BC Centre for Disease Control
An agency of the Provincial Health Services Authority

Summary Working Group Report of the Environmental Transmission of Norovirus into Oysters

following the 2016 / 2017 national outbreak of norovirus linked to the consumption of BC oysters

Authors: Aroha Miller, Emma Cumming, Lorraine McIntyre, and the Environmental Transmission of Norovirus into Oysters working group members

Final Report September 2018

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Suggested citation for this document:

A. Miller, E. Cumming, L. McIntyre and the Environmental Transmission of Norovirus into Oysters working group members. Summary working group report of the environmental transmission of norovirus into oysters following the 2016-17 national outbreak of norovirus linked to the consumption of BC oysters. Environmental Health Services, BC Centre for Disease Control. June 2018. Available on-line from:

This report represents the general opinion of the working group, and may not necessarily reflect individual opinions of working group members or the opinions or policies of agencies

Any questions may be directed to fpinfo@bccdc.ca.

Agencies who participated in this working group are gratefully acknowledged and include:

- Alberta Health Services
- BC Centre for Disease Control
- BC Ministry of Agriculture
- BC Ministry of Environment
- BC Ministry of Health
- BC Shellfish Growers Association
- Canadian Food Inspection Agency
- Centre for Coastal Health
- Department of Fisheries and Oceans
- Environment and Climate Change Canada
- First Nations Health Authority
- Health Canada
- Indigenous Northern Affairs Canada
- Public Health Agency of Canada
- Vancouver Island Health Authority
- Washington State Department of Health

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Executive Summary

Norovirus is a highly contagious virus that causes vomiting and diarrhea. While it is most commonly spread person-to-person, illness may also occur from consuming contaminated food or water (1). It is a resilient virus with a hard outer shell, and under favorable environmental conditions is able to survive for several months in water and several weeks on surfaces (2).

In November 2016, a norovirus outbreak linked to BC harvested oysters began. The outbreak affected more than 400 Canadians over six months; it was declared over on May 11th 2017 (3). Under the umbrella of the national Outbreak Investigation Coordination Committee, a working group was formed to explore potential causes of environmental norovirus contamination in the growing waters of oysters (Environmental Transmission of Norovirus to Oysters working group, Box 1).[1] Knowledgeable specialists from multiple disciplines including environment, fisheries, public health, regulators and shellfish industry farm owners and managers were invited to provide expert opinion. Experts from outside the working group provided information on specific topics to assist the working group discussions. The purpose of the group was to identify plausible sources of environmental norovirus contamination that may have led to this outbreak in order to mitigate risk of future illness.

Box 1. Environmental Transmission of Norovirus in Oysters Working Group Members

1. BC Centre for Disease Control
2. BC Provincial Ministry of Environment
3. BC Provincial Ministry of Agriculture
4. BC Provincial Ministry of Health
5. BC Shellfish Growers' Association
6. Canadian Food Inspection Agency
7. Environment and Climate Change Canada
8. Fisheries and Oceans Canada
9. Health Canada
10. Public Health Agency of Canada
11. Regional BC Health Authorities
12. Washington State Department of Health
13. Invited experts from the University of British Columbia, Centre for Coastal Health, Alberta Health Services, Applied Science Technologists & Technicians of BC and others

During this prolonged outbreak, 12 BC shellfish farms were closed. All farms were epidemiologically linked to norovirus illnesses. Tests of oysters from some of the implicated farms demonstrated contamination with norovirus, *E. coli* and/or elevated coliphage which is an indicator for enteric virus (see map). Economic losses to the shellfish industry arising from this outbreak were substantial ($9.1 million).

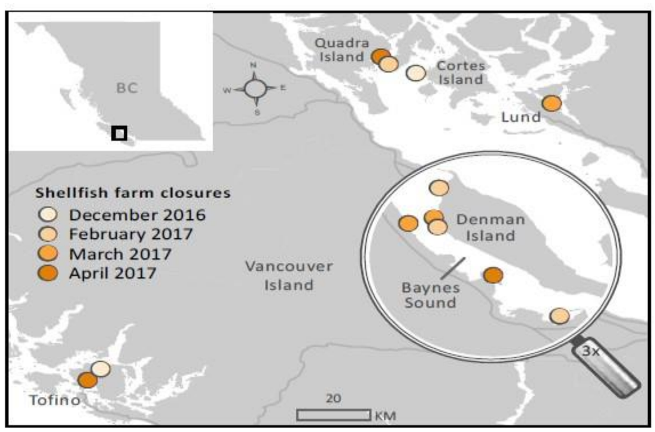

Figure 1. Shellfish farm closures in 2016-17

[1] Terms of reference for and roles and responsibilities of working group members can be found in Appendices 1 and 2.

BC was not the only location on the Pacific Northwest coast affected. Washington State also reported over 200 norovirus-like illnesses linked to more than a dozen Washington shellfish harvest sites – although the majority of illnesses traced back to a single growing area (4). Between December 2016 and April 2017, there were 145 separate case and case clusters of illnesses reported in Canada, and 49 case and case clusters reported in Washington State (3, 4).

The working group generated a list of plausible hypotheses for the environmental transmission of norovirus into oysters (summarized in Box 2) and gathered available evidence for and against each hypothesis.

Box 2. Summary of transmission pathways of norovirus into the environment

- Local and metropolitan wastewater treatment plant effluent (including system overflows)
- Land runoff and septic system discharges (including overflows from agricultural and community sources)
- Other sewage outfalls
- Discharge from boats and vessels (commercial, recreational, cruise ships, ferries)
- Wildlife (sea lions on shellfish docks)
- Movement (relay) of contaminated shell stock to a clean area
- Ill shellfish farm workers and/or float homes or float camps
- Wet-storage and processing plants
- Distributors, restaurants and retailers

Hypotheses were developed, based on knowledge of previous oyster and shellfish contamination events, and the expert opinions of working group members. The quality of evidence as to plausible source ranged from strong, i.e., direct evidence definitively proving or disproving the hypothesis, to weak i.e., indirect evidence or opinion suggesting that the hypothesis may be more or less likely. Evidence was examined as it related specifically to the 2016-2017 outbreak and, more generally, to the potential of the hypothesis as a source of contamination in BC shellfish. Arguments for and against each hypothesis were developed based on evidence collected through group discussion, expert opinion, literature review and included examination of data that informed the outbreak and working group investigations.

The working group activities included stakeholder surveys, in-depth literature reviews of specific topics, consultation with scientific and professional experts, collection and evaluation of supporting evidence, analysis of environmental parameters, sewage sources and consensus building discussions. Evidence gaps and research needed to fully evaluate these hypotheses were also discussed. Thirty evidence gaps were identified that hindered our ability to fully assess the plausible hypotheses. Evidence gaps and associated barriers were noted for:

- mapping,
- assessments of various sewage sources,
- baseline data,
- norovirus and indicator testing methods,
- norovirus behavior in marine environments, and
- epidemiological assessments.

Members were challenged by a lack of information, or where information existed, by barriers that made acquisition and interpretation of that information impossible. A status evaluation of the evidence gaps found 18% were completed and 38% were in progress by November 2017. However, for the majority of evidence gaps (43%), the working group did not know from whom to request information or agencies had no mandate or had not yet explored how to address the gap.

Working group discussions found multiple sources of human sewage contamination of the marine environment the most plausible explanation for norovirus contamination of shellfish farms. Two pieces of evidence support this conclusion.

❶ **The only way for a human to be infected by norovirus is through exposure to feces or vomit of another infected human.** Exposure to as few as 10 norovirus particles can cause illness (5). Norovirus is species—specific: only human strains of norovirus cause illness in humans. Although different strains of norovirus infect animals, evidence so far suggests these strains do not infect humans (6, 7). Animals are not infected by human norovirus, and will not amplify human norovirus even if they are exposed to it.

How did norovirus contaminate so many different shellfish farms?

Human sewage contamination of the marine environment.

Photos of sea lions adjacent to norovirus- contaminated oyster farms suggested the mammals as a plausible source; however, this hypothesis was ruled out based on direct evidence (testing of sea-lion scat in BC was negative for human norovirus) and literature review.

❷ **A single contamination event cannot explain the geographic distribution observed.** BC has linked previous norovirus shellfish illnesses to point-source contamination events in the past. In 2010, norovirus illnesses were linked to overboard discharge and dumping from a boat into one shellfish bed (8). By contrast, in 2016-17, despite an exhaustive investigation of possible pollution sources, no major issues were identified along the coastlines where oyster farms operated (9). Two minor issues were noted during the outbreak period, but neither occurred prior to the first occurrence of illnesses linked to oysters. These minor issues included a wastewater discharge >20 km away from an oyster farm, and the sighting of commercial fishing vessels in early March. Both issues could potentially have contributed to marine water contamination, and the ongoing illnesses but neither would explain earlier contamination. In the Baynes Sound area where the majority of shellfish farms linked to norovirus illnesses were located, from December onwards, there were no significant point-source contamination events that would explain the wide-spread contamination.

Actively feeding oysters can filter up to 10 litres of water per hour and will bind norovirus to their tissues (10, 11). During the winter norovirus season and because norovirus is a common disease estimated to cause 3 to 4 million illnesses annually in Canada, **all sewage discharge sources are expected to contain norovirus:** *between one to ten thousand norovirus particles per litre of water* (12).

Human sewage contamination of the environment from multiple sources is thus the most plausible reason for shellfish farm contamination and norovirus presence in oysters.

A third piece of evidence supports why norovirus, known to be present in human sewage, was able to survive in the marine environment and spread to shellfish farms in the fall of 2016 and winter of 2017.

❸ **Climate conditions affect survival of this virus. Heavy rainfall, low sunlight conditions,[2] down-welling[3] and colder than normal temperatures** allowed norovirus to persist in marine waters for extended periods (13). Norovirus is seasonal: most norovirus illnesses in North America occur in the winter (14). The 2016-17 season had a near-record rainfall event in November during the same month as the Tofino oyster festival where 118 people became ill (15). Temperatures were 2°C colder than average between December 2016 and February 2017 (15). Norovirus also survives longer in water of lower salinity (16). During extreme rainfall events, fresh-water currents floating on top of ocean water have the ability to carry marine viruses long distances. While few studies have been published on how far norovirus can travel from a source of pollution, norovirus has been detected 24 kilometers away from a sewage outfall in New Zealand (17). A United Kingdom study found norovirus levels able to cause illness in a shellfish site characterized by poor marine flushing shellfish and detectable norovirus levels in an open ocean shellfish site, both ten kilometers distant from sewage sources (18). Environmental conditions in BC in 2016-17 contributed to the widespread norovirus (sewage) contamination of the marine environment and oyster growing areas.

What caused the outbreak? Where did the human sewage contamination come from?

In BC, the most plausible sources of human sewage contamination (Box 3) are those nearest to the shellfish farms, although we were unable to rule out contamination from more distant sources. Other countries have shown norovirus levels nearer to wastewater treatment plants create a significant threat for shellfish farms and water quality (13, 19-21).

Box 3. Potential sewage sources impacting shellfish growing areas

Near to shellfish farm locations

- Septic seepage from private homeowners
- Local wastewater treatment plants, lagoons
- Sewerage overflow events from combined water/sewer drainage
- Discharge from commercial and recreational vessels
- Float-homes and float-camps

Distant to shellfish farm locations

- Metropolitan wastewater treatment plant effluent discharges

The greatest conceptual challenge was looking for a single transmission pathway to explain the outbreak.
While a single reason would be convenient,
the working group concluded that multiple sewage sources discharging under environmental conditions favourable to norovirus preservation most likely contributed to shellfish farm contamination.

[2] Strength and duration of sunlight, including ultraviolet light, is lower in the winter due to the angle of the earth relative to the sun. Incidence of rays is lessened, therefore less energy and penetration into marine waters allows for longer virus survival. Combined with cloud layer we called this low sunlight conditions.

[3] Downwelling is when wind and earth's rotation move surface water toward coastlines; upwelling is when surface waters are moved away from the coast.

We cannot fully explain the events of 2016-17: there remains uncertainty why some farms were affected while others were not, or why no norovirus illnesses were reported in other years with similar weather conditions. It remains unclear whether metropolitan wastewater treatment plants effluents [4]containing norovirus could affect distant oyster growing areas, although environmental conditions present during 2016-17 may explain how norovirus survived and why both near and distant sources of norovirus could have impacted shellfish farms.

Looking forward: solutions needed

This norovirus outbreak was not unique. A similar norovirus outbreak linked to oysters harvested from geographically dispersed farms in BC occurred in 2004. **To prevent contamination of oysters with norovirus we must control the amount of raw untreated human sewage entering the marine environment**. This will require multiple actions from multiple stakeholders at all levels of engagement: at community and government levels, with regulators, politicians, engineers, scientists and educators. The health of the public and the future of marine shellfish farming and wild harvesting are at risk from human sewage pollution. What occurred in the 2016-17 season will occur again — the only question is when. More action is required to address this public and environmental health issue immediately.

In summary, multiple sources of human sewage entering the marine environment were identified as the most plausible reason for oysters becoming contaminated with norovirus. The outbreak likely occurred in 2016-17 because environmental conditions allowed norovirus present in sewage sources entering the marine environment to be transported to shellfish farms, and to survive and accumulate in oysters.

[4] Metropolitan wastewater treatment plants were defined as plants near to urban areas and distant (>20 km away) from shellfish farms, e.g., plants located in Vancouver and Victoria.

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Glossary

There is a detailed glossary of terms relating to wastewater treatment in the literature review.
Consult the CSSP for more definitions related to oyster farming (shellfish).

Terms relating to oyster farming

Depuration: When water-dwelling animals are put into clean water for a period of time, allowing them to purge biological contaminants and other impurities.

Depuration plant and processor: A depuration plant is a facility of one or more depuration units. A depuration unit is a tank or series of tanks supplied by a single process water system. A depuration processor receives shell stock from approved areas or marginally contaminated areas and submits such shell stock to an approved controlled purification process (CSSP definition).

Float-camps: Floating accommodations for workforces, often in remote locations. Shellfish harvesting operations often use such camps to house workers.

Gage height: The depth of oyster beds relative to the surface of the water.

Relay: The transfer of shellfish from marginally contaminated areas to approved areas for natural biological cleansing using the ambient environment as a treatment system (CSSP definition). Shellfish are transferred from one growing site to another geographically different growing site as described above.

Wet storage: The temporary storage (less than 60 days) of "live" shellfish from approved sources, intended for marketing, in containers or floats in natural bodies of "seawater" or in tanks containing natural or synthetic seawater (CSSP definition). Once shellfish have left the processing plant they go to distribution and retail. Wet storage in these settings refers to shellfish held temporarily in water tanks to promote survival.

Terms relating to environmental parameters

Extreme rainfall event: When rainfall levels exceed the norm, i.e. are > 2 standard deviations above norm.

Relative humidity: The amount of water vapor in the air, expressed as a percentage of the amount needed to saturation at the same temperature.

Terms relating to sewage sources

Biological Oxygen Demand (BOD): The amount of oxygen required by micro-organisms to break down organic matter received in influent wastewater. This measurement is used by treatment plants to assess the amount of organic material in the influent, and the effectiveness of the treatment.

Biosolids: Biosolids are stabilized municipal sewage sludge resulting from a municipal wastewater treatment process or septage treatment process which has been sufficiently treated to reduce pathogen densities and vector (insects, birds, rodents, domestic animals) attraction.

Effluent: Liquids exiting a wastewater treatment plant in a treated or untreated state, released into the environment.

Fecal indicator bacteria (FIB): Fecal indicator bacteria include total coliforms, fecal coliforms, *E. coli*, fecal streptococci and enterococci. These microorganisms are used to detect sewage contamination in water. They are good indicators for bacterial pathogens, but do not perform well as indicators for enteric viruses, such as norovirus.

Influent: Liquids entering into a wastewater treatment plant, basin or reservoir. These can include grey water, black water and storm water runoff.

Male-specific coliphage (MSC): A coliphage is a microorganism that is able to infect bacteria. MSC is considered a good indicator to assess log reductions of enteric virus in wastewater and recreational water impacted by sewage contamination.

Non-point source: A source of pollution, such as sewage, that is a combination of many diffuse sources including land runoff, seepage, or drainage. Non-point sources of sewage include municipal drainage works, urban and agricultural runoff, discharges to ground from on-site sewage systems (normally septic tanks), and discharges from vessels.

Point source: A source of pollution, such as sewage, that is stationery and localized. These are more easily identified than non-point sources. Point sources of sewage include treated effluent from municipal and industrial wastewater treatment plants (WWTP) discharged into the environment via outfall pipes.

