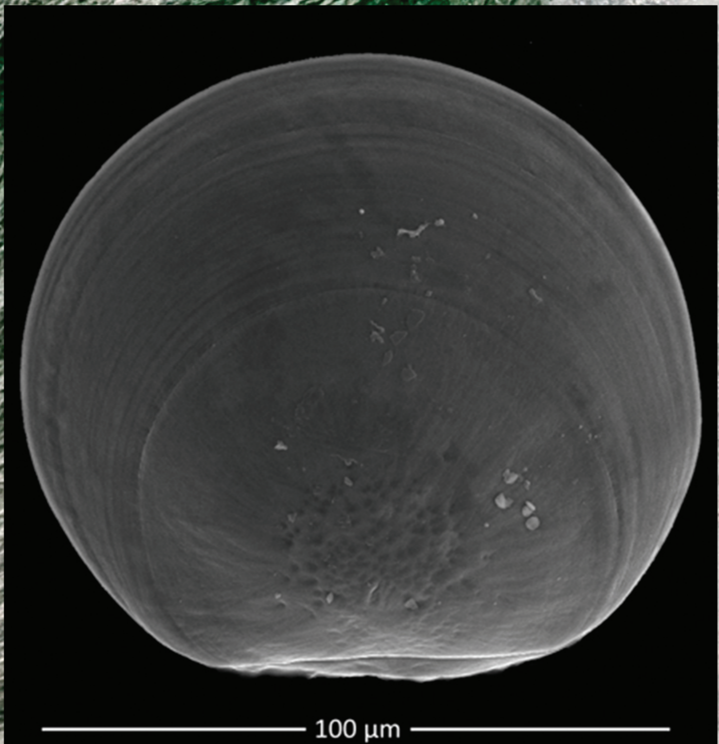
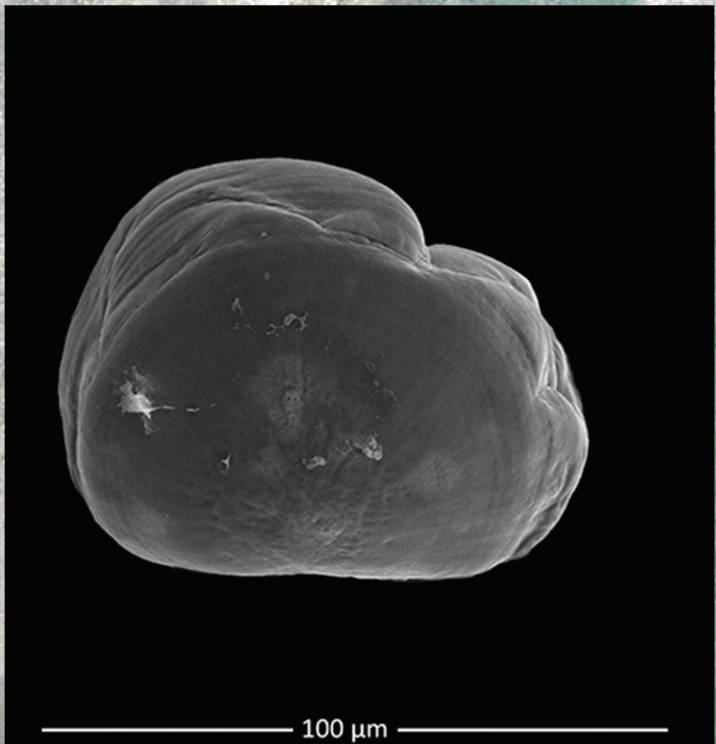
Bulletin
of the Aquaculture Association of Canada



Pacific oyster larva under optimal conditions



Pacific oyster larva under acidified conditions

Proceedings of the Atlantic and Pacific Climate Change and Aquaculture Workshops

(2015-2)

Gregor K Reid
Helen J Gurney-Smith
Guest editors

Bulletin

de l'Association aquacole du Canada

2015-2

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Cover: Pacific oyster (*Crassostrea gigas*) larvae from the same spawn at day 4 post-fertilization, in favorable (left picture, pCO_2 = 403 ppm, Ωaragonite = 1.64, and pH (total) = 8.00) and unfavorable (right picture, pCO_2 = 1418 ppm, Ωaragonite = 0.47, and pH (total) = 7.49) carbonate chemistry during the spawning period. Images are Scanning Electron Microscopy (SEM) of representative larval shells. Under more acidified conditions, right picture, development of shell is impaired. Photo credit- Brunner/Waldbusser, used with permission. Background waves\ image, courtesy of Bill Pennell.

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Introduction by the Aquaculture Association of Canada

Colleagues, it is with great pleasure that I invite you to peruse this issue of the Bulletin of the Aquaculture Association of Canada (AAC), which summarizes industry-led workshops on the research and development needs for *Climate Change and Aquaculture*. The issue focuses on the needs of both the shellfish and finfish aquaculture industry in Canada. Thanks to the Atlantic Canada Fish Farmers Association and the British Columbia Salmon Farmers Association for leading the workshops; to Drs. Gregor Reid of the University of New Brunswick and Helen Gurney-Smith of Vancouver Island University for facilitating and organization of the workshops and Proceedings, and to the Natural Sciences and Engineering Research Council of Canada, the Huntsman Marine Science Centre, Fisheries and Oceans Canada, and others that provided support to convene the workshops. This was a true partnership with industry, academia and government to discern the priorities for research support to our burgeoning aquaculture sector.

I am also very proud that the AAC is contributing and taking the lead in disseminating the workshop findings and conclusions, continuing our support of science-based communication of the Canadian aquaculture sector. The AAC has communicated aquaculture science for over 30 years in Canada, fostering this sector through promotion of research and development, innovation, and knowledge mobilization. It accomplishes this principally through its publications (The Bulletin, special editions, and workshop proceedings) and its annual conference, Aquaculture Canada, the largest national conference on the science, technology and business of Canadian aquaculture. I hope you find this issue as interesting as I do.

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Aquaculture Association of Canada | Association Aquacole du Canada

Climate change and aquaculture: literature review presentation summary

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Gregor Reid

Introduction

Climate change is the most pressing environmental concern of our era. Implications of ongoing and predicted climate change have the potential to affect almost all aspects of human activities. Globally we are heavily reliant on aquaculture production to ensure food security, especially as population growth and dietary preferences are increasing the demand for seafood. Some wild fisheries may experience short-term benefits from climate ch ange, but overall global landings are predicted to decrease 10% by 2050; aquaculture is expected to meet this anticipated demand (Barange et al., 2014).

Research on climate change has grown exponentially, with many new journals dedicated exclusively to the subject. However, climate change research on aquaculture is still relatively new. A 'big picture' overview requires multiple data gathering approaches beyond aquaculture research journals. This may include: extrapolation of effects from fisheries and feral species research, industry reports, comparisons with terrestrial agriculture, and international assessment initiatives. This presentation is intended to review climate change and aquaculture from a global perspective, while workshop sessions and break-out groups will have a regional focus.

Impacts and outcomes

Storms and rising waters

Physical effects of climate change on aquatic systems can be loosely categorized as sea-level rise, flooding, storms, ocean acidification, and temperature change. The Intergovernmental Panel on Climate Change (IPCC) is the leading international body for the assessment of climate change and released their Fifth Assessment Report in late 2013. The IPCC reports that oceans have become a sink for 93% of the earth's additional energy inventory in the period 1971-2010. Sea level rise has resulted from thermal expansion of seawater and glacier melting causing a mean global increase of 0.19m from 1901 to 2010. There is strong evidence of increased stratification, size of oxygen minima zones and wave heights in several regions. Anthropogenic carbon dioxide (CO_2) has caused a gradual decrease in pH, by 0.1 (≈ 26%) since the beginning of the industrial era.

Recent analysis of sea level rise report a global mean level rise of 1.2 ± 0.2mm per year between 1901 to 1990, and almost 3 times that (3.0 ± 0.7mm yr^{-1}) between 1993 to 2010 (Hay et al., 2015). Sea-level rise is not expected to be the same everywhere. There are hotspots of accelerated sea level rise, such as in the North

American Atlantic where the sea level rose ~3 -4 times higher than the global average, between 1950 to 2009 (Sallenger et al., 2012).

Most aquaculture is either located directly in water bodies, or on land close to a water source, which means facilities are often on potential flood plains. Sea level rise can impede river discharge to the sea, leading to longer flood periods and larger inundation areas (Nguyen et al., 2014). Fish kills from floods are mainly due to low oxygen in flood waters (Idris et al., 2014) and mortalities are often associated with pond culture (Bell et al., 2010) and hatcheries. An internet search of the terms 'fish hatchery' and 'floods' returns multiple results of fish loss from flooding as a result of rapid precipitation. There is strong evidence that the frequency and intensity of heavy precipitation events has increased in some continents such as Europe and North America and less precipitation and in other regions such as Southern Europe and Central America (IPCC, 2013).

Wind intensification is likely to increase at higher latitudes (Sydeman et al., 2014), possibly linked to stronger warming trends in polar rather than equatorial regions (Baumann & Doherty, 2013). There is low confidence of any trend of tropical or extratropic storm (storm system formed in the mid or high latitudes) frequency or intensity in any ocean basin, although there is robust evidence for an increase in the most intense tropical cyclones in the North Atlantic basin since the 1970s (Rhein et al., 2013). Increased occurrences of tropical cyclones in the Caribbean and landfall typhoons are expected in some areas (East Asia), but changes to hurricanes are uncertain (Stocker et al., 2013). There is evidence that wind stress has increased in areas such as the Southern Ocean and that average winter wave heights have increased in the North Atlantic (since the 1950s) with a reported trend of 20cm per decade (Rhein *et al.*, 2013).

Storms can be devastating to coastal aquaculture operations (Luening, 2013). High winds and waves destroy structures used for coastal aquaculture such as embankments, pond dikes, sluice gates, hatcheries, electricity poles and rearing structures (Rahman & Hossain, 2012). Large-scale escape events from sea-cages are correlated with storm events (Jensen et al., 2010). Inaccessibility to damaged cages due to ongoing weather severity (Dodd, 2011a), suggests even small containment breaches may facilitate large escapes given a prolonged time until repair. A 2010 Mexican experience illustrates the extreme potential for storm damage. Three storm events caused major flooding and structural damage, reducing the annual tilapia production by 80 percent due to the devastation of 1200 uninsured farms; the pre-2010 production level had not returned as of 2014 (Reid & Jackson, 2014).

Primary productivity and algal culture

Micro- and macro-algae account for 50% of global primary productivity (Longhurst et al., 1995) and account for ~50% of the global carbon biogenic fixation (Field et al., 1998). The entire global phytoplankton population is replaced on average every two to six days (Falkowski et al., 1998 ; Behrenfeld et al., 2006). Increasing ocean temperatures are likely to decrease phytoplankton abundance in tropical and mid-latitude regions, while increasing in higher latitude regions, due to nutrient limited tropical areas and light limited polar areas (Richardson & Schoeman, 2004 ; Doney, 2006). Changes in circulation, nutrient upwelling, salinity and sea level have caused many warm-water species to expand their ranges towards the poles, pushing cold-water algal species farther northward (Hallegraeff, 2010). There are about 37 separate algal species or species groups cultivated in 33 countries, with a total harvest of 23.8 million tonnes (wet weight) with about 9 million MT for human consumption (FAO, 2014). Macro-algal species which are currently CO_2 limited are expected to benefit from increases in atmospheric CO_2 and sea surface temperatures, more than species which are already CO_2 saturated (Beardall et al., 1998). Also, elevated temperatures are likely to increase macro-algal recruitment, but only to a point, as high temperatures have also shown to increase consumption of macro-algae by grazers (Lotze & Worm, 2002).

Temperature

Graphical data from the latest IPCC assessment report (Kirtman et al., 2013) indicates sea surface ocean temperatures from the equator to the upper and lower mid-latitudes, are projected to increase by approximately 1°C over the next 2 decades (2016–2035 relative to 1986–2005 under RCP4.5). This is an average however and does not reflect changes in extremes of either warm or cold temperature fluctuations. Nor does this reflect the short-term but more prolonged events such as multi-day extremes, which are arguably a greater concern for aquaculturists than a day-long event or changes to annual temperature means. There is also great uncertainty with projected temperatures in coastal areas at regional scales, which is of most importance to aquaculture. Consequently, applying average global scale projections of temperature to aquaculture should be interpreted with caution.

Not only will temperature influence growth rates of poikilotherms, it will also influence immune functionality, osmoregulation, pathogen life-cycles, predator range shifts, reproductive cues, larval survival, diet digestibility, gene expression, metabolic rate, enzyme functionality, and behaviour. Indirect temperature effects on the environment will also manifest, such as gas saturation, pH, and stratification. Environmental and biotic stressors, such as those expected to accompany climate change will reduce the temperature range of aerobic performance (Pörtner, 2008). There therefore exists a two-fold threat, where animals operating near their upper thermal limit are susceptible to small increases in temperature, while other external stressors are likely to reduce the magnitude of this limit.

Increase in mean temperature may intuitively seem like an advantage for Canadian aquaculture. A thermal growth coefficient model applied by the authors, predicts that an average 1°C increase will decrease time to market for Atlantic salmon by about 2 months. Such predictions are overly simplistic however, as many temperature mediated processes will occur simultaneously with potentially conflicting outcomes. Increased temperatures have been reported to improve growth performance for rainbow trout (Báez et al., 2011 ; Anon., 2013), European sea bass (Sfakianakis et al., 2013), Australian abalone in winter (Russell et al., 2012), feed conversion for the sea urchin, *Strongylocentrotus droebachiensis* (Siikavuopio et al., 2012), and reproductive management for the Japanese conger, *Conger myriaster* (Utoh et al., 2013). Increased temperatures have also been reported to cause reproductive problems for trout (Báez *et al.*, 2011) and Atlantic salmon (Pankhurst & King, 2010), reduced feed conversion in the sea cucumber, *Australostichopus mollis* (Zamora & Jeffs, 2012), increase expected summer mortalities for some Australian abalone species (Russell *et al.*, 2012) and cause developmental problems in European sea bass (Sfakianakis *et al.*, 2013).

Climate warming is predicted to drive species ranges northwards in the northern hemisphere and southwards in the southern hemisphere (Gianguzza et al., 2011). Range changes concern aquaculturists due to predation effects, disease potential, food supply for extractive species and shellfish 'seed collection' (metamorphosed juveniles or spat). Opportunistic species that are limited only by developmental temperature, will show an 'early-response' to range shifts such as the barrens-forming sea urchin, *Centrostephanus rodgersii*, on the Australian coast (Banks et al., 2010). Warming waters can also increase development rate, reducing the duration of the passive motile larval stage and therefore changing distribution potential. Since the duration of the larval period influences larval dispersal distance and survival, changes in ocean temperature could have a direct and predictable influence on population connectivity, community structure, and regional-to-global scale patterns of biodiversity (O'Connor et al., 2007).

Ocean Acidification

The carbon dioxide concentration in our atmosphere and its rate of increase, is greater than any time in the last 800,000 years (Fig. 1), due to manmade emissions. The oceans absorb about a quarter of the anthropogenic carbon dioxide released into the atmosphere (Le Quéré et al., 2013), but increasing levels of carbon dioxide in the atmosphere reduces the buffering capacity of the ocean, increases the hydrogen ion concentration, decreases the pH and consequently, the oceans have become more acidic. Ocean pH has declined by 0.1 unit (~ 26% increase in hydrogen ions) since the industrial revolution (Orr et al., 2005) and is expected decrease by another 0.2 -0.4 units by end of 2100 (Rhein *et al.*, 2013). Ocean acidification is a complex parameter to measure and predict. Localized inputs can increase levels of pCO_2 (Waldbusser et al., 2011), such as eutrophication (Casas-Monroy et al., 2011 ; Cai et al., 2011), river inputs (Salisbury et al., 2008) watershed changes (Dove & Sammut, 2007 ; Green et al., 2009 ; Salisbury *et al.*, 2008), and upwelling of CO_2 rich waters in coastal areas (Cooley & Doney, 2009 ; Panel, 2012).

Ocean acidification can cause major problem for organisms with calcium carbonate shells, such as shellfish (Gazeau et al., 2013). Impacts are typically most severe with larvae, and cause shell deformities, slow growth and poor metamorphic success. Ocean acidification has had a massive impact on hatchery production in the Pacific Northwest (WA State Blue Ribbon Panel, 2012) and wild seed recruitment, resulting in an estimated $110 million USD, jeopardizing 3,200 jobs (Ekstrom et al., 2015).

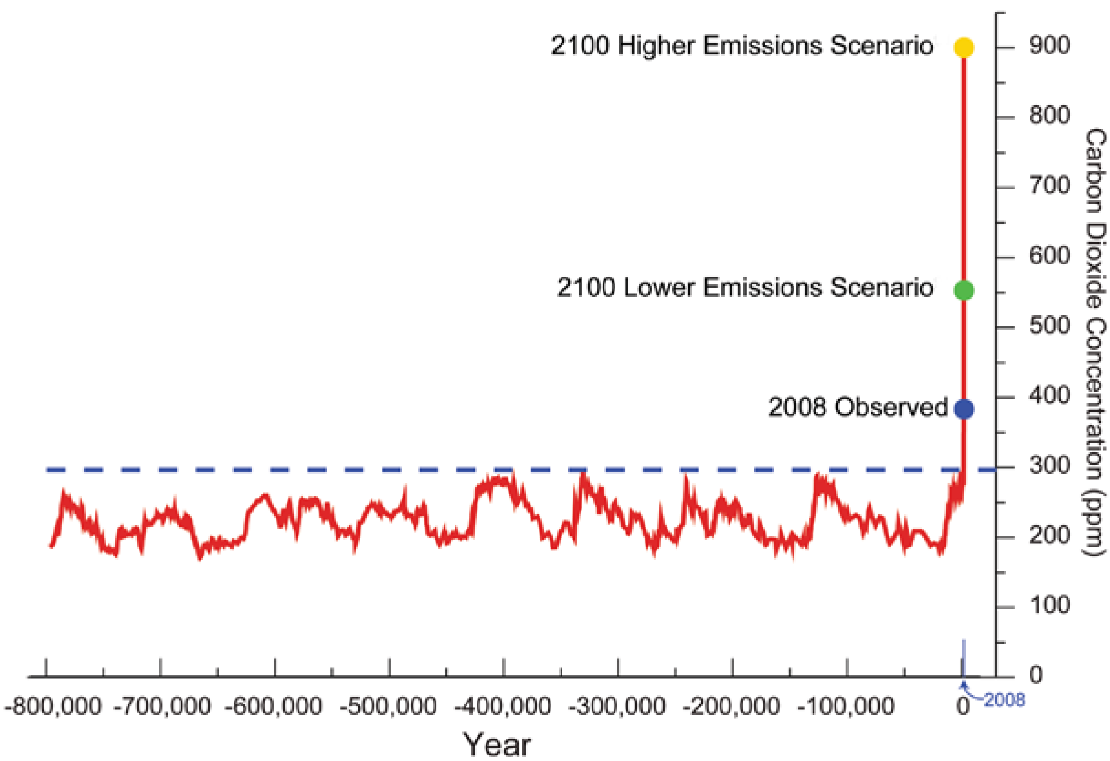

Figure 1. Analysis of air bubbles trapped in an Antarctic ice core extending back 800,000 years documents the Earth's changing carbon dioxide concentration. As a result of human activities, the present carbon dioxide concentration of about 385 ppm is about 30 percent above its highest level over at least the last 800,000 years. From U.S. Global Change Research (2009).

Saturation states (Ω) of calcium carbonate ($CaCO_3$) in seawater are used as a proxy for the ease in which calcifying biota such as bivalves can deposit calcium carbonate (Feely et al., 2004 ; Millero, 2007 ; Feely et al., 2008). Shell formation is complex and not the same in all species. In general though, shell formation begins as an aragonite shell in early larvae and then transitions to a calcite form as the animal matures. The aragonite form of calcium carbonate is ~1.5 times more sensitive to ocean acidification dissolution than calcite (Dickson, 2010). It was previously thought pH was the definitive measure, but aragonite has become the key variable to measure for biological studies.

Ocean acidification decreases the biological availability of calcium carbonate forms for Local invasions and extinctions (Doney et al., 2012). Ocean acidification has been implicated in high mortalities in larvae sensitive to calcium carbonate saturation states (Gazeau *et al.*, 2013), impairment of physiological functioning of organisms in different environments (Somero, 2012) and loss of ecosystem services (Cooley & Doney, 2009 ; Panel, 2012 ; Newell, 2004). Overall system vulnerability will be a function of marine ecosystem exposure, social vulnerability (market value and jobs), and adaptive capacity (scientific support + political capacity + diversification potential) (Ekstrom *et al.*, 2015).

Pathogen and disease potential

The effects of climate change on the health of both cultured shellfish and finfish is extremely complex, and to date, only a handful of published studies. There has been some focus on climate change stressors and aquatic parasitic infection, although this is still very little, compared to the terrestrial realm (Karvonen et al., 2010). Accelerating changes in environmental conditions, together with anthropogenic translocation of hosts and parasites, can act synergistically to produce hard-to-predict disease outcomes in freshwater and marine systems (Adlard et al., 2015). Potential, cascades, feed-backs and interactions are detailed in figure 2.

An important consideration for the assessment of health impacts is the potential for climate change mediated effects to translocate hosts and vectors that can facilitate disease emergence (Zell et al., 2008). Increased sea temperatures may affect transmission of parasites and pathogens through: direct enhancement of parasite/pathogen metabolic rate, increased transmission stages, improved parasite/pathogen survivability, faster disease spread; or temperature increases at either end of the life cycle, extending parasite/pathogen disease transmission potential (Karvonen *et al.*, 2010). Increasing temperatures have provided a conducive environment for nonindigenous marine pathogens introduced by storms and this effect has been linked to mass urchin mortalities in Nova Scotia, due to tropical cyclone-mediated introduction of amoebic disease (Scheibling & Lauzon-Guay, 2010). At the lower latitudes, disease progresses more rapidly and results in higher cumulative mortality and tropical countries suffer proportionally greater losses in aquaculture during disease outbreaks and have less time to mitigate losses (Leung & Bates, 2013). There are

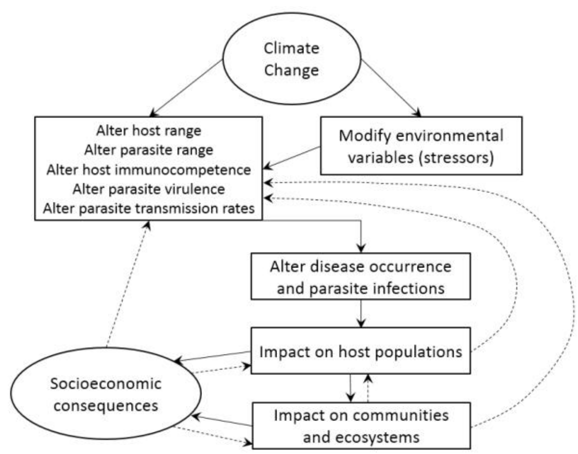

Figure 2. Climate change effects on parasites and hosts. Effects will cascade up impacting host populations, communities and ecosystems. Effects will be influenced by interactions with other stressors and environmental variables. Population and community effects will feed back to hosts and parasites (dashed lines). Modified from Marcogliese (2008).

also indirect effects on the host with respect to distribution, behavior, physiology, reduced immune functionality and mortality (Callaway et al., 2012). While there is the potential for increased disease prevalence from one or a combination of these factors, there is also the potential for decreased prevalence (Karvonen *et al.*, 2010). The more complicated the life cycle (host number and parasitic stages), the greater the chances parasites and pathogens will be impacted by climate changes (Overstreet, 1993).

Increased infection with elevated temperatures has been reported for: *Vibrio* sp. in Pacific oysters, *Crassostrea gigasoysters* (Wendling & Wegner, 2013); Furunculosis (*Aeromonas salmonicida*) infection of lake fish in Northern Quebec (Tam et al., 2011); Dermo disease *(Perkinsus marinus)* in the eastern oyster, *Crassostrea virginica* (Cook et al., 1998); and earlier onset of sea-lice infection (Boxaspen & Næss, 2000 ; Stien et al., 2005 ; ACFFA, 2014). Increased temperatures do not seem to effect cold-water disease (*Flavobacterium psychrophilum)* in salmonids (Harvell et al., 2002), low water temperature viruses such as viral hemorrhagic septicemia virus (VHSV), infectious haematopoietic necrosis (IHN), and *Oncorhynchus masou* virus (OMV)[1] (Callaway *et al.*, 2012); or tape worm infection in juvenile sockeye salmon (Bentley & Burgner, 2011). Impaired immune response for hosts under increased temperatures has been reported for the clam, *Chamelea gallina*, (Matozzo et al., 2012) and the sea urchin, *Lytechinus variegatus* (Branco et al., 2013), while no effect on the immune system was observed for the mussel, *Mytilus galloprovincialis* (Matozzo *et al.*, 2012), nor the sea urchin *Echinometra lucunter* (Matozzo *et al.*, 2012).

There is also greater potential for contamination under climate change due to flooding and intrusion. Under heavy rainfall (or snow meltwater) tertiary sewage treatment can be bypassed, discharging contaminated effluent in a raw or highly contaminated state. After human outbreaks of norovirus, the Shellfish Association of Great Britain has seen an increase in the number of incidents of norovirus associated with bivalve shellfish (Callaway *et al.*, 2012). A moderate flood event in Tasman Bay, New Zealand, resulted in a shallow low-salinity plume delivering elevated concentrations of Enterococci (*E. coli*) to a major shellfish production area resulting in ruminant faecal contamination in shellfish 6 km off-shore (Cornelisen et al., 2011). Salinity intrusion is already causing serious problems with freshwater prawn production in coastal Bangladesh, with increasing salinity linked to viral and bacterial infections (Ahmed, 2013).

Genetics

Examining genetic response of feral species and populations to climate change may provide some insight for aquaculture management. However, the effects of climate change on aquatic population genetics are difficult to isolate from other ongoing human influences such as overfishing, which cause changes in age structure, reproduction and a reduction in genetic diversity or variability. Climate change will affect aquatic species by altering geographic ranges and distribution, which in turn alter: population dynamics, effective population sizes (average number of organisms contributing genes to succeeding generations), genetic diversity (genetic variability), gene flow (genetic transfer or exchange of genes from one population of the same species to another resulting in change in gene frequencies), genetic drift (random fluctuations in gene frequencies), mutation and selection (e.g. Doney *et al.*, 2012 ; Jeppesen et al., 2012 ; Evans et al., 2015 ; Ferrari et al., 2015).

