Baynes Sound Environmental Intelligence Collaborative Workshop

March 27 and 28, 2019

Vancouver Island University
Deep Bay Marine Field Station

Organized by

Wiley Evans (Hakai Institute), Akash Sastri (Ocean Networks Canada), Tim Green (Vancouver Island University), Carl Butterworth (Vancouver Island University), and Darlene Winterburn (British Columbia Shellfish Grower's Association)

Statement from British Columbia Shellfish Grower's Association President Steve Pocock: Shellfish farmers are facing challenging times, ocean changes and disease risks are an ongoing concern. To be able to meet and interact with a wide range of scientists covering all of the main areas of our concerns in one place at one time and to feel the synergy of the ideas being proposed coming together to get the next steps in place was a really worthwhile process. With a spirit of co-operation between scientists and industry in place we have an opportunity to make real advances for our sector.

Background: Three challenges to the British Columbia (BC) shellfish industry have become an increasing concern over the last few years: summer mortality, infectious disease, and ocean acidification. The cause of summer mortality is not currently known, nor is if and how it may be linked to changing ocean conditions (*i.e.* ocean acidification and/or warming) or infectious disease. Summer mortality has been documented each year in the region over the last few years and evidence exists for a role of pathogens.

The BC Shellfish Grower's Association (BCSGA), the Province of BC, and the Hakai Institute initiated the Baynes Sound Environmental Intelligence Collaborative (BaSEIC) in 2017 to generate baseline physical and marine CO_2 system information in this poorly-studied albeit important region. BaSEIC has served an increasing role in coalescing the research and shellfish aquaculture communities, with now many institutions working together toward the goal of understanding and addressing these industry challenges. This first BaSEIC workshop aimed to establish the state-of-knowledge for Baynes Sound. The information provided at this workshop was then used to guide the discussion of short- and long-term research priorities needed to fill knowledge gaps and aid in shellfish industry adaptation.

Framework: A vulnerability analysis of the United States shellfish industry to ocean acidification by Ekstrom et al (2015) provided a useful conceptual framework whereby overall vulnerability is the sum of marine ecosystem exposure and the social vulnerability (Figure 1).

Social vulnerability includes both sensitivity, that is the local societal importance of shellfish, and adaptive capacity.

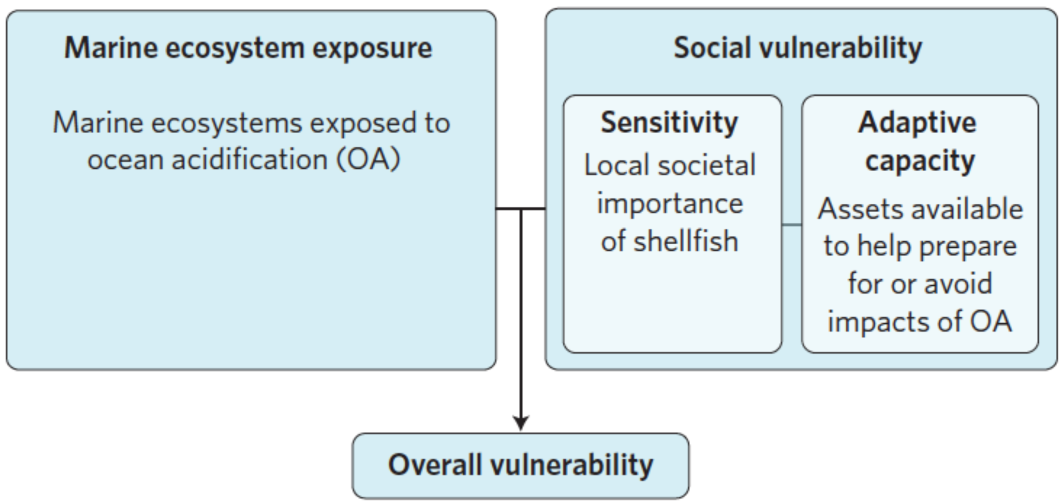

Figure 1: Conceptual framework of vulnerability from Ekstrom et al (Ekstrom, J.A., Suatoni, L., Cooley, S.R., Pendleton, L.H., Waldbusser, G.G., Cinner, J.E., Ritter, J., Langdon, C., van Hooidonk, R., Gledhill, D., Wellman, K., Beck, M.W., Brander, L.M., Rittschof, D., Doherty, C., Edwards, P.E.T., and Portela, R. 2015. Vulnerability and adaptation of US shellfisheries to ocean acidification. Nature Climate Change **5**(3): 207-214).

For the Baynes Sound workshop, we utilized this framework to help in addressing particular questions related to the three threats to the BC shellfish industry. Specifically, regarding marine ecosystem exposure, our aim was to provide information on known oceanographic patterns and, for the case of marine CO_2, provide estimates on how patterns might change in the future. In our case, social vulnerability was replaced with industry vulnerability, and questions regarding sensitivity were: i) what species are most vulnerable to exposure to adverse ocean conditions?; ii) how does this vulnerability vary across life stages?; iii) are there carry-over effects to subsequent life stages?; and iv) is there a CO_2 system parameter-specific vulnerability that may vary over life stages? Lastly, adaptive capacity was focused on ways to avoid exposure and the possibility of selective breeding as a path forward for the industry.

This approach helped frame the industry vulnerability, leading to the identification of short- and long-term research priorities as well as the following key recommendations.