Sewerage: Sewerage is the infrastructure that conveys sewage or surface runoff (storm water, meltwater, rainwater) using sewers. It encompasses components such as receiving drains, manholes, pumping stations, storm overflows, and screening chambers of the combined sewer or sanitary sewer. Sewerage ends at the entry to a sewage treatment plant or at the point of discharge into the environment. It is the system of pipes, chambers, manholes, etc. that conveys the sewage or storm water. (as defined by Wikipedia)

Scat: Animal feces

Primary wastewater treatment: The first process, mainly physical removal processes, usually associated with municipal wastewater influent treatment that removes the large inorganic solids and settles out sand and grit.

Secondary wastewater treatment: The second process, mainly biological removal processes, where organic matter in the influent is broken down by bacteria, algae and fungi through the use of various media (e.g., trickling filters, aeration tanks or lagoons). Disinfection and chemical removal of microbes may also be used in secondary treatment.

Tertiary wastewater treatment: The use of filtration, coagulation-sedimentation, and nitrification/de-nitrification to remove chemicals and microscopic particles from wastewater that has already received secondary treatment.

On-site sewage system: A wastewater disposal system that treats and disposes of sewage on the same property that the waste was generated. Septic tanks and drainage fields are an example of this type of system.

Holding tanks: Watertight containers for storing sewage until it can be pumped out for treatment. These tanks are used in areas were soil type is not appropriate for septic tanks and fields.

Combined sewer and combined sewer overflows (CSO): Combined sewers are designed to collect sewage from buildings as well as surface runoff from precipitation. When these types of sewers overflow, typically during wet weather events, it is called a combined sewer overflow (CSO).

Sanitary sewers and sanitary sewer overflows (SSO): Sanitary sewer pipes transport sewage from buildings to wastewater treatment facilities, and exclusively contain sewage and other wastewater. Overflow events associated with these pipe networks are called sanitary sewer overflows (SSOs).

Storm tanks and storm tank overflow (STOs): Storm tanks are often attached to WWTPs or sanitary sewer collection systems in order to collect excess rainfall runoff or CSO discharge in a separate basin prior to treatment, thus preventing overload of the plant. Storm tank overflows (STOs) occur when rainfall exceeds these tanks' capacity.

Sewage outfall: a point source location, often a pipe, where effluent is released into the environment.

Other terms

Virome: A collection of viruses, often describing variation within a host organism. The human virome includes all viruses in and on the human body.

Acronyms:

BCCDC: British Columbia Centre for Disease Control

BCSGA: British Columbia Shellfish Growers' Association

CFIA: Canadian Food Inspection Agency

CFU: colony forming unit

CSO: combined sewer overflow

CSSP: Canadian Shellfish Sanitation Program

DFO: Department of Fisheries and Oceans Canada

ECCC: Environment and Climate Change Canada

EOAS: Earth, Ocean and Atmospheric Sciences, University of British Columbia

ETNO: Working group on the Environmental Transmission of Norovirus to Oysters

FIORP: Foodborne illness outbreak response protocol

MSC: male-specific coliphage

MOE: Ministry of Environment, BC

OICC: Outbreak Investigation Coordination Committee

PHAC: Public Health Agency of Canada

SME: subject matter expert

SSO: sanitary sewer overflow

STO: storm tank overflow

UBC: University of British Columbia

WWTP: wastewater treatment plant

1.0 Introduction

1.1 What is norovirus

Norovirus, also commonly known as Norwalk virus, gastroenteritis, food poisoning, or winter vomiting, is a group of highly contagious viruses belonging to the Calicivirus family (22). Norovirus is very small, only 27 nm in size (Figure 1). There are six different norovirus genogroups, three of which affect humans (GI, GII, GIV). Within these three genogroups there exist many different genotypes, or "genetic clusters" (23).

Typical norovirus symptoms are gastrointestinal, and can be mistaken for other enteric illnesses. Symptom onset can be sudden, and typically occur anywhere from 12 to 48 hours after exposure (24). Symptoms may include vomiting, nausea, diarrhea, cramps, abdominal pain, chills, or low-grade fever. Muscle pain, headache, and fatigue may be present. Symptoms typically self-resolve in one to two days, although this can take longer for some people (24). Due to the vomiting and diarrhea that accompany this illness, dehydration is of particular concern for young children and the elderly (22). In severe cases norovirus can lead to hospitalization and death (25).

Norovirus is present in the faeces and vomitus as soon as symptoms occur, and can continue to be shed up to three days after symptoms resolve, although some people can remain contagious for up to two weeks (24). Some infected individuals may be asymptomatic, but can also spread the virus to others (23). Infected individuals can shed up to 10^9 (10 billion) virus copies per gram of faeces (25), and asymptomatic individuals can shed virus for over a month (26). An infectious dose is as little as 18 virus particles (27). Immunity to norovirus is short-term, with the majority of the population susceptible to infection, and up to 40% of population not susceptible to illness, dependent on individuals' histo-blood group gut antigens receptors which bind norovirus (25, 28).

Norovirus is often associated with a lack of proper hand hygiene, and outbreaks often take place in facilities where transmission can occur rapidly, such as day cares, schools, hospitals, and rest homes. Given the high number of virus particles shed in the faeces of both symptomatic and asymptomatic individuals, and the length of time particles can be shed, only a small number of norovirus-infected individuals are able to contaminate entire sewage systems (5). If the right conditions exist, such norovirus-infected sewage can contaminate shellfish beds.

Noroviruses are environmentally hardy, demonstrating long term survival in aquatic environments and resistance to freezing, heating, disinfecting agents such as chlorine, quaternary ammonium and hydrogen peroxide(25, 29).

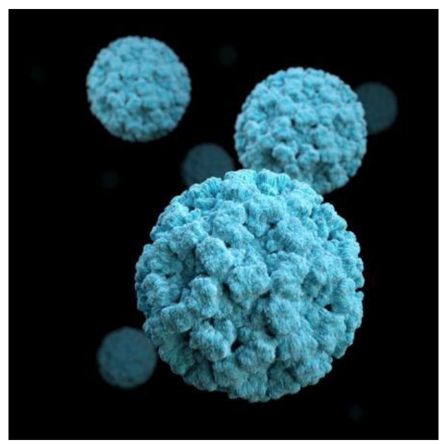

Figure 2. Electron microscopic 3D image of norovirus virions

https://phil.cdc.gov/Details.aspx?pid=21347

1.2 How norovirus gets into oysters

Norovirus is not a naturally occurring marine organism. It has to first come from somewhere – infected humans, according to current best evidence – to be present in the marine environment. There are multiple routes through which human sewage can contaminate the marine environment, for example from wastewater treatment plants, storm or sewer overflows due to extreme rain events, malfunctioning septic tanks and systems, or vessels directly discharging sewage into the water.

Oysters are filter feeding bivalves, meaning they filter the water around them to collect their food, ingesting whatever is in the water, including human norovirus bound to sediment particles or floating in the water. Oysters selectively bind norovirus particles to oyster tissues via a ligand bond (30, 31). Norovirus may persist in oysters for 4 to 6 weeks after a contamination event (17).

It is important to consider: how far are affected oysters from potential contamination sources? After some discussion within the Environmental Transmission of Norovirus into Oysters (ETNO) working group, distances from point of contamination to oyster beds were described as either proximal, i.e., within 20 km distance, or distant, i.e., located more than 20 km from the affected oysters. This was based on evidence from one study that noted norovirus can travel in the marine environment up to 24 km (17), while a distance of 10 km has been demonstrated under different marine environments (estuarine and open ocean) (18). While proximal sources of contamination appear more likely to cause contamination more frequently, there is no evidence to suggest distant contamination sources should be excluded. Thus, contamination sources from both near and far could introduce norovirus into the marine environment (figure 2), and therefore into oysters.

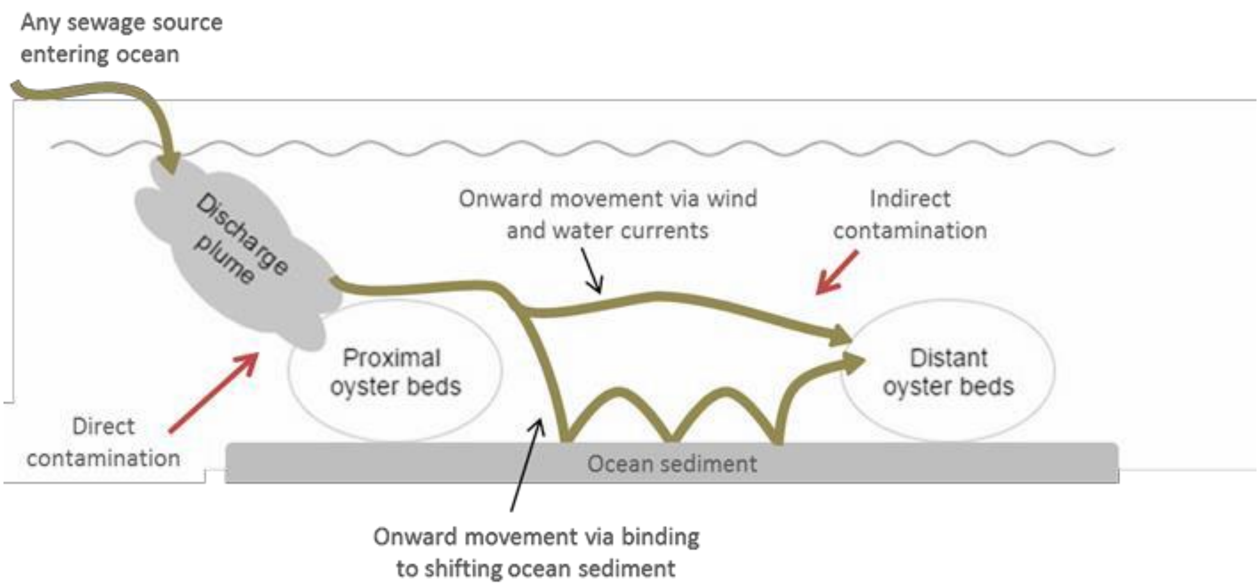

Figure 3. Theoretical transmission routes of norovirus to oyster beds in the marine environment.

1.3 The 2016-17 norovirus outbreak linked to BC oysters

In November 2016, a norovirus outbreak linked to British Columbia (BC) harvested oysters affected more than 100 patrons of an oyster festival in Tofino. Following this event, other clusters of illnesses were reported that were also linked to BC oysters. When this second outbreak was declared over on May 11th 2017, altogether these two outbreaks were responsible for more than 400 norovirus cases in BC, Alberta, and Ontario (32). Multiple illness clusters were reported through-out this second prolonged outbreak.

The **case definition** for these two outbreaks included being a resident of, or visitor to, BC or another province in Canada with lab confirmed norovirus infection or acute gastroenteritis (vomiting and/or diarrhea) within 48 hours of exposure to oysters. For the purposes of the epidemiologic investigation, secondary cases (cases that had contact with another case during their exposure period) were excluded. All cases reported having consumed raw or partially cooked oysters within 12 to 48 hours prior to becoming symptomatic (3). To successfully kill norovirus, contaminated oysters need to be cooked to an internal temperature of 90 degrees

Celsius for 90 seconds (33). Contaminated oysters cooked at a lower temperature or for a shorter period of time may still cause norovirus symptoms.

This outbreak affected multiple shellfish farms along the BC coast, with 12 shellfish farms being closed as a result of the outbreak (a complete list of shellfish closures posted on the DFO web-site is shown in Appendix 5). The economic impact of these closures was substantial for shellfish farms and seafood restaurants.

1.4 Previous outbreaks linked to BC oysters

Norovirus illness has been linked to BC oysters on two previous occasions.

In 2004, 14 shellfish farms on the east and west coasts of Vancouver Island were linked to 79 illnesses. Widespread geographic contamination was linked to consumption of raw oysters and illnesses spanned over three months. Multiple genotypes were detected in oysters and human samples. Genotype I.2 was most common. There were multiple suppliers (18) and points of purchase (45) recorded. The 2004 outbreak could not be traced back to a single point-source contamination event (34).

In 2010, 36 illnesses were traced to a single shellfish farm area. All illnesses were caused by consumption of raw oysters. In contrast to the outbreak in 2004, a single point-source contamination event was identified for this outbreak: an ill shellfish worker admitted to overboard discharge of vomitus while ill, and it is likely that this point-source contamination event resulted in contamination of the oyster bed (8).

1.5 Shellfish aquaculture

Commercial shellfish growing operations use a variety of methods based on site location, climate, potential predators in the site area, bylaws and regulations, and the grower's personal preference. Methods are typically categorized as bottom or off-bottom methods, i.e., oysters grown on the sea floor, or grown suspended above the sea floor. Growing methods do not refer to harvest methods, or larvae collection. The three most common growing methods, termed "grow out techniques" according to the BCSGA, are raft, longline, and intertidal systems (35). Raft systems are an off-bottom method, typically situated at deep-water sites, in which oysters are suspended from a raft in the water column. Raft systems may be used to suspend cages or trays of oysters, and must be anchored. Longline systems are also an off-bottom system, and are preferred in areas of high wave exposure due to their greater flexibility compared to raft systems. A length of line is anchored at both ends, with floats attached. Culture systems, e.g., bags, tubes, cages, are suspended along the line. Depending on site geography, the longlines can be anchored at one or both ends to the shore, or anchoring may be done in deep water. Intertidal systems are based in the intertidal zone where the oysters will be exposed to air at certain times during each tidal cycle. This is a bottom method, although can also be used as a near-bottom (epibenthic) method. Shellfish farmers will prepare the substrate and then seed the area with oysters grown on, e.g., racks, intertidal longlines etc. (35). Each of these methods has advantages and disadvantages, such as oyster shell strength produced by the method, percentage of crop lost to nature, ease of use, and cost-benefit of equipment needed to run each operation.

Harvesting methods sometimes include hanging oysters just below the surface of the water until pick-up at the harvest site. During this time period oysters are vulnerable to sources that contaminate marine surface water. Wet storage refers to the storage of live shellfish harvested from approved sites. Wet-stored shellfish are temporarily kept in containers or floats in in the marine environment or in tanks containing natural or synthetic seawater.

Shellfish harvested from marginally contaminated areas (as defined by shellfish regulators) may be relayed, or moved, to open clean areas under license or depurated in tanks for cleansing for a specified period. These activities are defined and managed by a federally regulated shellfish program.

1.6 Shellfish management

In BC and across Canada, shellfish are managed under the Canadian Shellfish Sanitation Program (CSSP) (36). The CSSP is a federal food safety program administered by the Canadian Food Inspection Agency (CFIA), Environment Canada and Climate Change (ECCC), and Fisheries and Oceans Canada (DFO). The CSSP has the goal to "protect Canadians from the health risks associated with the consumption of contaminated bivalve molluscan shellfish". A full description of the CSSP mandate is shown in Appendix 2. Shellfish are monitored for biotoxins regularly. Marine water quality is monitored for fecal coliforms, but does not currently include other recognized indicators of viral risk. These include enterococci used in assessment of recreational marine water and male specific coliphage (MSC), both more useful for determining viral level contamination (37-42). During investigations oysters may be tested for norovirus, but routine norovirus testing is not included in current monitoring programs. CFIA regularly tests for bacteria of concern (e.g., *E. coli* and *Salmonella)* during audits and high risk months, as well industry regularly monitors oysters and growing waters subject to a plan approved by their regulators under the CSSP.

The CSSP defines various geographic exclusion zones, where shellfish may not be harvested. These include exclusion zones of a minimum 300 m radius around points of continuous or intermittent discharge from a sanitary sewage system or industrial outfall; exclusion zones of a minimum 125 m radius around marinas, wharves, finfish net pens, float homes or other floating living accommodation facilities; a reduced exclusion zone of 25 m radius around any floathome or floating living accommodation with an approved zero-discharge plan located within a shellfish tenure; any areas around sanitary sewage discharge points that do not achieve adequate viral reduction; and areas where shellfish are unable to depurate a contaminant due to the concentration of contaminant in the water. Further details of these exclusion zones and how they apply can be found in the CSSP manual (43).