A few studies have examined genetic selection implications for climate change adaptation. Multiple generation cultured Arctic charr are better adapted to higher temperature growth compared to the offspring (F1 generation) of wild charr (Siikavuopio et al., 2013). Substantial phenotypic variation between 41 families of

[1] See comment by Veronique (Nikki) Le Page in 'Fish and Shellfish' Panel discussion

Atlantic salmon for thermal and oxygen tolerance has been reported as a function of ventricle mass and cardiac myoglobin levels (Anttila et al., 2013). Other genetic adaptive responses may occur on a smaller time scale.

Genetic variability is one method that enables species to respond to environmental change and this variability can promote adaptability in a changing climate through gene expression (variation we can see/measure) and gene regulation. However, typical broodstock selection can decrease variability in production stock, as only a handful of traits are targeted such as growth rate, survival, and disease resistance. A challenge for predicting climate change outcomes are unknowns around the capacity of short-term adaption, or epigenetic expression. Epigenetic expression is following, or not, the genetic instructions. It may or may not matter. Following existing instructions can be initiated though an environmental trigger. Some fish development is considered highly 'plastic' in this respect, with flexibility of developmental pathways, depending on environmental conditions. Many broodstock selected traits are polygenic; a specific phenotype (what we see/measure) is dependent on the interaction of numerous genes, rather than one or a few genes. This underlying compilation of genes interact to result in phenotypes (gene expression, gene regulation) and may enable aquatic organisms to be somewhat 'plastic' in their responses to climate change, especially if those changes are gradual (e.g., larval fish, Pittman et al., 2013). Such responses are supported in the literature with both cultured and feral species.

Feral juvenile salmonids exhibit phenotypic plasticity where life stages may become either anadromous or non-anadromous, depending on temperature or food resources (Benjamin (Benjamin et al., 2013). Family variation in response to stressors has been recorded for Rainbow trout (Weber & Silverstein, 2007), Atlantic cod (Hori et al., 2012).

Universal trends?

- The magnitude of the threat is a function of region, culture method and species
- Multiple stressors will occur simultaneously and have the potential for positive or negative interaction
- Response to climate change stressors between related species, and even between populations of the same species, is not universal
- Evidence to date suggests many adaptive responses (short-term) are a function of 'plasticity' or epigenetic expression
- In many species, successful adaptation is a function of parental investment or early life-stage exposure to stressors

Mitigation and Adaptation Potential

Nutrition

High food availability has been reported to promote greater resistance to ocean acidification in some invertebrates, such as *M. edulis*, (Melzner et al., 2011 ; Thomsen et al., 2013). Echinoderms such as the urchin *P. lividus*, have also responded to diet augmentation to modulate the Mg/Ca ratio to improve adaption to acidification (Asnaghi et al., 2014). In finfish, increasing dietary protein under elevated temperatures improved blood serum immune parameters (antioxidant enzymes, expression of the heat shock protein genes) for juvenile mirror carp (Huang et al., 2014). Propolis, an antioxidant resinous hive product collected by honeybees improved sea-bass resistance to low-temperature stress (Šegvić-Bubić et al., 2013). Bioenergetic factorial models for some species like rainbow trout (Hua & Bureau, 2009), tilapia (Chowdhury et al., 2013) and barramundi (Glencross & Bermudes, 2012) can estimate optional digestible protein and energy requirements under elevated temperatures. Skretting (Norway) has been investigating whether feed formulation can be used to reduce the impacts of rising seawater temperatures since 2011 (Anon, 2011).

Diet augmentation for fed aquaculture may be a practical mitigation tool. It will be a much greater challenge for species that extract their diet from the ambient environment, such as shellfish. Culture practices such as Integrated Multi-Trophic Aquaculture may provide diet augmentation opportunities through increased organic and dissolved nutrient availability (Reid et al., 2013). Rearing systems which enable greater environmental control (e.g. land-based) could enable more dietary control of extractive species.

Monitoring, early warning, prediction

Real-time monitoring, early warning and prediction are all variants of information provision, which differ in time frame and uncertainty. Real-time monitoring can alert famers to the presence of deleterious conditions that may not be obvious until the onset of behavioral or clinical symptoms. It has been common practice to measure oxygen and temperature, but recent developments have greatly expanded monitoring breath and capability. For example, microsensor technology enable shellfish heat rates to be monitored as a means to monitor animal response to environmental and biological stressors (Hellicar et al., 2015 ; Reid & Jackson, 2014). Ocean condition monitoring networks like the Integrated Ocean Observing System (IOOS, http://www.ioos.noaa.gov/) enable aquaculturists to track pH and other crucial water quality parameters in real-time.

Early warning of acute, deleterious events such as storms, flooding, CO_2 influx or water temperature extremes, can provide a window to enable management response. Xu and Zhang (2014) developed a GIS-based meteorological information system for aquaculturists in Zhanjiang, China, which warns farmers of pending weather extremes. In Australia, the Predictive Ocean Atmosphere Model for Australia (POAMA), can provide several months warning of adverse salmon culture temperatures (Spillman & Hobday, 2014). Early warning strategies have had some success; avoiding the use of low aragonite saturated waters when strong upwelling conditions occur, have enabled the significant restoration of oyster hatchery production (Barton et al., 2012).

Routine monitoring for serious and potentially reoccurring infection is a common aquaculture health management protocol in developed regions. For example, the web-based management program Fish-iTrends, maintains an evidence-based epidemiological sea lice database, that tracks temporal and spatial trends of regional salmon farm infection to provide decision support for treatment options (Hammell, 2014 ; Harris, 2015), providing a wealth of temperature data. At the global scale however, disease outbreaks often go unreported, standardized reporting of aquaculture-based epizootics and documenting conditions surrounding outbreaks is lacking, and such data are required to formulate adaptation strategies to climate extremes (Leung & Bates, 2013). Epidemiological modelling using mechanistic (process-based) or statistical approaches have the potential to predict the spread of diseases under a changing climate (Lafferty, 2009) and this capacity would benefit ongoing aquaculture viably. There has also been recent advocacy for the use of GIS based statistical models that allow spatially distributed determinants of aquatic health and disease to be fully evaluated through risk mapping (Thrush et al., 2011). Such models are also heavily data driven and further emphasizes the need for detailed monitoring as well as interdisciplinary approaches to mitigate disease impacts in aquatic systems (Adlard *et al.*, 2015).

Management and engineering solutions

The simplest, adaption strategies are based around management and husbandry practices.

These are frequently combined with engineering solutions, so these will be considered together. Protection against floods will be a combination of management strategies and age old engineering approaches such as increasing dike or embankment capacity. Flood response management strategies are routine in regions with predictable seasonal flooding. In Malaysian flood prone areas, fish are harvested prior to floods (Idris *et al.*, 2014) and water levels in ponds are dropped prior to flooding in Taiwan (Chang et al., 2013). Backup generators are common in land-based facilities to ensure aeration during power failures, but under extreme conditions where tanks may be destroyed or overtopped, fish evacuation may be necessary (Dodd, 2011b). Protection of land-based aquaculture facilities from land erosion and storm surges can be facilitated with appropriate natural barriers; restoration of reefs and coastal vegetation is reported to have the greatest potential to protect coastal communities from sea level rise and storm surges (Arkema et al., 2013).

Uncertainties of climate change extremes have introduced additional considerations for the design of aquaculture facilities (Alvarez-Lajonchère & Pérez-Roa, 2012). The storm Intensity-Duration-Frequency (IDF) curves used by engineers to guide design specifications, are changing with the climate and specifications are currently being updated for new scenarios (Liew et al., 2014). Although, failure of cages during storm events prompts redesign efforts regardless (Can & Tuan, 2012). Recent interest in off-shore aquaculture (Shainee et al., 2013) and submersible finfish (Shainee et al., 2014) and shellfish (Kim et al., 2014) systems has helped to develop technology for extreme weather conditions.

Choosing farm locations less impacted by climate change effects is a logical mitigation strategy. Some shellfish hatcheries have already moved to less acidic waters (Welch, 2012). GIS tools have long been used to select good aquaculture locations (Nath et al., 2000, Perez et al., 2005, Hossain et al., 2007, Radiarta et al., 2008, Hossain and Das, 2010, Mamat et al., 2014) and recently have been used to identify areas less threatened by climate change stressors (Handisyde et al. ; Hossain & Das, 2010 ; Khan et al., 2012). A potential complicating factor with the strategy of relocation to areas of optimal water quality is that conditions may not be optimal for all life stages. Báez et al. (2011) experiences with rainbow trout, suggests the fastest growth rates occur at temperatures which are detrimental to reproductive performance and have advocated separate site locations for broodstock and grow-out. In some circumstances, direct mitigation of the localized environment may be possible. For infaunal species in detrimental sediment saturation states, sediment buffering using crushed shells can increase the alkalinity, pH and aragonite saturation states of the sediment and decrease shell dissolution and / or promote larval recruitment (Green *et al.*, 2009), with some reported success (ANA2012). An inability to mitigate the environment may require the creation of an artificial one. Rearing strategies which enable environmental control to either protect sensitive life stages from environmental stressors or promote adaptive responses. Such strategies may require water quality control through either recirculation approaches (Timmons et al., 2002) or strategic water intake to avoid periodic stressors such as CO_2 upwelling (Barton *et al.*, 2012).

Diversification either at the regional level or at the farm level, such as Integrated Multi-Trophic Aquaculture, offers mitigation potential, avoiding overreliance on one-species and provides a contingency if one crop fails. Research into species-specific responses to threats can provide information to target culture of more resilient species (Cooley et al., 2012).

Genetics and biotechnology

The epigenetic response potential of fishes (Pittman *et al.*, 2013) and recent studies on marine invertebrates (Sanford & Kelly, 2011), suggest adaptive potential to climate change stressors, but there are many knowledge gaps. Adaptive capacity of marine populations to ocean acidification is largely unknown. Until recently, few studies have considered acclimation times of more than a few months (Doney et al., 2009 ; Harley et al., 2006 ; Kurihara et al., 2007 ; Gazeau *et al.*, 2013 ; Thomsen et al., 2010). 'Plastic responses' particularly in early life stages suggest greater environmental control during early rearing may help direct epigenetic responses, and hatcheries are already well positioned to do this. Significantly differing larval sensitivities to elevated pCO_2 conditions in wild and selectively bred populations have been observed in the Sydney rock oyster (Parker et al., 2012). Shellfish hatchery operations have already seen differences in calcification rates in selection programs, thereby proving its usefulness as a breeding strategy (Waldbusser et al., 2010). Selection of tolerant salinity tolerant catfish strains in the Mekong Delta, Vietnam is being advocated to mitigate effects of marine flood waters (Nguyen *et al.*, 2014).

Specific climate change traits should be incorporated into broodstock selection programs assessing family variation and retaining as much genetic variability as possible in the breeding nucleus. Maintaining genetic diversity could ensure preservation of rare alleles that may be associated with resistance to a future disease or increased survival in the presence of disease and environmental stressor. If the rate of climate changes exceeds breeding schemes based on recorded phenotypic data, adding molecular selection techniques (e.g., genomic selection) to phenotypic selection programs may prove essential. Some genomics approaches to identify genes associated with resistant traits are underway, such as genes associated with heat tolerance in Arctic charr (Quinn et al., 2011) and other genomic biomarker development in shellfish (Hüning et al., 2013). Recent advancements in commercial scale cryopreservation can enable 'gene banking' or retention of genetics from one parent (male), regardless of continued inclusion in a breeding programs.

Governance

Effective aquaculture governance requires accountability, effectiveness and efficiency of governments, equity, and predictability of the rule of the law. Sustainability of the industry is the principal goal of aquaculture governance and incorporates four aspects: economic viability, environmental integrity, social licence and Technical feasibility. Regional cooperation will be required as the gathering and sharing of data will be required on forecasted changes in the coastal environment, animal health issues, invasive species and sharing of best practices. The aquaculture industry may also need to join with other resource sectors in the coastal zone to influence policies and ensure that governments provide relevant data in a timely and effective manner.

What next?

There are still many unknowns on how climate change stressors may affect aquaculture in the future, whilst some sectors are already experiencing impact. Despite large knowledge gaps, there is the potential for tangible mitigation or adaptation strategies, which will evolve and expand as our knowledge and awareness increases. While this review presentation aimed to provide a global overview of climate change to help contextualize regional concerns, it is clear that the magnitude and timelines of stressors will be in part a function of region or local. Mitigation and research solutions may need to be focused accordingly. Workshop sessions, panel discussions and break-out groups will examine these in more detail at these scales. We also need to consider research and partnership outcomes that should be explored to address NSERC criteria for funding and supporting these workshops. These discussions should be preceded by considering the following questions:

1. Do we know enough to rank threat potential of climate change stressors and how this would reflect regions and species?
2. What research should be prioritized and how should this be done to maximize resources and minimize redundancy?

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Extreme lower temperatures at Pool's Cove, NL, February 2014. Photo by Jennifer Caines, Northern Harvest Sea Farms

Atlantic Workshop

April 29 – 30, 2015

Huntsman Marine Science Centre
St. Andrews, New Brunswick

Introduction by the Atlantic Canada Fish Farmers Association

Dear Colleagues,

Climate change has the potential to significantly impact aquaculture operations around the world. It is this concern that prompted the workshop, *Climate Change and Aquaculture in Atlantic Canada*. The workshop brought together industry professionals and researchers to discuss how climate change may affect aquaculture operations and to strategize research and other approaches to ensure the ongoing competitiveness of Atlantic Canada's aquaculture industry under climate change.

Approximately 60 participants from Atlantic Canada attended this workshop held on April 29 and 30, 2015 at the Huntsman Marine Science Centre in St. Andrews, N.B. The workshop began with a literature review from a global perspective, followed by presentations with regional emphasis, on ocean acidification, storms and rising waters, fish and shellfish health, and warming waters. Breakout groups in fish health, shellfish, genetics, engineering, governance and nutrition, discussed knowledge gaps and strategized approaches to adaptation. A workshop-wide discussion followed to determine research priorities and next steps.

This workshop template was used for a companion workshop in Pacific Canada, and it is hoped that these workshops will result in a national aquaculture climate change research network. The presentations, discussion outcomes and the future research needs identified from these workshops are summarized here in this Aquaculture Association of Canada publication. We hope that the information presented will be of assistance to industry and a reference for researchers.

We would like to thank Dr. Gregor Reid who worked in partnership with us to develop and organize this workshop with funding and support from The Natural Sciences and Engineering Research Council of Canada (NSERC), the University of New Brunswick and the Huntsman Marine Science Centre.

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Atlantic Canada
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Ocean Acidification Session

Ocean acidification in Canadian waters presentation summary

Kumiko Azetsu-Scott

K. Azetsu-Scott, Oceanography and Climate Section, Ocean and Ecosystem Sciences Division, Bedford Institute of Oceanography, Fisheries and Oceans, Canada

Ocean Acidification 101

The pH is a measure of acidity with lower values being more acidic. It is calculated as the negative log of hydrogen ion (H^+) concentration. About 1/4 of CO_2 released by human activities (anthropogenic carbon) since the start of the Industrial Revolution (1800's), has been absorbed by the oceans. This has caused about 30% decrease in ocean pH since preindustrial times. The current rate of ocean acidification is faster than any time in the last 300 million years (Turley *et al*, 2006).

The calcium carbonate saturation state of seawater (Ω) is a measure of potential to corrode the calcium carbonate ($CaCO_3$) shells and skeletons of marine organisms. A major concern for acidic waters is how the organisms with calcium carbonate shells and skeletons are affected. Waters rich in saturated calcium carbonate, help ensure aquatic species with shells or exoskeletons have the appropriate building blocks available to form hard calcified structures. Acidity reduces availability of carbonate ions, which are building blocks of shells and skeletons. There are two main mineral forms of calcium carbonate: calcite (eg. coccolithophores and foraminifera have calcite structure) and aragonite (e.g. pteropods and corals have aragonite structure). Aragonite is more soluble than calcite. Solubility of calcium carbonate increases with increased pressure and decreased temperature. When $\Omega=1$, it is known as the saturation horizon. At $\Omega>1$ shells and skeletons are 'alright' although many exceptions exist, and at $\Omega<1$ water is corrosive and mineral dissolution begins.

Local acidification in coastal areas, where aquaculture is mostly practiced, may be amplified by factors other than invasion of anthropogenic carbon. These may include: river runoff which is naturally more acidic; land-based nutrient runoff, which may cause eutrophication prompting organic matter decay, lowering oxygen and increase of CO_2; deep water upwelling of CO_2 rich waters to the coast; and emissions of other acidifying gasses, such as nitrogen oxides (Nox) and sulfur oxides (Sox).

Accurate and precise measurements of pH requires great care. Wet chemistry pH measures (e.g. spectrophotometric) have a greater precision, of around 0.005 pH units, compared to electronic sensors (e.g. Potentiometric method) with precision of around 0.02. Two types of measurement qualities need to be considered to answer the specific questions; to identify relative spatial patterns and short-term variation, for example, in coastal regions ('weather') and to assess long term trends ('climate'). Recommended precision for pH measures used to assess weather patterns is 0.02, and for climate change research it requires the level of 0.003! A Shediac station (NB) time series study in 2012 showed pH variations of 8.07-8.39 at surface (<10m) and from 7.73-7.88 at the bottom.

The field of pH scales and the study of acid-base reactions in seawater is one of the more confused area of marine chemistry (Dickson, 1984). There are 5 different pH scales (pH_a, pH_{NBS}, pH_F, pH_{total}, pH_{SWS}) and these can communicate quite different results. At 20°C, salinity 35, and 1 atm, units on the pH_{total} scale is about 0.13 unit lower than the pH_{NBS}

scale. pH can be highly variable at several scales, even at daily time scales. These challenges have prompted the development of data quality standards appropriate to study objectives (e.g. Global Ocean Acidification Observing Network, GOA-ON).

Some Carbon Dioxide, pH and Aragonite Saturation hot-spots

Canada's three oceans are connected by the flow from the Pacific to the Atlantic through the Arctic, with some contribution from Hudson Bay. This flow is acidic. North Pacific has high carbon with low alkalinity resulting in higher acidity than the Atlantic. This acidic Pacific water is further modified by Artic ice meltwater, river input, biological processes, and flows out to the Atlantic. Arctic outflow, corrosive to organisms with $CaCO_3$ shells and skeletons, can be traced along the western Baffin Bay to the south of the Labrador Sea. This overall route has coined the term the 'Canadian Acid Highway' (named by Robie Macdonald, Institute of Oceans Sciences, Fisheries and Oceans Canada) and is detailed in figure 1.

Off the west coast of USA and Canada, there is a seasonal upwelling of CO_2 rich corrosive intermediate water, with decreased Ω due to ocean uptake of anthropogenic CO_2 (Freely et al. 2008), which has already adversely affected major shellfish production. $\Omega_{arg}<1$ in the surface water on the Arctic continental shelf and Beaufort Sea has been reported (Yamamoto-Kawai et al., 2009). In Hudson Bay, freshwater input from rivers enhanced coastal acidification with variations due to the watershed geology (Azetsu-Scott et al., 2014). Acidification due to hypoxia has been reported in Lower St. Lawrence estuary bottom waters, where pH decreased by 0.2 to 0.3 units per year, the last 75 years; 4 to 6 times greater than decrease due to the surface anthropogenic CO_2 (Mucci *et al.,* 2011). There has been a relentless

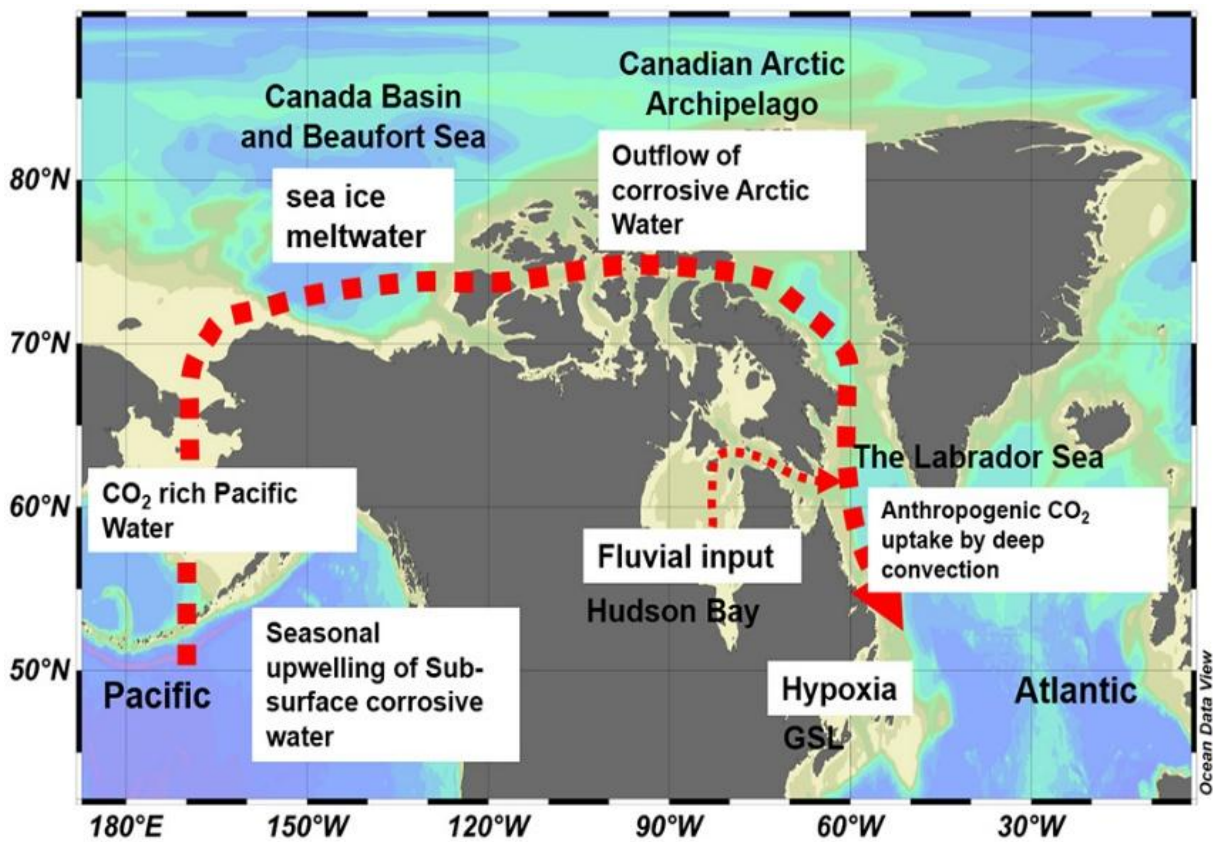

Figure 1. The 'Canadian Acid Highway' and regional amplification drivers

increase of total CO_2 concentrations in the Labrador Sea where deep convection in winter ventilate to the dpeths. The pH has decreased from ≈ 8.08 to 8.01. By the year 2070, organisms may have difficulty making shells and skeletons. Significant pH change has also been recorded off the Scotian Shell, where the 1930s pH of 8.22 is now around 8.01 (1996 – 2011). The pH decreases here at 0.003 yr^{-1}, faster than the global average decrease of 0.002 yr^{-1}. Canada's east coast is affected by Arctic outflow, corrosive to organisms with $CaCO_3$ shells and skeletons, and can be traced along the western Baffin Bay to the south of the Labrador Sea (Azetsu-Scott *et al*., 2010).

Biological response

Many life processes are sensitive to CO_2 and pH. However, biological responses are not universal and can be extreme complex. Ocean acidification and CO_2 may, reduce calcification, impair growth/development, impair reproduction and physiology, effect metabolic rate, depress immune systems, influence behaviour, survival and taste. Generally, biotic responses to ocean acidification are diverse, poorly understood and it is therefore difficult to predict ecological and biogeochemical consequences of continued oceanic CO_2 uptake.

The most direct impact would be to organisms that form calcium carbonate ($CaCO_3$) shells and skeletons because acidity increases the solubility of $CaCO_3$. Some of these include various types of phytoplankton (e.g. coccolithophores) and zooplankton (e.g. pteropods, foraminifera), echinoderms (sea urchins, brittle stars), crustaceans, and shelled molluscs. Pteropods (or sea butterfly) are ubiquitous in northern waters and an important food source for fish such as herring, salmon and cod. When placed in seawater, with Southern Ocean projected 2011 pH, shells began to dissolve in 48 hrs (Bednaršek et al. 2012). The size and shell thickness of larval quahogs (*M. mercenaria*) are both reduced as the ppm of CO_2 goes from 250 to 1500 (Talmage and Gobler, 2010). Taste may be impacted. Northern shrimp raised in tanks that simulate the more acidic ocean expected in the future just don't taste right (Dupont *et al*., 2014). Finfish are not immune. In more acidic waters clown fish wander too far from safety (interference with their sense of smell) - ocean acidification could cause sensory and behavioral problems (Fischetti, 2012). Some studies have investigated marine fauna in naturally high CO_2 environments (under-sea volcanoes), as assess a possible future ocean. 'Winners' are sea grasses, and brown algae, 'losers' are calcareous groups, and adopted species like gastropods were much smaller than normal (Hall-Spencer *et al*., 2008, Garilli *et al*., 2015); the so-call 'Lilliput effect'. Would the Lilliput effect have implications for aquaculture?

Aquaculture

Ocean acidification has most affected North American aquaculture shellfish production in the Pacific Northwest. Ocean acidification has been linked with larval oyster failure and collapse of seed production at some hatcheries (NSF, press release April, 12, 2012). The US shellfish industry had a total economic value of US$278 million in 2009 (Pacific Coast Growers Association, 2010) and these concerns prompted a Blue Ribbon Panel convened by the Washington Stage Governor (Christine Gregoire), which produced an extensive report of 42 recommendations and 28 key early actions.

