program for the summer of 2015 to begin to address the issue. In the mid-term (2-3 years), statistical model development, validation, and incorporation into the risk assessment framework and forecasting tools will need to be accomplished. Linking of hydrodynamic models with illness data was also a priority. This could be accomplished through the analysis of hind-cased data and WDOH illness records.

Models and calculators of purge rate were ranked highly in both the modeling and tools categories. Knowing how long to allow oysters to purge at various temperatures to ensure product safety would assist the industry in planning harvest. The development of models and tools for purge rate requires some additional research, which is being planned by FDA and Taylor Shellfish. Model and calculator development will follow assuming resource limitations are addressed (Table 3).

Other tools or information needs included spatially explicit maps of water and air temperatures in the growing areas and better oyster production numbers. Research models are currently available for the PNW, but are not currently running in real time. Other models for the region are coarse, and generally not resolved enough to cover individual growing areas, but offer some insight as model refinement progresses. These, as well as air temperature and *Vp* doubling time models have been added to the NWS web page since the workshop and are available at

http://origin.opc.ncep.noaa.gov/restricted/Vibrio/Vibrio_Forecasts.shtml
The username is “opcdata” And the password is “M@rine2012”.

Oyster production numbers are needed to gain a better understanding of risk. This process requires the attention of ISSC, industry and the WDOH. An effort to incorporate information on landings data has already been initiated by WDOH.

Finally, a variety of research needs were identified, but time did not permit addressing them thoroughly, with the exception of the top priority, identification of harvest and culture practices associated with *Vibrio* concentration and the effect of re-submergence of the product. With a variety of culture and harvest practices employed, some methods may limit *Vibrio* growth more than others. In the short term, an inventory of all current harvest and culture practices can be conducted as well as study design and planning. Implementation of research will require funding.

Table 2: Prioritization of needs for monitoring, modeling, tools and information and research

A: Monitoring Needs

Need	Currently provided?	Who provides or could provide?	What improvements are needed?	What data are needed but unavailable?	Who could fill this need?
More frequent supply chain sampling of product	N	Testing at growing area, processing point, retail	Systematic/representative sampling to validate risk & assess how retail handles product	Data by species and culture method (dipoid/triploid)	FDA, growers?
More frequent environmental sampling	Y	DOH. Dependent on availability of lab capacity	Improved lab capacity. Model-informed sampling (prioritized).	Bio/geochemical weather conditions and virulence. Hind- and forecast/correlated to tides, river flow	PNNL, NOAA, DOE, NANOOS, USGS
Monitoring of "less risky" areas for *Vp*	N	DOH could with increased capacity/resources; NANOOS	Increased lab capacity for *Vp* , model-informed sampling and increased sampling to inform model	Harvest data, water temperature, salinity, *Vp* population	Research: Academic partners (e.g., Sea Grant)
Identification of coolest H2O T for re-submergence	N	Hydrodynamic modeling	Temp between 50-60 close to growing areas. ID geographic areas for lowest water tempeature		NOAA, NANOOS
Measurement of Tissue Temperature	Y	Harvester at harvest time			

B: Modeling needs

Intertidal exposure modeling	Y (archived data)	FDA	Validation and updating of FDA models	Frequency of low/low tide & exposure time, testing against archived data. Exposure time.	Academic, NOAA, FDA
Modeling purge rate vs. water T	N		Timing – This summer if possible		FDA, DOH, industry (Taylor)
Hydrodynamic model coupled with illness data	N	ROMS/FVCOM modelers	Augment existing models for Sal/chlorophyll a, increased frequency	Salinity, chlorophyll, nutrients	NANOOS, DOE, DOH

Table 2: Continued

C: Tools and Information needed

Need	Currently provided?	Who provides or could provide?	What improvements are needed?	What data are needed but unavailable?	Who could fill this need?
Purge calculator (guidance tool to inform product management	N	FDA to provide framework & technical support.		FDA & WA DOH data	Linked to research
Spatially explicit maps of H2O and air T w/overlay of growing areas	N		Temporal resolution hourly	Reference model output items on flip chart (doubling time, etc. see above) AND heat map of consistently cool areas	
Oyster production numbers	N	Industry, DOH	Clarity from ISSC		Industry and DOH