As part of its CSSP role to develop classification recommendations for shellfish growing areas, ECCC has performed modelling to determine the direction and extent of spread of human sewage plumes from point sources, such as municipal wastewater treatment plants (WWTP). ECCC utilizes dispersion modelling to inform shellfish classification recommendations for shellfish harvesting areas adjacent to WWTP outfalls. ECCC's approach to modelling WWTPs was developed to meet the performance objective (PO) identified in Health Canada's Health Risk Assessment; *Enteric Virus Contamination of Bivalve Molluscan Shellfish in Harvest Areas Impacted by Waste- water Treatment Plant Effluent*, HRA Number 1290, August 2011. ECCC uses a number of models to assess fecal coliform impacts and the dispersion area required to achieve a 4-log reduction[5] in virus concentrations. These include box models, Visual Plumes and MIKE hydrodynamic models. ECCCs approach recognizes differences in decay rates of viruses and fecal coliforms. Often the modeling includes a decay factor for viruses, however some of the modeling incorporates a more conservative assumption of no decay, relying on dilution alone to achieve reductions in viral concentrations. The area required to meet the 4-log reduction is then recommended for a prohibited classification. During spill events models are revisited to determine if additional closures are required. Because norovirus can persist longer than fecal coliforms, models using only fecal coliforms may not describe the full extent of norovirus contamination from sewage sources (44). Some ETNO working group members strongly believe the validity of this model, and it will be mentioned throughout this report as evidence for/against various hypotheses.

[5] A 4 log reduction is equivalent to 10,000:1 dilution

1.7 Outbreak response – exploring the underlying cause of the outbreak

Under the umbrella of the national Outbreak Investigation Coordination Committee (OICC), a working group was formed to explore potential causes of environmental norovirus contamination in oysters. It was the task of this working group to explore mechanisms by which this environmental contamination could occur in BC oyster growing waters. This working group was led by the British Columbia Centre for Disease Control (BCCDC), and brought together experts and specialists from 13 different disciplines (Box 1), [6] including environment, fisheries, public health, regulators, and industry shellfish farm owners and managers. The purpose of the working group was to: "identify the cause of environmental norovirus contamination of BC oysters that led to the 2016-17 norovirus outbreak in order to mitigate future risk, to enable inter-sectorial communications about norovirus transmission into shellfish in order to propose hypotheses of norovirus contamination of BC oysters during the outbreak period, to inform the community about developing knowledge on this issue, and to identify evidence gaps and opportunities for collaborative research", as detailed in the terms of reference (Appendix 1).

From the group's onset, it was clear that identifying the exact cause of the 2016-17 outbreak was not possible for several reasons. In particular, the group was formed near the end of the outbreak, and it was not feasible to obtain environmental samples (oysters, water or examine septic inputs) relevant to the outbreak time period. Instead, the group focused its efforts on identifying sources of human sewage in marine waters near and around shellfish growing areas in BC that could lead to norovirus contamination of oysters. This work provides a starting point for the next norovirus outbreak in oysters; the hypotheses presented in this report will hopefully act as a short list that will focus and inform future investigations. It is also hoped that the group's work contributes to the longer-term goal of reducing the risk of effluent and human sewage from entering the BC coastal marine environment.

2.0 Methods

To achieve our objectives, a number of different activities were undertaken by the working group.

2.1 Meetings and discussion

Meetings were held bi-weekly or less frequently dependent on when new information was available to share new knowledge across the group. This allowed for discussion of new information as it was discovered, and helped guide the work forward. A full list of meetings and topics covered is shown in Appendix 3. Most ETNO members had constraints on what document sharing programs could be used due to agency confidentiality and privacy rules. A common space (SharePoint) was set up to share documents related to the outbreak across the whole group.

Reports provided to the ETNO working group, or created by the ETNO working group are available on request if permission was received from the owner. These supplementary materials are outlined in Appendix 4. Through- out this report various items will be referenced in this appendix as supplementary material.

2.2 Generation of plausible hypotheses

One of the first tasks was to develop a list of plausible hypotheses for how BC oyster farms could have become contaminated, thereby leading to outbreaks of norovirus in humans. Hypothesis generation was based on members' knowledge of previous norovirus outbreaks through oyster consumption, and other public health,

[6] Terms of reference, and roles and responsibilities of working group members can be found in Appendices 1 and 2.

epidemiological, environmental, and food safety knowledge. After much discussion and sharing of ideas, 20 plausible hypotheses were defined (Table 1). Throughout the life of the working group, several hypotheses in the original list of 20 were de-prioritized, as they did not address the mechanism of sewage contamination in the marine environment. These included those hypotheses relating to retail and distribution level contamination.

2.3 Subject matter expert presentations

The working group invited eight subject matter experts (SME) to present to the group. A table of SMEs names and details of the key points presented to the group is included (Table 2). Information from the SMEs helped the group consider the plausible hypotheses, providing expert opinion and a deeper understanding of the SMEs' area of knowledge.

2.4 Literature search

Responses to the first survey (below) helped guide a literature review. A literature scan was conducted during April and May of 2017 using various search terms via the databases Ebsco, Web of Science, and Google Scholar. Search criteria were narrowed until approximately 600 relevant results were retrieved. With further cross-referencing, over 700 references (both academic and grey literature) were reviewed. Literature was split broadly into four categories:

- environmental conditions that influence norovirus survival in oysters;
- major sources of sewage to the marine environment in coastal BC and elsewhere;
- an overview of wastewater treatment plants;
- a review of previous viral shellfish related outbreaks.

A full description of the literature search and the results of the literature review are available in a separate report as supplementary material.

2.5 Surveys

To streamline the group's investigations, given limited personnel and time resources, a short survey was devised to help prioritize the investigation of hypotheses. The survey was circulated Apr 2017 to the ETNO group, members of the OICC, and others. A second, follow-up survey was circulated in Dec 2017 to ETNO members. The purpose of this survey was to: 1) find out if the work conducted and knowledge shared had informed and/or changed the minds of ETNO members about the plausible hypotheses; and 2) provide a weight (weak, moderate, or strong) to each hypothesis based on the knowledge gained via the working group activities.

In Nov 2017, interviews of septic system experts in areas near implicated shellfish farms were conducted. A google search of "septic repair", "septic pump-out" and "septic" identified ten businesses of interest; five of these businesses replied to interview requests. Questions explored whether the business conducted septic inspections, repairs, or pump-outs, how long they had been in business and what geographic areas they serviced. Further questions related to their opinions of potential sewage seepage into the marine environment from systems they have inspected, and the estimated proportion of systems they observed with issues/malfunctions.

2.6 Identifying gaps in knowledge and barriers to investigation

Gaps in knowledge were identified based on:

- literature review findings;
- presentations made to the ETNO group;
- discussion generated from SMEs presentations.

Identification of knowledge gaps allowed the group to highlight areas that suffered from lack of research or knowledge, preventing the group from drawing solid conclusions about proposed hypotheses. The group also identified barriers that impeded the gathering and sharing of knowledge, and restricted the ability of the group to narrow down the hypotheses.

2.7 Synthesizing knowledge to inform plausible hypotheses

The final task of the ETNO working group was to synthesize the knowledge gained from the findings of the working group into a final report – this document – to:

- keep the process transparent;
- help drive future decisions and policy on any information found;
- provide background information for when such an outbreak reoccurs.

Here we provide detail related to each of the key activities, and present an overview of findings. Each hypothesis, or in some cases, hypotheses grouped by mechanism of contamination, are considered alongside the evidence for and against that was gathered in relation to each one. The source of evidence in each review is identified as originating from:

- literature review;
- working group discussion;
- expert opinion solicitation; or
- some other named source.

2.8 Marine mammal norovirus testing, descriptive time-series of environmental factors, and mapping of sewage sources

ETNO working group members collected evidence during 2017 to inform plausible hypotheses in three areas: testing of marine mammals for norovirus, modelling of environmental factors and mapping of sewage sources. Each activity is briefly described below.

2.8.1 Marine mammal testing for norovirus.

Scat from marine mammals was requested for testing, and collected by DFO and the Vancouver Aquarium. DFO collected six sea-lion scat samples from the Baynes Sound area on April 11, 2017. The Vancouver Aquarium collected 14 scat samples from rescue harbour seals and 32 scat samples from sea lions in the Tofino long beach area on May 9, 2017. All samples were tested for the presence of norovirus at the PHSA BCCDC Environmental Microbiology laboratory.

2.8.2 Descriptive time-series of environmental factors

A times-series analysis of BC environmental factors in oyster-harvesting areas was conducted for the period 2002 to April 2017. Monthly aggregates of rainfall, salinity, sea surface temperature, upwelling (an indication of the strength of the wind's force on the ocean), and sunlight (a.k.a. photosynthetically active radiation) for four geographic zones that have previously been associated with norovirus outbreaks. Although local winds, such as those seen through the Strait of Georgia and the Juan de Fuca (45) likely enable the spread of norovirus, winds were too site specific to be included in the four zones. We anticipated modelling these data would identify which parameters are most predictive of norovirus outbreaks in the BC coastal setting. However without ongoing monitoring of norovirus in either oysters or in the human population, and due to the small number of outbreaks, this was not possible. Instead, descriptive time series plots using parameter data, were used to visualize how environmental conditions varied during outbreak years and years with no recorded outbreaks .

2.8.3 Mapping of sewage sources

Wastewater treatment plant (WWTP) effluent outfalls in proximity to shellfish farm closures and sanitary closures were identified and mapped during the Oct 2016 to Apr 2017 period of the outbreak. WWTP category of treatment (no treatment, primary, secondary/lagoon and tertiary) and WWTP type of disinfection (UV, chlorine or none) were identified in two maps.

3.0 Results

3.1 Generation and evaluation of plausible hypotheses

Hypotheses considered plausible explanations for how oysters were contaminated by norovirus, leading to human illness during the fall of 2016 and winter 2017, were generated by the working group following its formation in 2017. For a hypothesis to be considered plausible, it had to satisfy certain transmission steps (Figure 4).

No plausible sources of contamination were found at processors, restaurants or retailers during the OICC investigation therefore the focus of the working group was on shellfish farm (oyster) contamination. Early in the working group's discussions, it became clear that any hypothesis involving a single sewage source could not explain contamination of **ALL** sites affected by the 2016-2017 outbreak, because affected oyster farms are far apart, existing on both sides of Vancouver Island. Hypotheses were therefore generated and evaluated with respect to the following question:

Could the sewage source in each transmission pathway (hypothesis) have caused contamination of **SOME** sites affected in 2016-17?

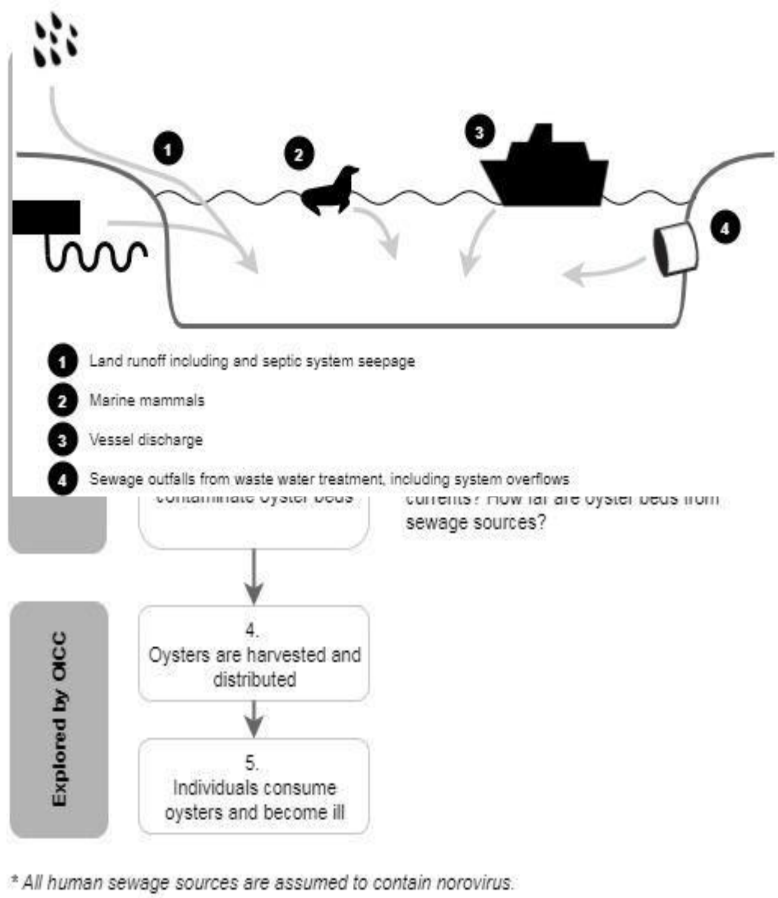

Figure 4. Necessary steps for transmission of norovirus to humans

The major hypotheses considered by the working group fell into four categories (Figure 5):

1. land runoff (including septic system seepage);
2. marine mammals;
3. discharge from various types of sea vessels (commercial fishing vessels, ferries, recreational boats);

4. sewage outfalls from waste- water treatment plants (including sewage at all stages of treatment and overflows from combined sewers and storm drains).

Other hypotheses included ill shellfish farm workers living in float camps and contamination during wet-storage and distribution.

Figure 5. Main categories of hypotheses considered by the working group

(Excluding product movement, wet storage and float homes)

Our investigation attempted to weigh the risk that each source contributed to the 2016-17 outbreak. Many of these sewage sources were not unique to this outbreak: they exist year round and have been present for many years. Norovirus is a common seasonal illness, and it is possible that illnesses or illness clusters in previous years occurred, but were underreported and therefore not traced to consumption of oysters. In the 2016-17 outbreak, other farms (and oysters) may also have been impacted by these sewage sources, but testing at those farms did not occur or did not find contamination when it existed, or product was not harvested or distributed to processors and restaurants, and was not subsequently implicated in illness and trace back to those farms.

All 20 hypotheses are listed below (Table 1), grouped into the four areas identified above. Between survey 1 and survey 2, some of the hypotheses evolved and were amended based on new information.

Table 1. Plausible hypotheses used in survey 1 and 2

Red text indicates where an hypothesis evolved between the two surveys.

Categories	**Hypotheses (survey 1)**	**Hypotheses (survey 2)**
Land runoff including septic system seepage	Land runoff and discharge (e.g., septic and storm water) Agricultural sources	Land runoff and septic discharges from private homes and small communities Agricultural sources
Marine mammals	Wildlife carriers (e.g., birds, seals, otters)	Wildlife carriers (e.g., birds, seals, otters)
Vessel discharge	Cruise ship traffic Ferries Recreational boats Commercial boats Float homes	Cruise ship traffic Ferries Recreational boats Commercial boats Float homes/float camps

Categories	Hypotheses (survey 1)	Hypotheses (survey 2)
Sewage outfalls from WWTPs, including system overflows	Discharge from a single metropolitan WWTP (single or multiple events) Discharge from multiple metropolitan WWTPs (single or multiple events) Discharge from local WWTPs near shellfish farms Other sewage outfalls (not WWTPs) near shellfish farms Other single point source contamination event/s near shellfish farms (e.g.,	Discharge from a single metropolitan WWTP (single or multiple events) Discharge from multiple metropolitan WWTPs (single or multiple events) Discharge from local WWTPs near shellfish farms Sewage outfalls and sewerage network overflows (sanitary sewer overflows, combined sewer overflows, storm tank overflows) Other single point source contamination event/s near shellfish farms (e.g.,
Other (these hypotheses are less about how sewage got into the marine environment, than about how the oysters became contaminated)	Other unexplained events (e.g., norovirus persisting or being transported in sediments) Wet storage contamination during distribution or retail Exposure to community sources of norovirus Contamination or loss of control at the processor plant Contamination or loss of control during distribution Contamination or loss of control at the restaurant/retail level	Other unexplained events Wet storage contamination during distribution or retail and product movement from a contaminated growing site to a clean growing site Exposure to community sources of norovirus Contamination or loss of control at the processor plant Contamination or loss of control during distribution Contamination or loss of control at the restaurant/retail level

3.2 Environmental factors influencing the risk of norovirus in oysters

In the environment, viruses, including norovirus, can bind to fine sediment particles, especially under conditions of low salinity, such as after extreme rainfall events (46). Binding to marine sediments can protect virus particles allowing them to remain infectious for several months (46). Other environmental conditions affecting the survival of norovirus in the marine environment include: temperature, humidity, rainfall, river flows, salinity, and solar radiation. Specifically, cooler water temperatures (13, 16, 47-49), low humidity (50), low salinity (46, 51, 52), excess rainfall (13, 53, 54), impacting river flows (55), salinity and seasonality (many conditions are worse in winter months) all contribute to prolong norovirus survival in the marine environment. Sunlight, or solar radiation, can reduce virus particles (56), thus decreased sunlight hours, as typically experienced over winter months theoretically promote norovirus survival. The longer norovirus can survive, the greater the likelihood that infectious virus particles can be carried longer distances, and be taken up by filter-feeding shellfish.

Several of the environmental conditions that promote norovirus survival were met prior to the 2016-17 outbreak. In BC, heavy rainfall events did occur prior to and throughout the outbreak period. A wetter than normal November was recorded (15). November rain events would have caused high river flows and lowered salinity, both factors associated with increased norovirus contamination and survival in the marine environment.