Many pH and CO_2 monitoring programs are off-shore or in non-aquaculture producing areas. Although, some 'farm data' is collected by producers or hatchery operators, privately and in collaboration with researchers. For example, daily measurements of salinity, temperature, aragonite saturation state and pH_{total} at the Pictou (NS) Lobster Hatchery are collected at the water intake. The pH has high daily variability, ranging from > 8.0 to < 7.6 over spring and early summer. More advanced monitoring programs for shellfish aquaculture are being developed, such as simultaneous observations of functional genomics and $CaCO_3$ mineral corrosiveness in the northern Salish Sea (Gurney-Smith and W. Evans, pers comm).

In order for monitoring to be the most value for aquaculture it is recommended that, high frequency temporal sampling (hours to year) for the 'weather' quality measurements' standard, as a minimal number of parameters (e.g. temperature, salinity, oxygen and pH). Measuring using the 'Climate' standard, including a full sweep of carbonate and other chemical parameters could enable an algorithm to estimate the missing parameters (for example, salinity vs. Alkalinity). Spatial variation should be clearly documented ensuring data collected by all parties are comparable.

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Ocean acidification panel discussion

Ocean Acidification Panel, left to right: Jamey Smith (Huntsman Marine Science Centre, workshop facilitator), Kumiko Azestsu-Scott (Fisheries and Oceans Canada), Samuel Rastrick (Institute of Marine Research, Norway), Julie Laroche (Dalhousie University), Helmuth Thomas (Dalhousie University)

Question - Jamie Smith: Could you tell us what some of the research priorities should be?

Kumiko - Variability of coastal ecosystems- we need everyone to come together to get the necessary data.

Samuel - Starting to look at how pH and animals interact, need to introduce experiments into the natural system.

Julie - Interdisciplinary research is key, ecosystem responses in general must be studied and understood starting with the microbial community and ocean acidification's effect on community structure.

Helmuth- How pH is regulated in the system.

Question - Gregor Reid: What is the present role of MEOPAR (Marine Observation Prediction and Response Network) in climate change research?

Paul Lyon (audience) - MEOPAR is funding ocean acidification projects, they have funding available specifically for instrumentation to be used in monitoring projects.

Helmuth - I am currently working on one of two ocean acidification projects being conducted by MEOPAR. Part of one project involves monitoring production at inshore sites and on the Scotian Shelf. Objectives are to monitor in cooperation with industry at particular production sites, to enable forecasts as a means to guide mitigation and ocean acidification adaptation for industry. This initiative also allows to assess variability of data. The 2nd project contributes to observing the marine system and responding to threats across Canada. On the east coast, ocean acidification research is heavily biologically focused, with much effort being made to separate ocean acidification risks and consequences from other factors in the environment.

Question - Thierry Chopin: The scale of things is important to keep in the discussion. Aquaculture in this region is primarily at a fine coastal scale, and a different monitoring strategy is required. What about biological mitigation? On such small scales could perhaps use seaweeds to mitigate ocean acidification rise.

Kumiko - Haven't seen any such projects here in Canada, but have been some sea grass projects in the Mediterranean.

Thierry Chopin - biological variation is what explains a lot of the variability in conditions in the coastal region.

Samuel - I believe a barrier to such work is that we don't really understand chronic versus acute effects on organisms. We have seen this large (pH)

Thierry Chopin

variability in tidal pools, where we see a sort of buffering that's occurring, which we don't fully understand. What would the cost be to a species if such mechanisms were constantly working? There is much that we do not yet understand about costs or long term effects of such mechanisms. I agree it is a topic that should be investigated further.

Question - Hamid Khoda Bakhsh: - Where are the highs and lows? Why is it more variable in different parts of the world? What are the key influences where aquaculture is occurring?

Samuel – I'm unfamiliar with Canadian conditions, but in general, mixing from wind directions and storms can be a big factor.

Julie - Variables are very site specific.

Helmuth - Temp and CO_2 are two large scale regulatory factors, on the small scale all those which were previously mentioned. However, we can't really simplify ocean acidification to one or two causes or stressors, all influences must be considered together to capture confounding effects.

Question - Donald Killorn: Conversations with the industry here reveals little to no concern over the effects of ocean acidification for their part. Any advice on how to get them interested in this topic?

Kumiko – The west coast is already seeing effects from ocean acidification. Not yet seeing it to that degree on the East Coast yet, but can we wait for disaster to strike before we act? Currently we don't even know what the effect of ocean acidification would be on Salmon.

Samuel – We don't fully understand how it will be effected especially in conjunction with things like temperature stress and salinity stress. These stressors acting alone, finfish may be fine, but what will their combined effects be in this region?

Kumiko – There are some studies conducted in the US on finfish, but haven't really seen such studies here in Canada yet.

Jeff Clements (audience) – There is some recent research on finfish and ocean acidification in the literature.

Julie - Following Samuel's point about not yet understanding the possible confounding effects, there are also considerations of indirect effects of ocean acidification in conjunction with food supply issues, changes to the microbial community, pathogens, etc.

Question - Donald Killorn: Will the buoy in the Saint John harbour inform the Charlotte County area?

Kumiko – No, harbour to harbour variability is high and likely will do little to inform locally.

Hamid Khoda Bakhsh

Question - Donald Killorn: Where does the Gulf of Maine stack up with $CaCO_3$ concentration, do we know?

Helmuth – The Gulf of Maine not as salty thus it is more vulnerable to ocean acidification. Salinity likely will be the largest difference more than ocean acidification.

Question - Peter Warris: What does the panel see as some early impact identifiers of ocean acidification?

Samuel – In early development we often find as the most vulnerable and where changes are often seen first. We need to be careful though when we talk about “impacts” and must always consider the length of exposure, concentrations and scale being spoken of. There will be effects, but we need to be conducting proper studies in the environment at the aquaculture sites, as this will be much more informative than lab studies. Also, journal publication are sometimes skewed towards not publishing “negative results”, and we need to make sure these studies also get out.

Rich Moccia (audience) - Many studies were conducted on the effects of acidification on finfish in a freshwater context during the 1940s-80s in response to the issues of acid rain. Canada was especially prevalent in that literature. It may be older, but perhaps it is time to re-examine some of those studies to inform today and direct projects for finfish and ocean acidification.

Question - What is the impact of photosynthetic biomass increase on aquaculture farms?

Kumiko – It is typically not on issue as it disperses in this area and results in little to no localized effect.

Julie – There are very few species of microbes that increase growth with increasing CO_2 as most are already CO_2 saturated so likely won’t be an issue.

Question - Tim Jackson: What are the plan for making Saint John harbour buoy data available?

Kumkio – There will be a real time website with data that will be available soon (within a year?).

Storms and Rising Waters Session

Sea level rise in Atlantic Canada presentation summary

B Greenan, Oceanography and Climate Section, Ocean and Ecosystem Sciences Division, Bedford Institute of Oceanography, Fisheries and Oceans Canada

Blair Greenan

Sea-level rise is a concern for Canadian aquaculturists as it can lead to much greater flood potential in culture areas and the potential for damage to support infrastructure such as small craft harbours. The 2013 fifth Assessment Report (AR5), from the Intergovernmental Panel on Climate Change (IPCC) reported that the rate of global sea-level rise since the mid-19th century, has been greater than the previous two millennia. From 1901 to 2010, global average sea level rose an average of 0.19m (with an uncertainty range of 0.17m - 0.21m). Global sea-level will continue to rise during the 21st century and will *very likely* exceed that observed between 1971 to 2010 due to increased ocean warming, and increased loss of water mass from glaciers and ice sheets. Sea-level rise will vary regionally due to a combination of differences in ocean circulation, vertical land motion and other local drivers. This means there will also be regional differences in flood potential (Fig. 1).

In Atlantic Canada, detailed sea-level measurements have been recorded in Halifax since 1920, and this data has shown a steady progressive rise (Fig. 2). The past and projected sea-level rise in Halifax and other locations, has prompted Fisheries and Oceans Canada (DFO) to determine vertical allowance estimates for coastal assets such as wharfs to accommodate rising waters. An allowance is defined as the amount by which a coastal asset needs to be raised in order to maintain the same likelihood of future flooding events as that site has experienced in the recent past (Zhai et al. 2014). The rise in sea-level and exceedances is not linear. The number of

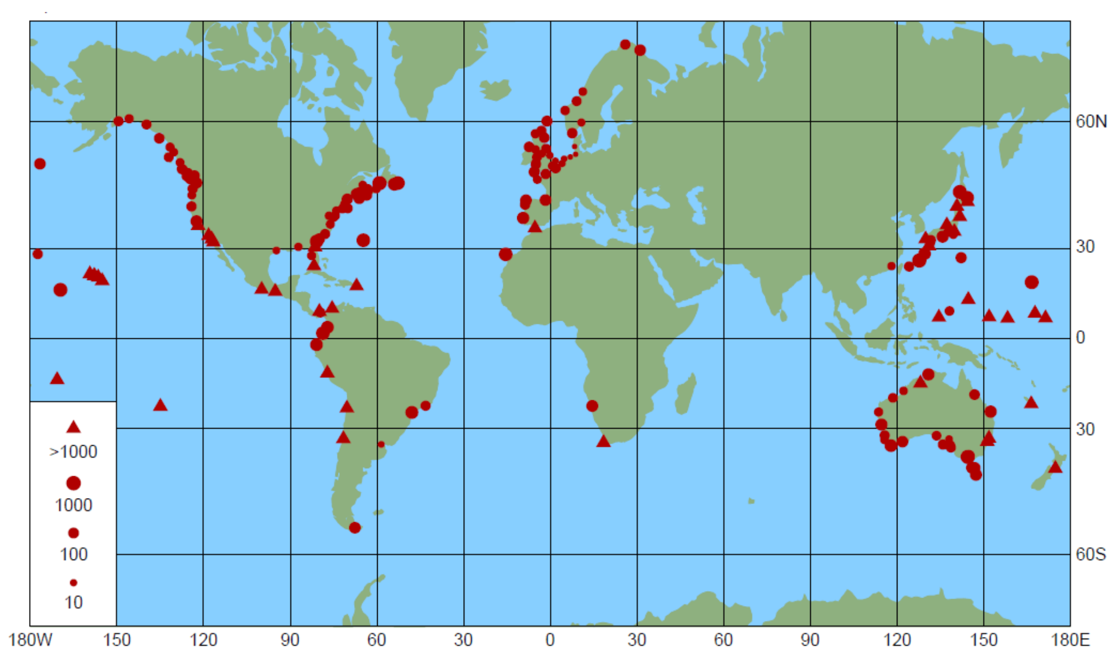

Figure 1. Increase in flood frequency for a global sea-level rise or 0.5 m (IPCC 2013)

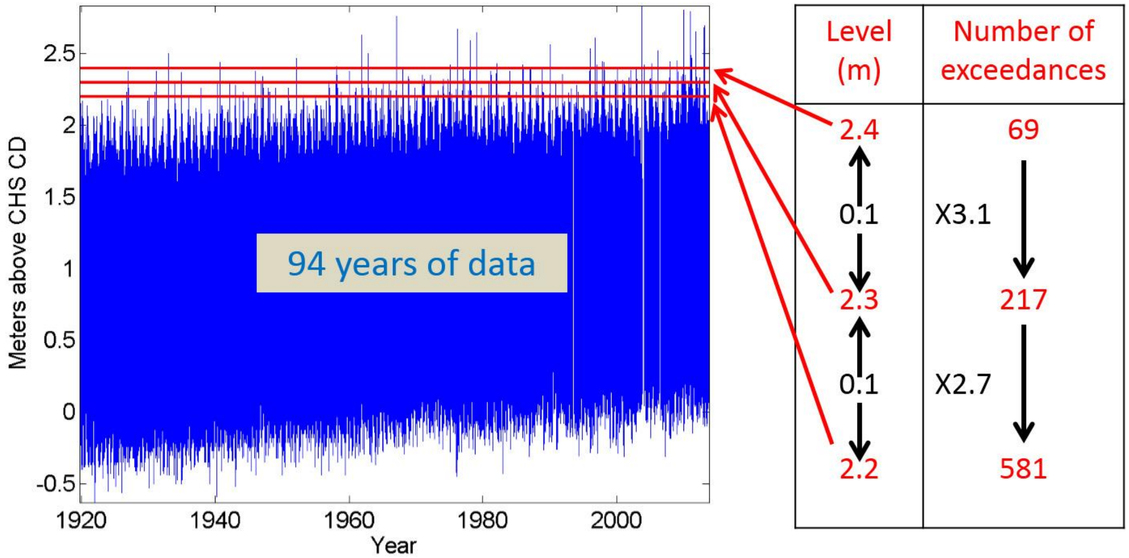

Figure 2. An example of the increase in flooding events at the location of the Halifax tide gauge for scenarios where mean sea level rises by 0.1m. The plot demonstrates that if sea level were to rise by 0.1m at this location, the number of flooding exceedances would increase by about a factor of three (e.g. 217 vs. 69 exceedances).

exceedances varies approximately exponentially with height. As a rule of thumb, a 0.1 m increase in sea level results in a factor of 3 change in the number of exceedances. DFO is presently completing the development of the Canadian Extreme Water Level Adaptation Tool (CAN-EWLAT) which will enable coastal users to determine future allowances for their particular area. CAN-EWLAT is expected to be available online shortly (see URL for additional details, www.rpic-ibic.ca/documents/2014_Marine_Workshop/CAN-EWLAT_RPIC_Jan2014_no_video.pdf). Other initiatives are also underway such as the development of a coastal vulnerability index for harbour infrastructure, which uses digital costal data as a means to assist in climate change adaptation planning.

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Zhai L., B. Greenan, J. Hunter, T.S. James, G. Han, R. Thomson, and P. MacAulay 2014. Estimating Sea-level Allowances for the coasts of Canada and the adjacent United States using the Fifth Assessment Report of the IPCC. Canadian Technical Report of Hydrography and Ocean Sciences 300: v + 146 pp. Available at: http://www.dfo-mpo.gc.ca/Library/353519.pdf

Sea level and the composite joint probability of distribution for tides, surges, waves: a presentation summary

William Perrie

W Perrie*, M Blokhina, B Toulany, Z Long, V Korabel
Bedford Institute of Oceanography, Fisheries and Oceans Canada

* Presenting author (remotely)

The vast majority of open-water aquaculture in Canadian marine systems occurs 'inshore' and shellfish and finfish operations can be affected by changes to waves, wind, and tidal surges. Land-based aquaculture is not immune to these influences either, as culture facilities are typically located near a water source to minimize pumping distance, and frequently on a flood plain.

Fisheries and Oceans Canada (DFO) is presently investigating how the predicted combined effects of changes in tides, surges, ice cover and waves, may manifest extreme coastal sea-levels (Fig. 1) throughout the Atlantic (Guo et al. 2015; Blokhina et al. 2015; Korabel et al. 2015). Prediction scenarios from the Intergovernmental Panel on Climate Change are combined with historical trend data of ice cover, wind and wave heights to model future outcomes.

Sea-level changes will create changes in the wave climate, including wave-effects, and events like wave-enhanced coastal flooding that didn't previously exist, which could promote damages in some exposed locations. Reduced winter ice-cover in some areas may provide greater open wave areas, and actual waves, for example in the Gulf of St. Lawrence, which had previously been frozen in winter, certainly affecting the winter wave climate in these areas.

Wave height is not necessarily expected to increase the same at all Atlantic locations and in some instances future coastal wave heights are predicted to decrease. Figure 2 details present and predicted future wave heights throughout the Atlantic. Surges however are expected to increase at most locations, and future predictions are detailed in figure 3, also showing the possible effects of tides.

In new approaches to this analysis, one should also consider the joint probability of waves and water level for coastal overwash events. It turns out that the choice of wave and water levels does matter when identifying flood hazards of a joint probability event for coastal infrastructure. Examples can show that *high water levels and low long swells* can be a *greater* hazard than *lower water levels and large wind waves*, with the same probability of occurrence. A good example is given by a recent study by Brown et al (2015) entitled, 'Flood risk uncertainty surrounding a 0.5% annual probability event'. See Figure 4.

Research is ongoing and models are presently being updated using the most recent IPCC scenarios.

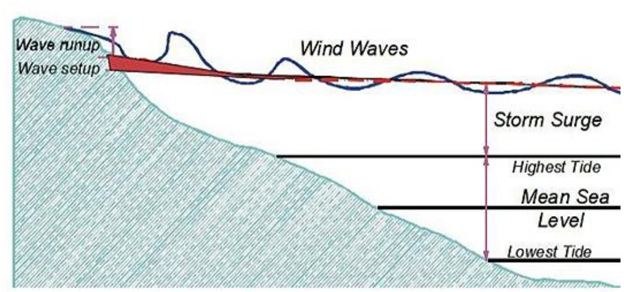
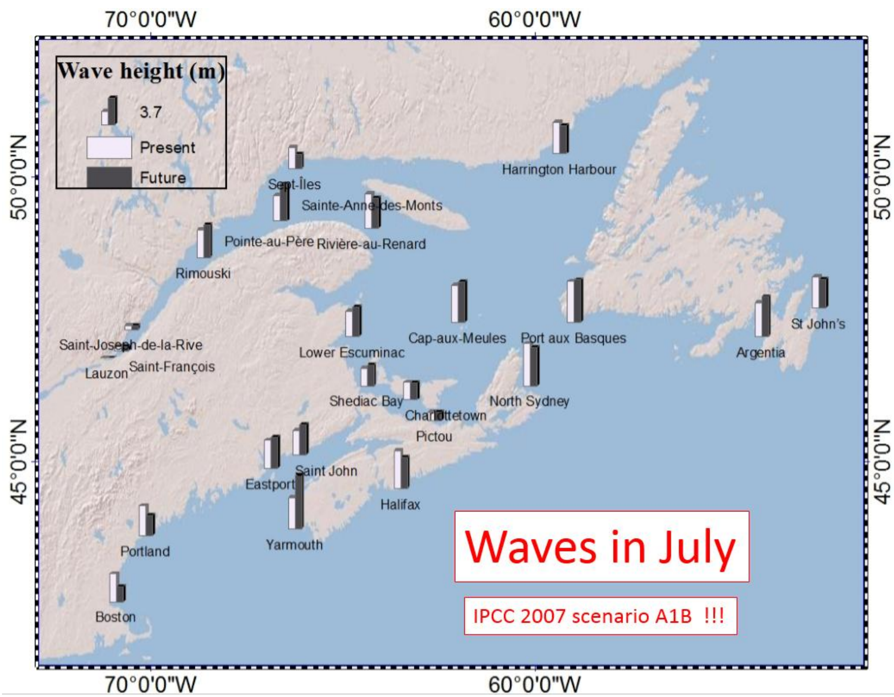


Figure 1. The possible contributions to extreme sea levels at the coast.

Acknowledgements

This work is made possible by funding from the DFO's ACCASP – Aquatic Climate Change Adaption Services Program, and OERD, Canada's Office of Energy Research and Development.



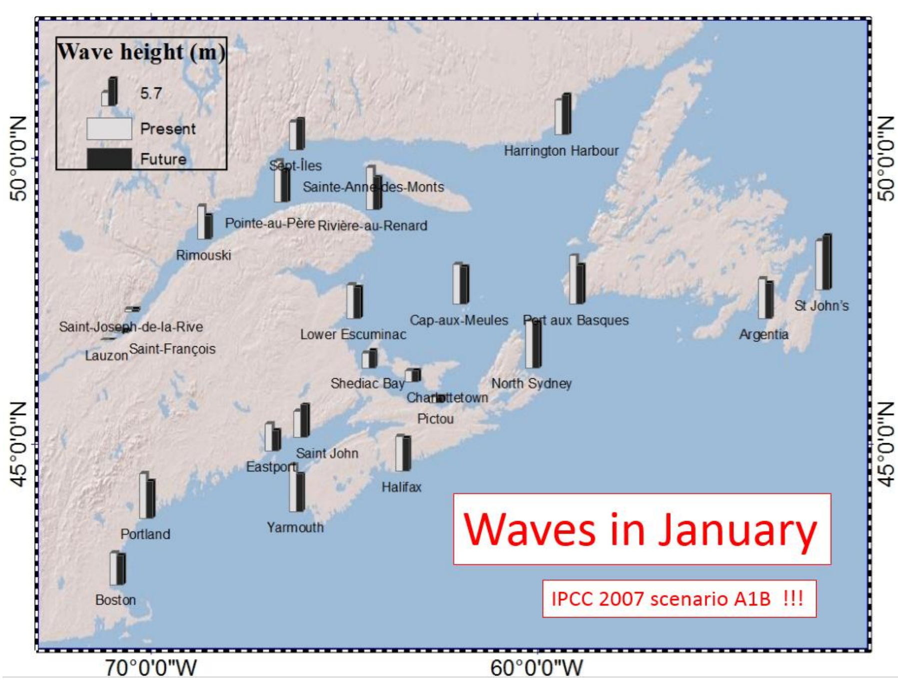


Figure 2. Present and future wave heights throughout the Atlantic coast. Summer heights in top figure and winter heights in bottom figure. Present conditions are simulated as the thirty years, 1970-1999, compared to future conditions in 2040-2069.

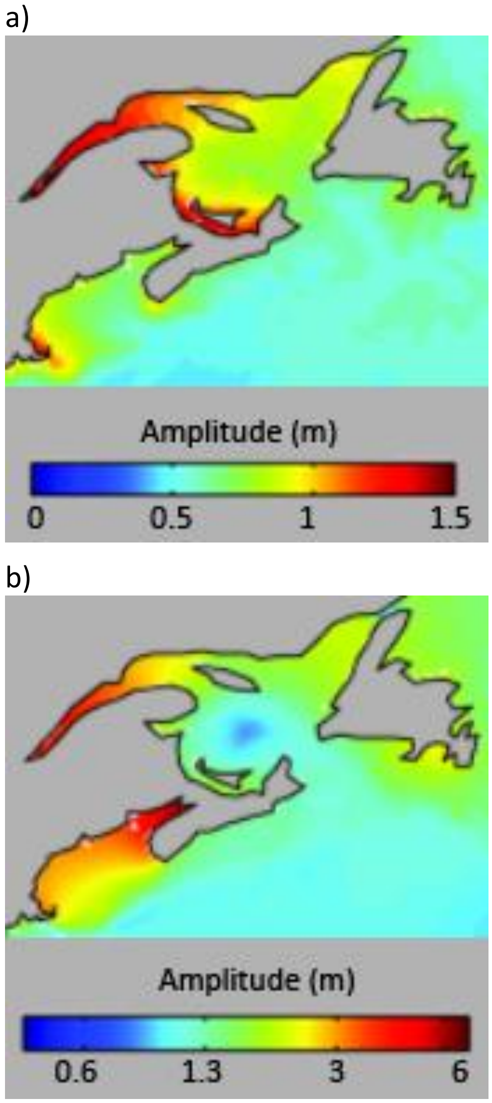


Figure 3. Distributions of 50-year extreme (a) sub-tidal storm surges, estimated from sub-tidal sea level fields (b) total sea levels (due to the combination of storm surges and tides). These are produced by a 2D circulation model using the generalized extreme value statistical approach. From Zhang and Sheng (2013).

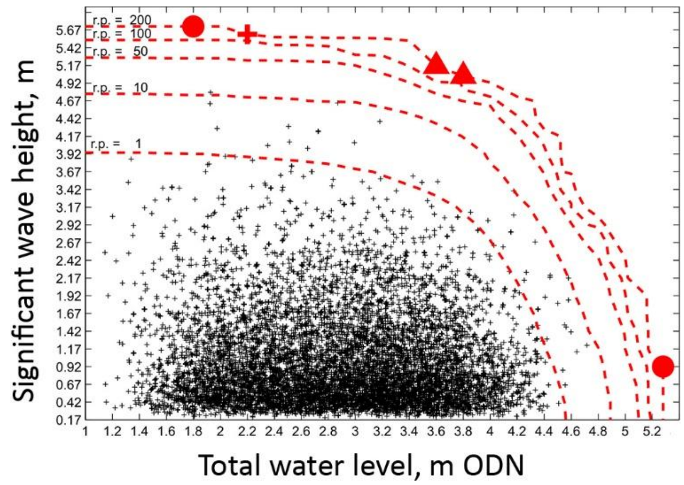


Figure 4. Joint probability curves. The red circles bound the section used in an uncertainty analysis, the red cross marks the tipping point when water-wave level conditions enable the overwashing of coastal defences, and the red triangles identify a second tipping point regime in the extremity of the coastal flood hazard. OMD refers to Ordnance Datum Newlyn, the historical UK sea level. With permission from Jenny Brown and courtesy of, Adaptation and Resilience of Coastal Energy Supply (ARCoES), project (EPSRC EP/I035390/1).

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Storms and rising waters panel discussion

Discussion Panel: Blair Greenan (Fisheries and Oceans Canada, remotely), Will Perrie (Fisheries and Oceans Canada, remotely), Don Jardine (University of Prince Edward Island), Don Killlorn (Eastern Charlotte Waterways*)*

Question - Anne Blondlot: Are there plans to look at the economic consequences of vertical allowances projecting?

Blair - No, we are looking at it from the infrastructure basis only. However a CanCoast[2] project is working with socio-economic data from the Ottawa database, and they are applying it to a vulnerability index. At present, there are no initiatives to determine if the building component is economically feasible.

Donald K - Economic feasibility has been used to guide prioritization of wharfs that would be most beneficial in the future and LiDAR[3] has been used to assist with decision making. It is also a great tool for visualizing possible changes and assessing worse case scenarios using graphical illustrations.

Don J - In Atlantic Canada under the ACAS (Atlantic Canada Adaptation Solutions) Large Economics Study the four provinces are currently assessing the economic consequences of coastal impacts from Climate Change and are costing out different methods to determine the most economically viable options via six case studies across the region. This is a cost benefit analysis of adaptation options is underway and led by Patrick Withey and Jonathan Rosborough of St. Francis Xavier University. It should be completed this year. There will then be an extension of this work outward to the rest of Atlantic Canada through various study sites, which have already been established in each province.

Kumiko Azetsu-Scott, Jamey Smith

Question - Jamey Smith: Is it a fair conclusion that we should be more concerned with sea-level rise then changes in waves?

Blair - There is a lot more uncertainty for the future with regard to wave projections. We can work with a good deal more certainty and understanding from mean sea level rise than wave projection.

Will - Changes in sea level and waves are not mutually exclusive, sea level change will create space for waves that didn't previously exist which could result in damages to some areas.

Blair- There are also increases in sediment transport from sea level rise, and waves will create issues with dredging.