D: Research Needs

Role of harvest and culture methods in *Vp* and levels during re-submergence	**N**				Academia
Post-harvest process that eliminates *Vp* and leaves oysters alive	**N**				Academia
Environmental and biological factors leading to increase in concentration of total and pathogenic *Vp* strains and associated illness	Some information available				Academia
Oyster stressors, genetics and response of oysters to stress	N				Academia
Virulence of *Vp* strains	N				Academia
Growth rate of *Vp*	Some				Academia
Purge rate of *Vp*	N				Academia
Breeding programs for Vibrio resistant oysters	Some				Academia

Table 3: Steps for implementation for items in each Category:

A: Monitoring

	Short Term Tasks (This Year)	Mid-Term Tasks (2-3 Years)	Long-Term Tasks (3+Years)	Who Is/Should Be Involved?	Funding/Resource Needs
More frequent supply chain monitoring	Develop sampling strategy and identify resources. National conversation on product transport. Introduce data loggers.	Conduct a pilot study.	Implement plan and integrate into harvest plan.	FDA and industry.	Funding.

b: Modeling

	Short Term Tasks (This Year)	Mid-Term Tasks (2-3 Years)	Long-Term Tasks (3+Years)	Who Is/Should Be Involved?	Funding/Resource Needs
Intertidal exposure models	Data collection/test areas. Capture WDOH monitoring information. Combine data with environmental parameters and NWS data.	Model development and refinement. Additional data. Proof of principle. Skill metrics. Stakeholder feedback.	Operational capability.	NOAA, academia, NANOOS. DOH Mangers, Users/Industry.	
Hydrodynamic model coupled with illness data	Generate hindcast data. Augment models with tide, temperature, illness, etc.	Validate against illness data. Assess and refine hindcast data. Collect user feedback.	Operational capability.	NOAA. FDA. DOH, Western Regional Aquaculture Center.	Funding/Post Doc.

C: Tools

	Short Term Tasks (This Year)	Mid-Term Tasks (2-3 Years)	Long-Term Tasks (3+Years)	Who Is/Should Be Involved?	Funding/Resource Needs
Purge Calculator	Study design and framework development.	Study implementation.	Refine, extend range. PHP labeling. Validation of calculator.	FDA lead with industry and State.	Funds to ship samples. Lab capacity for analysis.

D: Research

	Short Term Tasks (This Year)	Mid-Term Tasks (2-3 Years)	Long-Term Tasks (3+Years)	Who Is/Should Be Involved?	Funding/Resource Needs
Role of harvest/culture methods on *Vp* levels during re-sumbergence.	Inventory of harvest and culture practices (singles only).	Design/plan research study.	Results of study. ISSC proposal Integration into models and management.	PSI, DOH, Growers, Sea Grant, Academia.	Funding Lab capacity for analysis.

Conclusions and Next Steps

The Puget Sound Workshop provided an invaluable opportunity for sharing ideas and concerns among the shellfish industry, state and federal resource managers, and modelers. The goals and objectives of defining needs and identifying potential paths forward were largely met, and several new efforts will be undertaken beginning in 2015 based on workshop results. In addition, the prioritized list generated for the region will serve as a basis for future direction in research and model development.

The top priorities were:
Monitoring: Supply chain monitoring to validate risk assessment models from harvest to consumption and identify variability in handling.

Modeling: The development of intertidal exposure models to accurately predict oyster temperature and *Vp* abundance, and identification of cool water refuge for purging and wet storage of product.

Tools: The development of purge calculators to predict length of wet storage at various temperatures needed to ensure safe product.

Research: Research to define the relative influence of harvest and culture practice on *Vp* concentrations and effectiveness of re-submergence.

As a result of this workshop, efforts are underway in 2015 to address the top priorities in modeling and tool development. In addition, new products have been developed to forecast doubling time for *Vp* and surface air temperatures at a resolution of utility to growers. The next steps will be to continue along the path defined by this workshop in addressing research and modeling needs, and reconvene as a group in a few years to review progress and re-examine priorities.