This information strengthens the idea that the excess rainfall events experienced in BC in November 2016 may have triggered this outbreak.

Other environmental conditions likely contributed to this outbreak. Prolonged norovirus survival in the environment can be exacerbated by low salinity and high river flows, both related to excess rainfall; low water temperatures; and decreased solar radiation, i.e., sun penetration through cloud cover. Cold temperatures prolong the survival of norovirus in the marine environment. Average monthly surface air temperatures across Vancouver Island were warmer than average in November (+9°C) then colder than average from December to February (-2°C) (15). These cold temperatures may have assisted in perpetuating norovirus survival. As with the extreme rain events, low sea surface temperatures were recorded in years with and without recorded norovirus illnesses associated with oysters. Reduced solar radiation can be inferred from the weather conditions at the time (wetter and thus presumably cloudier than usual) during the rain events of November, providing another condition that may have perpetuated norovirus survival.

Studies modelling norovirus illnesses and environmental indicators found that environmental parameters may be predictive of norovirus outbreaks associated with contaminated shellfish (16, 56, 57). The time series plots suggest that known outbreaks have occurred during periods of heavy rainfall, low sea surface temperature, low sunlight, and during periods of downwelling, i.e. when the wind forces water in a downwards movement from the sea surface during fall and winter seasons. These charts are available in a supplemental report.

3.3 Sewage sources containing norovirus impacting shellfish farms

Sewage contamination sources can be categorized as point source or non-point source. Point source contamination refers to treated effluent from wastewater treatment plants (WWTP) discharged into the environment via outfall pipes. Non-point source contamination refers to more diffuse contamination: municipal drainage works, urban and agricultural runoff, discharges to ground from on-site sewage systems (usually septic systems), and discharges from vessels (i.e., boats/ships). Combined sewer overflows (CSOs), sanitary sewer overflows (SSOs) and storm tank overflows (STOs) can contribute to both point and non-point source contamination of both the freshwater and/or marine environments. Figures 6 and 7 depict WWTP and their disinfection and treatment category (provided by ECCC) alongside emergency closure information (provided by DFO) and shellfish tenure closure information. Areas permanently and partially closed, along with areas that remained open to shellfish harvesting are shown.

Figure 6. Wastewater treatment plant outfalls treatment level category in relation to shellfish tenure and sanitary closures

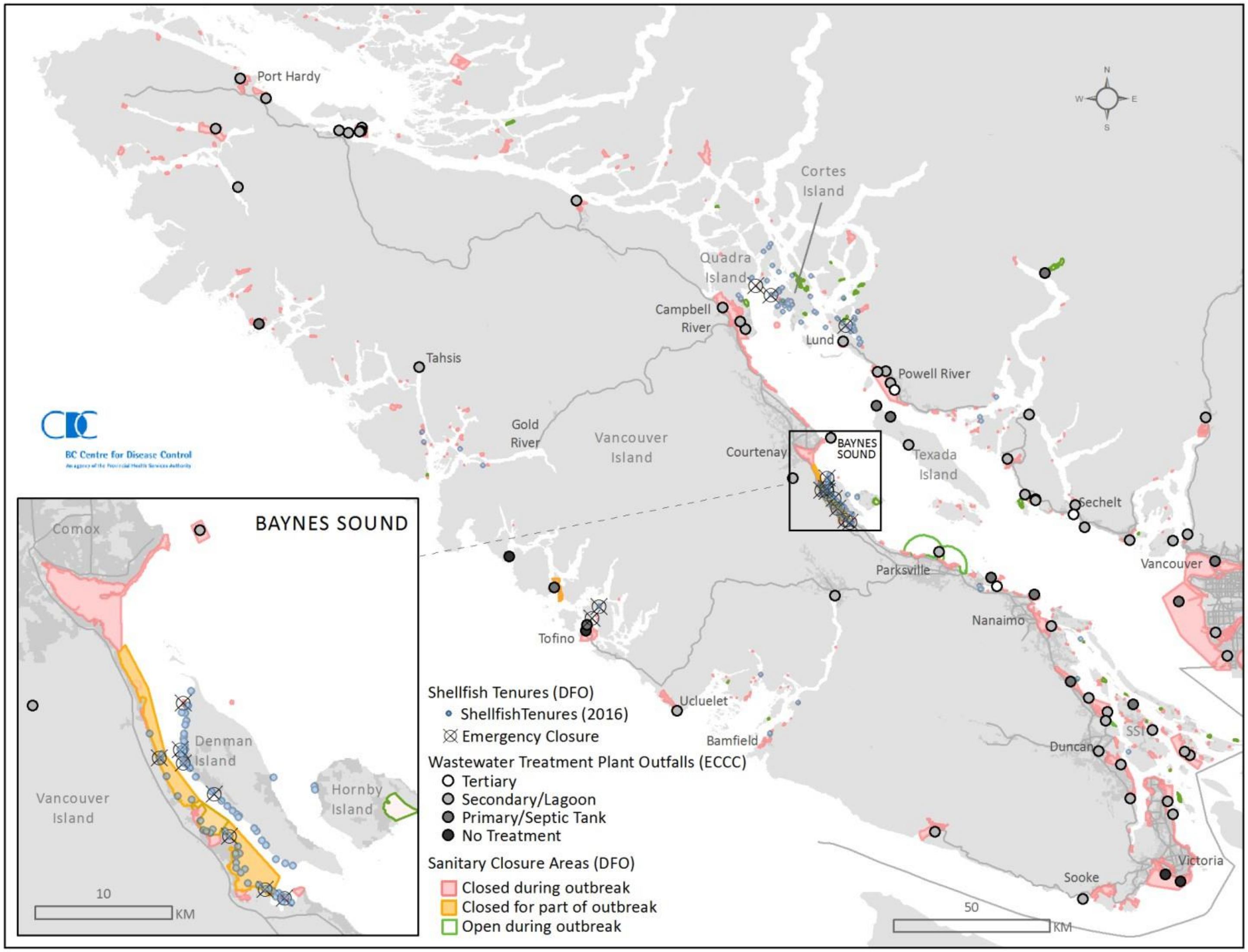

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Figure 7. Wastewater treatment plant outfalls by disinfection type in relation to shellfish tenure and sanitary closures

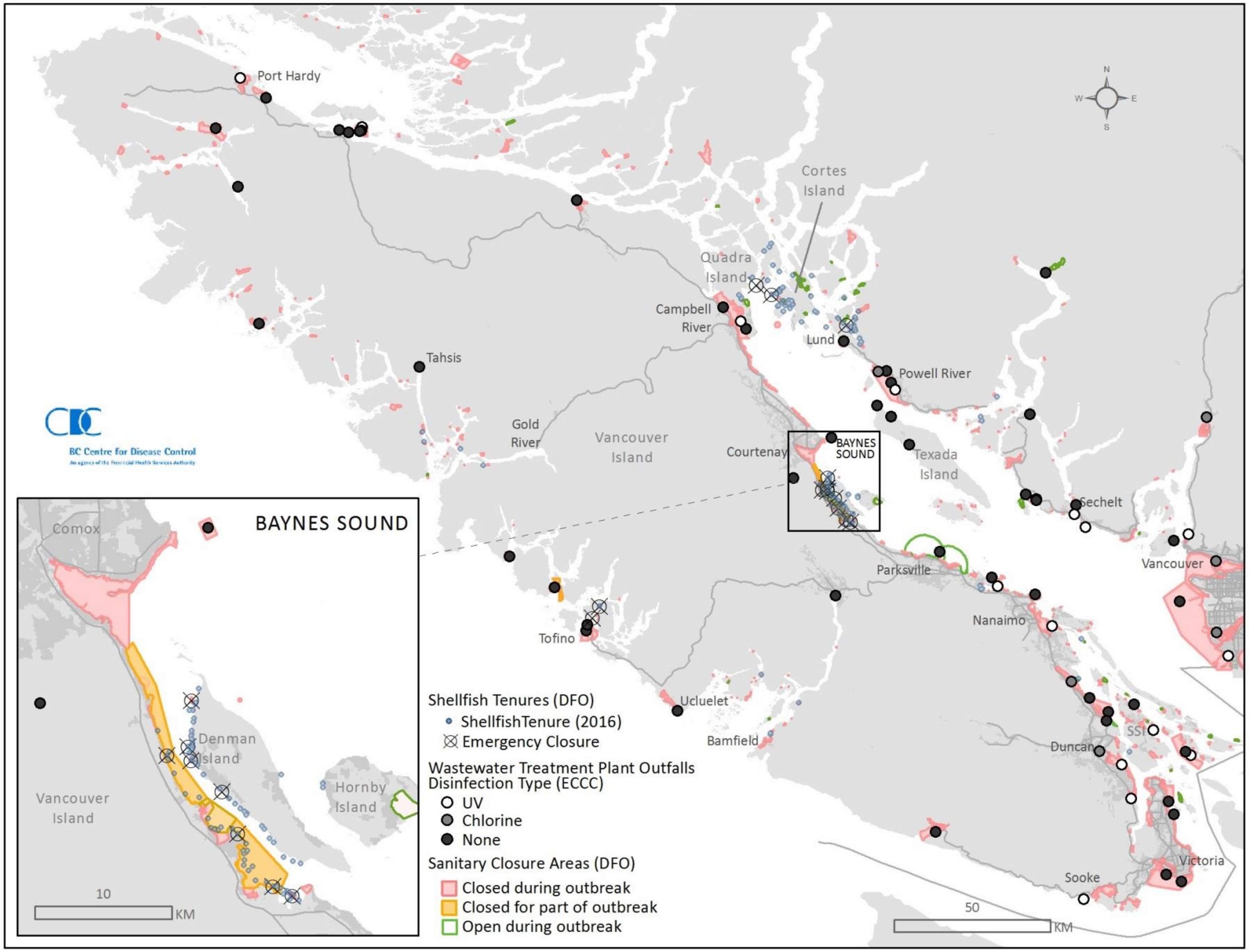

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Table 2. Summary of subject matter experts' key points

Name	Institute	Date	Key points
Dr. Curtis Suttle, Marine virologist	University of British Columbia	Mar 2, 2017	Marine viruses are very hardy and under certain conditions can survive for prolonged periods. Marine viruses may travel long distances in the marine environment, including on top of fresh water plumes.
Dr. Lilly Pang, Laboratory medicine	University of Alberta	Mar 30, 2017	Research on detection and quantification of viruses in wastewater samples in Alberta. In water treated by primary treatment, levels of NV are 10^6 genome copies per L. After UV disinfection, there is a 2 log reduction in NV, however the PCR method of detection does not distinguish between dead and live viral particles.
Dr. Greg West, Atmospheric scientist	EOAS, UBC	Apr 13, 2017	Weather in the affected area over the period of the outbreak showed temperature anomalies – warm Nov, cold Dec/Jan/Feb; and precipitation anomalies – wet Nov, drier than usual Dec/Jan/Feb. Solar radiation was not investigated.
Dr. Rich Pawlowicz, Oceanographer	EOAS, UBC	May 11, 2017	Salish Sea circulation/currents. Fraser River flow drives circulation in Georgia Strait. A "drifter" study showed it took about 5 days to reach land after being released from the Fraser River, well before reaching the Northern Strait. Mean transit time of water from Victoria to Tofino, approx. 2 weeks; Iona to N. Strait of Georgia approx. months. Concluded long-distance transport of virus possible but seems unlikely.
Dr. Abraham Deng, Water resources modeler	Dept. Civil & Environmental Engineering, Louisiana State University	Jul 18, 2017	Dr. Deng explained norovirus forecasting model and the environmental factors included (temperature, salinity, rainfall etc.). Norovirus from sewage is ALWAYS available in oyster growing waters following rainfalls when solar radiation is low. Oysters are filter feeders and pump water at approx. 5L/hour. Low gage height equates to shallow water depth over oyster beds, thus the water is as warm as the air temperature. Low gage height reduces dilution of sewage contaminated runoff from rainfall. This model useful to predict norovirus outbreaks in oyster growing areas in other areas in the US. Unclear how useful it would be in BC.
Ron Hein, Septic system specialist	Coast Mountain Earth Sciences (CMES)	Aug 17, 2017	Presentation on septic system findings from BC using 3 months of data collected from CMES. Key points – people do not know their responsibilities in regards to maintenance of their systems. Best estimates suggest there are more than 350,000 systems around the province: an estimated 80% of septic systems are in performance failure. It seems likely that norovirus can travel during rain or high ground water.
Tom Howell, Owner	Spinney Creek Shellfish	Nov 30, 2017	Presentation discussed the greater bioaccumulation and persistence of MSC and norovirus in bivalves in winter months. Log reduction affected by temperature – lower temperatures, longer time necessary to achieve the same log reduction as at higher temperatures. Different bivalve species bioaccumulate viruses (MSC) at different rates.
Ryan Powell, Lead technologist	Greater Nanaimo Pollution Control Centre	Nov 30, 2017	For Nanaimo, upgrading to secondary treatment is underway and is scheduled to be completed by the end of 2019. Current outfall pipe is 2km long and discharges into the Salish Sea.

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3.4 Summary of Presenters and Key Points

Subject matter experts (SMEs) were contacted to present on plausible hypotheses. SMEs were identified through working group members' networks, or contacted after literature searches identified experts on topics where knowledge was lacking. SMEs were frequently local, BC-based experts, who could speak specifically to conditions in coastal BC. A total of eight SMEs presented to the working group over the course of the year. The key take-home points from each presenter are summarized in Table 2. In part, the experts' knowledge shaped working group members' opinions on what were the most plausible and least likely hypotheses to have caused or contributed to contamination of shellfish farms in this area. A full list of meetings and topics reviewed by the working group is found in Appendix 3.

3.5 Survey Results

3.5.1 Stakeholder surveys – March & December 2017

An initial stakeholder survey, comprised of ETNO working group members or the OICC (n=16) and external participants (n=11) was conducted Mar 2017. The aim of the survey was to identify and discover which plausible hypotheses the members thought the evidence best supported as a cause of the recent outbreak. Members were asked to rank all 20 hypotheses in order of likelihood for having caused the recent outbreak, and to what degree each hypothesis may have played a role. The top six hypotheses of most concern to survey stakeholders at the beginning of the working group meetings (in March), by rank order were:

Rank	Hypothesis –
1	Local WWTP
2	Multiple metropolican WWTP
3	Other sewage outfalls near shellfish farms
4	Other single point source event(s)
5	Land runoff and discharges
6	Single metropolitan WWTP

Following this activity, the working group focused on investigating hypotheses ranked higher in the survey. . The full survey report is available on request (Supplementary materials – Stakeholder Survey March 2017).

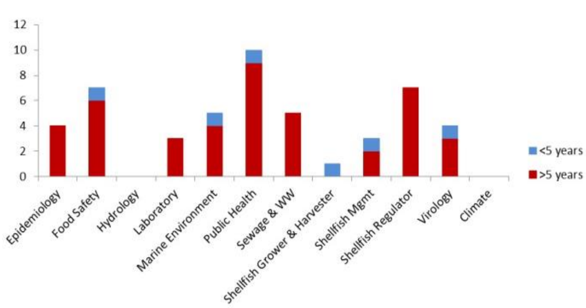

Figure 8**.** Number of years of experience by survey respondents.

A follow-up survey of ETNO working group members was conducted at the conclusion of the working groups activities in December 2017.

The aims of this survey were to determine if the working group process was valuable, and if members' opinions on what caused the outbreak had changed. Respondents answered that the working group was a worthwhile process and that they gained knowledge by taking part. Knowledge gained changed how 13 of 17 (76%) members weighted the plausible hypotheses. Significantly, 16 of 17 respondents (94%) thought it most likely that multiple plausible hypotheses caused the outbreak.

All ETNO members were asked to provide their fields and years of experience (figure 8). The most common areas of experience were identified as public health (n=10), food safety and shellfish regulators (n=7). No respondents checked climate or hydrology as their area of expertise.

Multiple metropolitan WWTPs, local WWTPs, and sewage outfalls/ sewerage network overflows, i.e., CSOs, SSOs, and STOs, followed by commercial vessel traffic and septic issues were the five hypotheses respondents felt most strongly could have caused or contributed to the norovirus outbreak (figure 9) and even more likely to have caused the outbreak (figure 10) in comparison to initial survey results. Single metropolitan WWTP, ferries, and wildlife carriers were deemed less likely to have caused the outbreak compared to what was previously thought. This signifies a shift in opinion: members originally considered a single metropolitan WWTP alone could have caused the outbreak for e.g., untreated effluent from Victoria or Vancouver may have caused all shellfish contamination.