Donald K - We are already experiencing a great deal of variability in this region, but for now we only see sea-level rise as a huge issue under "perfect storm" conditions. Increased variability in storm surges and projections indicate some issues at Indian point in St Andrews, NB. However, we have to keep in mind that these projections are

[2] Natural Resources Canada

[3] A remote sensing technology that measures distance by illuminating a target with a laser and analyzing the reflected light. Can be used to determine height above sea level.

Peter Warris

focused on high tide events, and it's not very practical to assume that all storms will surge during high tide. Storm water management might also be an issue for some communities but in the five Charlotte County communities, we are fortunate that it will not be an issue based on current projections. So in this region really, the biggest threat is from increased storm frequency and severity.

Don J – Local fisheries will be impacted by ocean acidification but sea-level rise shouldn't be a huge issue given the variability of the tide and current management. Fishermen have been adapting to sea level rise and coastal erosion over the years. However PEI has been noticing issues related to wave heights and has caused a major economic impact on infrastructure. There was a great deal of damage to the wharfs in PEI after the Dec 2010 storm surge (also caused a lot of damage here in Charlotte County). PEI lost many bridges as well. High rain levels were a significant issue in a recent rain storm on December 11, 2014. We are seeing more of these severe storms and more frequently. We have to prepare for increases in storms.

Question - Peter Warris: With respect to future adaption plans for waste water treatment plants, what's currently being done?

Donald K - For Charlotte County, LiDAR models and the 8.5 IPCC models were used for the lines. Based on those lines, the wastewater treatment in this area appeared to be safe from damage. However, for municipalities where this will be an issue, preparations will come at a significant cost. It is therefore important that the federal government continues and increases its support for municipalities in the future if they are to be properly prepared. Severe storms can still be an issue though, not only in regard to flooding, but because of a need to separate the storm water management from sewage in the future.

Don J - Five of the communities in PEI are at risk with their waste water management systems. One treatment plant in North Rustico has already been moved. Charlottetown is spending $30 Million to separate storm and sewage. LiDAR in both places had identified areas at risk, therefore we know where they are at and know what needs to be done. Money to adapt is the issue now.

Fish and Shellfish Health Session

Effects of climate change on fish and shellfish health presentation summary

S. St-Hilaire, Atlantic Veterinary College, University of Prince Edward Island, Charlottetown, Prince Edward Island

Sophie St.Hilaire

Climate change will be accompanied by increases in average temperatures, regional changes in precipitation, extreme weather fluctuations, and acidification of surface waters. These environmental changes will not occur in isolation and are potentially multiplicative; not only affecting hosts but also pathogens. Environmental extremes can stress hosts increasing susceptibility to infections, and may also promote pathogen development through increased virulence and transmission potential (Konkel and Tilly, 2000). How will climate change affect susceptibility of a host to pathogens, critical pathogen-host densities, and exposure patterns? Will this increase disease manifestation and will it have population level impacts? Possible effects of climate change impacts on marine host-pathogen-environment relationships are summarized in Figure 1.

There are direct health effects resulting from increased temperature. The rate of temperature change is important as it affects the magnitude of animal stress. Rapid changes in temperature have been associated with outbreaks of endemic diseases. In addition, increases in temperature will

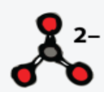
Changes in host	Climate factor	Changes in pathogen
• Increased susceptibility • Change in behavior • Invasions • Range shifts	1 	• Increased activity • Change in virulence • New emergence • Invasions • Range shifts
• Increased susceptibility (?) • Change in larval survival/recruitment • Change in behavior • Reductions in diversity (?)	2  2– H^+ H^+	• Change in virulence • Change in abundance
• Increased susceptibility • Nutrient stress • Salinity stress • Contaminant stress	3 	• New emergence • Change in virulence • Invasions • Range shifts • Increased nutrients
• Increased susceptibility • Physical injury	4 	• New emergence • Invasions • Range shifts • Mixing/resuspension of particles

Figure 1. Climate change impacts on marine host-pathogen-environment relationships. From Burge et al (2014).

accelerate metabolism and growth until upper thermal tolerances are reached. For finfish aquaculture species, this will result in the need for more feed use per unit time and may have implications on the feed conversion ratio. Temperature also has indirect effects on fish health by affecting the metabolism of pharmaceuticals used to treat bacterial and parasitic pathogens. For example increases in temperature, may result in increased dosages of florfenicol, an antibiotic that is rapidly metabolized, especially at high temperatures, to achieve the necessary therapeutic steady state level in target tissues.

Increased temperature may also facilitate the growth of aquatic pathogens. We found a correlation in the incidence of *piscirickettsiosis*, a bacterial disease of Atlantic salmon, with temperature (Fig. 2) (Rees et al 2014). In general higher temperatures increase bacterial growth rates and decrease the generation time of parasites (Groner et al. 2014). An example of this may be Dermo disease (*Perkinsus marinus*) in oysters, which has expanded northward along the US Atlantic since the late 40s. This is thought to have been facilitated by long-term warming winter temperatures, and an increase in temperature mediated susceptibility of the oyster host (Cook et al. 1998). It is not only the range change of pathogens that can initiate novel exposures, hosts may also expand their home ranges and introduce 'new' pathogens to naïve populations.

Increase in storm potential can increase incidence of acute stress detrimental to fish health. In the marine salmon culture environment, this would include billowing nests (reducing cage volume), rapid changes in water quality and could result in fish loss, reduced feeding, and pathogen introduction. In the freshwater land-based culture environment, storms may cause physical damage such as flooding, surface water contamination, super saturation of groundwater (spring precipitation), and also additional exposure to pathogens. Rapid precipitation, run-off and flooding can also cause stress and mortalities in bivalves, through rapid change in siltation and salinity, contamination and pathogen proliferation.

Ocean acidification can impair calcification of bivalve and crustacean shells during larval stages and post moulting, leading to reduced survival. Larva of sea urchins, oysters, mussels and corals

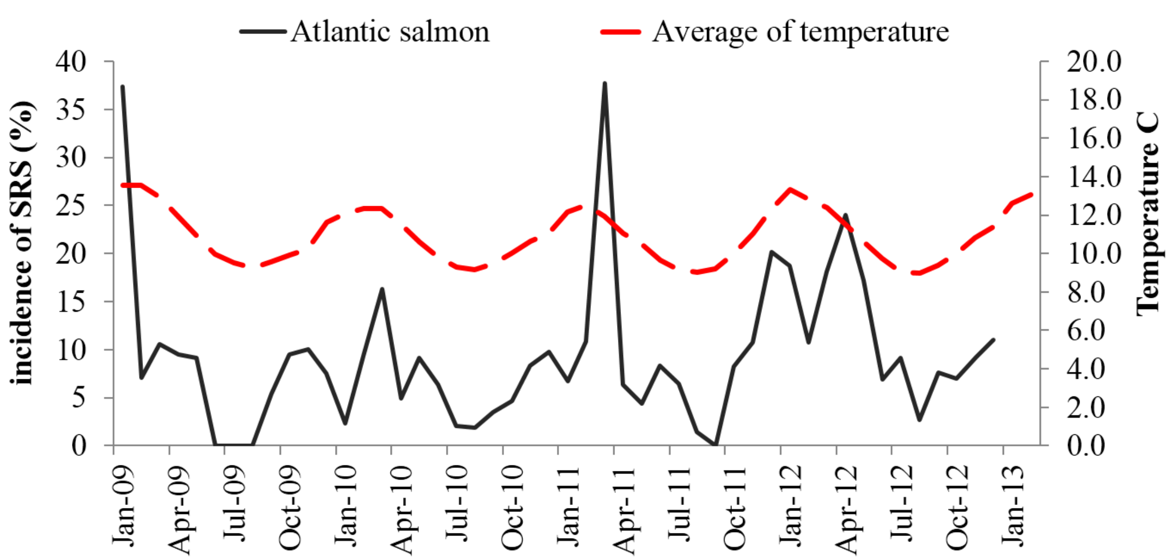


Figure 2. Relationship between *salmonid rickettsial septicaemia* (SRS) on Atlantic salmon and water temperature. From Rees et al. (2014).

have all demonstrated developmental difficulties at CO_2 concentrations at 1000 and 2000 µatm (Kurihara 2008). Effects to early life stages of finfish is still uncertain, but it its known that nephrocalcinosis can occur at low pH in freshwater. There is a significant amount of literature on the negative impact of fresh water acidification on salmonid populations in the mid 1900's. To fully understand the potential effects of ocean and freshwater acidification on populations, we need to look beyond single stage studies and examine ocean acidification effects on multiple generations.

Mitigation of climate change impacts on health may include a variety of strategies. Controlling the water source is an intuitive step to maintaining fish health. This can occur through strategic water draw, farm placement, or closed containment approaches such as recirculation systems. Disease resistance can be improved through vaccination, selective breeding, and immune-stimulants for critical periods. Adopting treatment strategies that provide adequate time for response, such as early detection and reducing the zone of infection around farms to minimize spread to neighboring farms would help reduce losses. For shellfish, hatchery reared larva, buffering (regulating pH) intake water, may guard against calcification issues. Species fitness in general can be improved by selective breeding or culturing a better adapted species if necessary. Finally, the long term solution to climate change impacts is to reduce carbon emissions.

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Fish and shellfish health panel discussion

Fish and Shellfish Health Panel, left to right: Sophie St. Hilaire (University of Prince Edward Island), Peter Sykes (Aquaculture Association of Nova Scotia), Veronique 'Nikki' LePage (University of Guelph), Julie Laroche (Dalhousie University)

Comment - Rich Moccia: We also need to look for opportunities, not just the negatives. These could include new species opportunities, new sites, etc. It should be the mixture of changes not just a focus on the negatives.

Sophie – We have been focusing on mitigation, but yes, the business aspect should focuses on opportunities. Nevertheless, early mitigation is important as it aids in long and short-term preparedness.

Peter – Agreed. If we can get a 1 or 2 degree change in March in Nova Scotia, that would open the doors for more production in the province, especially for Salmon. We could take seasonal sites and convert to full year production if waters get warmer. Businesses should also be speaking with scientists about climate change models to identify opportunities. The models and tools are getting better and these could greatly help with initiatives.

Marie-Josee Abgrall (audience) - For regional shellfish, observations of changing temperature are having some positive effects, such as earlier spawning times and increased growth rate. However, there are also increases in disease, moon snail predation, and green crab (invasive species) expansion.

Kurt Gamperl (audience) - It is the extremes that are going to be an issue, not the day to day but the extremes. In combination with temperature, there will be hypoxia issues, along with other stressors.

Questions - Hamid Khoda Bakhsh: Should we be looking at engineering solutions to help in future? Are new systems, new methodology for aquaculture needed? Is it technology that should be changed to better manage fish health risks and effects?

Sophie - To answer that we would need to look at first, the cost-benefit to identify the risk and second, whether it be mitigated in economical way.

Nikki - It is situation based. We know a lot of ways to protect fish, but for many of them, the cost and resources needed would be too high.

Julie - Early protection systems and constant monitoring can help to protect. What's been done in respect to optimal conditions for pathogens? There is a need to map optimums for predicted environmental changes. Ocean acidification is unlikely to cause more disease, but rather a shift in pathogens.

Observing and predicting pathogen adaptation

Nikki - Freshwater pathogens are greatly affected by temperature. We know a great deal about the common pathogens. We have observed cold water disease shifting to survival in higher temperatures. We have lots of data on some pathogens, but we have little to nothing on others that are new or less common. Those may become more common with warming waters.

Sophie – There is also the issue of optimal growth vs. virulence, they can be different. For example in some labs, pathogens will grow very well at high temperatures but are more virulent at lower temperatures. Stressing pathogens can sometimes cause them to express genes that increase their virulence.

Kurt Gamperl (audience) - Studies on how pathogens adapt to climate changes are needed but that could take years for this work.

Julie - If the pathogen can be isolated it can be easy to work with using gene sequencing. Genome sequencing is fairly cheap these days. That's something that shouldn't be a stumbling block and will help to understand what is happening to physiology. This approach can then paired with protein sequencing.

John Grant (audience) - The greater variation is also considered a change. There are extremes and highly variably at upper and lower ends. Ocean acidification will likely cause greater variability on the lower and higher end therefore we will see a decrease in our abilities to predict outcomes. Extremes are key.

Thierry Chopin (audience) - The photosynthetic world is also having its health problems. Photosynthetic organisms act as buffers already, if they are having health issues also, this has the potential to affect everything else even more.

Question - Bev Bacon: Can pathogens adapt better than the host and if so, how?

Julie - In general, pathogens will just mutate or change to become something else. Adapt faster.

Bev Bacon

Question - Bev Bacon: How does that affect farmers?

Julie - "Know your enemy". You have to monitor and pay attention to how it changes and keep treatments up to date.

Peter – There has been a lot of talk about adaptation but we also need to keep eyes open for new things as well. It would be valuable to develop networks to investigate current and new pathogen emergence to better predict what ones will manifest with increasing temperatures

Sophie - You can say that pathogens replicate faster than hosts so they would be able to adapt faster.

Bev Bacon (audience) – The industry still has to be able to generate products even when we don't have the full story. Perhaps we need to be more proactive at characterising one aspect first, such as identifying areas where most vulnerable to extremes and work from there. We might not be able to pinpoint thresholds but we could identify peaks and troughs for the industry with the help with site selection.

Gregor Reid (audience) – There is a need for data and monitoring. We do know some things, but what is the bare minimum we need to be doing and how can we do this? What's the minimum we need to be doing to make it applicable at the farm level, today and tomorrow?

Jamie Smith (facilitator) - DNA samples via sediment samples, guts, and skin swabs may help to improve monitoring for pathogens and not too costly. Such ongoing data collection is needed to

Anne Blondlot

trace back to determine when the pathogen emerged.

Peter - Fish health data is usually developed by vets and therefore is often confidential information. Thus confidentiality has been a bit of an issue for much of the tool development initiatives in this field. Sea lice data has been an exception though. The Sea lice approach for other pathogens would be very helpful.

Nikki – There are disease surveillance programs being used in Ontario now. It is easy for me as I am the only fish vet in Ontario at the moment, so I can see the province wide picture. Collecting some data over time though would be very helpful. We have adapted a program used in Quebec for the last 22 years [similar to the Canadian Wildlife Health Cooperative (CWHC) which is mainly for wildlife disease surveillance].

Question - Tim Jackson: With respect to vaccines, does the current tracking system look at different strains appearing in different regions to assess how effective vaccines are across regions?

Sophie - Companies that produce the vaccines do that work as part of their licencing. For example they are looking to see if vaccines developed in Europe would work on pathogen strains found here.

Question - Fernando Salazar: Should research be focused on developing field kits that farmers could use for monitoring pathogens? What things can done at farm level monitoring to help with early identification?

Sophie – Early detection is very important. Good diagnostics are required but we also have to think about strategic sampling. It is difficult to identify which populations to target for sampling. Often it is not the diagnostics that are the issue, but rather the sampling strategy.

Question - Fernando Salazar: Is this a matter of reactive vs. proactive response? What can the farmer do before waiting for the vet to come?

Anne Blondlot (audience) - This is all useful in stakeholder discussions. In Quebec there has been an evolution of crop-pest modeling with climate analogue, that has been practical a may be the most practical approach to effectively communicate. Perhaps this approach should be more widely applied?

Peter - Certainly talking about pathogens that are occurring, greatly helps with preparation and awareness for how to deal with it.

Kurt Gamperl (audience) – It would be valuable to look at the Tasmanian industry and compare issues as they already at temperatures we are projecting for next 25 years.

Tim Jackson

Warming Waters Session

Warming waters presentation summary

T. Benfey, University of New Brunswick, Department of Biology, Fredericton
New Brunswick

Tillmann Benfey

Temperature has wide ranging influences on aquatic animals, affecting enzyme reaction rates, metabolism, oxygen demand, cell division, development, growth, and reproduction. Reaction and process rates tend to increase until the optimal temperature is reached, with less scope above optimal temperature than below (fig. 1). The range of tolerable temperatures may vary for different life stages (fig. 2) or physiological processes.

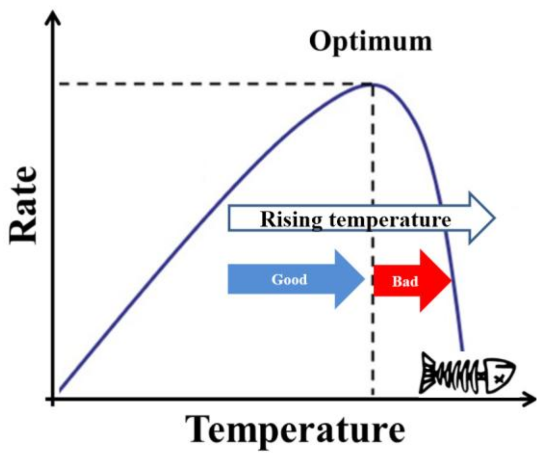

Figure 1. Reaction rates increase until optimal temperature is reached.

There will be 'winners' and 'losers' among aquatic species in response to changing temperatures. In the northern hemisphere, eurythermal species that are at the northern limit of their distribution (e.g., sturgeon, striped bass, eels, oysters and dulse in Atlantic Canada) are likely to adapt better to temperature change and variability, compared to stenothermal species at the southern limit of their distribution (e.g., cod, charr, halibut, scallops, some kelp species in Atlantic Canada).

As temperature increases, gas solubility decreases, including oxygen. Aquatic animals have a minimal oxygen requirement, known as the critical oxygen concentration, below which full activity cannot be maintained. Unfortunately, oxygen demand is highest when solubility is lowest, due to the positive effect of increasing temperature on metabolic rate. This means the critical oxygen concentration will shift under different temperatures. This effect can be substantial: the critical oxygen concentration for goldfish (*Carassius auratus*) is almost doubled at 20°C compared to 10 °C (Fry and Hart 1948).

Two measures that are useful for determining stressful and optimal temperatures are aerobic and cardiac scope, i.e., the difference between resting and maximum oxygen consumption rate and heart rate, respectively. Both scopes are largest at the optimal temperature and decline as temperature stress increases (Casselman et al., 2012). These measures can help aquaculturists determine how much of a 'physiological buffer' exists until sub-optimal and lethal temperatures and oxygen concentrations are reached.

Diet is highly relevant to meeting physiological and production needs at different temperatures. When fish are exposed to temperatures higher than their optimal, more energy will be directed to maintenance energy than growth. For example, barramundi (*Lates calcarifer*) greater than 1 kg in weight will expend approximately 30% of their total available energy on maintenance at 30°C, compared to only 10% at 10°C (Glencross & Bermudes, 2012). Such processes can have a significant negative effect on feed conversion efficiency.

Fish and shellfish pathogens and parasites will also be affected by temperature, often to the detriment of aquaculture operations. For instance, sea-lice population growth and attachment rates increase exponentially with rising temperatures of even a few degrees (Groner et al., 2014). Infectious agents that are limited only by lower temperatures are apt to expand northward in the northern hemisphere as waters warm. This has been reported with the shellfish parasites, *Haplosporidium nelsoni* (MSX disease) and *Perkinsus marinus* (Dermo disease), that have gradually advanced northward from the southern US Atlantic coast in the late 1940s to Maine by the late 1990s (Cook et al., 1998). Harmful algal blooms have been predicted to expand with temperature in some locals such as the North Sea (Glibert et al., 2014). Most pathogen, parasite and pest species also have a greater potential for multi-generational adaptation than fish, due to their shorter generation times. However, there are many variables to consider and it should not be assumed that temperature increase will automatically result in increased infection potential.

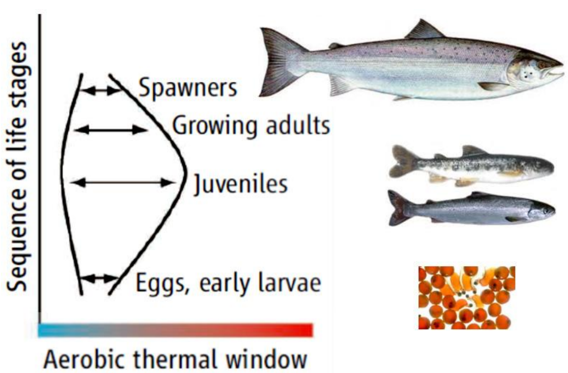

Figure 2. Relative range of optimal temperatures for different life stages of Atlantic salmon (Pörtner and Farrell, 2008).

Gene expression is influenced by temperature. Acclimation of Atlantic cod (*Gadus morhua*) to 16°C and 19°C increased gene expression for several immunity-related genes compared to cod at 10°C (interleukin-1b, b2-microglobulin, major histocompatibility complex class I, and immunoglobulin M light chain), but reduced the expression of others (immunoglobulin M heavy chain) (Pérez-Casanova et al., 2008). Hori et al. (2012) investigated the effects of moderate increase in ambient temperature on Atlantic cod spleen transcriptome response to intraperitoneal viral mimic injection. At 6 hours post-injection, 279 genes were expressed more highly at 16°C compared to only 11 genes at 10°C. However, at 24 hours post-injection, only 36 genes were expressed more highly at 16°C compared to 303 genes at 10°C. This suggests that not only is the magnitude of temperate change important, but also the duration. Consideration for how climate change affects ambient temperature fluctuation may be just as important as changes in average temperature over a production cycle.

The ability of animals to adapt (in an evolutionary sense) to change in temperature can be taken advantage of in aquaculture. Differences in temperature tolerance among wild stocks have been demonstrated in numerous species, including the Pacific mussel, *Mytilus californianus* (Logan et al., 2012), and the sockeye salmon, *Oncorhynchus nerka* (Eliason et al., 2011). Similarly, there is extensive within-species variation in thermal tolerance among domesticated strains, and even among families within strains, of cultured brook trout, *Salvelinus fontinalis* (McDermid et al., 2012), and a high degree of variation among families of Atlantic salmon (*Salmo salar*) for hypoxia tolerance has also been reported (Anttila et al., 2013). While salmonids appear to have good potential in general for adaption to warming temperatures, recent research has reported that local adaption to high temperatures may not necessarily be tailored to local biogeography as had been previously thought (Anttila et al., 2014).

Mitigation approaches for warming waters are most likely to centre on site selection, engineering, diet, breeding programs and disease management. Monitoring and modelling of limnological and oceanographic conditions will help to identify suitable sites for culture. Land-based culture systems will have the potential for greater control over temperature. Nutrition may be the ‘low hanging fruit’ for finfish culture, by targeted feed formulation that meets elevated temperature requirements (e.g., energy levels, fatty acid composition, feed stimulants, etc.). However, it is not so easy to control the diet of extractive species, such as with open-water shellfish culture. Warming waters may warrant greater vigilance for monitoring changes in virulence, immigration of new pathogens, efficacy assessment of current chemo-therapeutants at higher temperatures, the development of new treatments, and ongoing research into immune–related temperature effects. Breeding and biotechnological solutions have good potential to help mitigate against some climate change effects such as temperature tolerance. Ultimately, we must understand the biology of the culture species of interest and its interaction with its abiotic and biotic environment, in order to develop appropriate mitigation measures for climate change.

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Warming waters panel discussion

Discussion Panel, left to right: Tillmann Benfey (University of New Brunswick), Kurt Gamperl (Memorial University of Newfoundland), Nathalie Le François (University of Quebec).

Question – Dounia Hamoutene: In Newfoundland, oceanographic conditions are described around aquaculture sites, and this is useful for highlighting extreme areas, through risk identification and mapping. Another aspect however, is storm risk and frequency, which can introduce rapid changes in temperature. Are there thoughts about the effect of these sudden changes from storms and wind, etc. on fish physiology?

Kurt - Thermal tolerance is always highest when temperature change is the shortest. The greatest concern is not short-term, but prolonged changes in temperature, such as a week of elevated temperatures rather than rapid change for just 1 day. Fish can often recover from the latter.

Tillmann - There is no acclimation involved with rapid temperature change. If the change remains, it is obviously an issue, but the sudden change itself is not a big concern. Survival can be surprisingly high, if the time periods are short.

Question - Hamid Khoda Bakhsh: How can we organise and fund adaptation measures?

Nathalie - One approach would be through predicting and modeling parameters for species we already culture or are considering culturing. If we have this data compiled it can be used to inform decisions on improvements and diversification potential, and then we can decide what changes are required. Whether it be an engineering, biological, genetic response or other.

Tillmann- At the moment we are speaking to risk management; just the 1st step to this process. Informing producers and regulatory agencies is the next level.

Kurt- Team building is important, such as research through strategic networks. People from the management and regulatory sides also need to be part of the discussion.

Pam Parker (audience): With regard to picking species, consumers pick species not industry. Better to mitigate effects on current species, than, basing farming practices on other species that will do well based with predicted parameters.

Nathalie- Not really what I meant. I was referring more, to artificial breeding to maximize species choice and approaches like hybrid production. However, the market can be changed, and can be open to other species in my opinion. Easier to change the market than biology.

Tillmann- It is really about augmenting production with additional species, building the industry, not replacing it. With any change, there will be different “winner” and “loser” species. Salmon should be alright, but the aquaculture industry could be augmented with some of the "winners".

Paul Lyon (audience): With regard to team building comment- DFO has recently conducted a Climate Change risk assessment, which required a huge team and huge skill set. We looked at science projections, impacts, vulnerability, opportunities, and embedded economics with science and socioeconomics impacts. Clients were DFO species at risk staff, mangers and industry partners. The risk assessment was conducted with all expertise together. The results are encouraging so far but the issues are very complex. A consultant was hired to rank the risks and issues, then returned to the group with a framework and adjusted it based on their priorities. This takes a lot of expertise with different skill sets to be brought to the table and have these discussions. An awareness of this is the key and it is occurring here, but it is a many step process.

Question - Gregor Reid: If we select fish to adapt to high temperatures does that negate low temperature tolerance?

Tillmann- This is not clear cut. It is difficult to select for both extremes, but is not out of the realm of possibility. It depend on species.

Kurt- If we look at the cunner for example, it can tolerate both low and high temperatures, but such tolerance is species specific.

Paul Lyon

Question - Jeff Clements: Can the critical thermal maximum shift in response to other stressors?

Tillmann - The critical thermal maximum will be dependent on what other stressors are occurring simultaneously and prior treatment, such as feeding history.