Key recommendations from this workshop:

(1) Strengthen bi-direction information transfer between scientists and shellfish growers.
(2) Centralize science information on a community webpage that would include a catalog of available data, model forecasts, and list serve for email alerts.
(3) Enhance coordination between research institutions conducting observing, modeling, and experimental work.

Agenda: Day 1

9:00 – 9:45 Opening:

1. Welcome to Deep Bay – Carl Butterworth
2. Overview of concerns from the aquaculture industry – Steve Pocock
3. Outcomes from the 2015 climate change and aquaculture workshop – Heather Almeda
4. Overview of BaSEIC and meeting objectives – Wiley Evans

9:45 – 10:00 Coffee Break

Topic Discussions:

10:00 – 11:00 Topic 1.
Physical oceanography in Baynes Sound. Long-term trends in temperature and salinity. Questions to address: Is data available? Where? What are the gaps? Speakers: Richard Dewey (circulation) and Tim Green (temperature trends)

11:00 - 12:00 Topic 2.
Chemical oceanography in Baynes Sound. Catalog efforts to date. Questions to address: What do we know so far about CO_2 variability? O_2 variability? Nutrient dynamics? Is data available? Where? What are the gaps? Speaker: Wiley Evans

12:00 – 13:00 Lunch

13:00 – 14:00 Topic 3.
Drivers of infectious disease in Baynes Sound. General patterns, linking long-term trends in temperature and salinity to disease risk. Do we understand the drivers? Is data available? Where? What are the gaps? Speakers: Malcolm Cowan, Nicky Haigh, Tim Green,

14:00 – 1500 Topic 4.
Modeling efforts to date in the region. Anything operational? Where to get output? Can we track plumes? What are the gaps? Speakers: Susan Allen (UBC)

15:00 – 1515 Coffee Break

15:15 – 16:15 Topic 5.
Experimental work. What has been done to date? What results are available? Where are we going from here? What are the gaps? Speakers: Tim Green, Iria Gimenez, Chris Pearce, Brenna Collicutt.

16:15 – 17:15 Open Discussion with Stakeholders:
What is science missing? What would the industry like to see in terms of access to data and products?

17:30 – 18:30 Dinner

<u>Agenda: Day 2</u>

8:45 – 9:00 Coffee

9:00 – 12:00
Science only – how do we meet the needs defined by the discussion on Day 1? Immediate products, longer term product goals, where to host, alert systems, proposal collaborations including existing funding/resource opportunities/programs, and are their up-coming programs we should target.

Participants:

Day 1:

Akash Sastri	Ocean Networks Canada
Wiley Evans	Hakai Institute
Tim Green	Vancouver Island University
Carl Butterworth	Vancouver Island University
Steve Pocock	BC Shellfish Growers Association
Susan Allen	University of British Columbia
Chris Pearce	Fisheries & Oceans Canada
Myron Roth	BC Ministry of Agriculture
Jan Finke	University of British Columbia
Naomi Tabata	North Island College
Allison Byrne	North Island College
Malcolm Cowan	University of Victoria
Richard Dewey	Ocean Networks Canada
Jennifer Jackson	Hakai Institute
Iria Gimenez	Hakai Institute
Brenna Collicut	Hakai Institute
Kate Nolheiser	Hakai Institute
Eric Peterson	Hakai Institute
Tereza Jarnikova	University of British Columbia
Heather Almeda	Marine Environmental Observation Prediction and Response Network
Nicky Haigh	Microthalassia
Catriona Mallows	University of Victoria
Lu Guan	Ocean Networks Canada
JP Hastey	Nova Harvest
Mica Verbrugge	Effingham Oysters
Kala Mackintosh	Evening Cove Oysters
Andrew Dryden	Evening Cove Oysters
Alex Munroe	Taylor Shellfish
Ed Bereziak	Aphrodite's Garden
Sandra Lopez	Aphrodite's Garden
Mark James	Summer Breeze Aqua
Erik Lyons	Bee Islets Growers Corp.
Richard Ross	Manatee Holdngs Inc.
Vittorio Venturini	NewAqua Solutions
Blake Barton	CCAD Enterprises Ltd.
Julia Creuer	Bee Islets Growers Corp
Richard Hardy	K'omoks First Nation

Kelli Fleming	Island Scallops
Keith Reid	Stellar Bay Shellfish
Dave Ritchie	D Ritchie Holdings
Nick Davey	Vancouver Island University
Nicole Vaugeois	Vancouver Island University
GordyMcLellan	Mac's Oysters LTD
John Foster	Mac's Oysters LTD
Natalie Khtikian	Vancouver Island University

Day 2:

Akash Sastri	Ocean Networks Canada
Wiley Evans	Hakai Institute
Tim Green	Vancouver Island University
Carl Butterworth	Vancouver Island University
Susan Allen	University of British Columbia
Chris Pearce	Fisheries & Oceans Canada
Myron Roth	BC Ministry of Agriculture
Naomi Tabata	North Island College
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Richard Dewey	Ocean Networks Canada
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Iria Gimenez	Hakai Institute
Tereza Jarnikova	University of British Columbia
Heather Almeda	Marine Environmental Observation Prediction and Response Network
Nicky Haigh	Microthalassia
Lu Guan	Ocean Networks Canada
Natalie Khtikian	Vancouver Island University

Day 1 Topic Summaries:

Topic 1: Physical Oceanography of Baynes Sound

Richard Dewey: Baynes Sound is an isolated body of water in the northern Strait of Georgia, located between Vancouver Island and Denman Island. It has two connections to the Strait, north and south of Denman Island, however the northern connection is shallow, with maximum depths of only a few metres, while the southern entrance has a depth of 40m. The oceanography of the Sound is dictated, as is most of the Strait of Georgia, by tides, wind, and river discharge.