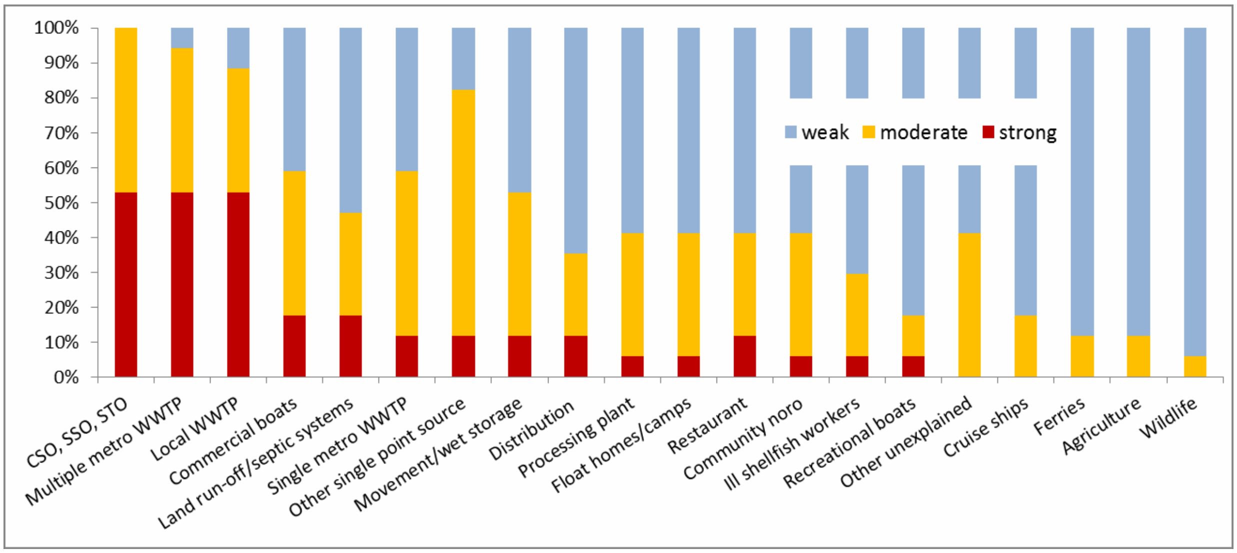

Figure 9. The relative strength of each plausible hypothesis as having caused the norovirus outbreak

Ferries, cruise ship traffic, recreational boats, wildlife carriers, agricultural sources, ill shellfish farm workers, were all thought to be 'weak' causes for the outbreak, similar to initial survey responses. There was little change in opinion for other hypotheses, e.g., contamination or loss of control at the restaurant or retail level, at the processing plant, or during distribution; float homes/camps; agricultural sources; and ill shellfish farm workers.

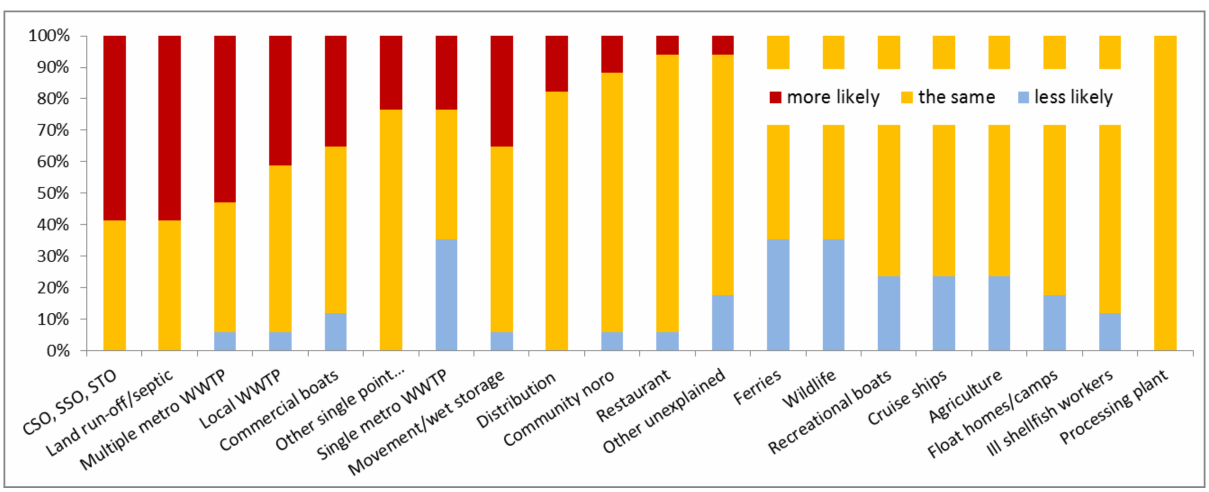

Figure 10. Whether respondents thought plausible hypotheses were more likely, the same, or less likely to have caused the outbreak

The hypotheses voted as most likely to have caused the outbreak are presented in table 3.

Table 3. Responses from ETNO members ranking top 10 hypotheses most likely responsible for this outbreak.

Hypothesis	Overall Rank
Sewage outfalls and sewerage network overflows (CSO, SSO, STO)	1
Discharge from local WWTP near shellfish farms	2
Discharge from multiple metropolitan WWTPs	3
Land runoff and septic discharges from private homes and small communities	4
Discharge from single metropolitan WWTP	5
Commercial boats (fishing vessels)	6
Other single point source contamination events near shellfish farms	7
Ill shellfish farm workers	8
Float homes/camps	9
Wet-storage contamination during distribution or retail leading to contamination of multiple oyster batches from different farms / product movement from a contaminated site to a clean site	10

3.5.2 Septic survey results – November 2017

Five of ten businesses serving the area between Duncan and Campbell River responded to telephone interview requests from BCCDC. Of these five businesses, two only conduct pump-outs or minor repairs and were unable to provide information on septic systems. Information collected from three of the businesses substantiated what was presented to the working group by Ron Hein, specifically, that septic issues have been noted by septic operators in residential areas adjacent to shellfish growing areas such as Bowser, Union Bay, Quadra, Cortez, Maple Bay, Baynes Sound area, and Hornby. The full extent of septic failure is unknown, although the responses from septic service operators suggest it could be extensive. Findings of concern from this telephone survey are summarized in Table 4.

Table 4. Septic survey operators feedback from Vancouver Island, collected November 2017.

Business #1	- Many problematic systems are located near the shoreline. Have seen septic plumbed directly into ocean. - Residential lots are not big enough for septic field, set-backs are not far enough (from ocean). - Soils are heavily contaminated/saturated with septic outflow, cannot reuse the field. - Union Bay residents recently voted against connecting to municipal sewage, as residents cannot afford the cost ($20K per household). - Older systems dating back to the 1970s have issues. - Clients don't wish to spend the money to install updated systems.
Business #2	- Clients do not understand importance of functioning septic systems, perceive the cost as too large to update/maintain. - No enforcement if home owners don't service their systems. - Have seen and reported break-outs (septic seepage overflows). Issues occur with older grandfathered systems, i.e., those built under older, less stringent regulations.
Business #3	- Most systems in Baynes Sound are failing or have failed. These are Type 1 systems that don't pass today's standards. Have seen and reported break-outs. - North of Courtenay is a bad area, top soil stripped off to sell, in the 1960s lots were sub-divided and poor quality septic systems installed. - Clients only call when their toilet does not flush anymore or when raw sewage is in their yard. - Suggest cost can be taxed and amortized over 20 years.

3.6 Gaps, barriers and research needs

During discussions of plausible hypotheses it became clear that there were evidence gaps preventing the working group from having a more fulsome understanding of what caused the outbreak for a number of reasons:

- information was not collected;
- a lack of appropriate timeliness in receiving information;
- research has not been conducted on the subject of interest;
- there were institutional barriers (e.g., confidentiality) preventing information from being shared; or
- information was collected in a manner that could not be easily analyzed (e.g., stored in paper form).

Working group members used several meetings to discuss what information would inform the following:

- mapping of data relevant to the outbreak;
- how norovirus behaves in the marine environment;
- epidemiological assessments;
- sewage sources from land;
- sewage sources from vessel traffic; and
- methodological gaps.

Details of gaps, barriers, and research needs are provided in Appendix 6. Gaps are incorporated throughout discussion of the plausible hypotheses in the following section. Overall, the working group identified more than 30 evidence gaps. Approximately 38% of the evidence gaps were considered "in progress", indicating that there is current work addressing the particular gaps. At the time of writing this report, 43% of identified gaps remain unexplored by any agency or researcher.

3.7 Hypothesis summaries

The original 20 hypotheses identified by the working group were assessed as high, moderate or low-priority, and are summarized in Box 4.

Box 4. Overview of hypothesis summaries

3.7.1 Runoff from land, i.e., non-point land sources of sewage

1. **High priority hypotheses**: Seepage from septic tanks and other on-site sewage systems
2. **Low priority hypotheses**: Agricultural runoff

3.7.2 Wildlife

1. **High priority hypotheses**: Marine mammals

3.7.3 Vessel traffic

1. **High priority hypotheses**: Commercial fishing vessels
2. **Low priority hypotheses**: Cruise ships, ferries, recreational crafts

3.7.4 Sewage outfalls from municipal sewage networks

1. **High priority hypotheses**: Multiple WWTPs, sewage network overflows (CSOs, SSOs, STOs)

3.7.5 Other

1. **High priority hypotheses:** Product movement from contaminated to clean shellfish farm sites and wet storage contamination
2. **Moderate priority hypotheses**: Float camps for shellfish and other workers
3. **Low priority hypotheses**: Other sources such as community, retail, distribution and

For each hypothesis, we outline arguments for and against its plausibility; present evidence gaps; and provide conclusions. Arguments were constructed using evidence from the literature, outbreak investigation findings, and consultation with SMEs. Evidence for hypotheses should explain how transmission from source to oyster beds is possible as depicted in figure 3. Each plausible hypothesis is defined as a point or non-point source of contamination.

3.7.1 Land runoff and septic discharges from private homes and small communities

3.7.1.1. Seepage from septic tanks and other on-site sewage systems

Hypothesis description

Non-point sources of human sewage to the (marine) environment include seepage from septic tanks and other on-site sewage systems. Septic systems are used in areas that cannot be connected to municipal sewer systems.

Septic systems range in size — servicing a single home up to a small community of typically not more than 150 persons: the Sewerage System Regulation stipulates this as less than 22,700 litres of domestic sewage per day (58). Onsite systems have a tank in which sewage solids collect and settle out, while the remaining liquid flows through a network of perforated pipes into the surrounding disposal field (figure11).

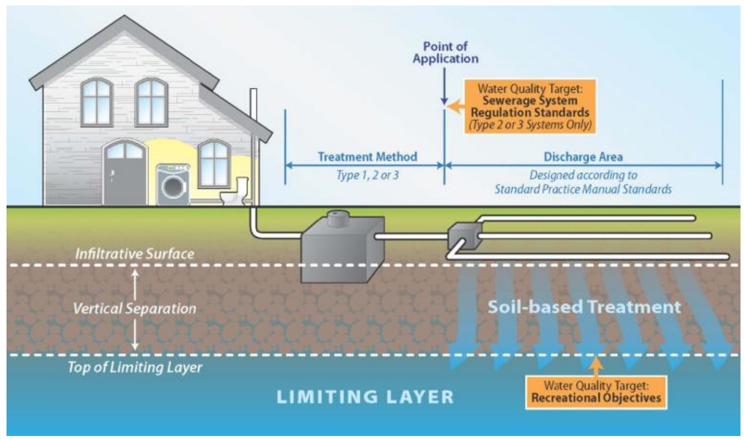

Figure 11. Schematic of a basic septic tank and ground disposal field for a single home

There are various types of on-site systems with different disinfection add-ons that can improve the quality of discharge released into the environment(59). There are specific coastal BC areas of concern where (1) there is high ground water particularly in the winter; (2) there are small lots with no areas for replacement septic drainage fields; (3) soils are inadequate, either shallow or silty-clay where drainage occurs too quickly; and (4) occupation is considerably higher than what the systems were designed for. Areas mentioned that are potentially problematic include Royston (south of Courtenay and Comox, area 14-14); and Ships Point (near Fanny Bay, area 14-8). Other areas of concern include Bowser (south of Denman Island, area 14-5) and Union Bay (north west of Denman Island, area 14-5) (60).

Key questions

- **Can enough sewage/norovirus be transferred from a septic system in performance malfunction to the marine environment to cause contamination of shellfish farms?**

Arguments for and against hypothesis that land runoff and septic discharges from private home and communities caused some of the contamination observed in 2016-2017.

ARGUMENT FOR

- Studies conducted in the US and Canada have reported outbreaks of norovirus and other gastrointestinal illness as a result of seepage from on-site septic systems into ground water (61-64). Studies in the US found that higher density of septic systems was associated with viral diarrhea (65-67). Additionally, viral tracer studies have described the movement of virus from homes into the Atlantic ocean (67), demonstrating the feasibility of this in BC. *Literature review*

ARGUMENT FOR

- Septic system operators in BC estimate that as many as 80% of the 350,000 systems in BC are in performance malfunction, which may lead to seepage into the surrounding environment. (Ron Hein, Coast Mountain Earth Sciences, *pers. comm*).[7]
- In many remote areas near oyster farms, homes are not served by large WWTPs and homes are not connected to municipal sewage infrastructure and treatment. On-site septic systems are the primary method for sewage disposal. *Working group discussion*
- Many systems do not show obvious signs of damage and can continue to seep sewage for extended periods. These systems are not typically repaired or inspected unless there is obvious damage/obstruction or during a request for inspection by new home purchasers. A wetter than average November was seen in BC, and could theoretically have increased the amount of seepage that enters the marine environment directly from seepage or from land runoff containing seepage from inland areas. *Expert consultation*
- The majority of closed shellfish farms were less than 5km from septic sources (77%). Of these, the majority were within 5km of septic sources from more than 50 homes (62%) or by more than 500 homes (54%).

  Five of the closed shellfish farms had fewer than 50 homes near their location (n=2), or were located greater than 5 km away from more than 50 homes (n=3). *Shellfish farm closures review.*
- Royston and Union Bay areas have shallow water tables. Elevated fecal coliform counts between 2004 and 2014 suggest on- site septic systems were malfunctioning (60). Based upon rates of septic systems assessed, failures were estimated to be on the order of 35-50% during a "typically wet winter", and could be higher during extreme precipitation events (60). *Expert opinion*

ARGUMENT AGAINST

- On-site sewage systems have existed, many in disrepair, for many years. Without an extreme precipitation event causing larger-than-normal runoff from this existing sewage source, this hypothesis alone cannot be the cause of the 2016-17 outbreak.

Gaps in evidence

- There is no accurate map of *all* septic systems and other types of rural sewerage systems in BC. It would be useful to determine if on-site sewage system density is correlated with oyster farm contamination. Census data could be used to compare the proportion of the population served by WWTPs, with the remainder assumed to be using septic system services.
    - A useful overlay of such a map would be the soil/drainage type, to enable identification of high- risk areas where soil/rock drains seepage at a faster rate.
- No tracer studies have been conducted in BC demonstrating the pathway of enteric viruses from homes, septic systems, and into the marine environment, particularly in shellfish growing areas.
- We do not have an accurate estimate of the number or location of on-site sewage systems that require repair, or historical abandoned systems, and what number may be contributing to marine contamination.
- It is unclear how many norovirus-contaminated septic systems would be required to pollute nearby marine environments.

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[7] Mr. Ron Hein provided a comprehensive document entitled *Onsite Sewage System Background.* This document, along with the *Literature review of environmental factors and major sources of sewage affecting norovirus* are available as supplementary materials on request. Refer to Appendix 5

Conclusions
—septic tank seepage was considered STRONG as a plausible explanation for contamination—

This hypothesis emerged as a strong contributor to sewage contamination of marine environments in rural coastal areas in BC. Following excess runoff during a large rainfall, it is possible that seepage from damaged or improperly located on-site systems could have contributed to the outbreak. Regardless of whether this was the main contributing source of sewage for the 2016-2017 outbreak, on-site septic systems near shellfish farms should be investigated in future outbreaks.

3.7.1.2. Other hypotheses considered

Agricultural runoff could include a) livestock sewage and b) human-sourced fertilizer (biosolids) used on produce or other crops. Non-human animals have not been demonstrated to carry human norovirus, so it is unlikely that livestock contributed to this outbreak. Use of biosolids has typically been used for mine reclamation, rangeland and agricultural land soil improvement and forest applications; however widespread use of biosolids for produce and other edible foods is not widely applied in BC (68). In BC, oyster harvesting areas are remote, and are not located near major agricultural growing sites. This hypothesis therefore seems less likely to have contributed to the 2016-17 outbreak.