Kurt - One of the keys is to see what is going on at the cage site and duplicate these conditions in the lab to help identify confounding or additive effects. Monitoring at the sites will be key to conducting useful experimentation. We will have to depend on industry to provide data in order to build appropriate models.

Breakout Group Discussion Summaries

Fish health breakout group

Left-right clockwise: Julie Laroche (Dalhousie University), Peter Sykes (Aquaculture Association of Nova Scotia), Mark Kesselring (Northern Harvest Sea Farms), Veronique 'Nikki' LePage (University of Guelph), Richard Moccia (University of Guelph), Jon Grant (Dalhousie University), Kurt Gamperl (Memorial University of Newfoundland), Cyr Couturier (Memorial University of Newfoundland).

The 'Fish health breakout group' focused on identifying emerging and ongoing issues, with emphasis on surveillance needs for current and novel pathogens. This monitoring needs to target both pathogen and host response to multiple climate change stressors. Adaptation approaches concentrated primarily on methods to resolve data gaps, while improving risk assessment and knowledge transfer.

Knowledge gaps

- Stress and immune response to environmental fluctuations and maximum-minimum extremes
- Response of pathogen distribution and virulence under a changing climate
- The role of multiple stressors such as, acidification, temperature, and dissolved oxygen on shellfish health and production viability
- The role of ocean acidification on pathogen occurrence and algal blooms

Potential adaptation strategies

- *In situ* monitoring of microbes and pathogens (e.g. DNA extraction techniques) for enhanced pathogen surveillance
- Compile long term nearshore environmental data archives to support predictive modeling, and available to stakeholders in real time
- Better knowledge mobilization to industry
- Improve site selection through predictive modelling of environmental conditions
- Improve risk assessment models for siting and predicting disease outbreaks
- Study therapeutant efficacy under changing environmental conditions
- Develop markers for selection of improved immune response and disease tolerance
- Enhance surveillance and diagnostic programs for emerging pathogens
- Improve risk assessment models for predicting disease outbreaks

Genetics and biotechnology breakout group

Left-right clockwise: Tillmann Benfey (University of New Brunswick), Aaron Craig (Northern Harvest Sea farms), Amber Garber (Huntsman Marine Science Centre).

The 'Genetics and biotechnology breakout group' discussed issues of pathogen-host interaction and the mitigation potential of broodstock programs. Broodstock programs have the potential to select for resistance against a variety of climate change stressors. Various adaptation measures were explored to maintain genetic diversity and traits that may be needed to adapt to climate change.

Knowledge gaps and research questions

- Greater research efforts are needed to investigate specific pathogen and host interactions at the genomic level
- Susceptibility and resistance to specific pathogens within broodstock programs
- Should researchers add additional 'tiers'/treatments when challenging fish, such as immune boosting feed, vaccines, etc., to investigate potential additive benefits of resistance?
- Should research focus on mutations or differences in pathogen gene sequence to assess adaptation potential?[4]
- Research approaches are needed to investigate susceptibility and resistance to specific pathogens under climate change stressors while simultaneously assessing mutations, adaptations, etc.
- Difference in response of temperature and pH changes at the individual and family level

Potential adaptation strategies

- Investigate stressor response of the organism though individual and family challenges
- Identify genes that affect susceptibility and resistance to specific pathogens; possibility to use single nucleotide polymorphisms (SNPs) or sequencing toward genome-wide association studies (GWAS) and pair with estimated breeding values (EBVs) for larger effect on selection
- Change weighting of traits in breeding index (total merit index), with greater emphasis on fish health, temperature tolerance, pH traits, etc.
- Creation of different climate change and pathogen/parasite resistant 'strains' within current strain classifications such as within, fast growth, fillet quality, etc. These 'strains' could then be hybridized to potentially create a better adapted organism
- Maintain genetic diversity in the breeding nucleus or through cryopreservation as a

[4] The pathogen, *Moritella viscosa* (winter ulcer disease) was formerly a winter affliction only, but is now a year-round in saltwater. This raises such questions as, is there a difference in *M. viscosa* sequence/strength different locations geographically? Saltwater/freshwater? Temperature? Efficacy of vaccination (same/different isolate)?

contingency in case families are removed for performance with other traits
- Assess or re-assess wild strains to see if present strain used for culture is less fit with respect to climate change related traits than the present wild strain or another wild strain that may be in a similar geographic area

Engineering breakout group

Left-right clockwise: Don Jardine (University of Prince Edward Island), Hamid Khoda Bakhsh (University of New Brunswick), Paul Lyon (Fisheries and Oceans Canada), Tim Jackson (Nation Research Council of Canada), Bev Bacon (Consultant).

The Engineering Breakout Group discussed data for management support, better smaller-scale environmental information, real-time monitoring and predictive scenarios. Adaption options focused on better use of existing resources and aquaculture industry involvement.

Knowledge gaps and needs

- Continental scale predictions need to be down-scaled for greater relevance at regional and local levels
- Increasing temperatures will promote more fouling, and likely more net management
- Improved analytical investigation of system stresses to better guide cage and site design
- Intense storms mean lower energy sites will need high energy systems
- Real-time environmental monitoring in Atlantic Canada is needed for better management and strategic decision making

Adaptation through improved data use

Several data sources and programs could be better applied for aquaculture adaptation:

- The University of Prince Edward Island Climate Group research (e.g. site selection)
- National Resources Canada – Climate Change Adaptation tool to assess risk and vulnerability of infrastructure
- Fisheries and Oceans Canada, Aquatic Climate Change Adaptations Services Program
- Small Craft Harbours (Fisheries and Oceans Canada) have installed weather stations. Could they be coupled with instrumentation to collect oceanographic & atmospheric monitoring in real time?

Improved Involvement of aquaculture industry is required for climate change adaptation

- Better linkages to climate change research
- Involvement in wharf retrofits and breakwaters
- An entity is needed to connect aquaculture to relevant climate research, coordinate data collection/projects, identify knowledge gaps, align with other sector experts, committees and groups

Fish nutrition breakout group

Left-right clockwise: André Dumas (Coastal Zones Research Institute), Nathalie Le François (University of Quebec), Betty House (Atlantic Canada Fish Farmers Association), Kurt Simmons (University of New Brunswick), Gregor Reid (Canadian Integrated Multi-Trophic Aquaculture Network), Tom Taylor (Cooke Aquaculture), Alan Donkin (Cooke Aquaculture).

The 'Fish nutrition breakout group' identified that many of the knowledge gaps and production challenges for fish nutrition are ongoing issues, but with the uncertainties of climate change these challenges are likely to become more pronounced.

Knowledge gaps and data needs

- More information on the effects of extreme stressors, as this is important for nutritional considerations
- Improved documentation of events is required (e.g. winterkill) and better stress indicators are needed to guide nutritional response, especially if increasing frequency of extreme events (also low temp extremes)
- Nutritional knowledge must be contextualized in light of changing genetics (e.g. nutritional genomics)
- An ongoing challenge for aquafeed production is matching dietary requirements of the animal with nutrients from available raw material supplies. This may be more of a challenge under conditions of pending climate stressors
- Balancing amino acids and fatty acids in diets for future stressors

Nutritional research recommendations for climate change adaptation

- Augment existing research on lipid sources for energy optimization and omega-3 EPA + DHA
- Bioeconomic assessment of feed sourcing under a changing climate
- Additional research into alterative ingredient sources (e.g. insects); some may become more appealing as global population increases and climate change increases cost of human food
- Enabling regulations are needed, such as decreased approval time for new ingredients (e.g. maximum antioxidants), from the Canadian Food Inspection Agency
- Research into gut flora and response to pH (e.g. prebiotic potential)
- More research on compensatory growth, as some feeding strategies (e.g. ration timing) can promote 'catch-up' in several species from stress mediated growth reduction

Shellfish breakout group

Left-right by row: Kumiko Azetsu-Scott (Fisheries and Oceans Canada), Susan Waddy (Fisheries and Oceans Canada), Thomas Guyondet (Fisheries and Oceans Canada), Jeff Clements (University of New Brunswick), Terry Ennis (Canadian Cove Culture Shellfish), Vicky Merritt-Carr (Fisheries and Oceans Canada), Sam Rastrick (Institute of Marine Research, Norway), Marie-Josee Abgrall (University of New Brunswick), Peter Warris (Prince Edward Island Aquaculture Alliance).

Priority needs identified by the 'Shellfish breakout group' were data requirements and an effective mechanism for communicating this information. Industry climate change awareness was also discussed. Focus at the management level is mainly on day to day issues where most problems are addressed as they happen. This approach is more challenging for addressing climate change issues.

Knowledge gaps

- Difficult to rank threats, but in the east, the priority order is likely temperatures, ocean acidification, and storm surges. It is also important to consider how climate change will impact existing shellfish industry priorities, such as invasive species, predators, disease and overall production.
- There is an immediate need for better data collection, particularly monitoring of water quality, disease and invasive species
- If winter temperature lows increase, how will this impact cultured shellfish species, reproductive cycles and over wintering?
- What is the climate change impact on larvae and natural spat collection?
- How will climate change impact food availability for shellfish (e.g. plankton community)
- When will climate change take key parameters outside the range of natural cycles?

Adaptation needs

- Better site selection with greater lease access, to enable more options
- Genetic research to guide strain selection
- Explore alternative (resistant) species as required, assuming market acceptance and addressing regulatory requirements for non-native species
- Better infrastructure
- Continue and improve ongoing monitoring for disease and invasive species
- More interdisciplinary science is needed
- Given the earlier onset of acidification impacts on the west coast, can the east coast learn from west coast approaches?

Industry communication and network needs

- Scientific advice for management and for industry
- Need for effective communicators for different audiences
- Communication needed between, research and Industry; federal, provincial, municipal, industry

Improved data collection and monitoring needs

- Better data gathering, analysis and communication must begin immediately
- Standardized data collection methods
- Training for field scientists
- Archive data and make it accessible
- Investigate past data; there is more data in some areas than others, will it be comparable?
- Sample collection to archive current conditions for future reference

Management and governance breakout group

Clockwise from left front: Taryn Minch (University of New Brunswick), Fernando Salazar (Ulnooweg Development Group), Samantha Thurlow (University of New Brunswick), Snorkel the seal (Huntsman Marine Science Centre), Lara Cooper (Fisheries and Oceans Canada), Roger Wysocki (Fisheries and Oceans Canada), Dounia Hamoutene (Fisheries and Oceans Canada), Thierry Chopin (University of New Brunswick), Bob Sweeny (SIMCorp), Christy Bourque (Mitchell McConnell Insurance), Pam Parker (Atlantic Canada Fish Farmers Association), Anne Blondlot (Ouranos).

The 'Management and governance breakout group' discussed the role of governance in information management, dissemination and data collection. Governance also has an important role coordinating multi-stakeholder research initiatives. This is especially important for climate change and aquaculture initiatives, since many climate change initiatives are likely to involve stakeholders outside of the aquaculture community. Improved coordination would foster stronger linkages between processes that already exist, such as improved coupling monitoring and prediction.

Roles for governance

- Scientific advice for management and for industry; ensure access to pertinent information and expertise for better decision making
- Initiatives to compile and collect water quality data at the regional and local levels
- 'Data mining' and compiling water quality information should be a priority. It is unknown how much aquaculture industry water quality data collected is available, but it could be substantial. There is existing water quality and benthic data routinely collected at farm sites.
- Standardization of data collection
- Ongoing data collection initiatives will not only require initial funding, but also ongoing funding to ensure existence of longer term data sets
- Greater effort needed identifying and quantifying climate related stressors to guide management and governance response
- Regulatory flexibility and enabling legislation which to facilitate adaptive response by industry (e.g. site selection)

Atlantic workshop-wide discussion summary

Introduction

The workshop-wide discussion was the final activity of this two day workshop. The discussion aimed to build on preceding information sessions, and take advantage of experts from several disciplines in the same room, as a means to better assess research priorities. The major points of discussion are summarized below.

Dounia Hamoutene, Kurt Gamperl

"We are still in the dark with data"

Limited data and information was highlighted as one of the largest impediments for assessing potential climate change effects on aquaculture. These data gaps impede priority setting of mitigation approaches because the industry is often lacking the information necessary to make informed decisions. For example, it is routine to collect good environmental baseline data to inform *new* site selection, but there is also a requirement for *ongoing* monitoring of environmental risk factors, not only for environmental sustainability but to identify extremes, inform projections, and communication.

There is an acute need for more environmental monitoring at the scales in which aquaculture is practised. Water quality needs discussed included detailed seawater temperatures, pH, salinity, turbidity, chlorophyll, nutrients and ongoing sediment monitoring (chemistry, sediment sulfides). There was also emphasis on improved understanding of currents and flows at the bay and harbour scale, which can be linked with atmospheric, ocean, and sea ice data.

Richard Moccia

The aquaculture community and other coastal users have been collecting water quality and benthic data at sites for years. There are small databases everywhere, but the amount of data accumulated is unknown. There was a diversity of opinions on the amount of data, with comments ranging from, "there is more data then we think there is" to, "there is less data than we think there is". An initiative is required to gather this data and house it in a central depository that can be accessed. There are some successful examples of these database initiatives such as GenBank (a genetic sequence database, an annotated collection of all publicly available DNA sequences), which started out with sporadic data storage of genetic fragments but is now is a large, and widely used database. Such a dataset will need quality control, management, focus, and long-term investment. Privately collected data should be checked against more sophisticated/accurate water analysis. A value on such data needs to be assigned it in order to maintain such an initiative (historical and ongoing). Most water quality data

Susan Waddy, Jamey Smith

is not collected altruistically and there will be a cost to ensure the resolution and longevity that is needed.

Enabling legislation and organizational support

The regulatory process is restrictive and slows down solutions to problems. For industry, regulatory flexibility would be extremely helpful if based on good information. Strategies need flexible and enabling regulatory support. An example of this is facilitating good site selection or site relocation in a timely manner. Historically, the aquaculture industry has been able to react quickly to environmental constraints on production. The industry has this capacity for climate change stressors assuming there is enabling governance.

The multi-disciplinary nature and extensive data dissemination needs associated with climate change, may be better facilitated if Canada had one organisation/sector responsible for the management of coastal zone (such as in the US). Having this type of organization would be an assist coordinating various approaches and jurisdictions needed address data gaps necessary for strategic aquaculture management under a changing climate.

Research priorities

Prioritizing research was deemed difficult without fully understanding specific problems and the timelines. These challenges are further complicated, as different stakeholders will have different research priorities. Research planning needs to include diverse clientele such as veterinarians, coastal managers, producers, regulators and policy makers. It was, however, cautioned that stakeholders would naturally gravitate towards their own area of expertise when identifying research needs and this could skew prioritizing. To better prioritize research it was suggested that short, medium and long-term needs of the aquaculture industry should be identified first and this could be based on immediate, 5 and 10 year time frame. It was also noted that many aquaculture climate change related research needs could be met through augmentation of existing research initiatives.

Specific research needs

- Better overall identification of stressors
- Effect of changing storms on containment
- Changes to algal blooms
- Differentiate between regional and global climate change effects
- Genomic responses to climate change
- Effects to sea lice cycles
- Changes to super-chill frequency
- Improved knowledge of pathogen profiles, environmental variables affecting hosts, pathogens and disease mitigation options
- Species and trophic interactions with animal health and ecosystem health

Concluding statements

There was reflection on the complexity of the issues presented and discussed over two days, and the formidable challenge of ranking threat potential to define research needs. Nevertheless, there was a common sentiment that if collectively, we don’t start to address climate change and aquaculture issues now, when do we start? It was generally agreed that, for now, efforts should be focus on information gathering, prediction, and communication. What remained unresolved, was the best method for achieving this and who should do it?

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Note takers: Kurt Simmons, Samantha Thurlow, Taryn Minch

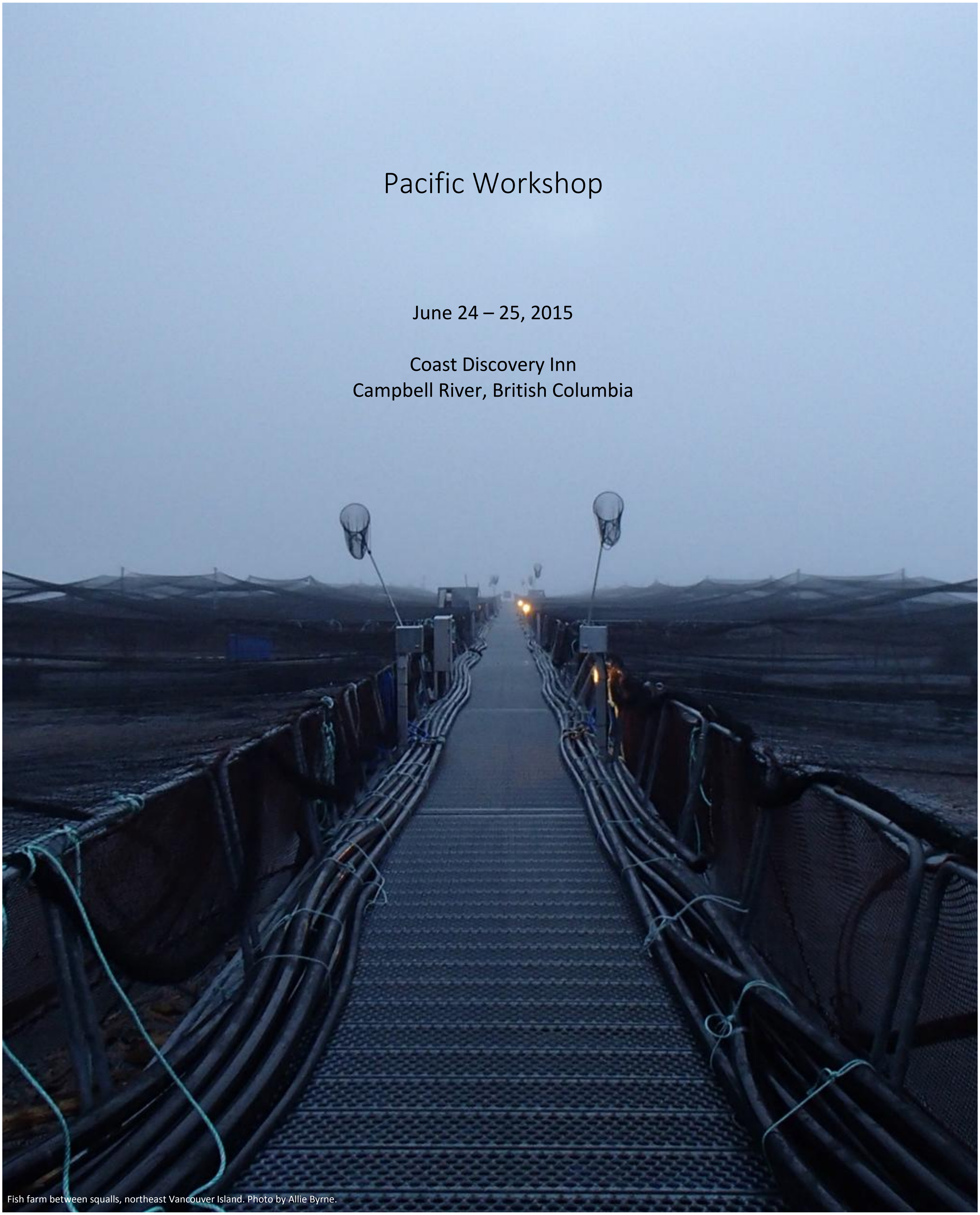
Day two workshop participants

Jamey Smith, Lara Cooper, Keng Pee Ang (back), Paul Lyon, Roger Wysocki, Betty House, Alan Donkin, Susan Waddy, Tillman Benfey (back), Thomas Guyondet, Don Jardine, Veronique 'Nikki' LePage, Samuel Rastrick, Hamid Khoda Bakhsh, Nathalie Le François, Andre Dumas, Peter Warris, Amber Garber, Terry Ennis, Gregor Reid, Tim Jackson, Richard Moccia, Fernando Salazar (back), Thierry Chopin, Cyr Couturier, Aaron Craig, Marie-Josee Abgrall, Pam Parker, Vicky Merritt-Carr, Bev Bacon, Jeff Clements, Kurt Gamperl, Anne Blondlot, Janelle Arsenault (back), Dounia Hamoutene, Shawn Robinson, Kurt Simmons, Bob Sweeny, Peter Sykes (back), Samantha Thurlow, Christy Bourque.

Pacific Workshop

June 24 – 25, 2015

Coast Discovery Inn
Campbell River, British Columbia



Fish farm between squalls, northeast Vancouver Island. Photo by Allie Byrne.

Introduction by the British Columbia Salmon Farmers Association

Dear Colleagues,

The Pacific Northwest is one of the most productive coastal environments in the world, providing an excellent environment for aquaculture. Its waters are highly influenced by not only the annual cyclical trends of the Pacific Ocean, but climatic changes and temperature anomalies that are becoming more common. Understanding how such effects will impact aquaculture is fundamental in order to develop effective adaptation strategies.

Aquaculture success necessitates an optimal operational environment. Shellfish and finfish farmers in BC are increasingly challenged by the changing oceanographic environment, which affects decision-making and adaptation in operational standards for both finfish and shellfish growers. Such climate change challenges may include, an increasing prevalence and toxicity of harmful algal blooms, more severe storm events, warming waters, increases of southerly-ranging species, more dissolved oxygen problems, and ocean acidification.

There is a pressing need to stay apprised of pending climate change impacts that may affect BC aquaculturalists, in order to effectively mitigate and adapt to changing culture environments. Shellfish and finfish growers are uniquely positioned as stewards of the coastal environment and as such are often among the first to experience and identify environmental changes. For this reason, they are optimally placed to be leaders in oceanographic monitoring and participate in initiatives that investigate changing conditions. Such roles have an important impact beyond aquaculture, and better enable our society to predict the impact of coastal changes on food security and ecosystem sustainability.

This NSERC-supported workshop provided an excellent opportunity to bring together shellfish and salmon farmers, government regulators, scientists, academia, and other research organizations to discuss climate change related issues. In addition to a forum for discussions of how climate change may affect aquaculture, the workshop has also enabled collaboration discussions between the finfish and shellfish industries, whom normally operate independent from one another.

As you'll find in these proceedings, there is much information to be disseminated, and many questions yet to be answered. Nevertheless, this workshop provided an excellent forum for these discussions and have initiated valuable collaborations on this important issue.

Sincerely,

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BC SALMON FARMERS ASSOCIATION

Storms and Rising Waters Session

MEOPAR Salish Sea research and climate change in marine BC presentation summary

Susan Allen

Susan Allen, Department of Earth, Ocean and Atmospheric Science, University of British Columbia, Vancouver, BC

Introduction

The NSERC funded Network of Centre of Excellence (NCE), Marine Environment Observation, Prediction and Response (MEOPAR) has both long time scale and short time scale projects in British Columbia. In this presentation, I focused on three short term projects: the Salish Sea Ocean Model, the Coastal Hazard Vulnerability Indicators and a Sea-level Rise Case Study for Vancouver.

Salish Sea Ocean Model

The goal of this project is to configure and evaluate a coupled biological-chemical-physical model of the Strait of Georgia (Soontiens et al. 2015) for prediction and nowcasts (Fig 1). To produce this model we need to configure a community ocean model (in our case the NEMO model) and evaluate the model against observations to make sure it's getting close the correct answer. Then we run the model daily with hindcasts for the last 24 hours and forecasts for the next 30 hours. We share the results on salishsea.eos.ubc.ca/nemo/results. Currently the model is configured and evaluated for sea surface height (storm surge) and predictions can be found on the storm surge portal: salishsea.eos.ubc.ca/storm-surge. Our focus now is on accurate temperature, salinity, nutrients, phytoplankton and zooplankton, currents at all depths and object trajectories.

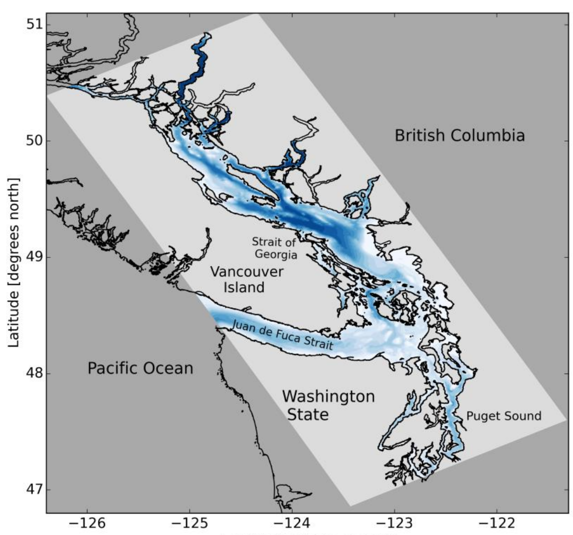

Figure 1: Domain of the Salish Sea Model outlined in light grey.

Coastal Hazard Vulnerability Indicators

Stephanie Chang's group at UBC has extended the concept of hazard vulnerability indictors to ask "What communities are similarly vulnerable?", rather than the traditional question of "What communities are most vulnerable?". Focusing on similarity allows communities to share resources, plans and policies. A community can study the impact of a historical hazard on a similar community to help in their own preparedness. The hazard similarity index for 50 Strait of Georgia communities has been calculated based on 5 dimensions (size, spatial structure, composition, participation and change) and 4 capitals (economic, social, built and natural). They are working on extending the index to including institutional and hazard capitals, increasing the number of communities and building a web platform for communities to access and interact with the information.

Sea-level Rise Case Study

Jackie Yip and Stephanie Chang have been working with the City of Vancouver to do a robust impact assessment for sea-level rise and coastal flooding adaptation in the City of Vancouver (Chang et al 2015). They are developing a new analytical approach to identify coastal flood impacts that are robust across a wide range of future flood scenarios.

Climate Change in Marine BC

Variability: Variability in the marine atmosphere and ocean occurs both due to natural variability and to anthropogenic climate change. Natural variability acts at daily, seasonal, inter-annual periods and also at long periods (decadal). Anthropogenic climate change signal is a slow change not only in the mean, but in the extremes. What we get is the combination of the two. Daily and seasonal variations are easy to deal with: we can consider averages over a day or daily max/min. Similarly we can compare January to January. Inter-annual (3-7 years) variations can be handled if we restrict ourselves to long time-series; thirty years is good. Long period variations (multi-decades) are very hard to separate from anthropogenic climate change. Below I catalogue the observed and predicted variations due to climate change with the clearest changes first.