The tides are characterized as “semi-diurnal mixed”, which means they have a fortnightly variation and modulate from diurnal (one major tide each day) to semi-diurnal (two tides per day) over the fortnightly (14 day) cycle. The tides are more diurnal just after the spring tide peak (full and new moon), and more semi-diurnal just after the neap tide (first and third quarter moon). In Baynes Sound, the surface waters exchange (alternating flood and ebb) through both entrances, but deeper water, and more net volume flows into the Sound through the southern entrance, between Mapleguard and Repulse Points. The tidal currents (flood and ebb) tend to be weak near the centre of the Sound, near the Ferry crossing at Buckley Bay, where the northern and southern tidal currents meet. Nutrients primarily enter the Sound with deeper salty waters during each flood tide.

The winds in the Sound tend to be aligned with both the Sound terrain and the main axis of the Strait of Georgia, along a general NW and SE line. Stronger winds occur in the fall and winter, and are most often correlated with the passage of large weather systems. Stronger winds will result in waves along the Sound, and will also slightly push water either towards the north (a SE wind) or the south (NW wind), enhancing the exchange at the associated entrance.

River discharge and input of fresh water into the Sound is dominated by the Courtney River at the north, and the 13 smaller creeks along the west shore of the Sound. In all cases, the river and creek flows are highly seasonal, with peak discharges associated with both snow melt in the late spring (May) and rain in the late fall (Oct-Nov). During the summer months (August), river discharge is at a minimum. River (fresh) water is buoyant and will remain near the surface layer of the water column (upper 5-10m), and when the rivers are at their peak, the fresher surface layer highly stratifies the water column, resulting in a warmer fresh surface layer distinct from the cooler, saltier deep water. At peak river flow, the surface waters predominantly flow outwards through the northern entrance. During the periods of the year when river discharge is low, the surface waters will be cooler and saltier, with less difference (stratification) from the deeper water layers below 10-20 m.

Pulling all these influencing parts together, the oceanography of the Sound is both complex and varies on a variety of time scales from weekly to seasonal. The water column has varying levels of stratification from top to bottom, and north to south associated with strength of discharge and proximity to the Courtney River. Stronger stratification leads to reduced vertical exchange (mixing) of properties from the deeper water (colder, saltier, and higher nutrient content) and surface waters (warmer, fresher, and lower nutrient content).