3.7.2 Wildlife vectors

3.7.2.1. Marine mammal carriers (sea lions, seals, otters, etc.)

Hypothesis description
Marine mammals, including sea lions, seals, otters, and sea birds, might contaminate oyster beds via their excrement. Mammals could act as a vector by ingesting norovirus via sewage plumes from WWTPs or sewage discharge from vessels, or ingest fish or other species that have been exposed to such plumes (Figure 12).

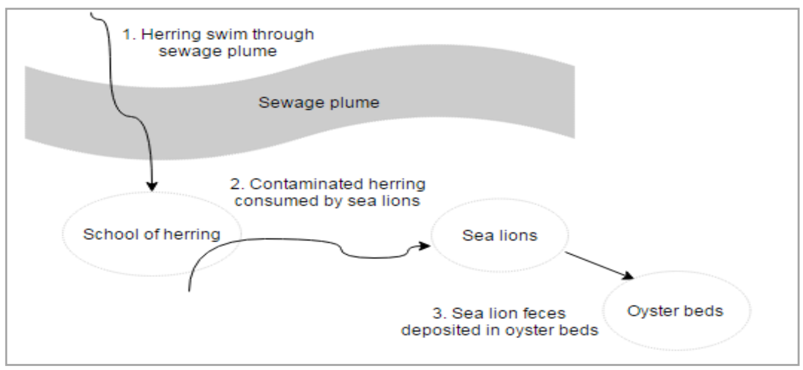

Figure 12. Hypothetical pathway of sea lions as sources of norovirus- contamination

This hypothesis arose following observation by ECCC staff of numerous sea lion haul- outs adjacent to some norovirus outbreak- implicated oyster farms.

Key questions

- Is there evidence that marine mammals can carry human norovirus

Arguments for and against hypothesis that marine mammal carriers caused some of the norovirus contamination

ARGUMENT FOR

- Observation of numerous sea lion haul-outs proximal to several norovirus implicated oyster farms in Baynes Sound and elsewhere. *ECCC report* "Summary of ECCC pollution source investigations and water quality in proximity of emergency closure areas"

ARGUMENT AGAINST

- Sea lion and harbour seal scat tested by PHSA labs did not detect human norovirus. One sample was positive for norovirus, but had only 70% homology to human calicivirus, the family to which norovirus belongs. Sea lion (n=38) and harbour seal (n=14) scat was collected by DFO and the Vancouver Aquarium from Baynes Sound, Tofino, and rescue animals in April and May 2017. *PHSA laboratories*
- While other strains of norovirus have been detected in sea mammals, human norovirus strains have not (69). *Literature review*

Gaps in evidence

- Viromes in marine mammals have not been fully characterized by research.
- We don't know the mechanism by which norovirus would be transmitted from sewage to marine animals to the marine environment and subsequently to the oysters.

Conclusions

—marine mammals was considered WEAK as a plausible explanation for contamination—

This hypothesis cannot explain contamination in all or any harvest areas during the 2016-17 outbreak and seems unlikely given that marine mammals have not been demonstrated to carry human norovirus. Following PHSA laboratory testing, no further work is planned on this hypothesis.

3.7.3 Vessel traffic

3.7.3.1 Commercial fishing vessels

Hypothesis description

Commercial fishing vessels, e.g., those from the crab, herring, and salmon fisheries were considered as potential sources of sewage. These vessels occasionally fish and anquor for extended periods in proximity to oyster farms. Vessels that weigh less than 400 gross tons and carry ≤15 passengers are required to provide on-board containment of human waste, but may discharge sewage directly into the marine environment at specific distances from shore, depending on the level disinfection to the sewage in the holding tank (70). Should vessels not store sewage in holding tanks, i.e. they discharge directly to the water, or discharge nearer to shore than prescribed in the regulation and should workers be ill while on board these vessels, norovirus-contaminated vomit or feces would contaminate the environment and any oyster farms in the nearby vicinity. A separate working group led by DFO was formed to investigate commercial vessel traffic in the vicinity of the affected oyster farms during the outbreak period.

Key questions

- Were any commercial fishing vessels operating near shellfish harvesting areas in late 2016-early 2017?
- Do fishing vessels pump out sewage or discharge into the marine environment?
- Are existing regulations governing discharge from commercial vessels adhered to?

Arguments for and against hypothesis

ARGUMENT FOR

- A review of fishing vessel traffic during the outbreak period found four of seven outbreak affected harvest areas (57%) were impacted by salmon, herring, shrimp, crab and urchin fisheries. *DFO*
- At least one vessel was reported to have discharged sewage while harvesting near oyster farms in February 2017. One worker on board this vessel was reported ill with GI symptoms. While this does not explain the beginning of the outbreak, it suggests that such events are possible and this particular discharge may have contributed to the continuation of the outbreak. *DFO*
- Commercial vessels are permitted to discharge untreated sewage if they comply with Transport Canada regulations: discharge >3 nautical miles (>5.5 km) from shore may occur when travelling at the fastest

feasible speed. Vessels with marine sanitation devices may discharge closer to shore (within 1 nautical mile).
- Commercial vessels have not been observed to use pump-outs in the Baynes Sound area
- Fully-crewed commercial vessels will often anquor and fish in proximity to shellfish farms for several days.

ARGUMENT AGAINST
- We are unaware of other discharge events predating the outbreak beginning in fall 2016

Gaps in evidence
- Not all accidental or illegal discharges are reported.
- Worker illness is not required to be reported.
- The extent of risk posed by commercial fishery vessel traffic to oyster farms is unclear.

Conclusions
—commercial vessel traffic was considered MODERATE to STRONG as a plausible explanation for contamination—

This hypothesis emerged as a moderately likely contributor to sewage contamination of marine environments in areas where commercial fisheries occurs. To occur, certain conditions, such as worker illness and sewage discharge to the environment must be present. It is possible that vessel discharge contributes some sewage and norovirus into BC shellfish waters; however there was only one specific incidence reported (noted above) which may have contributed to ongoing contamination during the 2016-17 outbreak. It is possible this issue is under-reported and other discharges may have occurred.

This hypothesis was considered of interest to DFO and other partners; a separate working group was established.

3.7.3.2. Other vessels hypotheses

Cruise ships, ferries and recreational vessels were all determined to be less likely to have been non-point sources of norovirus contamination in the 2016-2017 outbreak.

- **Cruise ships**: Cruise ship traffic is minimal during the late autumn and winter (October to April) when shellfish farms are most at risk for contamination. Further cruise ships are required to either contain all on-board sewage for pump out, treat on-board waste before discharge, and/or dump at a prescribed distance (5.5 km or more) from coastal areas (71). This hypothesis was considered unlikely.
- **Ferries**: In the past, shellfish operators have complained about ferry discharge near shellfish harvesting waters; however this practice has ended. All ferries currently pump out sewage on shore. *DFO*
- **Recreational boats**: Recreational boat traffic is busiest in spring and summer months, during tourist season, and minimal in October to April along both the east and west coasts of Vancouver Island in shellfish growing areas. *ECCC records*. The tourist season has typically ended by autumn. This would not explain how shellfish harvesting areas become contaminated by sewage during fall and winter seasons. *Working group discussions.*

3.7.4. Municipal and metropolitan wastewater treatment systems

3.7.4.1. Wastewater treatment plant (WWTP) effluent

Hypothesis description

This hypothesis considers the impact of multiple plants together, as it is unlikely that a single WWTP could have contaminated all of the sites affected during the 2016-2017 outbreak.

WWTP effluent is considered as point source contamination through the discharge of effluent from WWTP outfall pipes to the environment. Sources may include treated effluent and when effluent overflows or by-passes the treatment process. Provincial and federal regulations governing wastewater effluent, and further information about WWTP, including treatment types, can be found in the literature review (72, 73).[8]

WWTPs are designed to remove organic and chemical contaminants in wastewater gathered through sewer and storm pipes. Treatment facilities range in size and capacity to filter contaminants from influent sewage and grey water. Small facilities may serve a single trailer park or school, while large plants serve metropolitan areas. Treatment ranges from

no treatment where sewage may be put through a grinder station and discharged directed to the environment, to

primary, in which influent waste is screened for larger solids and waste is removed via settling ponds, to **secondary** and **tertiary** treatment, which add on various chemical and mechanical processes to remove organic waste from influent. Treatment types may be mechanical or lagoon based, with or without use of disinfection agents. In the current regulatory standard, the requirement for disinfection is dependent on many factors, such as: outfall location in proximity of recreational and shellfish uses, volume of discharge and the receiving environment's ability to dilute. There are many generations of permits and registrations that have different requirements. Older permits are less likely to have any disinfection requirements, where new registrations under the Municipal wastewater regulation are more likely to have disinfection (72).

Among these treatments, none is able to fully remove norovirus from influent waters; disinfection with UV or chlorine is considered the most effective method for achieving significant log-reductions of norovirus in waste-water effluent. The effectiveness of wastewater treatment processes in removing norovirus is highly variable and can be influenced by the amount and speed of water entering the system, the amount of norovirus in the influent, and the type of wastewater treatment. For example, during rainfall events, wastewater moves faster through WWTPs and spends less time undergoing treatment. WWTP "near" shellfish farms are considered by the working group as those within 20 km.[9] This was based on reviews for distances norovirus travelled to shellfish: one study stated norovirus was detected at up to 24 km away from an outfall (17) while 10 km was noted in estuarine and open ocean marine environments (18). Under the CSSP volumes, flows, and capacities are taken into account, rather than distance alone.

Key questions

- Where do WWTPs exist in BC in relation to shellfish farms?
- What is the baseline amount of norovirus in WWTP effluent?
- How far do sewage plumes travel from WWTPs, accounting for BC currents?
- Is norovirus accurately represented in sewage plume models?
- Are any oyster farms close enough to WWTPs (i.e. within 20km) that they may be impacted by

[8] A more in-depth review of treatment practices, estimations of norovirus in influent and effluent, and effectiveness of disinfection can be found in the literature review "*Literature review of environmental factors and major sources of sewage affecting norovirus*" prepared for the ETNO working group, November 2017

[9] The distance chosen to define "near" as 20km was arbitrary, and could be much smaller, <10 or <5km.

WWTP effluent?

- Do WWTP treatments in BC remove norovirus from influent? What level of treatment do BC plants have?
- What are the regulations in BC and Canada for wastewater treatment in relation to norovirus?

Arguments for and against hypothesis that municipal and metropolitan WWTP systems caused some or all of the norovirus contamination

ARGUMENT FOR

- 19% of the 93 WWTPs in coastal BC release effluent that has not been treated beyond coarse screening. WWTP nearest affected shellfish farms use lagoon treatment, which is less effective than mechanical treatment for norovirus removal. Only 2% of these 93 WWTP employ tertiary treatment. *Literature review, white papers.*
- There are no federal regulations governing viral concentrations of WWTP effluent. *Expert opinion* (Jeff Stobo, expert working group member).
- Fecal coliforms are recognized as poor indicators of enteric virus in aquatic environments (38). Because norovirus is known to survive longer in marine water in comparison to fecal coliforms, during extreme environmental conditions (high precipitation, cold temperatures etc.) some working group members believed contamination could have spread beyond plume model closures. *Literature review, working group discussions.*
- Norovirus levels are expected to be higher in colder seasons and during peak community outbreak periods (Oct to Mar) in the north-western hemisphere. Influent is expected to contain norovirus. Concentrations vary between studies, between 1.5 and 6.8 $\log_{10}$ genome copies of norovirus per litre (12, 74). *Literature review.*
- Norovirus survives longer during cool conditions, which were observed prior to the 2016-17 outbreak. In the absence of tracer studies that would provide direct evidence, it remains possible that sewage plumes containing norovirus could travel further following a rainfall event, reaching shellfish beds. *Expert opinion and working group discussion.*
- There is varied use of disinfection which could include: all year disinfection, seasonal disinfection for recreational use purposes (during summer months) to no disinfection. *MOE and working group discussion.*
- Half of closed farms were located less than 20km from WWTP. The four WWTP nearer to the 12 closed shellfish farms were Cumberland lagoon (50%, n=6), Campbell River WWTP (n=3), Tofino WWTP (n=2), and Lund WWTP (n=1). Of the farms nearest to Cumberland lagoon, four were less than 20 km distant, and two were less than 10 km away from this effluent sewage source. All shellfish farms adjacent to the Campbell River WWTP were more than 20 km away from this effluent sewage source. The two shellfish farms adjacent to the Tofino WWTP were both less than 10km away, while the farm nearest to the Lund location was greater than 20km away. *Shellfish farm closures review.*
- It is possible that sewage from a WWTP can impact areas up to 50 km away (T. Howell referring to anaerobic digestion chamber discs found up on Plum Island following a flooding event). *Expert opinion.*

ARGUMENT AGAINST

- Many of the shellfish farms affected by the 2016-2017 outbreak are more than 100km from large metropolitan WWTPs, such as the ones at Nanaimo, Sechelt, or the Metro Vancouver area. *Working group discussion.*
- Modeling completed by ECCC predict plumes would meet the log reduction targets identified in the HC HRA 1290 prior to reaching the shellfish farms closed in 2016-2017. Further, the sewage discharge would have achieved the 4 log reduction recommendation. *ECCC investigation report*
- A documented spill on November 25, 2016 occurred in harvest area 13, one week after the Tofino oyster festival and norovirus illnesses. Therefore this event could not explain the source of contamination for the oyster festival.

ARGUMENT AGAINST

- Evidence for BC water currents provided by Dr. Rich Pawlowicz suggest contamination would not travel large distances based on drifter studies. His research found drifters (floating rubber objects) released into the Fraser River outflows hit land within about five days, well before reaching the Northern Strait. *Expert Opinion, Publication In Progress*
- WWTP have existed for many years.

Gaps in evidence

- There is no baseline for norovirus concentration in WWTP influent or effluent in most BC sites. Seven WWTP across Canada were assessed in the Health Canada HRA 1290 document. Recent work on this has been conducted in rivers in Alberta (75). Washington State plans to monitor MSC in the primary growing area that experienced the norovirus outbreak in 2017 during the 2017-18 norovirus season. WWTPs in BC do not monitor norovirus concentration, but rather use biological oxygen demand (BOD), fecal coliforms, and other bacterial measures which are not directly comparable to norovirus concentration.
- Location information, i.e., GIS of all actual and potential sources of sewage is available from ECCC and MOE records; however this information is not readily accessible on maps and does not include an exhaustive list of municipal and private sewage sources. The length of time norovirus can survive in benthic sediments is unknown. An analyses of benthic sediments around WWTPs is under consideration; however data were not available for review by this working group.
- Sewage plumes specific to norovirus (not fecal coliforms, *E. coli* or virus in general) have not been constructed for all WWTP in BC.
- The length of time norovirus can survive in marine water and fresh water plumes is unknown. How far norovirus can travel in the BC marine environment following release from WWTPs and other sewage sources is also unknown. Washington State is conducting a growing area study in 2017-18 to inform this question; this study will specifically examine whether the nearby WWTPs could have been a major contributing sewage source.
- It is not known if, during the norovirus season, BC WWTPs deploy secondary treatments that would inactivate enteric viruses.
- Across BC WWTP facilities, it is unknown to what extent quality targets vary for effluent with respect to enteric virus or whether any monitoring is conducted.
- The catchment sizes of WWTPs in BC and how this affects norovirus levels in effluent seasonally is unknown.

Conclusions

—WWTPs were considered STRONG as plausible explanations for contamination—

WWTPs continuously contribute treated effluent (sewage) into the marine environment in BC. Current waste-water treatment processes do not fully remove norovirus from WWTP effluent. It is therefore likely that WWTPs contributed, at least in part, to the burden of norovirus in the marine environment, and to the norovirus contamination that led to the 2016-17 outbreak. However, other than permitted WWTP discharges, no sewage spill events or discharges were recorded. While models do not predict that metropolitan WWTP plumes could have reached oyster farms affected by this outbreak, models do not explicitly describe norovirus movement and survival in BC waters. There remain a number of research and information gaps, hampering the ability to objectively inform this hypothesis.

It is unlikely that a single WWTP caused norovirus contamination in oyster farms on both sides of Vancouver Island. However, the contributions of multiple WWTPs have the potential to have *some* impact on oyster farms, although the extent of this contribution has not been quantified.

3.7.4.2. Sewage network overflows: CSO, SSO, STO

Hypothesis description

This hypothesis includes several types of sewage network overflows, including combined sewer overflows (CSOs- Figure 13)(76), sanitary sewer overflows (SSOs), and storm tank overflows (STOs). CSOs, SSOs and STOs can contribute to both point and non-point source contamination of both the freshwater and/or marine environments. Sewerage network overflows refers to issues with the infrastructure that carry sewage.