Appendix A – Workshop Participants

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* Participation via WebEx

Appendix B – Workshop Agenda

Tuesday, April 28, 2015

8:00 Registration/Coffee

9:00 Welcome and Introductions, Allison Allen, NOAA, NOS

9:30 Ecology of *Vibrio parahaemolyticus* in the Pacific Northwest, Rohinee Paranjpye, NOAA, NWFSC

9:45 Session I: Panel Presentations - Current Management and Risk Assessment in Washington, Moderator: Suzanne Skelley, NOAA, NOS

1. Overview of Illness Occurrence and Regulations in Washington State, Laura Johnson, Washington State Department of Health
2. Overview of Washington State's *Vp* Risk Assessment, Hillary Browning, Washington State Department of Health
3. Current FDA *Vp* risk assessment and vision for updating and regionalization, Angelo DePaola, FDA

10:55 Break

11:10 Session II: Panel Presentations - Overview of Washington Shellfish Industry, Moderator: Julie Horowitz, Office of Governor Jay Inslee

1. Adam James (Hama Hama)
2. Bill Dewey (Taylor Shellfish)
3. Ken Wiegardt (Wiegardt Brothers)
4. Tamara Gage (Port Gamble Tribe)

12:15 Lunch on your own

1:45 Session III: Panel Presentations - Vibrio Forecasting and Environmental Observations, Moderator: Chris Brown, NOAA, NESDIS

1. NOAA/FDA Vibrio forecasting, John Jacobs, NOAA, NOS
2. Overview of (FVCOM-ICM) Salish Sea Model and its Application to Intertidal Nearshore Environment, Tarang Khangoankar, PNNL
3. Modeling Puget Sound and the Washington coastal ocean using ROMS, Parker MacCready, UW, School of Oceanography
4. NANOOS: Tools for Accessing Ocean and Coastal Data for the Northwest, Amy Sprenger, UW, Applied Physics Lab

2:50 Break

3:00 Breakout session I: This work session will generate input on the data and information needed to improve resource/harvest management operations. Results from this session will inform the next day's workshop activities (Facilitators: Timi Vann and Ruth Howell)

4:30 Closing remarks and adjourn, Allison Allen, NOAA, NOS

7:00 No Host Dinner at Ramblin' Jacks (520 4th East 4th Ave, Olympia, WA 98501).

Wednesday: April 29, 2015

8:00 Coffee

8:30 Welcome and Day 2 Overview, Allison Allen, NOAA, NOS

9:00 Working Session on Refining Management Applications Requirements: Harvesters, public health practitioners, and researchers provide input on opportunities for improving current tools and/or developing new tools and techniques for *Vibrio* spp. risk assessment and harvest management (Facilitators: Timi Vann and Ruth Howell).

10:30 Break

10:45 Working Session, continued - Refining Management Application Requirements and Next Steps: Participants will be asked to engage in discussion on paths forward (Facilitators: Timi Vann and Ruth Howell).

12:00 Wrap-up and adjourn Allison Allen, NOAA, NOS

12:30 Lunch

2:30 Optional farm tour at National Fish and Oyster Company: 5028 Meridian Rd. NE, Olympia WA 98516

Appendix C: Questions for participants

RESOURCE AND INFORMATION REQUIREMENTS FOR VIBRIO FORECASTING IN WASHINGTON STATE

We will be discussing the questions below during the breakout session Tuesday afternoon. Please review these questions and jot down any notes during the panel presentations that morning. This information will inform the development of tools for Vibrio forecasting in Washington State. We will also collect these at the end of the day.

Shellfish Growing Operations

1. What data and information do you need to improve resource/harvest management operations?

2. What types of tools and research efforts would be most useful for your commercial growing operations?

   - Do you need hourly, daily, weekly and/or seasonal predictions?

   - Do you require a true forecast or only a modeled guidance?

Health Policy and Management

1. What data or information will be needed to improve vibrio risk assessment for WA state?

   - Do you need to model the bacteria, the health outcomes, risk per serving, or all the above?

   - Vibrio strain level specificity or species?

   - How would the modeled data or forecasts be incorporated into the Vibrio management plan?

2. What types of tools and research efforts would be most useful for managing public health risk?

Model Development

1. What data streams could be most useful in increasing the precision and accuracy of vibrio risk modeling?

2. Is there sufficient Vibrio data to evaluate skill of FDA statistical models?

3. Is there an observational network in place for key environmental parameters?

4. What is the state of development and skill of currently available circulation models for Puget Sound?

5. Is the resolution sufficient for the product(s) identified above?

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Penny Pritzker
Secretary of Commerce

National Oceanic and Atmospheric Administration
Kathryn D. Sullivan
Under Secretary of
Commerce for Oceans and Atmosphere,
and NOAA Administrator

National Ocean Service
Russell Callender
Acting Assistant Administrator