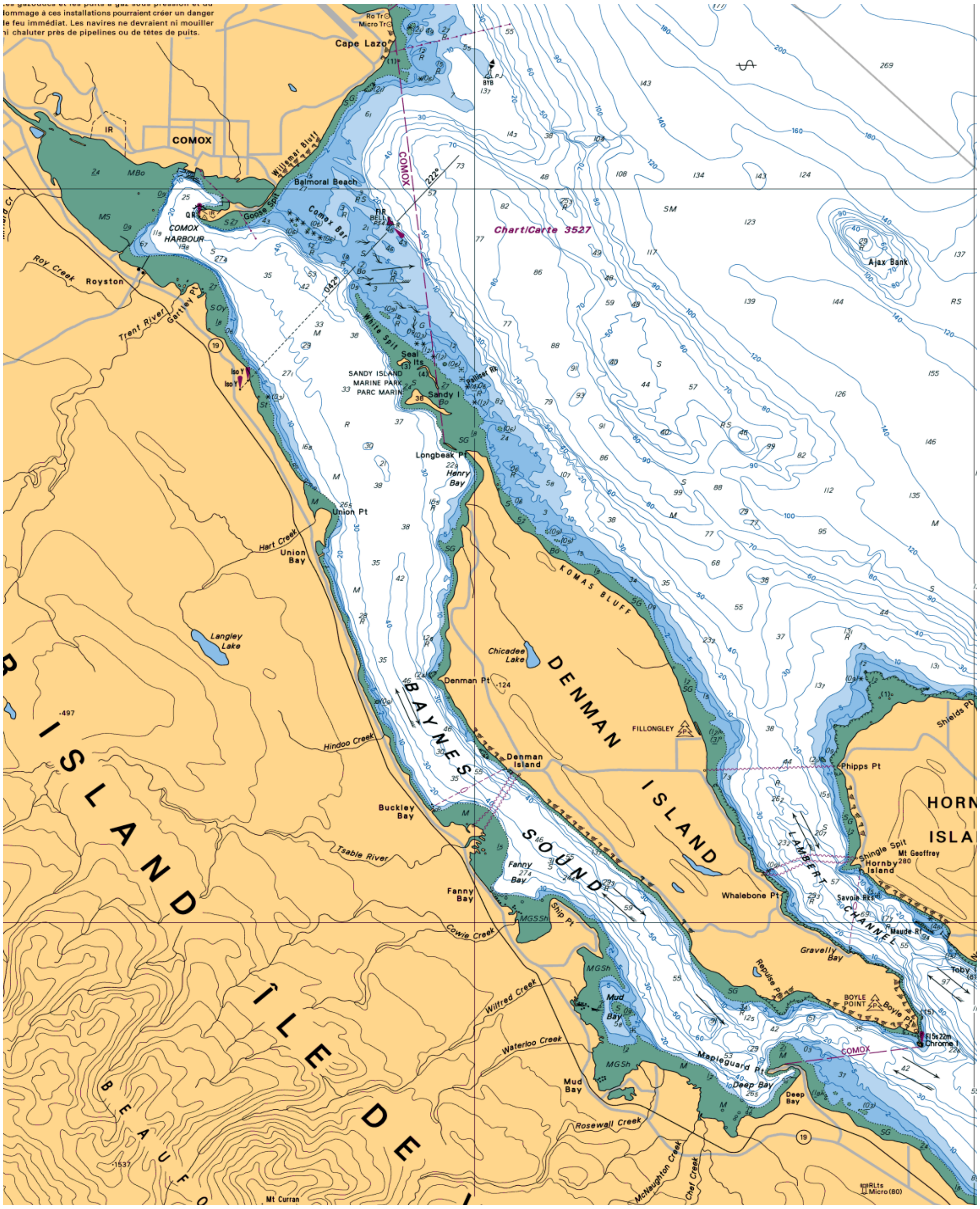

Figure 2: Canadian Hydrographic Survey chart of Baynes Sound with depth in meters.

Tim Green: Daily sea surface temperature observations have been made at Chrome Island Lighthouse at the southern entrance to Baynes Sound since 1961. We obtained this dataset from the Canadian Department of Fisheries and Oceans and used it to assess the frequency of marine heatwaves. Marine heatwaves were defined as an anomalously warm event that lasted for five or more days, with seawater surface temperature warmer than the 90th percentile based on at least a 30-year historical baseline period (Hobday, A., Alexander, L.V., Perkins, S.E., Smale, D.A., Straub, A.C., Oliver, E.C., Benthuysen, J.A., Burrows, M.T., Donat, M.G., Feng, M.F., Holbrook, N.J., Moore, P.J., Scannell, H.A., Gupta, A.S., and Wernberg, T. 2016. A hierarchical approach to defining marine heatwaves. Progress in Oceanography **141**: 227-238). The frequency of marine heatwaves in Baynes Sound is increasing at 0.08 incidences yr^{-1} (linear regression, n = 49, $r^2 = 0.31$, $p < 0.0001$). The majority of marine heatwaves have occurred during the spring (33 %) and summer (31 %). The average intensity of marine heatwaves is greatest in the summer (4.4 ± 1.3°C above climatology), but the average duration of marine heatwaves is longest in winter (10.1 ± 5.4 days).

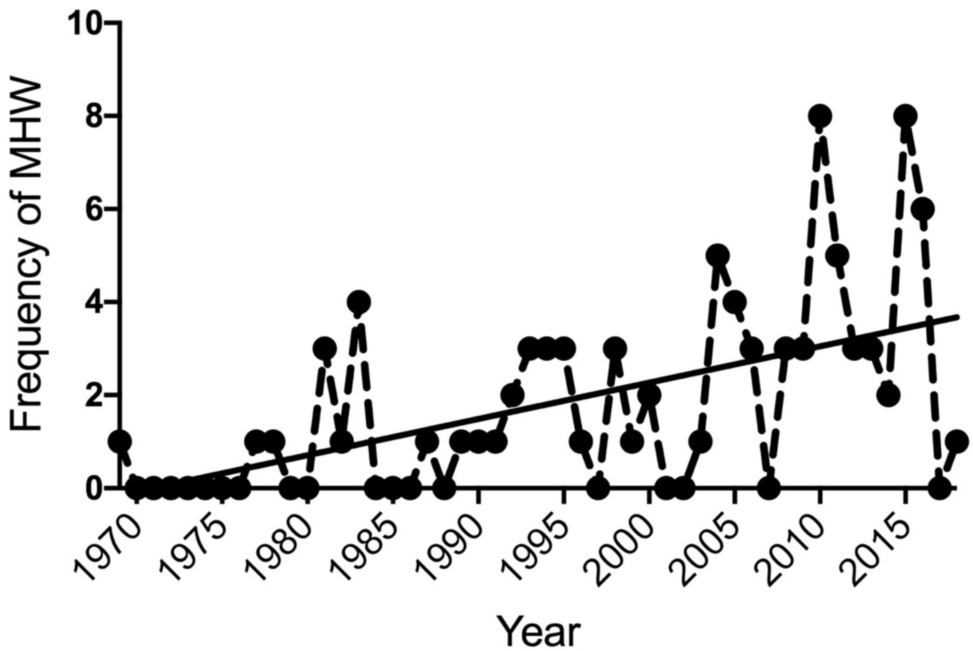

Figure 3: Increasing frequency of marine heatwaves (MHW) in Baynes Sound.

Topic 2: Marine CO_2 patterns in Baynes Sound

Wiley Evans: The marine CO_2 system in Baynes Sound has been investigated through a collective of observing efforts linked by BaSEIC. These include discrete samples collected by the Pacific Salmon Foundation Citizen Science Program (2016-2017), discrete samples collected by shellfish growers (2017-2018), continuous measurements from a Burke-o-Lator pCO_2/TCO_2 analyzer deployed at Fanny Bay Oysters (2017-present), and oceanographic surveys conducted by the Vancouver Island University Deep Bay Marine Field Station (2018-present; Figure 2). Together these datasets have revealed a number of key attributes of marine CO_2 in Baynes Sound.