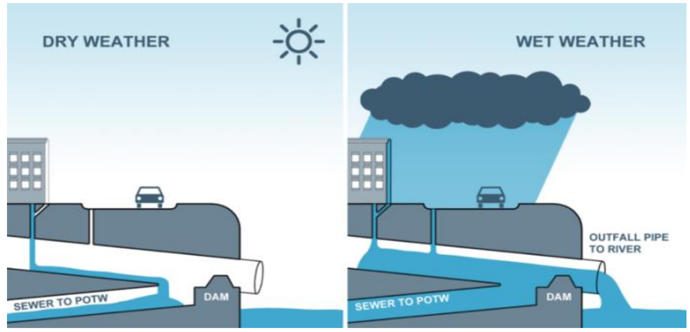

Figure 13. Combined sewer during normal and overflow conditions. figure from Daniel Overbey with permission http://danieloverbey.blogspot.ca/2014/10/indianapolis-digs-

Overflows are events in which raw sewage enters the environment via accidental or planned discharges from municipal sewer systems, storm drains, or via seepage from damaged sewage pipes. **CSOs** occur during wet weather events when the volume of rainfall overwhelms a combined sewer's capacity, and sewage is released into the environment. **SSOs** occur when sanitary sewers, containing only grey water and sewage, are damaged or begin leaking for any reason. SSOs can occur anytime, arising from blocked pipes, pump failures and inflow and infiltration (I&I). I&I can be caused by groundwater or rainwater entering damaged infrastructure or through deliberate or accidental cross connection with storm water collection systems. Storm tanks may be attached to WWTPs or at other points within a sewage network in order to collect excess rainfall or CSO discharge prior to treatment, thus preventing overload of the plant. **STOs** occur when rainfall exceeds these tanks' capacity, but they are rare in BC.

Key questions

- Do CSOs and STOs occur in areas proximal to contaminated oyster farms?
- How often do overflows occur?
- Where do combined sewers exist in BC?
- Were any overflows reported preceding the 2016-2017 outbreak?
- How are overflow events reported? To whom?

Arguments for and against hypothesis that sewerage network overflows caused some or all of the norovirus contamination

ARGUMENT FOR

All three types of overflow events have been implicated with norovirus contamination of shellfish farms with human illness around the world (e.g., France (46), Japan (53, 77), UK (17, 55, 78), Australia (79), New Zealand (55). *Literature review*

Overflow events were noted in the ECCC investigation report at one site in Courtenay from a blocked main on October 24, 2016. Very little sewage was spilled into the storm collection system, and it was hydrovacced up from ditches. ECCC modelling found the spill to achieve the reduction target within the existing sanitary closure. *ECCC investigation report*

Under the right climate conditions (excess rainfall), it is feasible that multiple sewerage network overflow events in multiple areas could be triggered, causing norovirus contamination in geographically distinct areas.

ARGUMENT AGAINST

- No serious overflow events were documented and revealed by OICC investigations.
- There are few CSOs remaining in BC; they are being phased out. *MOE, discharge authorization list*
- It is impossible for a single overflow event in one location to impact sites on both sides of Vancouver Island. *Working group discussion*

Gaps in evidence

- Sewage discharges data from MOE discharge authorization spreadsheets require cleaning and interpretation before it can be shared with the public. These data do not include municipally registered discharges, which may include more CSOs.
- While Greater Vancouver monitors CSOs during overflow events and presents results in an annual report, these and data from other coastal communities is not readily available or a part of a real-time surveillance system. Plant records are not easily available or accessible to public health.
- The impact of SSOs and CSOs on sewage contamination in the marine environment in BC is not quantified.

Conclusions

—CSOs, SSOs and STOs were considered STRONG as a plausible explanation for contamination—

While CSOs, SSOs, and STOs likely contribute to a number of contamination events in BC and elsewhere, they were unlikely to be the sole cause of contamination leading to the 2016-2017 outbreak. A single CSO could not have caused contamination in oyster farms on both sides of Vancouver island.

However, under the right climate conditions (excess rainfall), it is possible for multiple overflow events to be triggered, leading to norovirus contamination of adjacent marine waters and shellfish farms. There is no evidence that this occurred in a widespread manner during 2016-17, however sewage overflows still exist as possible contributors to contamination of BC waters now and in the future.

The working group highlighted several important gaps around this hypothesis, particularly the ability to conduct real-time surveillance of overflow events, including mapping events.

3.7.5. Other hypotheses

3.7.5.1. Shellfish product movement between clean and contaminated harvest sites and wet storage contamination

Hypothesis description

Shellfish product movement from a contaminated site to a clean site: Oysters may be moved from one location to another without a special license[10] as long as both sites are approved or conditionally approved, and are in 'open' status (i.e. not closed for reasons such as biotoxin or sanitary closures). All shellfish products are required to be tagged (i.e. labeled) as soon as they are harvested. This tag must bear certain information including the site of harvesting. If oysters have been moved from one site to another prior to harvest, and if they were wet stored at the second site for fewer than 14 days, the tag must identify the original site as the location of harvest (See Chapter 7 of CSSP Manual of Operations). In addition, although this information does not appear on the tag record, when product is moved from one tenure to another, shellfish farmers are required to keep detailed records of the product movements.

Research indicates that norovirus remains in oyster tissue for 4-6 weeks, so it is possible that oysters transferred from norovirus-contaminated sites (that have not been closed) to previously-uncontaminated sites, which are *not* harvested within 14 days of arrival at the new site, will not have information about the original contaminated site on the tag. While information about all product movement is recorded by

[10] The "Introductions and Transfers License" is not always required, however, the Shellfish Aquaculture License contain specific conditions for movements of shellfish product.

processors, this information may not be on the tag, making it difficult for public health investigators to establish the history of product movement based on shellfish tag information alone.

Additionally, oysters can be moved under DFO license from a marginally contaminated site to another site that is either approved or conditionally approved for harvesting. This process, called relay, is done in order to allow shellfish to depurate and be cleansed of contaminants. This type of product movement was not identified by investigators as a concern during the 2016-2017 norovirus outbreak.

Wet storage contamination: Wet storage is defined by CSSP as the temporary storage (less than 60 days) of "live" shellfish from approved sources, intended for marketing, in containers or floats in natural bodies of "seawater" or in tanks containing natural or synthetic seawater. While wet storage harvesting is not common in BC, it is possible that oysters from norovirus-contaminated sites that have not yet been closed could contaminate other wet storage harvesting locations. While oysters cannot be co-mingled in wet storage, it is possible that they could be stored next to each other at the same time as oysters from other harvest sites. Theoretically, it is possible that contamination could occur from contaminated to non-contaminated oysters during this holding process.

Key questions • Can norovirus contamination of oysters occur via contaminated product movement or during wet storage?
Arguments for and against hypothesis that product movement or wet storage caused some of the norovirus contamination **ARGUMENT FOR** - Oysters from norovirus contaminated sites (farms) could have been moved to other geographic areas. The original growing area and movement history of the shellfish is not required to be declared on the shellfish tag. *CFIA/DFO and working group discussions.* - Extent of oysters moved between open/approved shellfish farm areas during the 2016-17 season was not known. *Working group discussions.* - Contaminated oysters from one growing area moved to another clean growing area could potentially have exposed other oysters to norovirus. *Working group discussions.* - Distributors and retailers use wet storage holding tanks for a variety of products. *Working group discussions,*
ARGUMENT AGAINST - Product movement could not have explained the full geographic pattern or distribution of the outbreak. *Working group discussions.* - It is uncommon for BC processors to use wet storage tanks; however, wet storage in marine environment is practiced. *CFIA and Working group discussions* - The wet storage plausible hypothesis is based on a less likely route of contamination as it is not directly associated with discharge of contaminated human sewage into the marine environment. It is predicated on the theory that norovirus would unbind from contaminated oyster tissues, be present in the shared marine water during wet storage and that ‘clean’ oysters would filter feed and bind this norovirus to also become contaminated. - There were multiple processors and distributors implicated in the trace back portion of the investigation, making it unlikely a single processor or distributor was responsible for a wet storage contamination issue that would explain a large portion of the outbreak.

Gaps in evidence

- Tags identifying where oysters were grown often only relate to the final harvest site, rather than the full movement history, including wet storage, of the shellfish and the farms and growing areas. However, these movements are captured in separate records kept at the aquaculture facility.
- Mechanisms for norovirus transfer between oysters held in proximity in either a marine grow-out site or in wet storage are unknown.
- It is unknown whether norovirus may transfer from one oyster to another through water

Conclusions

—Product movement and wet storage contamination was considered MODERATE to WEAK as plausible explanations for contamination—

Potential product movement from previously contaminated sites hypothesis may have caused some of the contamination that was linked to sites, i.e. through shellfish tags to shellfish farms that were not situated in geographic areas known to be subject to human sewage contamination but there is no evidence to support this.

No single land based processor, distributor or retailer was shown to carry any greater risk over another processor, distributor or retailer. There was no information collected on the extent of wet storage during the outbreak and no evidence to suggest contamination could transfer to other oysters held in the same wet-storage facility. Even if this were possible, this mechanism would not fully explain how contamination occurred in oysters that were not wet-stored.

3.7.5.2. Float camps for shellfish workers/float homes

Hypothesis description

This hypothesis considers contamination of the marine environment via sewage discharge directly from single or multiple float homes (termed a float camp; often used to house shellfish farm workers near or on-site). Some float homes are owned by the tenure holders and exist as a part of their permit plan, whereas others have no legal status. Other floating living accommodations are large, housing 20 or more workers. These float camps are contracted by forest companies and may be placed in shellfish growing areas. Currently, these large floating accommodations appear to be outside government oversight and regulation.

Key questions

- Do float camps/homes exist in areas proximal to contaminated oyster farms?
- Is sewage discharged directly to the environment?

Arguments for and against hypothesis

ARGUMENT FOR

- There are some float homes in existence, as documented by ECCC, in areas near oyster farms. *ECCC investigation report*
- Some float homes have no legal status. Thus it is difficult to know what level, if any, of compliance is undertaken and whether sewage discharge may occur from these homes. BC Ministry of Forests, Lands, and Natural Resource Operations is attempting to develop standards for unauthorized float homes, implying there are currently no standards in place. *Working group discussions.*

ARGUMENT AGAINST

- Closures and zones of prohibition exist around float homes and camps. *DFO*
- Levels of compliance with CSSP regulations were examined at the time of the outbreak. No deficiencies

were found. *DFO/ECCC.*

- There are few float homes or float camps in the affected areas. *ECCC investigation report*

Gaps in evidence

- There is no information whether unauthorized float homes follow regulations.
- It is unclear whether the prohibition zones (125m) are large enough to prevent shellfish bed contamination.

Conclusions

—Float homes and float camps were considered MODERATE to WEAK as plausible explanations for contamination—

It is impossible for a single float home or camp to have caused the 2016-17 outbreak. However, float homes/camps could have contributed to some of the contamination. Nonetheless, in comparison to other sewage sources discussed earlier, sewage contributions from these structures appear minimal.

3.7.5.3. Others

The following hypotheses were investigated by the OICC: contamination at processing plant; contamination during distribution and contamination at the restaurant or retail level. These hypotheses were not explored in depth, as they do not answer the question of how human sewage initially entered the marine environment. As noted above for wet storage, no single processing plant, distributor, restaurant or retailer demonstrated any greater risk of handling contaminated oysters over any other. Although individual products or lots may be affected in this way, this would have accounted for the extent of contamination observed in this outbreak.

4.0 Discussion

The purpose of this working group was to identify the sole or multiple causes of environmental norovirus contamination of BC oysters that led to the 2016-17 outbreak. To achieve this goal, the working group developed plausible hypotheses, consulted experts, reviewed existing literature, conducted surveys, identified gaps in knowledge and barriers to our investigation, and discussed the plausible hypotheses. Concepts previously held as true by working group members were challenged throughout discussions, and lessons were learned that may inform future norovirus outbreaks linked to consumption of raw or partially cooked oysters. This report summarizes the synthesized knowledge of the working group.

No single environmental transmission source was identified that would explain all the contamination. Rather, general consensus amongst the group was that multiple sources of human sourced sewage contributed to the outbreak, with environmental conditions (heavy rainfall, cold temperatures, low sunlight, downwelling) creating circumstances where norovirus could survive and spread in the marine environment.

Working group members collectively increased their knowledge about norovirus, shellfish growing, sewage sources, and environmental conditions that contributed to this outbreak. Norovirus-like illnesses in Washington State linked to oyster consumption from Washington shellfish farms also occurred, indicating that multiple geographic sites in the Pacific Northwest became contaminated with norovirus in 2016-17. Dr. Curtis Suttle, a marine virus expert, informed us that marine viruses can travel extensive distances in fresh water plumes atop marine water. This revelation led the group to consider that norovirus may have travelled further than initially thought, and to consider the role metropolitan WWTPs may have played in this outbreak.

4.1 Significant sewage sources: WWTP and septic systems

4.1.1. WWTP

The group investigated geographic locations and treatment processes of WWTPs relevant to this outbreak. Influent water into WWTP is expected to contain norovirus, particularly during the winter when norovirus is prevalent in community outbreaks (80). Secondary mechanical and tertiary treatments that employ disinfection are more effective at reducing incoming norovirus loads than secondary lagoon and primary treatments. Unfortunately in BC, more than one quarter of WWTP impacting marine environments (27%) have either no treatment or primary treatment. Disinfection strategies in WWTP range from none to disinfection use year-round, with some WWTP using disinfection during summer months to improve water quality for marine recreational swimming. This is in stark contrast to the province of Alberta, where over 78% of the population is serviced by tertiary-level wastewater treatment, as that province discharges to drinking water sources (81). In many parts of BC, we can therefore expect that norovirus is flushed out with effluent into the marine environment.

ECCC modelled BC WWTPs effluent to determine its direction and extent of spread. Based on 4-log reductions from WWTP influent concentrations, shellfish farms should not have been at risk from enteric viruses such as norovirus. However, in certain challenging environmental conditions models may not fully account for the distances norovirus could travel.[11] Further, the model does not include cumulative sewage impacts from on-site septic systems or other potential sewage inputs into the prediction. Some studies have attempted to measure the distance norovirus can travel from point sources using shellfish located at various distances from the source: at least one study demarks norovirus as 24 km from the site of contamination (17). A recent study from the United Kingdom suggests norovirus levels capable of causing illness (i.e. >1000 genome copies/g) can be found in shellfish 10 km distant from a sewage source is estuarine areas characterized by poor marine flushing; however, norovirus is still found in shellfish in open ocean conditions 10 km away, albeit at lower concentrations (i.e. approximately 100 genome copies/g) (18). In most studies, shellfish were not located far enough from the outfalls to determine the actual outer limit or boundary zone (17, 21, 55, 82).

4.1.2 Septic Systems

BC septic systems are a possible source of norovirus and untreated effluent (human sewage) to the marine environment, based on expert opinion and literature review results. Septic fields and septic systems have been linked to illness in other jurisdictions. A higher density of septic systems was associated with viral diarrhea in the US (83). A tracer study conducted in Florida found that virus could enter adjacent canals and the wider ocean in a matter of hours (84, 85). An extensive meta-analysis by the Public Health Agency of Canada found septic systems were an important contributor of contamination to ground water (64).

Ron Hein, a septic system specialist in BC, estimates up to 80% of septic systems in coastal BC are in "performance malfunction" – meaning there is potential for human sewage to leach into the environment, either through saturated soil, groundwater, or directly into the marine environment. Vancouver Island septic system business operators confirmed that performance malfunctions do occur. One operator mentioned they had even seen septic systems piped directly into the ocean. While these problems have been recognized by the Island Health Authority for over a decade, and many fines issued, communities are still not required to connect to municipal sewage treatment (60). Recently, residents of this area voted down a sewer project due to taxation costs involved —the Comox Valley Regional District requires a successful elector consent process to proceed (86).

[11] Plume models were not reviewed in this working group, however, a presentation about the ECCC models was given to some stakeholders on Feb 22, 2017

Consensus from the working group was that improperly maintained septic systems are most likely another source of human sewage and norovirus into the marine environment, and into oyster beds. These non-point sources of contamination are likely continuous, rather than event specific: malfunctioning septic systems continuously contribute human sewage to the marine environment, adding to the reservoir of sewage already present. Septic system failure rates during wet periods can also be significant in areas adjacent to shellfish growing areas.

Multiple human sewage sources from WWTP and septic systems contaminate on an ongoing basis into BC marine waters. This working group concluded that norovirus, from effluent and septic discharge (i.e. human sewage sources) is always present in the BC marine environment within proximity to significant effluent and septic system sources. Furthermore, it is more likely that multiple sources, some continuous and some single events contributed to an underlying reservoir of norovirus in the marine environment. Modeling work conducted in Louisiana shellfish growing areas (16) takes this concept a step further, and assumes that there is norovirus/sewage present in shellfish waters at all times.