Warming: Temperatures have and are projected to warm throughout BC (BC Ministry of the Environment, 2007). Sea surface temperatures are rising (Perry 2014) as are temperatures at deeper depths. The Strait of Georgia is warming faster than the Pacific Ocean at similar depths (Mason and Cummins 2007).

Sea Surface Height: The sea level change we observe depends on: 1) the global change in volume of the ocean due to land ice melt or warming oceans and 2) changes in the land height due to subsidence/erosion or tectonic action (Thomson et al. 2008). For Vancouver, Victoria and Prince Rupert, global change in volume of the ocean dominates and the sea surface height is rising. For the Fraser River delta region, subsidence is also important so sea level is rising faster compared to the land there. For Tofino, tectonic motion currently dominates and sea level height is decreasing relative to the land (Perry 2014, Thomson et al. 2008].

Glaciers: BC glaciers are melting with 5% loss in the volume so far. About 70% loss is expected by 2100 (Clarke et al. 2015).

Rivers: BC rivers can be roughly separated into those that receive most of their precipitation as rain and so have high flows in fall through early spring, and the those that receive most of their precipitation as snow and so have highest flows, a freshet, in late spring to early summer. Climate change in the first group are not clear. The Fraser, a snow melt river, is experiencing a shift to earlier freshets and is seeing more flow in the winter as more precipitation falls as rain (Environment Canada 2015, Riche et al. 2014).

Salinity: Annual salinity changes show small freshening (Perry 2014). Especially near the Fraser River I would expect seasonal changes in salinity are higher but I don't know of a study.

Precipitation: To 2007, we have seen drying in the winter and wetting in the summer. Projections into the future suggest the opposite (BC Ministry of the Environment, 2007).

Winds: Future projections from climate models suggest not much change. For the West Vancouver Island shelf a slight angle change in summer is significant (Merryfield et al. 2009). Cautionary tale: in 2005, I thought the average winter wind speed in the Strait of Georgia was decreasing but it was just part the natural decadal variability that is particularly strong in our area. We will not get a clear anthropogenic climate change signal in our winds until late in this century (Deser et al. 2012).

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Storms and rising waters panel discussion

Left to right: Susan Allen (University of British Columbia), John King (Aon Risk Solutions), Mathew Clarke (Marine Harvest), Ryan Nicoll (Dynamic Systems Analysis)

Question - Gregor Reid- How do we consider changing storm conditions for aquaculture structural design?

John - We are always looking at the literature and is something that we keep a close eye on.

Mathew- We refer to and follow the Norwegian standards, as there are no Canadian standards. However, it is always in flux.

Ryan - International standards helped to develop the mooring standards and design important safety factors.

Question - Ryan Nicoll: Are there any long term standards that can be developed from MEOPAR predictions?

Susan - Project 1.2 is short term, but other groups are working on that.

Question - Stewart Johnson: A lot of changes are hard to measure (due to noise) - are there going to be any signals that come out of the noise (any features such as wind, sea surface temperature, etc.)?

Susan - Good question. Maybe with strong local phenomena; more river flow or some wind patterns perhaps. I can't speak as to which way it would go.

Question - Stewart Johnson: Noise in local areas- if reducing the observation area, will signals become more noticeable? Not on a larger level?

Susan - Yes, maybe with a strong local phenomena (e.g. Squamish or Qualicum winds)

Question - Richard Beamish: Do you have any evidence that winter winds are weakening or strengthening in any direction? Winds in general, timing, direction, intensity, and seasonality? Or evidence of more rainfall in the winter?

Susan - Yes, they are changing, but they are harder to predict due to the natural variability. We do not understand the natural variability patterns very well. They are changing, but it is not a global climate change signal. BC Ministry of Environment reports state that there is less rain in the winter, but the predictions are for more precipitation.

Question - : Is the level of snow still the same throughout the year?

Susan - The biggest change is seasonal (e.g. Fraser River- snow pack), the total change is slow and hard to predict. Precipitation is difficult to detect because it averages out between the summer and the winter months.

Ken Denman (audience) - Some of the maps can probably be updated with the PCIC (Pacific Climate Impacts Consortium) resource at UVIC.

Question - Gordon King: Farmers don't usually look 20-30 years in the future. They don't anticipate big storm surges and it is very difficult to predict what will happen at a particular site. Farming traditionally deals with it when it happens. Industry sees that it is a problem with climate change. Is there a way of looking in the future? How can you resolve this dilemma?

John - From the insurance perspective, we can make suggestions on risk management, but it is up to the farmers to do their own assessments (i.e. bigger deductibles, build up reserves, etc.). But ultimately, it is up to the farmers as to what they want to do.

Matthew - Coming back to standards (Norwegian standards/ guidelines) and adjust for risks due to local conditions. For instance, building codes are updated as experts see new risks (e.g. earthquakes). Adaptions or regulation to a code of that level.

Ryan - Standards meet the minimum requirements, from the perspective of someone operating the farm. Therefore, it is important to build on top of that.

Gordon King (audience) - There are very few standards for the shellfish industry, compared to the finfish industry.

Mathew - There are no Canadian Standards, therefore, you have to source standards from elsewhere. Safety factors are built into all standards. It is hard to justify expenses without standards.

Kevin Onclin (audience) – Having experience creating finfish farms, the minimum standard was always 3:1 safety margin. From a finfish perspective, we are well in pace to embrace change; moorings have to be inspected all of the time and must be replaced after a certain amount of time. I think we are doing a good job in preparations and the changes appear to be subtle. The pace that I see these changes, I don't think these are a significant issue.

Matthew Clarke

Matthew - I agree. One thing that is changing is the model, based on new information. There is still a constant change in projections, but it still comes back to the standard- what is the 1 in the 3:1. If the 1 is less, what does it matter? Nobody is enforcing that moorings have to be inspected. For smaller farms, they don't have the same expectations and/or requirements, so they will have a tougher time.

Question - Stewart Johnson: With respect to international standards, how often does the climate change topic come up with engineers?

Ryan - There are so many standards- I work in a new industry and in a small part of the engineering standards. The concern is capturing the primary effects in your specific location. You need to know the 100 year storm projections and design a platform for the 100 year trend. I think to some degree they are factored in to the standards and they will get updated as more theoretical/analysis comes up. Standard development is very important but you also need the engineer.

Roberta Stevenson (audience) - Unfortunately, we have lost the resources to give advice and provide standards to shellfish farmers. We can no longer give free advice on anchoring systems. Most of the farms are set up for South-East prevailing winds, but we had a South-West wind and lost a lot. Capacity for management needs to be revised. It's a shame- huge economic lost.

Question - Gregor Reid: How much of a concern is it to have a surge stronger than anticipated?

Gordon King (audience) - It depends how much over-loading; there are no standards- the standard is whatever works.

Ryan - Standards are not useful, unless they are enforced. There must be an incentive.

Roberta Stevenson (audience) - The incentive is that you don't want to lose your entire personal wealth. You cannot apply for insurance or borrow money. Shellfish farmers have their personal loss at risk. It is unfair for shellfish farmers to have to invest in an engineer.

Gregor Reid (audience) - If standards were available, farmers could choose to abide.


Ryan Nicoll

John - There are some global experts out there that we could call for advice, if you are interested. Experts can apply the engineering to a site and would have the insurance to cover it.

Ryan - The real limitation is the expertise, which we need to accurately assess how the systems behave. People must be trained in schools, which is a great way to foster some interest with university involvement. Need more engineering expertise in the industry.

Question - Gregor Reid: We have seen aquaculture get massive temperature fluxes, due to upwelling- is this something we can expect more of?

Susan - Expect the unexpected. It can certainly increase in still waters.

Ken Denman (audience) - Susan only showed one time series over 100 hundred years. When we talk about designing for a 100 year event, we are talking about predicting events we have not even observed ourselves (i.e. hard to predict for rare events that we do not have the data for). We must be careful when talking about predicting the 100 year storm.

Question - Gregor Reid: Is it a matter of simply scaling up relevant functions within the projections?

Susan - I don't think it is a scaling issue (it is downscaled). Precipitation is very much wrapped up in storms, which is wrapped up in winds. Precipitation and wind have a very large natural variation, which makes prediction very difficult.

Question - Gregor Reid: Any finfish experts experiencing warming water events?

Dean Trethewey (audience) - There is better growth with warmer waters (growth increases 14% for every degree increased). However, with increasing temperature, also comes increased pathogens and disease. Last year, the temperature did not drop below 10°C and was the first year we ever saw AGD (amoebic gill disease). Warming temperatures has been an advantage so far, but over 18°C, is detrimental to fish health.

Audience - It is not only are the farmed fish being impacted. Local forage fish and smolts severely impacted. If it becomes more frequent, we will run into more issues with salmon and herring. The impacts can be both aquaculture and fisheries.

Question - Gregor Reid: Panelists, what are the main concerns with climate change in your area/field?

John - So far, finfish guys are doing a fantastic job preparing for storm surges. Few losses so far.

Matthew - I have not seen any evidence to concern me with making drastic changes in the engineering approach. As data becomes more available, we will act on that. Right now seems like a very gradual trend. My main concern is the biological side.

Ryan - Only ongoing questions at your specific location. What are the weather conditions? So that we can make the necessary recommendations, for mechanical systems.

Fish and Shellfish Health Session

Climate change and aquaculture in Canada: potential impacts on aquatic animal health presentation summary

S. Johnson, Program for Aquaculture Regulatory Research, Pacific Biological Station, Fisheries and Oceans Canada, Nanaimo, BC

Stewart Johnson

For a number of important human and terrestrial animal diseases climate change has been identified as one of several factors affecting changes in disease distribution, prevalence and intensity. However, there remains uncertainty with respect to the relative importance of climate change as a driver. Determining the magnitude of the effect caused by climatic factors from those caused by numerous other abiotic and biotic environmental, behavioural and social factors remains the challenge.

It is well recognized that features of the host (or host population), the disease causing agent (infectious or non-infectious agent or their populations thereof) and the environment can change independently or as a result of complex interactions between any combination of them. For this reason our ability to predict disease occurrence outside of very controlled laboratory conditions is poor. When you consider the high level of uncertainty that surrounds the direction and magnitude of climate change and how these effects will be expressed in aquatic systems it is easy to realize that our ability to predict how climate change will effect diseases in aquaculture is very limited.

At a very general level climate change effects on aquatic systems will include changes in: temperature, pH (acidification), patterns of precipitation/evaporation, water column structure/ stability and patterns of circulation and the frequency and magnitude of storm events. It is important to remember that these effects will be occurring in the presence of other small and large-scale environmental changes that are not necessarily caused by climate change (e.g. changes in land use; eutrophication to name a few). These changes may impact aquatic animal health directly or through their interactions with climate induced changes.

The direction and magnitude of the impacts of climate change on aquatic animal health will vary depending on the host, the disease causing agent (infectious and non-infectious agents) and the environment (fig. 1). It is important to recognize that not all impacts will be detrimental.

In general climate change will affect the risks to aquatic animals posed by diseases by: 1. changing in the susceptibility of host species to enzootic

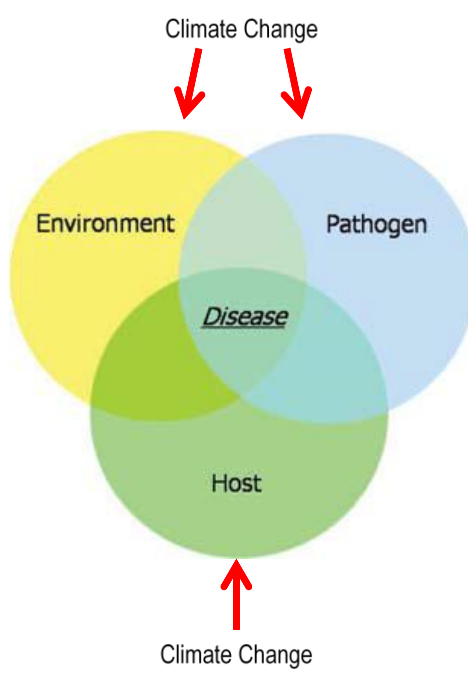

Figure 1. Possible routes of climate change influence on disease

disease-causing agents (including introduction of non-native or naive host species to offset effects of climate change); 2. affecting the distribution, abundance and virulence of disease-causing agents including incursion (and persistence) of non-enzootic agents; and 3. affecting the effectiveness of therapeutants, vaccines and other disease management practices.

It is likely that climate change will affect the direction, magnitude and duration of stressors, as well as the frequency of their occurrence. In some situations such changes may result in stressful situations for the host affecting physiological and/or immunological status, leading to increased host susceptibility and risk of disease development. Climate change may also affect naturally occurring or man-made, changes in other ecological factors such as: changes in abundance of wild or cultured hosts, or in the case of parasites, their intermediate hosts; changes of prevalence of infection in wild or cultured hosts or intermediate host populations, range extensions of wild or cultured hosts and/or intermediate host species. Such changes may be ultimately reflected in changes in the distribution and abundance of disease-causing agents (infection pressure), as well as increase the potential for the introduction of non-endemic disease causing agents.

The following is an example of how risk of exposure of farmed fish to disease-causing agents may change. Declines in the abundance of sockeye salmon, especially in southern waters, have been attributed to changing climate with declines expected to continue as climate continues to change (Martins *et al.* 2012 and references therein). Infectious hematopoietic necrosis virus (IHNV) is endemic in sockeye salmon stocks on the West Coast of North America and IHNV carriers are present in marine waters. Atlantic salmon can be exposed to IHNV from wild sources and can develop serious disease unless they are vaccinated. Climate change driven declines in sockeye salmon abundance may reduce the risk of IHNV exposure to farmed fish. However, any reduction in risk could possibly be offset by increased incidence of IHNV carriers in wild fish, and/or changes in susceptibility of farmed fish to IHNV.

Virulence is the degree of pathogenicity of an agent, as indicated by the severity of disease produced and the ability of the agent to invade host tissues. Climate change may affect the virulence of infectious agents directly or through changes in the susceptibility of hosts to infection. For example, infectious agents that are a-virulent in healthy hosts may become virulent if hosts become compromised due to processes related to climate change. There is also the potential for increases, decreases or shifts in windows of infection or timing of disease occurrence.

Changes in the frequency and severity of disease outbreaks may require revision of current, or development, of new fish health management strategies/plans. For example, higher rates of disease progression could necessitate changes in which therapeutants are used, how they are applied, as well as affect their effectiveness. In situations where temperatures increase there may be increased risk associated with the use of some therapeutants (eg. hydrogen peroxide, formalin). Elevated temperatures may change the level and duration of protection afforded by current vaccines as shown for the DNA vaccine for salmon alphavirus (Hikke *et al.* 2014).

Climate change may also affect the distribution and abundance of non-infectious disease agents. For example, climate-related changes to physical (stratification/stability) and chemical properties of coastal waters are expected to impact plankton communities and possibly favor some forms of harmful algae. Expansion of harmful algal species ranges, increase in abundance and/or duration of annual occurrence, and increased toxicity are possible outcomes.

In summary, climate change will affect relationships between disease agents, hosts and the environment. The amount of impact will vary globally and most likely at smaller scales and will be combined with impacts from other anthropogenic factors. Climate change effects on diseases may be neutral (no effect), detrimental or beneficial. The outcome will depend on the disease, the host and the geographical location/environmental situation and the direction and magnitude of climate-related changes.

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Aquatic animal heath panel discussion

Left to right: Gregor Reid (Session Facilitator, University of New Brunswick), Stewart Johnson (Fisheries and Oceans Canada), Grace Karreman (Syndel Laboratories), Simon Jones (Fisheries and Oceans Canada), Jim Powell (BC Canadian Academy of Health Sciences)

Question - Daniel Rabu: How does a shellfish farmer know whether it's worth the investment to expand a scallop farm, in regards to Scallop SPX (*Perkinsus qugwadi*)? SPX is becoming more prevalent with warmer waters and climate change.

Stewart - We need to focus on shellfish and the environment. There is so much uncertainty to how climate change is driving all of these things. We need to develop tools and assessment techniques to answer how the impacts will affect the production, and not how climate change is affecting species. It is all about surveillance. CFIA has done a really good job in providing good information about the health status of shellfish in BC. The next step is to culture SPX and do the studies on the relationship with the host (lab work and then applying this to field work).

Grace - I'm not sure there is a good practical answer- you're talking about a structured risk assessment. Need to look at risk factors and find out what are the most probable causes for creating those pathogens (literature research). Map out oceanographic conditions and look at your oceanographic conditions. Alternatively, look at oceanographic conditions in a similar geographic location. Multi-disciplinary approaches are needed to answer this question. From having worked for CFIA, you must go through a structured risk assessment.

Question - Gregor Reid: Are we better off putting our efforts in monitoring/surveillance rather than predicting efforts?

Simon - All of the above. Monitoring and surveillance are the heart of it. Well-designed surveillance efforts are a huge part of the risk assessment.

Jim - You don't know what you don't measure. Hakai Institute has remote sensing, and data might be available for scallops. There may be other GIS models.

Simon - In the last 11 years, we've been surveying pathogens and a suite of parasites in the Quinsam River (Campbell River, BC), where we have recognized 4 or 5 parasites that occur year after year, but it is always changing. The statistics are not consistent with the level of infection. Presence of a microbe that can cause disease doesn't always cause disease. There is a lot of noise in many of the biological things we measure, including microbial disease. We need a long term time series of data.

Kevin Onclin (audience) - We all have different perspectives. If you look at it from business perspective, you can monitor until the cows come home. If I'm making an investment, monitoring is not going to tell me where I should spend my money. We would rather not be making the investment- why would I? There's going to have to be multiple approaches, we should spread our risk.

Question - Gregor Reid: This is one of the reasons we have these workshops. What information would you need, in this area, to make a good business decision?

Kevin Onclin (audience) - It depends what your end game is- is 10 or 20 years sustainable? I need some reassurance that we can make a reasonable risk assessment that is worth the investment. The answer is very time frame dependent.

Question - Daniel Rabu: SPX has not killed any scallops in the Haida Gwaii area. Is there a link between warming waters and SPX? We turn to the researchers- should I be investing in Haida Gwaii? Or will it hit there in 5-10 years? In my opinion, the scallop die-off is not because of OA, but rather because of SPX. What is the trigger?

Question - Gregor Reid: Can you challenge scallops in the lab?

Stewart - Aquatic and terrestrial environments are facing the same uncertainty, it is not predictable. You have to keep the animals healthy. The only way you can reduce the risk is maintaining a healthy animal, which is the only thing you have control over. No one can tell you what the real risk is.

Grace - I would like to build on the agriculture thing and disease, modelling- pathogens are extremely complex. We are close to prediction with GIS, but it is still not ideal. There has been a fair amount of research and modelling with temperature effects on plants/crops. We need to look at some of these models for short term/long term investments. We must also talk about risk consequences, catastrophic events, and emerging diseases (e.g. IHNV 2001). Sub clinical problems- chip away at efficiency and production. We can only respond and make good therapeutic decisions based on what you can measure, to see what the effects are (e.g. feed conversion, etc.). I'm concerned with the idea of therapeutics; with increasing temperature you get increasing bacteria turnover (replication), which means resistance may be an issue. You need to prepare tools and manage consequence. Do we have enough therapeutics to manage such consequences?

Kevin Onclin (audience) - I would like to clarify, we need to monitor and collect more data, but from an investment/business point of view, you need to know where to put your money.

Ben Koop (audience) - We do know from an ecological perspective, we have a latitudinal diversity gradient- you can make a prediction that species diversity will increase the farther north you go (warmer water species predicted to move pole ward) . In general, we know that we will have a lot more species to deal with. Which means more and more issues will develop. Monocultures in an increasingly diverse environment will have more issues.

Gregor Reid - In the IPCC reports, there are certainly some things we are becoming more certain about. With respect to aquaculture diseases, in the tropics aquaculture diseases appear to spread more rapidly, but are not generally reported. Latitude paper- generalities reported, but not enough to make predictions.

Question - Gregor Reid: I'm going to play devil's advocate here - if we are dealing with so much uncertainty, why bother doing research?

Simon - We live in a world of uncertainty, but we expect it. I suggest that we would have much greater difficulty in predicting the health of wild animals if we didn't monitor that of aquaculture. Certain features of aquaculture will eliminate some uncertainty so that we can be profitable and manage accordingly. Research efforts target those aspects in aquaculture that we have control over, but we can never eliminate the uncertainty. Research can provide sufficient information so that we can be confident the industry can perform in a profitable way. The effort of science research is very valuable.

Jim - We have the infrastructure, we have some good oceanographic conditions, we have those overlays to somewhat manage that risk (Merlot grape example).

Roberta Stevenson (audience) - That is all good with the grape analogy, but in this political industry, the media is not going to report what might be good, they are going to take the negatives. The negatives are grabbed more quickly and then taken up the by the politics. We must be careful and cautious what we say.

Question - Gregor Reid: Why can't we take some scallops, put them in a lab and challenge them (SPX) to provide industry knowledge and advice on risk assessment?

Simon - There are labs that can do this and disease challenges have been done. I suspect that this can be done in an area where it occurs naturally, but it would be better to explore the native fauna in your area. May be important to rule out the presence of a local infectious agent. Look closely at your local environment and specific risks.

Daniel Rabu, Jay Pudota

Question - Daniel Rabu: I like the merlot grape analogy - if this happened in France, they would be knocking at your door, asking how to help. I don't know where else to turn to get a better answer. I've called CFIA and there has been no SPX monitoring in Haida Gwaii. I've tried calling CFIA several times, but not helpful- Who do I turn to?

Kevin Onclin (audience) - Whether shellfish or finfish, we are going to have a problem in BC. Right now salmon farming has stayed the same the last 15 years. If you look at other jurisdictions (Norway), every farmer makes sure they spread the risk- they have broodstock spread throughout. We do not have that type of working relationship, none of these companies spread the risk. When we get into regular discussions, we need to have some understanding of mitigation. There's a lot of risk and ways to mitigate the risk, but we do not have a willing jurisdiction to help mitigate our risks, or enabling governance to manage risks.

Gordon King (audience) - I don't know if that is the case. There are a lot of dormant sites that are not being used to their potential. There are significant differences between shellfish and finfish- for instance, there is no medication for shellfish. The biggest economic impact is not being able to harvest due to harmful algae blooms. PSP, DSP, vibrio has become a significant problem in the last several years, and now are prevented from harvesting in the summer.

Roberta Stevenson (audience) - agrees.

Question - Has there been any work done on genetic comparisons with amoebas?

Jim - We look at one point in time and yes, there is a difference, but not enough to make conclusions. Some fish health concerns are different to what we were seeing the last few years. Things are changing. There is not enough data to say what the causative agent is. Look in the future and get ready to react.

Question - Stewart Johnson: Have we missed the opportunity to look at the data that salmon farms are collecting every 15 mins? No one has ever taken or used any of this data. Is that something of value?

Jim - Part of the problem is that it was entered and taken by humans. It takes a lot to clean up that data, to remove outliers and noise. But you are right, it is an absolute gold mine; we need to put in the money to sort it out.

Stewart - All of these groups collect information, but how valuable is this farming information? Probably valuable for some, but not for others. There is value, but Canada does not have a very good system to house, archive, and share data. If companies go bankrupt, all the data is lost. The aquaculture industry collects a lot of valuable information that people are now recognizing, but there is no system in place to collect and maintain that information.

Grace - In regards to the quality of the data collected from the far, it is very good and statistically solid. It has been used to figure out whether BC was Infectious Salmon Anaemia (ISA) free. Farmers know what they are doing, the problem is more about the system.

Gregor Reid (Session facilitator) – Natural Resources Canada has a research fund to disseminate climate change information. Tackling existing information is a big issue, which was a prominent discussion topic at the Atlantic workshop.

Warming Waters Session

Warming waters presentation summary

T. Benfey[1], GK. Reid[1,2,*]

Gregor Reid

Tillmann Benfey

[1]University of New Brunswick, Department of Biology, Fredericton New Brunswick
[2]Canadian Integrated Multi-Trophic Aquaculture Network, University of New Brunswick, Saint John, NB, Canada, E2L 4L5
[3]Fisheries and Oceans Canada, St. Andrews Biological Station, St. Andrews, NB, Canada, E5B 2L9

*Presenting Author

The Warming Waters presentation for the Pacific workshop was a repeat of the presentation given by Tillman Benfey at the Atlantic workshop, with the addition of some Pacific Coast temperature data. The presentation summary is on page 42 of this proceedings, and the additional temperature data is shown below.

Example of 'local increases' in annual surface temperatures

A number of shore stations (mostly at light houses) throughout BC have been collecting water quality data for decades (fig. 1). The station located closest to the Pacific workshop venue (Campbell River, BC) is Chrome Island. Data analysis shows temperature has increased between 1.5-2.0 °C in 50 years (fig. 2).

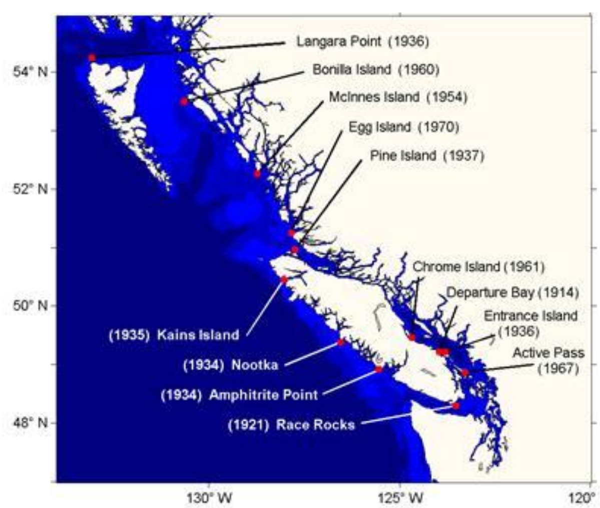


Figure 1. Locations of British Columbia Shore Station Oceanographic Programs there are 13 participating stations. All but three stations (Race Rocks, Amphitrite Point, and Active Pass) are at lighthouses staffed by Fisheries and Oceans Canada. From DFO (2015).