The surface layer in Baynes Sound varies substantially on seasonal and sub-seasonal timescales. Like the patterns observed in other areas of the Salish Sea (Evans, W., Pocock, K., Hare, A., Weekes, C., Hales, B., Jackson, J., Gurney-Smith, H., Mathis, J.T., Alin, S.R., and Feely, R.A. 2019. Marine CO2 Patterns in the Northern Salish Sea. Frontiers in Marine Science: doi: 10.3389/fmars.2018.00536), winter conditions are corrosive to the biomineral aragonite whereas summer conditions typically favor aragonite precipitation. Favorable summer conditions can be disrupted by physical forcing. High surface water pCO_2, low pH, and corrosive conditions for aragonite have been observed during neap tides in late summer into early autumn (July – October). Below the surface layer, conditions in Baynes Sound are corrosive for aragonite year-round. Discrete samples from both the Pacific Salmon Foundation Citizen Science Program and the Deep Bay Marine Field Station's oceanographic surveys show a zone of high sub-surface CO_2 in the northern region relative to the southern region of Baynes Sound between summer and autumn. Observations of seawater corrosive to the biomineral calcite were made in this zone, indicating the tendency for all forms of calcium carbonate to dissolve. Seawater corrosive to calcite has also been observed in the surface layer over short time intervals ($\leq$ 1 day) associated with outgoing tides and northwesterly wind events during the neap tide phase. At this point, it is unclear whether there is any coincidence between the observed marine CO_2 system variability and shellfish mortality events.

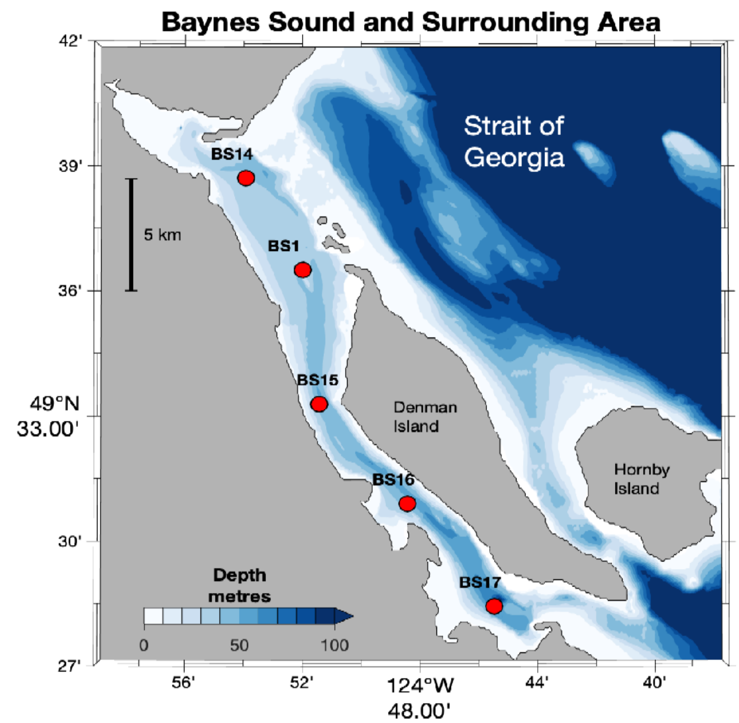

Figure 4: Oceanographic survey stations occupied since August 2018 by the Vancouver Island University Deep Bay Marine Field Station. Stations BS14 and BS17 are water collection sites that have been sampled for seawater pCO_2 and TCO_2 at six depths every month up to the time of this workshop. BS15 was added as a third water collection site following this workshop.

Topic 3: Drivers of Infectious Disease

Timothy Green: The Pacific oyster, *Crassostrea gigas*is cultivated in many regions of the world. In cultivation, adult *C. gigas* are prone to mass mortality events during the summer months. A complex combination of environmental and biological parameters has been suggested as the cause of this disease. In recent years, summer mortality has had a significant economic impact on oyster farms in British Columbia, Canada. Questionnaires completed by members of the BC Shellfish Growers Association have indicated that oyster mortality rates are >50 % per year (2018 ACRDP oyster mortality workshop). OIE notifiable diseases, such as Ostreid herpesvirus, are not the cause of mortality based on shellfish pathology submissions to Canadian Department of Fisheries and Oceans (correspondence with Dr. Gary Meyer, DFO).

From late July 2018 to August 2018, mass mortalities were reported in adult Pacific oysters cultivated in Baynes Sound, British Columbia. Up to 95% mortality was reported in diploid and triploid *C. gigas*. Farmers in Baynes Sound first reported mortalities of adult oysters on the 24th of July, which coincided with a spike in sea surface temperatures (SST) in the Sound above the 90th percentile for 3 days (SST = 20.9 ^{o}C, 2.7 ^{o}C above climatology). Histological examination of moribund *C. gigas* collected during the mortality event displayed early stage tissue necrosis combined with systemic bacterial infections comprised of bacteria with uniform short rod-shape morphology. Microbiological characterization, combining 16S rRNA amplicon sequencing with bacterial culture, revealed the microbiome of moribund oysters were dominated by bacteria that are closely related to *Vibrio aestuarianus*. These observations build upon previous studies that identified summer mortality of *C. gigas* is caused by temperature stress and opportunistic *Vibrio* pathogens.

Risk factors and triggers for summer mortality events in Baynes Sound need to be determined. Controlled laboratory challenges of adult *C. gigas* with *V. aestuarianus* at varying seawater temperatures need to be undertaken to confirm Koch's postulates and demonstrate that rapid rising seawater temperatures trigger mortality. It should be noted that many biotic and abiotic factors change with seawater temperature, including growth rates/virulence of microbes and dissolved oxygen/carbon dioxide levels in seawater.

Nicky Haigh: Shellfish growers are traditionally concerned with harmful algal blooms (HABs) for the role they play in shellfish marketability, for example the "red tide" species *Alexandrium catenella* and diatoms in the *Pseudo-nitzschia* genus are the causative species for Paralytic Shellfish Poisoning (PSP) and Amnesic Shellfish Poisoning (ASP) respectively. Less attention is paid to the role algae species play in shellfish health and nutrition. Globally, shellfish health impacts from algae have been reported to include: toxicity, in causing direct mortality to adults, juveniles or larvae, reduction in growth rates, reduction in filtration rates, reproduction and recruitment failure, and cellular damage in gut; smothering, by large sticky algae cells, which may also clog gills; low dissolved oxygen, especially with thick blooms in areas of low flushing; and as environmental stressors that increase susceptibility to parasites, viruses or bacterial infection. The role of algae in shellfish nutrition is obviously critical, but poorly studied. Factors that are important in nutrition are thought to be algae group (e.g. diatoms, dinoflagellates, raphidophytes, etc.), and also cell shape and size. HAB species that are known or suspected to have impacts on shellfish health that are found in BC are: the dinoflagellates *Alexandrium catenella, Cochlodinium fulvescens, Noctiluca scintillans*, and *Karlodinium* species; the raphidophyte species *Heterosigma akashiwo*; the silicoflagellates *Dictyocha fibula* and *Octactis speculum*; and haptophytes in the *Chrysochromulina* genus. Although there has been interest in monitoring algae and its impact on shellfish in BC in the past, research has been patchy, with a significant data gap on the extent and impacts of these species in local shellfish growing areas, including Baynes Sound.

Addition from Curtis A. Suttle and Jan F. Finke: The Shellfish Gene Project is a joined project between research groups at UBC, DFO, VIU and the Hakai Institute, supported by the Gordon and Betty Moore Foundation. The project strives to understand the causes and risk factors of mass mortalities in oyster aquacultures. This research problem is addressed threefold, by investigating the diversity of local oysters and the susceptibility to mortality through genome wide association studies; by describing the variation in oyster microbiomes and the search for bacterial, eukaryote and viral oyster pathogens through sequencing of marker genes and metatranscriptomics; and by exposing oyster spat to stressors in order to induce and identify mechanisms of mortality. To date we have examined samples form previous oyster aquaculture mortality events and wild oyster samples. For the genome wide association studies we identified ~2000 markers across the oyster genome to describe the diversity of wild oysters in B.C. in comparison to international samples and the diversity among farmed oysters. The microbiome studies established characteristic microbial compositions at different life stages of oysters and developed a method to reveal viral pathogens of oysters. In collaboration with the Hakai Institute and VIU we conducted two challenge study experiments exposing oyster spat to stressors with more experiments scheduled in the summer of 2019.

Topic 4: Modeling efforts in Baynes Sound

Susan Allen: The SalishSeaCast system includes a three-dimensional physical ocean model with coupled biological and carbonate chemistry modules. The domain runs from the mouth of Juan de Fuca Strait to near Port Neville in Johnstone Strait. The main model has resolutions of 440 m (across-strait), 500 m (along strait) and 1-20 m (in the vertical, highest resolution near the surface). The Baynes Sound "zoom" has horizontal grid spacing 1/3 as large. The model is forced by results from the Environment and Climate Change, Canada HRPDS hourly meteorology at 2.5 km resolution, climatological rivers (150 of them), daily observations for the Fraser River, western boundary conditions from the Live Ocean model (faculty.washington.edu/pmacc/LO/LiveOcean.html) and north boundary conditions from a climatology provided by the Hakai Institute (www.hakai.org). The model is compared to observations from various sources including Ocean Networks Canada, Pacific Salmon Foundation and Fisheries and Oceans, Canada. Model-observation agreement is strong in sea surface height, temperature, salinity, deep currents, nitrate, and total alkalinity. Surface currents need further evaluation. Dissolved silicate and dissolved inorganic carbon are currently being tuned. The seasonal cycle of chlorophyll, a proxy for biomass, is captured but the magnitude of variability in the model is lower than in the observations. Results are published daily to the web as graphs at salishsea.eos.ubc.ca/nemo/results/, are available as data from our erddap server salishsea.eos.ubc.ca/erddap/ and nitrate, temperature and salinity are available on the nanoos.org data viewer. Present results go back to 2014 but a hindcast back to 2007 is planned. SalishSeaCast has the ability to forecast 1 day in advance, and this is used to predict storm surge (https://salishsea.eos.ubc.ca/storm-surge/). While at a lower spatial resolution, the Live Ocean model has forecast capability in the region.