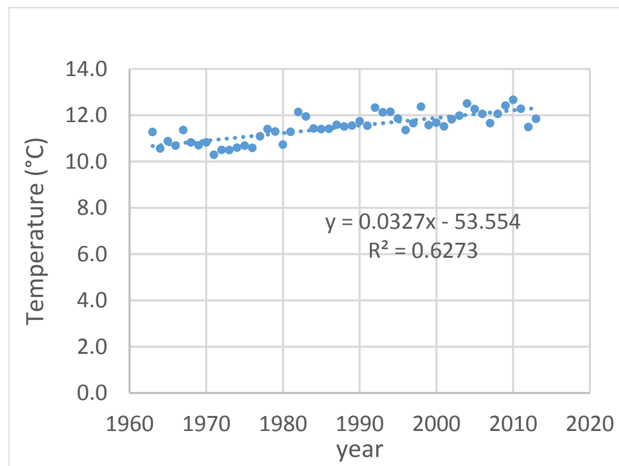
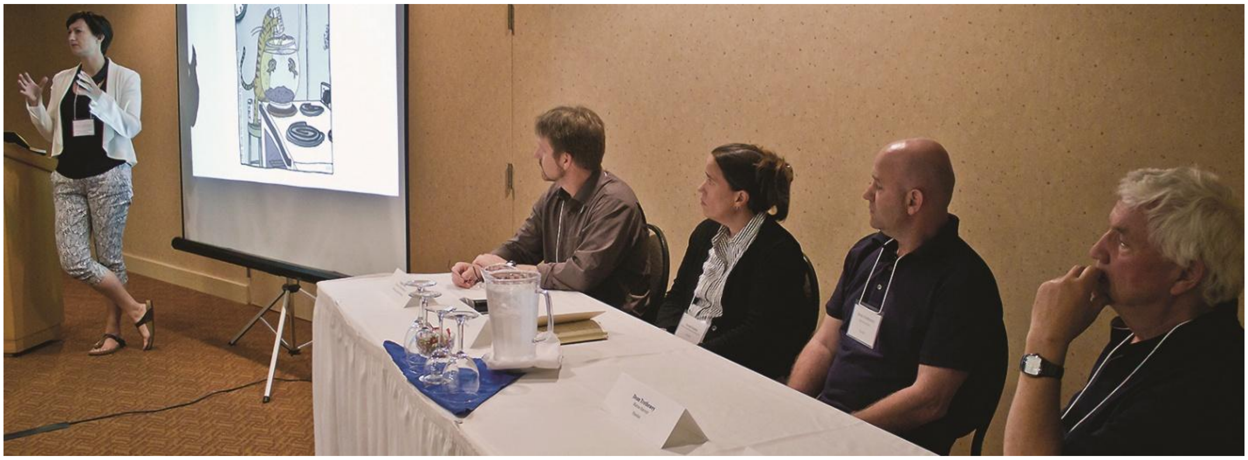


Figure 2. Mean annual Chrome Island sea surface temperatures from 1963 – 2013. Compiled by GK Reid from BC shore station water quality data records (DFO 2015).

References

DFO. 2015. Data from BC Lighthouses. http://www.pac.dfo-mpo.gc.ca/science/oceans/data-donnees/lighthouses-phares/index-eng.html. Accessed, April 26, 2015. Government of Canada, Fisheries and Ocean

Warming waters panel discussion



Left to right: Helen Gurney-Smith (Session Facilitator, Vancouver Island University), Gregor Reid (University of New Brunswick), Sarah Dudas (Vancouver Island University), Dean Trethewey (Marine Harvest Canada), Richard Beamish (Fisheries and Oceans Canada, emeritus)

Question - Daniel Rabu: In regards to the 'warm water blob', do you have any thoughts on if it will have an effect on deep water upwelling?

Kevin Onclin (audience) - A study showed it's confined to upper 100 m, and is not a deep water effect.

Helen (Session facilitator) - Some researchers think it could be related to a fresh water layer on the surface creating a lens and increasing the surface water temperature.

Gregor - Some reports suggest there hasn't been as much cooling in the winter.

Richard - It could also be related to weakening of winter winds. If this is a possibility, it could represent a substantial change in the North Pacific.

Susan Allen (audience) - It has to do with interesting wind patterns in the winter, but it is a controversy of whether it is a weather phenomenon or a fluctuation. El Niño causes our water to warm due to water layer thickening a bit.

Question - Helen Gurney-Smith: Richard, do you have words of wisdom to give to the aquaculture industry in terms of aquaculture species?

Richard - One of the first indications of global warming, was the loss of Atlantic cod- the eggs were not hatching in warmer waters, but when the water cooled, the cod increased again. The first good example of a global warming effect on fish in BC (that I wrote about in the mid 90's), proceeded nicely until 2002, where waters cooled and numbers increase. The point is the cooling started 7 years ago in Strait of Georgia and the trend is still there (It has been cooling for the last 8-9 years). We are back to where we were in the 70's in terms of salmon survival. In other words not much happening now to indicate global warming impact.

Question - George Waldbusser: How much of that is related to the Pacific Decadal Oscillation (PDO) current effect?

Richard - A lot is related to that. But the point is that what I had written about in the 90's is no longer valid.

Question - Gordon King: A lot of salmon stocks are doing well in the United States, but not the Chinook salmon. I hear it is the case here also. Do we know why Chinook salmon are not doing well? Yet in Alaska, salmon are doing better than ever.

Richard - Chinook stocks coast wide are not doing well, including Alaska. They started to deteriorate in the late 70's in BC, where in the Strait of Georgia, stocks went down to 20,000 fish due to natural reasons. You mentioned salmon are doing well in the North Pacific- where the dominate group of fish here are Pacific salmon. This is mostly because the pink salmon are doing well; the odd year pinks are doing better than the even year pinks. Chinook salmon enter Strait of Georgia later than other salmon- entering when warmer and lower salinity.

Question - Daniel Rabu: Strait of Georgia waters are getting cooler, not warmer?

Richard - Started cooling since around 2000.

Question - Daniel Rabu: So my concerns about the SPX situation can be ruled out if waters are cooler? Scallops are not going to be affected by the warming of waters?

Richard - Most believe the cooling trend is relatively short term, but some of my colleagues in Russia think it could be 30 years.

Question - Helen Gurney-Smith: I have a question for Nicky- are you seeing any correlation between harmful algae blooms and temperature?

Nicky Haigh (audience) - Not that we can see, but there is inter annual variation, so can't say (about 16 years of data). We are seeing outside sites (west coast) having water temperatures 2^{o}C higher than normal. We are seeing different things, but whether it is because of climate change- who knows? With less snow pack, high salinity, and low freshwater input- maybe won't see as much *Heterosigma akashiwo* because they like freshwater. These are not long term effects, just what is happening this year. So difficult to say when so many factors are in consideration.

Gregor - Back to Daniel about ruling out certain diseases due to temperature change - Nikki LePage, an Ontario fish veterinarian on the fish health panel at the Atlantic workshop, questions the merit of calling some fish diseases, 'cold-water

Susan Allen, Gordon King

diseases', as she has seen these function in warmer temperatures. Adaptation? This may be a cautionary tale - we need to be careful we don't rule out disease potential based just on temperature range.

Question - Stewart Johnson: In regards to Tillman's slide about how different species deal with temperature- one of the things missing was the vast difference in performance. The question I have is, through our farm salmon selection programs, how much genetic diversity do we have to deal with?

Dean - This is difficult to tell in our sites – with slow decrease in oxygen, salmon do better. We put in alarm systems to assist with some of mitigation techniques for moving the water for them. We have not seen deaths due to this in the last 5 years, and we feed salmon even when oxygen is down to 30% saturation. Faster rising temperatures - earlier plankton.

Yvonne Sheehan (audience) - We make sure we have huge genetic diversity that is maintained, with high performers and lower performers. We have not bred the salmon to select for better low oxygen adaptation. To be a sustainable industry, we try to maintain high genetic diversity, which is part of our mandate for breeding programs. Biggest commitment is the backups- we have a 3 way backup in our freshwater facility, which is a huge risk and expense, but maybe we need more (plus frozen sperm).

Question - Rob Marshall: You were talking about a cooling trend since early 2000s, at what water depth does this occur at?

Richard - I cannot recall how far down, but I believe it is surface waters.

Question - Helen Gurney-Smith: This question is for Sarah - with warming waters, do you think there is a potential for more invasive species spread?

Sarah – With respect to warming waters, Pacific oysters can only reproduce at certain temperatures. There will be more naturally producing species of the native Olympia oyster. I am concerned with what temperature invasive species could start reproducing (e.g. green crabs, invasive tunicates etc.). How are these warming waters going to affect aquaculture interactions? How will it affect predation rates? Is there increased predation rates with warmer waters (e.g. sea stars, moon snails, more fouling)?

Helen Gurney-Smith

Ocean Acidification Session

A crash-course in ocean acidification: shellfish edition presentation summary

George Waldbusser

G. G. Waldbusser, Assistant Professor of Ocean Ecology and Biogeochemistry, Oregon State University, College of Earth, Ocean, and Atmospheric Sciences

I. Ocean Acidification: The Basics

Why doesn't our exhalation contribute to ocean acidification? Or does it? The carbon dioxide we exhale is derived from plants we eat (directly or indirectly), that was circulating in the atmosphere within the past couple years. In other words, we are exhaling carbon that was in the atmosphere very recently, so it is a short-cycle time scale for that carbon to be turned over. The carbon emitted from combustion of fossil fuel took millions of years to form as deposits within the earth's crust, and through mining and extraction we are removing and combusting it on time-scales of decades to centuries. We have short circuited the normal geologic time-scales for those carbon pools, and our activities are directly to blame for this rapid atmospheric increase in carbon dioxide.

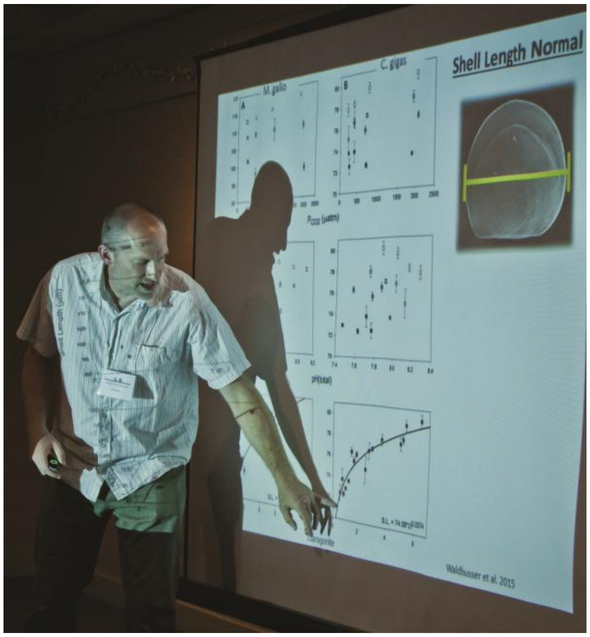
From a geological/earth history perspective the primary problem of ocean acidification is a discontinuity between the timescales at which the earth can buffer increases in global carbon dioxide levels, and the current rate of increase of atmospheric carbon dioxide. In the earth's geologic past volcanism is often a root cause of increasing atmospheric carbon dioxide (CO_2) levels, and the plate tectonics associated with globally increase volcanic release of CO_2 also results in uplift and increasing weather or primary continental rocks, which increases the delivery of alkalinity to the world's oceans. The rapid increase of atmospheric CO_2 results in significant uptake by the world's oceans into the dissolve inorganic carbon pool, which represent the largest pool of reactive carbon on the planet. Over time that carbon will be absorbed into various components of the earth, and if we stop anthropogenic CO_2 emissions today, it will take roughly 1 million years for that anthropogenic carbon to be re-absorbed into the earth through various geologic processes.

II. Ocean Acidification: Local Scales

Many of the organisms we are concerned about live in local waterways, and within these near-shore local environments the increase in atmospheric carbon dioxide can interact with local processes to exacerbate acidification. The processes of eutrophication, upwelling, river-discharge, and deposition of other acid forming compounds from the atmosphere may all contribute to the variability occurring on local scales. From an organismal perspective, it is the local scale that matters most, organisms experience the local variability, not the gradual global change. An analogy can be drawn with climate change, what we experience, and what affects human populations most are changes to local weather conditions, and to regional climatology. Fortunately those short time-scale changes in local conditions rarely have major immediate impacts on organisms or living resources. The cumulation of extreme events over time will however result in ultimately cascading effects on communities and ecosystems as systems become less stable and less conducive for the organisms that evolved in those systems.

III. Other Species Responses to Ocean Acidification (non-bivalves)

A tremendous amount of experimental work has been completed in the past 5-10 years on organismal responses to ocean acidification. A very broad look across those studies suggest about half of all organisms that have been challenged by ocean acidification show some kind of negative



George Waldbusser

response. While this metric may be more encouraging then some perceptions of the threat of ocean acidification, if these negative impacts results in population declines or loss of half of the ocean's species, this is not very positive. It is also very important to note the challenges in culturing and maintaining organisms in laboratory settings often results in experimentalists working on relatively easy to culture (and often hardy) species. There are many, many organisms that are extremely difficult or impossible to cultivate in laboratory settings, preventing us from truly evaluating their response to acidification.

Two commercially important groups of organisms that have received some attention and study are fish and crabs. The responses of these two groups are mixed, and not generalizable, as of yet, but as we develop better understanding of modes and mechanisms of failure perhaps we may gain some insight. While much effort has focused on the impacts of acidification on calcium carbonate forming organisms, fish have been shown to have responses to acidification in other less obvious ways. Two interesting examples are the effects on sensory organs, most likely driven by changes to neurotransmitter compounds, particular GABA, which is responsible for modulating the firing of synapses. Some studies have found increasing carbon dioxide leads to loss of smell or more erratic swimming behavior. Another study on fish illustrated a change in fish otolith size, due to increasing bicarbonate ion concentration from acidification, and a concurrent increase in the ability of fish to sense auditory signals while also altering the ability for fish to maintain orientation.

IV. The Whiskey Creek Story and Oyster Seed Crisis.

Bivalve larvae have been well documented to be sensitive to acidification; however when the Whiskey Creek Shellfish Hatchery in Netarts, Oregon began having significant and long-lasting failures of oyster larvae in 2006, acidification research on temperate organism response was still in its infancy. Two of the three major commercial hatcheries in the US Pacific Northwest have sustained failures over several years, and attempts to mitigate possible disease issues were successful in removing pathogens from the hatchery, but failed to correct the failures. Through interactions with scientists at Oregon State University (OSU) and National Oceanic and Atmospheric Administration, and the forward thinking of hatchery operators, a link was soon determined between times of elevated CO_2 during oyster spawning and the failures of cohorts. Alan Barton, the hatchery manager was the first to identify the link. The link was then found also at the Taylor's Shellfish Hatchery, and the recognition soon followed in the industry that the lack of seed would soon threaten the entire west-coast industry. Interestingly, concurrent with the hatchery failures, Willapa Bay, WA (the largest endemic population of Pacific Oysters along the US west coast) also saw below commercially viable recruitment over this period in time. While direct monitoring data is not available to make the same causal link, recent work lead by Hales shows how increasing anthropogenic CO_2 has made the windows of time favorable for successful recruitment smaller some years. The primary reason the industry did not collapse was due to the monitoring put in place by Burke Hales from OSU, and the collaboration that emerged and has continued to grow between industry, academia, and federal scientists.

V. Bivalve Responses to Ocean Acidification

The careful evaluation and publication of the hatchery records from Whiskey Creek Shellfish Hatchery related to the chemistry data during the 48 hours post-fertilization made it very clear this early stage was critical for successful development and survival of larvae. National Science Foundation funded research on mechanisms of larval bivalve responses to acidification began in 2010, led by Waldbusser at OSU. The results of this work has clearly illustrated that during the initial shell forming period bivalves are sensitive to saturation state of the water because of rapid calcification, limited energy, and what appears to be greater exposure of calcification surfaces to surrounding waters. Several experiments using unique carbonate chemistry manipulations on a few species now have documented this to be true; in fact bivalve larvae can get through the initial shell forming stage with no direct acute effects at extremely high CO_2 and low pH, as long as saturation state is elevated. An interesting case however emerged. While this pattern was consistent between native and non-native mussel species to the US west coast, the native oyster species, *Ostrea lurida* appeared resistant to acidification during this early developmental period. The group at OSU were able to extract and rear brooded larvae from *O. lurida*, and rear them successfully to settlement, allowing for direct acidification challenges while removing the maternal effects. It turns out that *O. lurida* develop far more slowly and calcify more slowly, suggesting the lack of acute acidification impacts during the initial shell formation is due to slower calcification, providing a negative proof of the kinetic hypothesis for acidification sensitivity of marine bivalve larvae. Therefore, the mode of reproduction (broadcast vs. brooding) may be far more important to determining sensitivity than many of the previously proposed metrics for understanding species-specific responses.

VI. Adaptation Strategies

Now that a culprit for the seed crisis has been identified, and the underlying reasons for the acidification impacts illuminated, strategies may be employed by industry to adapt to a changing ocean. Within the hatcheries, the first and easiest strategy, once real-time carbonate chemistry monitoring was installed, was to take advantage of the natural variability of the highly productive waters in the region, and pump water into the hatcheries in the afternoon, when primary production had naturally lowered the ambient CO_2 conditions. While this provided a good first step, it required work at odd hours, so soon after the hatcheries installed buffering systems to chemically buffer the water with sodium carbonate. Using a pH sensor and feedback controller, the hatcheries are now buffering their waters to estimated saturation state levels between 4-5. A secondary benefit was seen in the Taylor hatchery, with this increase buffering, survival of geoduck seed increased. In addition to water quality manipulation, efforts by the OSU Molluscan Broodstock Program has helped support the industry by taking advantage of years of controlled breeding and is currently working on identifying bred families of Pacific oysters that may have increased resistance to acidification stress.

Work is now underway to also examine post-set larvae, and very early juveniles, with both exploration of vegetated habitats as potentially providing refugia for oysters and other shellfish in an increasingly acidifying ocean, as well as the potential role of dead shell material in providing a source of alkalinity to locally buffer the habitat in which the new oyster seed are planted. Finally, within my own group, we are adapting staining techniques to relatively cheap hand-held microscopes for use by the industry to evaluate seed condition before outplanting.

Ocean acidification panel discussion

Left to right: George Waldbusser (Oregon State University), Rob Saunders (Island Scallops Ltd.), Debby Ianson (Fisheries and Oceans Canada), Wiley Evans (University of Alaska Fairbanks).

Question - Daniel Rabu: In a hatchery with limited resources, should we invest in monitoring pH?

George - Measure all those things, it's relatively cheap to buffer water and monitor pH. If you keep oysters healthy, they have no *vibrio* (Whiskey Creek Hatchery). There are ways of chemical monitoring without spending lots of money.

Wiley - There was a document published with detailed strategies this year from the California Current Acidification Network. It contains details on different types of sensors, costs, etc.

Question - Gordon King: Will CO_2 remain constant? If the atmospheric CO_2 increases, will the ability of the ocean to absorb it decrease?

George - Yes, the ocean's ability to absorb CO_2 will drop as it gets further saturated (buffering capacity goes down).

Ken Denman (audience) - A more complex issue is that the system can't get extra CO_2 into the deep ocean waters because we are increasing the rate at which we are putting it in. If you look at the increasing percentage of CO_2 going into the ocean, it may also be a function of the rate. The deep-water system can't get that from the surface. There is also the issue ultimately of buffering capacity and time scale.

Question - Chris Pearce: George, you mentioned multiple stressors - has there been much work on multiple stressor reactions (pH, temperature, pCO_2)?

George - In general, not a lot has been done. When you add more stressors, the effects becomes more extreme. The response curves we were looking at excludes all the other impacts. There are some cases where moderate temperature increases (that don't exceed the tolerant range) are beneficial, which helps the organisms calcify with increasing CO_2. If you have lower temperatures with increasing upwelling events, it gets more complicated. Generally, if you have two stressors acting on the organism, the combined stress is worse than a single stressor.

Debby – Yes, there are more extremes with synergistic effects.

Question - Grant Hunt: In the hatchery, we see some seasonal fluctuations throughout the year (changes in pH and CO_2); what are some of the seasonal influences for us to predict better water quality or windows of good opportunity?

George - Coastal upwelling is a big one. Usually the start of oyster production is around the time when upwelling occurs. From natural populations, you have to balance out when the conditions will be best. Native oysters have three spawns- usually during the beginning and end of upwelling. Mussels spawn in winter, outside of upwelling cycle. In the winter, down-welling and other conditions are much more stable.

Foreground: Chris Peace, Rob Marshall

Question- Grant Hunt: Does it reverse in winter and you get more down-welling?

Debby - Here, upwelling occurs mainly on the outside coast, but on the inside (i.e. Strait of Georgia) there are seasonality changes. In the winter, the surface is undersaturated and in the summer, it is reversed (radically different).

Wiley - Helen (Gurney-Smith) and I are taking continuous surface water readings on Quadra Island - when the spring bloom occurred, things changed radically on a daily basis.

Debby - On the MEOPAR website, we have live data and predictions available from samples taken throughout water column. We have a one dimensional model that goes 40m deep.

Question - Daniel Rabu: You mentioned deep upwelling is up - is the chemistry different in 10-20 years? What percent of the Strait is affected by OA? How tightly coupled is OA to the upwelling?

George - The timing and intensity of upwelling varies from year to year. You can project, but every year it is a little bit more, raising the upper limit. But, we do know it's going to get worse.

Debby - The upwelling signature is there, but the outer ocean conditions are heavily modified before it comes in (to the Strait) and actually raises the pH of the water. As the waters become more carbon rich, it's going to make things worse. Things in the Strait are a little more delayed but can be more intensified.

Question - Gregor Reid: Rob, what are your concerns and thoughts?

Rob - I have a different opinion. The Strait acts different; we can see pH changes within hours. We lost most of our production in 2013; we initially saw stress, but lost 10 million animals by end of summer. We are monitoring pH and buffering our seawater, so I have no clue why we cannot grow anymore. Our oyster larvae are increasing in size (380µm oyster larvae), but this enormous sized larvae will not settle (same thing seen in China). We switched to rock scallops last year and initially we were very encouraged; they spawned several million and grew well, but now we are having a lot of difficulty with them. We tried to get some support from Genome Canada to get marker assisted selection. There are lots of things that have impacted our company. We measure parameters 3-4 times a day (pH, alkalinity, aragonite, salinity). Last year we saw some interesting things- live oysters in ditch in 22-23 ppt salinity, so started pumping ditch water into the hatchery; we were doing well, growing, and they stopped dying so we thought it was a freshwater issue. Everything we tried worked for a short period of time, but then things were not so good. We then started to think it was some sort of pathogen. I'm not sure what the issues is. If it is a virus, why do some groups perform well and others don't?

Question - Rob Saunders: Are they any markers with some resistance to pCO_2 or aragonite resistance?

Gordon King (audience) - In the Taylor hatcheries, we are trying to breed different lines of oysters. We are having lots of problems, with poor survival. We can't maintain the lines, so we are trying to grow some seed, and getting some good sets with larvae. I don't know that there are genetic markers for resistance- always a challenge.

Question - Daniel Rabu: My partner owns a hatchery and I am trying to put my finger on why we are reporting higher oyster production, close to Island Scallops (100km North). Is it a water issue? There seems to be a disconnect.

Rob - I agree. We tried changing our water source several times. I'm not sure what your salinity is- maybe it is your water quality that is different than ours? We can buffer the water, get larvae, and just before harvest, they all die (spent a fortune). We gave away a lot of rock scallops, where some had success, but others didn't. I personally think that we should be trying to identify markers of survivals to breed for optimum conditions.

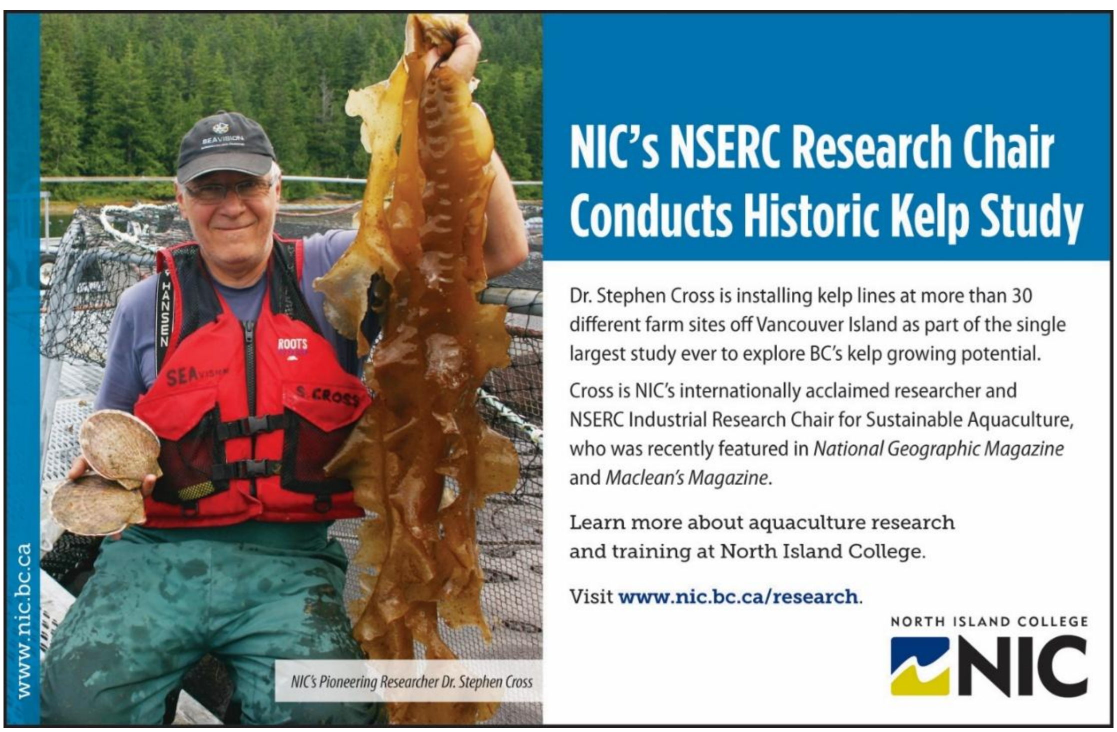
George - If we look at the Whiskey Creek example, they had Type 1 and Type 2 failures. Type 1 (early) was solved by buffering, but this does not help Type 2 (later). It is not *vibrio*, as this comes in when things start dying. Although, it might be disease related. A lot of work needs to be done through collaboration and breeding programs.