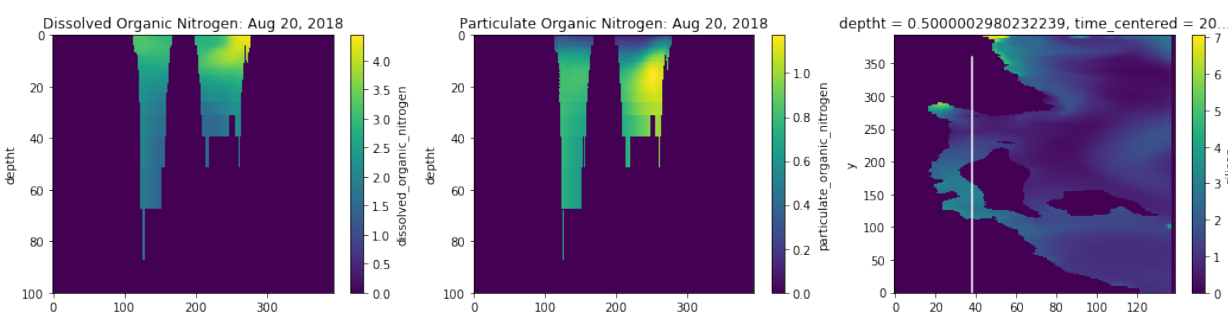

Figure 5: Hind-cast model output of dissolved (left) and particulate nitrogen (middle) along a transect of Baynes Sound (indicated by white line in right panel) for August 20, 2018. The zone of high particulate organic nitrogen in the northern portion of Baynes Sound represents an area

of retention where organic matter remineralization would drive the observed high sub-surface CO_2 content.

Topic 5: Relevant Experimental Work

Iria Gimenez: Many bivalves affected negatively by ocean acidification (OA) display periods of enhanced sensitivity within and across life-stages, and some sublethal exposures result in carry-over effects. Yet, coastal zones are highly dynamic and PCO_2, pH, and saturation state (Ω) can decouple. The incorporation of environmental variability at physiologically relevant space and time-scales to refine sensitivity thresholds and the identification of the individual effects of carbonate chemistry parameters on physiological processes are crucial to improve predictions of the fate of bivalve species under future climate scenarios. Batch-culture parameter decoupling techniques developed by our group revealed differential sensitivities among early larval stages of native and non-native oysters and resolved Ω as the parameter driving development responses in oyster and mussel species negatively affected. Building on this work, we developed our prototype Dynamic Ocean Acidification Manipulation Experimental System (DOAMES), a feed-forward, flow-through carbonate chemistry control system capable of decoupling PCO_2, pH or Ω and simultaneously producing stable, dynamic and off-set (i.e. mimicking future environmental conditions in naturally variable environments) experimental treatments suitable for organismal studies. In January 2019, we installed an improved version of DOAMES in the Hakai Institute Marna laboratory, located in Quadra Island, BC. Novel approaches and metrics are also needed to incorporate complex environmental variability into meaningful physiological indexes that capture ocean acidification stress in dynamic environments. We developed an index- Ocean Acidification Stress Index for Shellfish (OASIS), based on published sensitivity thresholds and through the partial integration of stressful conditions and a modification to account for exacerbated sensitivity in early larval stages. OASIS was able to predict survival of Pacific oyster larvae - from fertilization to pre-settlement- on two out of three cohorts raised in naturally variable conditions. Though OASIS is a promising new metric, DOAMES can also serve to identify, parameterize and validate new stress metrics similar to OASIS.

Tim Green: VIU is undertaking a 5-year project to investigate evolutionary adaption potential of *Crassostrea gigas* to ocean change: ocean acidification, marine heatwaves and vibriosis. By identifying the genetic and epigenetic mechanisms involved in oyster adaption, this project intends to future-proof the BC oyster industry against the threats associated with climate change.

Chris Pearce: The effects of environmental variables, culture depth, and phytoplankton abundance and composition on juvenile Pacific oyster Crassostrea gigas growth and mortality were studied between June and October of 2008 at 4 sites in the Strait of Georgia, British Columbia, Canada. In addition, the effects of temperature-triggered depth manipulation on growth and mortality of oysters were examined in order to assess potential control measures for mitigating high summer mortalities associated with high temperature, harmful algal blooms (HABs), and other environmental stressors. Control oysters were held at constant depths of 3, 10, and 15 m, while experimental oysters were kept at 3 m depth and lowered to 10 or 15 m when the surface water temperature reached 14, 16, or 18°C. Site and Depth significantly affected the growth and mortality of control oysters. At the site with the best growth, cumulative mortality was low (range: 6.4 to 19%) and negatively correlated with temperature and positively with transparency. At the high-mortality site (range: 64 to 98%), mortality was positively correlated with temperature, chlorophyll concentration, and the biomass of diatoms and potentially harmful algae. Cumulative mortality was generally higher at 3 m than at 15 m depth. Significantly larger oyster volume was obtained with the oyster controls at 3 m than with those held at 10 or 15 m at most sites. Temperature-trigger treatments did not significantly affect oyster volume or cumulative mortality, and oysters moved to 10 and 15 m had final volumes similar to the 10 and 15 m controls, independent of trigger temperature. Oyster growers could select their sites for maximal growth and minimal mortality based on temperature profile, freshwater input, and phytoplankton abundance and composition. We are presently building an OA/Temperature system at PBS. Capable of producing 3 CO2 levels (4 with ambient) and 3 temperatures (4 with ambient) to conduct multi-stressor experiments on organisms. Hope to have the system functional some time in FY 2019-2020.

Brenna Collicutt: The Hakai Institute located on Quadra Island has many research programs including those looking at ocean acidification and shellfish. A number of years ago, the shellfish program began with Helen Gurney-Smith and the implementation of an experimental shellfish raft just offshore of the Quadra Hakai facility. Shellfish genomic responses of differing ocean conditions are being assessed and paired with ocean carbonate chemistry information from the Burkolator run by Wiley Evans and his team. In 2018, the Marna Lab was built to facilitate controlled laboratory experiments on organisms with various climate change stressors including pH and temperature. The laboratory hosts 1 μm filtered and UV sterilized water feeding 40 independently temperature and pH regulated mesocosms that manipulate pH using CO_2 bubbling, a smaller volume chemical manipulation system for more precise carbonate system control, continuous environmental chemical oceanography monitoring, two 1250L bioreactors to produce live algal feed and a fully functioning dry lab specializing in genomic preparations. Initial trials have focused on system characterization with respect to carbonate variables and temperature and will move forward with experiments examining the effects of ocean acidification and temperature on larval and juvenile oysters this spring/summer.

Day 1 Discussion:

Discussion on day 1 focused on the lack of knowledge for the causes of mortality. A key element revealed by this discussion was the lack of bi-directional information transfer between shellfish growers and scientists. Information is being generated by scientists that may not be making it to the grower community as fast as is needed, and growers have a wealth of information akin to traditional knowledge that should be tapped in order to help refine science questions and objectives, and ultimately meet industry challenges. Scientific information should be centralized, with a community webpage and data catalog. Enhanced coordination between research institutions is needed and especially important for those conducting experimental work. Such experimental work needs to extend beyond *C. gigas* to other economically important species, fine-scale oceanographic variability needs to be understood, and differences in seed source need to be considered. Areas where no mortality has been reported need to be considered alongside those with reported mortalities. Scientists need information on the location, timing, and magnitude of mortality events. Information on mortality events is currently only word-of-mouth, which does not allow for a robust assessment of predictor variables. A form was distributed following the 2018 BC Seafood Expo but has not been utilized. In general, farmers expressed willingness to collect weekly scientific samples and contribute mortality information. The important point was made about considering large-scale and local changes such as marine heatwaves. Combined OASIS and marine heatwave indices were discussed, as was the need to extend pathogen sampling and examine small-scale variability within farms. Another common discussion theme was that slower growing animals tend to do better, and an important question was asked regarding what growers would do if the cause of morality was known and advanced warning was possible. The response was to not touch the oysters over the course of the incident as doing so would add additional stress.

Day 2 Discussion:

The discussion on day 2 began with the ONC platform with input requested on sensor depths. A sensor package with CTD, O_2, and pCO_2 will be located at 45 m. Another two similar sensor packages may be located at 1 and 5 m. An ADCP was requested for vertically-resolved current information at the ONC platform site. It was discussed that the ONC platform would not be ideal for serving as a testbed for other sensors. Following the framework listed above, the discussion of gaps and recommendations was divided into marine ecosystem exposure, organism sensitivity, and industry adaptation. Stronger coordination with annual meetings were recommended for this group. Coordination between experimental facilities was specifically highlighted.

Marine Ecosystem Exposure

GAP: reporting back to the shellfish growers. Current info exchange is by NANOOS NVS, presentations at AGM, and periodic data reports.
GAP: seasonal and spatial patterns in deep CO_2 hot spot. How does this water move around the sound? Where and how is it ventilated?
GAP: what do we know about deep water exchange in the northern portion of the sound? Can we use the VIU ADCP to assess this?
GAP: O_2 sampling.
GAP: Marine CO_2 patterns in model.
GAP: reporting and link to mortality events.
RECOMMEND: Integrate observing between current and new infrastructure.
RECOMMEND: email alert system based on when conditions above certain criteria (i.e. temperature, pCO_2, pH). Support with community webpage.
RECOMMEND: BCSGA assess ability to provide location, timing, and magnitude information on mortality events.
RECOMMEND: catalog of available data.

Organism Sensitivity

GAP: forensic information for both periods with and without mortality. Currently only have information for mortality events with no control sampling.
GAP: Information on different conditions between wild and farmed oysters.
GAP: Large-scale experiments run on farms.
GAP: Information on responses from multiple stressors, etc. temperature, CO_2, HABs.
GAP: Information on vulnerability of seed source to stressors.

GAP: Information on the toxicity response of Vibrio to environmental triggers such as pH. Is growth rate also impacted?
GAP: Information on responses to dynamic conditions versus static conditions
GAP: Information on whether putting dead oysters back in the water is an issue
RECOMMEND: Expand experimental work in coordinated ways to address gaps.

Industry Adaptation
GAP: Can results from sensitivity experiments feed into best practices at the hatchery level
GAP: Information on success of diversifying species, mariculture, kelp production, and using shell material to buffer conditions
GAP: Reporting of science results beck to the shellfish growers could be enhanced.
GAP: Multifactorial field experiment at a commercial site. Looking at handling depth, tray design, families, seed source
GAP: Response of imported seed versus local seed
RECOMMEND: Using real-time data for planning
RECOMMEND: Slower growth
RECOMMEND: Use of resilient families once determined by VIU breeding program

Short-term (1 year) objectives:

(1) Complete ONC platform setup
(2) Establish additional water sampling for M. Cowan final project year
(3) BCSGA to implement mortality reporting
(4) Deep Bay to power experimental raft
(5) Add temperature strings at select farms to assess fine-scale variability
(6) Establish sentinel HAB site in Baynes Sound
(7) C. Pearce to operationalize experimental laboratory at PBS
(8) I. Gimenez to conduct decoupling and dynamic variability experiments with *C. gigas* spat

Long-term (5 year) objectives:

(1) Analyze success of VIU breeding program
(2) Assess the impact of long term changes in marine heatwaves and ocean acidification
(3) Assess statistics on trends in mortalities. How do we know we are doing better without mortality reporting?
(4) Run field experiments supported by successful funding