Question - Daniel Rabu: What is the cost of buffering and fixing water?

Rob - It is cheap. We use calcium hydroxide and sodium bicarbonate, which is less than 5% of hatchery costs. It might be my pessimism, but I don't think we can ever get back to that state of producing large quantities. I think scallops are an early warning sign. One of the interesting things we saw last year was a 5ºC temperature drop last year in August. We thought it was an error, but saw same thing at Chrome Island. What drives that (cool deep water)?

Gordon King (audience) - Low O_2 and high CO_2 comes in late summer.

Debby - The canal event is closely related to the upwelling that is occurring. Chrome Island has a lot of back eddies and odd things happening, but a lot of time it is not related to that.



Breakout Group Discussion Summaries

Genetics, genomics and biotechnology breakout group

Left-right clockwise: Maureen Ritter (Cyrogenetics), Ben Koop (University of Victoria), Helen Gurney-Smith (Vancouver Island University), Katie Lotterhos (Northeastern University Marine Sciences Centre), Monique Raap (Vancouver Island University), Yvonne Sheenan (Marine Harvest Canada).

The 'Genetics, genomics and biotechnology breakout group', discussed limitations such as: existing broodstock inventory, infrastructure and qualified staff for maintaining broodstock strains, trait focus priorities, and differences of stressor sensitivity between strains. Research and mitigation responses are highly species specific but diversification and increasing roles for genomics targeting organism health show promise.

Knowledge gaps and challenges

- Need well established broodstock and broad base of inventory, prior to moving forward
- Need stable infrastructure for maintenance of broodstock and qualified staff
- Focusing on the desirable traits for selection given the stressors and production needs
- Optimizing desired traits by using highly selective breeding programs
- Industry needs to be aware of the stressors specific to the product that they are raising
- Because we may not always be able to continue to grow in the natural environment we have to continue to research other viable options
- Policy and financial constraints

Research response

What stakeholder should be involved, and what specific actions could each take?

- Industry, academics, governance
- Selection of priority of species (industry diversification)
- Endemic vs. exotic species should be considered as possibilities for diversification and sustainability
- Limitations are, lack of supporting genomic information for some commercial or related species, needed as basis for selection programs
- Looking at effects of disease and specific issues (pH, temperature) using transcriptomes (more accessible research)
- Greater research efforts are needed to investigate specific pathogen and host interactions at the genomic level

Can research needs be met by enhancing existing initiatives or are new initiatives needed?

- Depends on the species but for some, we have good characterization for others less (salmon better, shellfish less)
- Researchers are not always able to support non-native species or geographic zones

- Short-term and long-term actions dependent on amount of genomic information currently available
- Government initiatives are needed to improve support of this type of research
- Selective broodstock programs are being discusses for shellfish

Are there particular groups which can provide support or services to facilitate research needs, and if so in what capacity?

- Universities interested in doing research for aquaculture and have less political interests
- We need more than just government support. We need industry, university, academia as well as a national strategy not only for existing initiatives, but to drive new initiatives forward.
- Genomics are part of this research, but as a longer term plan

Ranking of potential threats

Shellfish

1. Ocean acidification, number one threat
2. Disease
3. Lack of diversity of culture species

Finfish

1. Oxygen and temperature, but we can select through broodstock programs
2. Benefits of salmon is that they are highly adaptable
3. A large limitation for sablefish culture is the lack broodstock programs

Mitigation approaches

Finfish

- Currently monitoring for oxygen and upwelling systems in an engineering context, to reduce impacts of algal blooms
- Mitigation strategy going forward, a highly diverse breeding program for future use
- Maintaining the wild populations for a future gene banking

Shellfish

- Mitigation strategy going forward, a highly diverse breeding program for future use

Maureen Ritter, Ben Koop

Additional aspects

Finfish and Shellfish

- Maintaining genetic diversity for future threats
- All female stocks
- Triploids
- Hybrids (maintaining two parental stocks)
- Genome banks (cryopreservation) for multiple species

Fish health breakout group

Left- right clockwise: Dean Trethewey (Marine Harvest Canada), Stewart Johnson (Fisheries and oceans Canada), Grace Karreman (Syndel Laboratories), Ahmed Siah (BC Centre for Aquatic Health Sciences), Kyle Garver (Fisheries and Oceans Canada), Simon Jones (Fisheries and Oceans Canada).

The 'Fish health breakout group' discussed the need for a broader definition of fish health and several knowledge gaps, such as, information absence on the effectiveness of various mitigation/adaptation strategies. A particular concern was the very limited assessment of existing data, its value, and the lack of communication between stakeholders on these data. Research response is likely to be regional specific, by needs to be cross-disciplinary. Threats are also, likely to be regional or site specific. Harmful algal blooms, water quality, effects to phytoplankton and a lack of mechanism to understand effects of multiple stressors on 'health', were emphasized.

Knowledge gaps

- We are not presently looking to mitigate/adapt what is happening now (e.g. changes to duration and magnitude of severe events)
- We are not taking advantage of existing data sources (e.g. physical, chemical biological and disease), lack of data integration and lack of resources to analyse, interpret and store these data
- We have not defined the value of these data outside of the area of aquaculture (e.g. inherent value to other coastal users)
- What is the value of ongoing company-based monitoring to the company, and other related groups?
- Limited communication between interested parties on existing available data (e.g. public health, wild fisheries)
- Who should take responsibility for collecting maintaining and interpreting data?
- The degree to which data collected by finfish and shellfish groups are complementary
- There is a need to determine how sustainable our current mitigation/adaptation strategies are in an environment where unfavorable conditions may be increasing in magnitude and frequency.
- What are the limitations of the current mitigation techniques and consequences to the bottom line?
- If we are interested in how changes in the magnitude and severity of stressors impact aquatic animal health what are we going to measure as the endpoint (growth, survival, metabolic functions)? What would it cost to get there?

Research response

Can research needs be met by enhancing existing initiatives or are new initiatives needed?

- Research priority setting requires: cross disciplinary/cross industry approach to identify and focus on priorities based on our shared understanding.
- A shared industry health, harmful algal bloom, etc. database, will help identify priorities for research needs and response
- Objective measurements are needed to enable comparisons across industries and long term trends (e.g. productivity/ value/ survival/ growth/ feed conversion)

Are there particular groups which can provide support or services to facilitate research needs, and if so in what capacity?

- Insurance companies
- Industry stakeholders (fish and shellfish)
- Governmental agencies

Stewart Johnson

Ranking of potential threats

- Many threats can be identified, but current information is needed to rank and set research priorities on threats. These threats will also vary depending on whether it is a specific site, regional or global problem. Some specific threats discussed included:
- Harmful algal blooms; we need to understand interactions between physical and chemical factors
- No mechanism for understanding the consequences of multiple stressors on 'health'
- Other current high priorities include, phytoplankton, dissolved oxygen, and salinity

Mitigation approaches and strategies

- Predictability goes a long way to developing and supporting mitigation
- Measure outcome of different climatic-driven factors across different life-history stages

Some current mitigation strategies currently being employed:

- Coordination of feeding with flood tide
- Phytoplankton and temperature monitoring

Other considerations

- We need to assume a broader view of 'fish health'
- Cost benefit analysis is required on any mitigation/adaptation strategies
- We are not directly addressing the issue of climate change issues *per se*, but indirectly through health issues related to extreme events (duration, frequency, consequences, catastrophic and chronic)
- Strong finfish bias on aquaculture health focus

Nutrition breakout group

Left- right: Gregor Reid (University of New Brunswick), Ian Forster (Fisheries and Oceans Canada), Jason Mann (EWOS), Odd Grydeland (Odd Grydeland Consulting).

The 'Nutrition Breakout Group' highlighted knowledge gaps, in areas of nutrient utilization (shellfish and finfish), nutritional augmentation for disease mitigation, and low oxygen feeding, under changing seawater conditions. Sourcing of finfish feed ingredients under already dwindling pelagic fisheries was a particular concern. Some mitigation aspects that were discussed, focused on improved feeding strategies for low oxygen, specialty diets under high-stress conditions, oral vaccine delivery, and development of 'recovery feeds'.

Knowledge gaps

- Potential changes in nutrient utilization by finfish with changing seawater
- Climate change effects on already dwindling supplies of pelagic fisheries as a key source of raw materials
- Low dissolved oxygen in seawater and how to feed fish (e.g. salmon) under more stressful conditions
- Changing seawater conditions and the effects on shellfish nutrient needs
- New disease challenges under changing seawater conditions
- How functional feed components can help salmon farmers
- Maintaining omega 3 fatty acid levels in farmed fish is important

Research response

What stakeholders should be involved, and what specific actions could each take? A government response is required under changing climate trends to assist:

- By-products industry – re-route waste into raw materials
- New finfish species to use by-products
- Fish farmers – for field trials
- Feed industry - to help support development of local raw materials and the growth of fish farming
- British Columbia Salmon Farmers Association, DFO, Vancouver Island University, for practical research
- DFO and BC Governments to help us grow aquaculture

Can research needs be met by enhancing existing initiatives or are new initiatives needed? Existing *and* new initiatives are needed. Some options detailed below:

- To develop diets and additives under new climate and seawater conditions, Western Diversification, DFO, and Joint/collaboration of industry partners should work collectively to support practical and applied research.
- Genetics related work is needed to focus on ingredients, fish genetics selection

What groups can provide support or services to facilitate research needs, and if so in what capacity? NSERC, National Research Council, Industry, British Columbia Salmon Farmers Association Science Advisory, Vancouver Island University, DFO Fish Nutrition, Genome BC/Canada, University of British Columbia

- All groups to work on applied and practical work to help answer industry problems
- Adopt the Western Regional Aquaculture Centre (US) concept, extension of results
- DFO nutrition research related to aquaculture is primarily done in collaboration with industry partners to prioritize relevance and application. The DFO and industry-funded ACRDP program has phased out funding for production-based research. However, the potential role of nutrition-related research to improve climate change adaptation and improve sustainable ingredient sourcing, may warrant a revisit of the DFO aquaculture nutrition strategy

Ranking of potential threats to adaptation

Challenges can be loosely classified under breakout group categories. We rank limitations in the following order:

1. Management, governance & infrastructure (regulatory red-tape)
2. Research on nutrition and fish health and genetics, genomics and biotechnology; tied here
3. Need for additional biological, chemical and physical monitoring

Jason Mann

Ian Forster

Mitigation approaches and strategies

- Recovery feeds needed for long missed feeding periods
- Oral vaccines, to help improve fish health under demanding conditions
- Alternative species/strains better adapted and matched with related diets under warming waters
- Feeding practices and training of feed technicians under ever-increasing periods of low dissolved oxygen (due to climate change)
- Specialty diets and functional components which can be used to increase the fish's tolerance to perform under warm water or low dissolved oxygen conditions
- Finfish diets suited for low dissolved oxygen and warm-water conditions
- Explore micro-algal production as an alternative feed ingredient, along with the potential of using fish nutrient waste to fertilize the algae

Additional aspects

- Consider a hybrid approach of current practices (e.g. shorter sea grow-out time for salmon- being tried in Norway). Raise in freshwater to a size of one kg, then introduce into seawater cages, improving environmental control in a changing environment. (e.g. prevent Dodge mouth rot).
- Net pen liver disease is an emerging condition needing practical solutions, possibly through diet
- Diets for new species (to be identified) more suited for the warming conditions we are seeing in the Pacific Northwest waters

Management, governance & infrastructure breakout group

Left - right clockwise: Michele Patterson (University of Vancouver Island), Don Tillapaugh (Vancouver Island University), Nathan Blasco (Fisheries and Oceans Canada), Kevin Onclin (Badinotti), Grant Warkentin (Cermaq), Rachael Ritchie (Genome BC), Matthew Clarke (Marine Harvest Canada), Naomi Tabata (North Island College).

The 'Management, governance and infrastructure', breakout group, discussed concerns and knowledge gaps within governance and management of BC aquaculture, in the context of climate change. Primary concerns, included limitations of government support for adaptive policy and research, unknown impacts of climate change on farm-raised species (particularly shellfish) and, a lack of a coordinated industry effort for advocating industry issues. A key research and mitigation suggestion, was an improved knowledge base of climate change effects for specific aquaculture regions. This could be developed as a network of aquaculture companies with key partners, to compile historical environmental data, make it accessible, while enabling future data storage. This would require support by funding agencies and enabling government policy. It would be a good first step engaging the industry and assessing historical environmental trends needed for climate change adaptation.

Knowledge gaps

Overarching concerns included:

- Policy gap: Standards development and policies needed with respect to climate change and aquaculture
- A need to respond quicker – important for federal government to support an adaptive management approach to help enable responses to climate change
- Uncertainty, complexity, and confounding nature of climate change impacts/potential responses (e.g. organism response – difficult to govern or manage without knowledge of how animals will respond to anticipated conditions). Many changes will occur over next 10-20 years and uncertainty, as to how regulations, economics, and politics may affect the ability of companies to respond to those changes (e.g. Atlantic salmon – most suited to aquaculture – but will the predominant culture species need to change if it don't adapt well?).
- Is more culture diversification, or are different locations needed to spread risk?
- Slow rate of change, action and support by government (the industry has successfully developed despite limitations in government support and lack of a lead agency. This has not been conducive for future investment).
- Government limitations in research funding, resulting in a poor research investment. More

research infrastructure and support is needed nationally.
- Lack of a common aquaculture industry advocate and research direction. There is a perception that finfish issues are prioritized over shellfish issues.

More specific concerns include:

- Knowledge gaps of climate change implications for new shellfish species
- Are we prepared with appropriate broodstock?
- How will climate change affect invasive species?
- Engineering solutions needed, for effective mitigation strategies, techniques for algae blooms, siting locations, minimum standards, offshore issues
- Physical ocean monitoring and modelling needs
- Lack of capacity for research in shellfish industry; finfish companies have greater capacity to manage research projects internally
- There is a lack of basic information and data. The industry needs long term data sets to be able to make predictions into the future. No specific institute is currently coordinating a team based data gathering effort (e.g. freshwater lakes monitoring program).

Research response

- A network of aquaculture companies (big and small) and partners for ocean monitoring should be established
- Assess historical monitoring data already collected (e.g. federal government)
- Oversee data quality
- Potential application of extension services (e.g. disseminate research)
- Funders that can support/facilitate research needs
- Include modellers and other pockets of expertise to assist management and analysis of data

What stakeholder should be involved, and what specific actions could each take? Government, First Nations, academia, community, private sector, all need to be involved at some point. We suggest the following recommendations:

- A 'Blue Ribbon Panel' approach for Canada
- Lobbying for increased resources for the sector
- A network approach to bringing all the data together from all stakeholders
- An asset scan

Don Tillapaugh

Can research needs be met by enhancing existing initiatives or are new initiatives needed? We need to know state of the environment first, but new initiatives are likely to be needed.

Requirements for research response:

- Define particular groups which can provide support or services to facilitate research needs on climate change and aquaculture, and their relative capacity
- Need to better utilize and look outside traditional Federal/Provincial government (policy, political) processes to propose new policies relevant to climate change and aquaculture
- Need new capacity, resources, coordination and infrastructure to deal with existing data, collect new long term data, monitor, etc.
- Need supportive environment for innovation in technology, and using adaptive mechanisms to look at issues with respect to climate change (new species development, breeding, siting, new genetic material, therapeutants, pests, etc.)
- Geographic risk management should be applied in the policy environment so companies have some freedom to innovate.

- Need breeding programs which will be more temperature tolerant/ adaptive

Ranking of potential threats

Finfish

1. Slow response of Provincial government to respond in a timely manner to new sites, or site adjustments needed for climate change adaptability
2. Access to additional, improved pharmacological/organic-style solutions to new problems/emergency situations, in light of climate change

Shellfish

1. There are several threats to shellfish industry; some specific to climate change but also ongoing issues, that will be exacerbated under a changing climate. Potential threats include, no standard operating procedures, no stable supply of seed, no hatchery stabilization, no data in many parts of the coast, understand species biology (8 species), limited R&D investment, no capital, limited local knowledge base and ocean acidification issues exacerbated by lack of a strong science foundation.

Mitigation approaches and strategies

Finfish

- More partnerships with First Nations
- New self-regulations/standards developed by companies
- Fast track geographic diversity. Create new protocol for timely government response to industry issues.

Shellfish

- Acquire baseline biological data to make better decisions on siting, monitoring etc. and to expand operations

Biological, chemical and physical monitoring breakout group

Left- right clockwise: Barb Bunting (Island Scallops Ltd.), Gordon King (Taylor Shellfish Canada), Grant Hunt (Island Sea Farms), Jay Pudota (Marine Harvest Canada), Karen Hunter (Fisheries and Oceans Canada), Elana Downey (BC Centre for Aquatic Health Sciences), Sarah Dudas (Vancouver Island University), Susan Allen (University of British Columbia), Debby Ianson (Fisheries and Oceans Canada), Ken Denman (University of Victoria), Nicky Haigh (Microthalassia Consultants Inc.), Tamara Russell (Vancouver Island University), Wiley Evans (University of Alaska Fairbanks), Daniel Rabu (Haida Seafood Products Ltd.), George Waldbusser (Oregon State University), (absent from photo, Rob Marshall- Mac's Oysters Ltd), Yves Perreault (Little Wing Oysters Ltd.), Chris Pearce (Fisheries and Oceans Canada).

The 'Biological, chemical and physical monitoring group' discussed current knowledge and programs conducting monitoring in BC, with a view to identifying effective resource utilization for monitoring currently, as well as historic data and under future climate change modelling scenarios. Primary concerns included scale of coastline and variability, resources available and levels of threat to mitigate for future climate change scenarios.

The take home message of this group was that stakeholders believe monitoring is essential, but we need to be able to use the data to identify climate change / ocean acidification related phenomena, to help the industry.

Questions posed:
What are the major knowledge gaps or limitations?
Can research needs be met by enhancing existing initiatives or are new initiatives needed?
What stakeholder should be involved, and what specific actions could each take?
What is the threat potential and possibilities for mitigation strategies?

Knowledge Gaps

- Spatial and temporal variability of pH and pCO_2 around BC coastline poorly sampled and understood
- Physical gaps: winds, waves, storm surges?
- Site specific observations? What variables?
- Lack of comprehensive historical data
- Uncoordinated data gathering / reporting (need for standardized monitoring, both in data collection and variables)
- Problems with ease of data access and coordination between different sectors

Identifying limitations

- Have existing data from many sources - need standardization of methods for comparison purposes, centralization of data, mentors and new methods incorporated
- Need funding for data management and expertise for interpretation
- Need support data for developing validated models

Research Response

- Possible working group: BC Shellfish Growers Association, BC Salmon Farmers Association, Department of Fisheries and Oceans, BC government, academia (universities), established networks (Ocean Networks Canada, MEOPAR), First Nations and nonprofit partners
- Sharing existing data – website: new or existing?
- Are there particular groups which can provide support or services to facilitate research needs, and if so in what capacity? Involve First Nations and industry – foster cooperation and raise political profile. Need coordinate effort between all groups to ensure consistent repeated messaging to politicians and policy makers (the formation of a "Blue Ribbon" expert panel was discussed)
- Develop a combination monitoring approach for supporting data gathering and local stakeholders, providing real-time data and validated models of current and future conditions and threats
- Collate current historical data from industry to help develop baseline data for BC
- Data must be used for generated peer-reviewed papers to assist in guiding policy


Debby Ianson, Ken Denman

Research Ranked Priorities

1. Ocean acidification
2. Increase spatial coverage
3. Integration of monitoring data
4. Temperature / salinity
5. Physical threats

Mitigation Measures

- Develop monitoring programs and data access that can be used by governance and industry for management purposes (e.g. hatchery water intake, juvenile out-planting, site regulation)

- Develop coordinated database to enable central data sharing for academics and any interested user group such as public (including citizen science contributions)
- Include farm health data to help establish links between harmful algal blooms and stress / mortality responses (to enable prediction of occurrence and level of toxicity) as early warning system for operations
- Enable optimum site selection for new sites based on practicality (industry) and usefulness (science)

Pacific workshop research strategies and next steps

At the end of the second day, a general discussion was held to reflect upon the topics presented, explore where we should go next and consider possible research strategies. Most of this discussion ultimately fell under two categories: How to resolve data issues around water quality monitoring, and the need for enabling governance. These discussions are summarized below.

The data dilemma

Historical data, such as water quality, rainfall and current flow are needed to determine the amount and rate of environmental change in marine systems that has occurred in recent decades. Such data is also crucial to support climate change projections, which are needed to guide decision making and adaptive response for all costal users. A reoccurring theme of discussion was the lack of consolidated information on marine environmental change throughout inshore areas in BC, where most aquaculture operations are located. Ironically, a wealth of data has been collected by finfish and shellfish producers since the 80s to support operational management and strategic decisions. Despite the potential wealth of this resource, these data have not been compiled, collectively stored or analyzed. This information is needed in order to help inform the aquaculture community or other coastal stakeholders on what past conditions have been, changes observed over that decade (plus) and what the ramifications may be for coastal BC productivity in future climate conditions.

Possible approaches to collect and analyze this data were discussed. The amount of data is unknown and it was acknowledged that data would have varying degrees of accessibility. Some larger companies have water quality data highly organized and 'cloud stored'. Some data, collected by companies which have gone out of business, may be lost forever. There was some discussion on data quality, but it was suggested that most data would be of high quality, as it was collected by professionals and good quality data is routinely needed for day-to-day management decisions.

It was emphasized that data is of limited usefulness unless it can be turned into useable information. Enumerating, gathering, assessing quality, storing and analyzing this historical data is likely to be a very large task. The example of genomic data collection was given; where a vast amount of information has been stored, but despite good funding, the rate at which the data is being processed is still very slow.

Extensive cooperation and a team approach is needed to accomplish this type of project. Not only between finfish and shellfish operators, but with cross-disciplinary researchers, IT professionals and other stakeholders. Such an endeavor would also be a good opportunity to benefit from coop and graduate student support. Multiple levels of communication would ultimately be required: one for stakeholders, one for the public and a mechanism to make raw data availed to researchers, etc. The project scale though, would make it very difficult to accomplish without some funding and good leadership. The general consensus was that in the absence of sufficient resources, aquaculture operators will continue to collect water quality data as they always have, but most data will not have

Simon Jones

opportunity for critical analysis needed in order to quantify climate change mediated environmental stressors.

Making publically available, a valuable resource for climate change adaption to the benefit of all coastal users is stewardship. This information will benefit fisheries, eco-tourism, the resource sector, transportation, First Nations and the public. An initiative of this nature, could enable new partnerships and facilitate access to resources not typically available to the aquaculture community. In this context, some regional, national and international funding options were discussed and there was advocacy to look beyond typical aquaculture funding research avenues, such as DFO. However, the BCSFA Marine Environmental Research Program was mentioned as a good starting point for initial project work. The creation of a small team was suggested to bring this intuitive forward and a number of participants volunteered to plan a follow-up meeting.

Gregor Reid

Enabling governance

A reoccurring theme in aquaculture has been the need for enabling effective governance. While this has always been an ongoing issue, the need for timely and responsive government has become even more acute under a changing climate in order to better facilitate adaptive and mitigation responses. While some adaption, such as engineering solutions, can be undertaken quickly, usually without the need for government approval, other solutions are subject to timelines of regulatory approval. Some examples mentioned include, the approval rate for new feed ingredients (e.g. for stress 'recovery' diets), timely access to alternative culture sites (e.g. better water quality), culture species (e.g. diversification potential) and the rate of emergency drug approval (e.g. accelerated infection rate under warming waters).

Odd Grydeland

One of the perceived impediments for improving enabling governance, was the lack of a unified voice from aquaculture. It was mentioned, that this workshop was one of the few times in recent memory that both BC finfish and shellfish producers have been in the same room. Even the finfish producers have reported difficulty meeting together on common issues, amongst themselves. Some workshop participants work with First Nations, and suggested that they are the greatest opportunity to evoke change and want to engage them in these type of meetings.

An effective communication strategy is needed. It should be simple, aiming for middle school level to ensure clarity. Such an effort, needs to be well coordinated to produce results. There is a coordinated voice on the US west coast, and it was suggested that this was in part why the only NOAA (National Oceanic and Atmospheric Administration*)* program not cut, was the Ocean Acidification Program. A lead agency in Canada, with an internet portal, would be a big assist for a coordinated communication strategy. A white paper such as the 2003 IHN report, was also suggested as a proven approach to get traction.

Left – right: Kevin Onclin, Grant Warkentin, Rachael Ritchie, Matthew Clarke

In Closing

The climate change issues discussed at this workshop are about more than just aquaculture. Research and decisions that help inform aquaculture for mitigation and adaption will also benefit other coastal users. This is about the coastal economy and the coastal environment.

Workshop feedback was very positive. One participant stated he gained personally from this workshop, and was going to implement what he learned and discuss with others, that are also affected by these issues.

One of the primary NSERC objectives for funding these workshops is the initiation of research proposals. Plans made at the workshop to affect monitoring data solutions, attest to the initial progress already made. Some final thoughts were discussed on funding options and it was agreed that good ideas can get funding, assuming the problem is framed correctly and has a practical outcome. It was felt that the Proceedings of this workshop will have value as a citable document that frames climate change and aquaculture problems both regionally and nationally, but also suggests potential solutions that can be used to support future research direction.

Left-right foreground: Gordon King, Debby Ianson, Joanne Liutkus

Acknowledgements

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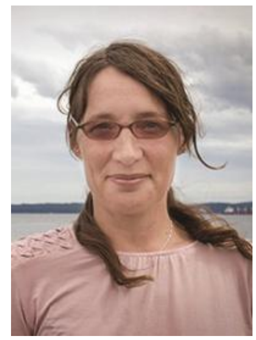
Simah Dodd

Kayla Mohns



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Aquaculture Canada and Cold Harvest 2016 Conference and Tradeshow

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- Aquatic Animal Health and Integrated Pest Management
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- Aquaculture and Coastal Management
- Benthic Monitoring
- Nutrition and Feeding
- Genomics and Breeding
- Physiology
- Integrated Multitrophic Aquaculture and Aquaponics
- Labour Market
- Land-based Aquaculture
- Advances in Shellfish Aquaculture
- Advances in Finfish Aquaculture
- Innovative Technologies

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