However, the presence of norovirus, while a necessary step in transmission for an outbreak, was not a new or one off event. These and other sewage sources such as vessel traffic discharges have existed in the BC coastal environment prior to and following the duration of this outbreak. Surveillance systems for norovirus illness and reports linked to oyster consumption are good, although it is possible that some illnesses were missed in previous years. Why were so many more picked up in 2016-17 and what else occurred that allowed an outbreak to develop in 2016-2017 and not during other years?

4.2 Weather and environmental conditions exacerbated the risk

Environmental conditions impact survival of norovirus in the marine environment and/or in shellfish and oysters. Of note:

- **Rainfall events** increase the amounts of contaminated land runoff, of septic failures, of surfacing of poorly treated effluent, and reduce the amount of time that sewage spends undergoing treatment at WWTPs. Rainfall also lowers the salinity of seawater, improving conditions for norovirus to bind to sediment. When norovirus is bound to sediment, UV light (sunlight) is less effective at inactivating virus, thus enabling norovirus movement and survival in effluent plumes.
- **Cool temperatures** promote survival of norovirus. Norovirus will stay bound to oysters longer when temperatures are colder. Effluent plumes and marine waters contaminated with norovirus could theoretically travel further from WWTPs and other sewage outfalls.

Exacerbating factors preceding and during this outbreak appear to have been *adverse weather events*. Extreme rainfall events are a common trigger for sewage-related norovirus outbreaks and other enteric pathogens affecting shellfish and drinking/recreational waters (54, 56, 87). Excess rainfall causes flushing of the systems and overloads WWTPs, resulting in CSOs, SSOs, and STOs, i.e., the direct flow of raw sewage into the (marine) environment.

Excess rainfall can also aggravate sewage issues arising from malfunctioning septic fields and septic systems. The rate at which contaminants enter the environment is increased by large rainfall events, and physical damage to, or faulty installation of, sewerage infrastructure exacerbates the problem. A review on the subject of norovirus outbreaks associated with shellfish noted that “the most common route for accidental contamination is sewage overflow and discharge into the aquatic environment during heavy rainfall events” (46). Rainfall data showed that while an extreme rain event did occur in November 2016, it is not the only year when this has occurred (e.g., extreme rain events were recorded in January 2010 across some sites), and yet outbreaks were not reported in these instances.

4.3 Existing regulations and programs for the control of norovirus in the marine environment

Marine waters along the coast of BC are often impacted by human sewage sources. Existing regulations to limit norovirus from entering the marine environment include:

1 Provincial regulations to address septic seepage from residential communities fall under the *Sewerage System Regulation*.[12] The discharge of domestic sewage into marine water is prescribed as a health hazard. Land owners must ensure they do not cause a health hazard, and that their system is constructed and maintained responsibly so as to not discharge into marine waters.

2 Provincial regulations to address effluent discharges from wastewater treatment facilities fall under the *Municipal Wastewater Regulations.*[13] These regulations are based on permits for discharge that may not include requirements for year-round use of disinfectants, which may reduce levels of enteric virus in effluent waters discharging to marine environments.

3 Transport Canada regulations[14] that prohibit commercial and recreational vessel discharge of untreated sewage to water less than three nautical miles (5.5 km) from shore. Holding tanks in vessels should be used and pumped out to designated shore based facilities when vessels are located in areas where this is not possible.

4 Canadian Council of Ministers of the Environment Canada-wide strategy for the management of municipal wastewater effluent 2014 report[15] that recognized impact of viruses from effluent sources into shellfish growing areas. Primary goals of this strategy are to improve human health, environmental protection and clarity over municipal wastewater effluent management.

Aside from exceptions to regulations, ***To protect the marine environment from norovirus contamination these regulations must be strengthened and must be enforced.***

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[12] The Sewerage System Regulation fall under the Public Health Act. It governs discharges of <22,700 L per day. http://www.bclaws.ca/Recon/document/ID/freeside/22_326_2004#

[13] The Municipal Wastewater Regulations fall under the Environmental Management Act. It governs discharges of ≥22,700 L per day. http://www.bclaws.ca/civix/document/id/lc/statreg/87_2012

[14] Vessel Pollution and Dangerous Chemicals Regulation to govern discharges from commercial and recreational vessels. http://laws-lois.justice.gc.ca/eng/regulations/SOR-2012-69/ This may be interpreted from this Transport Canada poster http://www.bccdc.ca/resource-gallery/Documents/Educational%20Materials/EH/FPS/Fish/PUBLICATION_OBS_PREVENTINGMARINESEWAGEPOLLUTION1_ENG.pdf

[15] Canadian Council of Ministers of the Environment (2009). Canada-wide Strategy for the Management of Municipal Wastewater Effluent. 2014 Progress Report. http://www.ccme.ca/files/Resources/municipal_wastewater_efflent/cda_wide_strategy_mwwe_final_e.pdf

Several controls are already in place to manage risk of contamination in shellfish farms and in oysters. Current control options include:

1 CSSP monitoring of pollution sources and sanitary conditions in the marine environment.

2 CSSP processor control measures in federally-registered shellfish processing facilities, and provincial Ministry of Agriculture processor control measures address risk of contamination in Quality Management Plans, Hazard Analysis Critical Control Point plans, inspection, and testing.

3 Industry voluntary self-monitoring of environmental factors and testing of water and oysters for contaminants.

4 Restaurant and retail inspections and information to premises serving oysters for raw consumption are provided by regional health authorities.

5 Current consumer controls include posting of consumer advisories in all BC premises to inform consumers that eating raw meat proteins, including raw oysters, are a risk for gastrointestinal illness.

4.4 Knowledge gaps and lessons learned

Throughout the working group's progress, various knowledge gaps challenged the group's ability to fully assess all plausible hypotheses. Gaps were divided into six main areas – 1) mapping; 2) norovirus behaviour in the environment; 3) epidemiological assessment; 4) sewage sources from land; 5) sewage sources from vessel traffic; and 6) methodological. The number of research gaps identified underscores the difficulty of precisely locating, quantifying and understanding the behaviour of norovirus and the sources of sewage contamination containing norovirus in the coastal environment. These gaps are instructive for all agencies, associations, and researchers that have a mandate to manage risk of enteric viruses entering marine water and shellfish in BC.

Every ETNO member who responded to the second survey agreed that they had learned something new by participating in the group. Key lessons learned fell broadly into two categories – lessons learned related to the working group's process, and lessons learned in relation to factual knowledge.

4.4.1 Work process

As members' understanding of environmental factors, shellfish farming practices and contamination sources increased, understanding of terminology initially developed for plausible hypothesis also changed. A good example pertains to definitions of septic and sewage sources. Initially, few ETNO members had a clear idea of what "septic sources" really meant, and the phrasing of several hypotheses changed as the group learned more about the subject. The literature review presentations also advanced understanding and consensus between members, thereby improving communication and discussion. Nevertheless, it was a steep learning curve for all members.

There were enormous amounts of information to wade through, distill, and synthesize.

4.4.2 Facts

Throughout the life of the working group, important facts relevant to the outbreak were discovered. These will be valuable for future outbreak investigation teams.

Sewage Related

There is human sewage in BC's marine environment. Consequently, norovirus particles are likely present, within reasonable distance from sewage sources, especially during winter months.

- Treatment used at most BC WWTPs will only partially remove viruses. Many WWTPs in coastal BC use either no treatment, primary treatment, or lagoon or mechanical treatment (equivalent to secondary treatment). Only two of 93 coastal BC WWTPs use tertiary level treatment, required to most effectively remove virus from effluent. Lagoon treatment, especially in cold environments, was discovered to be only marginally effective (59). Disinfection is variable among BC WWTP: ranging from no treatment to seasonal treatment for summertime recreational water quality improvement to year-round use of disinfectant.
- Many small communities and individual households use malfunctioning septic systems that leak sewage and contaminated water into the environment.
- Commercial fishing and recreational vessels and unauthorized float homes discharging untreated sewage into marine waters in proximity to shellfish farms are also recognized as a risk.

Environment Related

Environmental conditions: rain, temperature, salinity, humidity, and others prolong the survival of norovirus. While these factors are not quantified, they likely allow norovirus to travel further than expected. With current climate change modelling predicting more extreme weather events, we can expect an increase in the frequency of these conditions, e.g., heavy rains affecting salinity, and future pathogen outbreaks linked marine food consumption.

Laboratory testing of sea lion and harbour seal scat and the literature review results demonstrated that transmission of human norovirus does not occur from these species.

5.0 Conclusions

Norovirus outbreaks are common. Most norovirus illnesses are spread by infected humans through their feces and vomitus to others by way of a person-to-person transmission cycle. Norovirus outbreaks linked to food and water sources are less common: norovirus illness may also occur if humans consume food and drinking water that has been contaminated with the virus. In BC, the Environmental Microbiology PHSA Laboratory detected norovirus in 72.8% or 903 of the 1241 gastrointestinal outbreaks investigated between 2011 and 2017. During this time period few outbreaks were attributed to shellfish sources, the majority were believed to arise from person-to-person exposure rather than through consumption of contaminated foods or drinking water. Norovirus is not spread by other animals, such as birds or seals, because evidence to date suggests they do not become infected with human norovirus, and therefore do not amplify or shed it in the environment. However, person-to-person, or community outbreaks of norovirus peak seasonally during winter months; consequently, sewage and sewage effluent sources are expected to contain higher levels of this virus during norovirus outbreaks in the winter.

5.1 Norovirus surveillance in the community, in oysters, and in the marine environment

Surveillance of norovirus in the population is based on epidemiological and molecular methods that have been in place for over 15 years. While community based norovirus remains a significant concern in BC, norovirus illness arising from the consumption of raw and undercooked oysters and other marine foods is increasing. Methods for detection of norovirus or norovirus indicators in oysters are poor, expensive and require significant technical expertise. Current surveillance programs for oysters do not detect norovirus before the product reaches the marketplace. In fact, the shellfish industry is consistently meeting all regulatory requirements prior to shipping product. Further, marine water surveillance that uses fecal coliforms (indicator bacteria) to detect sources of sewage contamination is not always effective for detection of virus.

5.2 Likelihood of the marine environment (and oysters) becoming contaminated again

The likelihood of the marine environment and BC farmed oysters becoming contaminated in the future is significant. Effluents and untreated human sewage continually provide a source of norovirus into the marine environment. Climate conditions including heavy rain, cold temperatures and low sunlight (all common in BC winters) enable norovirus to reach shellfish farms and bind to oysters. Climate changes globally support concerns these conditions will likely recur with greater frequency, particularly extreme precipitation. Should extreme weather events occur and heavy rain overwhelm WWTP and septic systems, effluent will be flushed into the marine environment with predictable results: oysters will be at greater risk of becoming contaminated with norovirus.

5.3 Issues to be considered and rectified based on key points of discussion in the working group on how to mitigate risk of norovirus from entering marine foods

Discussion in ETNO working group meetings focused on existing controls and programs, enhancing existing controls, and consideration of new controls within the categories of sewage, environment and general awareness of these issues.

Controls for human sewage sources

Human sewage from multiple sources discharged into the marine environment under favorable environmental conditions (extreme rainfall, cool temperatures) contributed to the survival and spread of norovirus into shellfish growing areas and were likely responsible for the 2016-17 norovirus outbreak. To prevent future outbreaks sewage sources entering marine environments need to be better managed.

1. Control and remove untreated sewage sources entering the marine environment through a combination of improved infrastructure, regulation, compliance, education and enforcement. Address the core issue: untreated human effluent entering the marine environment.
   - Community and individually-owned septic system discharges should be moved to municipal treatment systems. Better management and control of sewage discharges, such as WWTP and septic systems, would lessen impacts on marine environments.
   - Sewage discharges from commercial and recreational vessels must be monitored, reported, and managed to ban discharges near shellfish farms and areas where marine foods are grown and harvested.
2. Include environmental impact assessment prior to approval and issuance of building permits in communities that do not have adequate wastewater treatment facilities in place to meet current and projected development. Require all communities to be hooked up to community sewage discharge, rather than continue to use septic tanks.
3. Develop accountability for untreated sewage in the marine environment by actively auditing for discharges. For example, dye marker studies in community septic systems and commercial and recreational vessels could be used to trace inappropriate discharges.
4. Develop and re-evaluate norovirus specific plume models under challenged environmental conditions. Since sewage may travel further in water than previously thought, shellfish farms located further from known sewage sources still have the potential to become contaminated when environmental conditions are favorable and triggers are met.
5. Improve current spill event reporting to be real-time and electronically accessible; improve mapping of all discharges to the marine environment and make accessible online.

6. Improve WWTP infrastructure, particularly in areas of discharge to the marine environment, and incorporate treatments that will better inactivate enteric viruses. Wastewater treatment plants should incorporate testing strategies to evaluate the amounts of viable enteric virus being discharged in effluents.
7. Improve understanding of norovirus loading into marine environments through examination of WWTP catchment size, secondary WWTP treatments, and seasonal changes in treatments.

Monitoring norovirus in the environment

Given that we currently have no capacity to monitor when norovirus constitutes a threat in the marine environment, several improvements were discussed.

8. Improve the science to understand the impact of human viruses in the marine environment and the transmission path from human effluent to marine foods. Research needs include improving norovirus and norovirus indicator detection methods (including ability to demonstrate viability, having validated protocols that are transferable to more laboratories, and allowing for higher throughput), genotyping capability to provide epidemiology linkages from farm to fork, and establishing seasonal baseline levels of norovirus and/or indicators.
9. Study the role and impact of environmental factors. Monitor environmental factors, such as rainfall, temperature, down-welling and other parameters to predict norovirus contamination risk. Science needs to be developed to provide an early warning detection system for when norovirus is a threat to marine foods and shellfish farms.

Awareness and Opportunities

Explain the effects of human sewage entering the marine environment to the public, to commercial businesses, and to governmental authorities. Implement opportunities to foster change.

10. Controls necessary to improve the marine environment will require the cooperation of multiple stakeholders, including the public, industry, and from all levels of government: municipal, regional, provincial, and federal. Solutions are available, and we must recognize there is not one single stakeholder or agency responsible to fix all the problems. Transparency and frank discussions are needed to evaluate how to change existing policies, roles and oversight of human sewage discharge to the environment.
11. First Nations are impacted by the failure to adequately control human sewage sources from entering the marine environment. First Nations rely heavily on marine foods as a traditional food source, and food security is a concern when these foods become contaminated. Illnesses or lack of access to foods arising from these impacts is of particular concern to First Nations.
12. Educate homeowners with septic systems about their responsibilities for maintenance, and the impacts failing systems have on neighboring marine environments and farmers.
13. Offer rebate programs for inspections and repairs of private on-site septic systems. Consider amortizing taxation costs for hooking up house-holds on private septic to municipal infrastructure.
14. Educate developers and emphasize why wastewater treatment is needed to protect shellfish farming from poorly designed development projects.
15. Educate the public, recreational and commercial fishers about their responsibilities to manage human sewage, garbage and waste on-board their vessels. Create awareness campaigns to encourage and promote the use of pump-out stations for sewage.

Appendix 1. Environmental transmission of norovirus into oysters (ETNO) working group terms of reference

Background: As a result of the 2016-17 national outbreak of norovirus in oysters, a multi-sectorial approach to investigate environmental sources of norovirus was proposed.

Purpose: To identify the cause of environmental norovirus contamination of BC oysters that led to the 2016-17 norovirus outbreak in order to mitigate future risk. Additional aims of this working group are to enable inter-sectorial communications about norovirus transmission into shellfish in order to propose hypotheses of norovirus contamination of BC oysters during the outbreak* period, inform the community about developing knowledge on this issue, and identify evidence gaps and opportunities for collaborative research.

Terms:

- To review existing knowledge by speaking with scientific experts and investigation partners; to review existing literature; and to discuss plausible pathways of norovirus contamination in BC oysters and shellfish sources in the winter of 2016-17;
- To communicate regularly and share knowledge;
- To propose/conduct studies and analyses to assess proposed hypotheses;
- To propose steps needed to understand and manage risks;
- To identify opportunities for collaborative research.

Scope: norovirus in BC oysters and BC oyster growing areas

Note: topics and subjects not considered in the scope of this group include: (1) business relationships and work related roles between agencies/associations; (2) process related inquiries about decisions; (3) evidence that oysters are the source of norovirus illness.

Deliverables:

- Report findings to the Outbreak Investigation Coordination Committee during the national outbreak investigation;
- Develop plausible hypotheses for environmental contamination of BC oysters and BC oyster growing areas;
- Based on evidence and expert opinion, assign each plausible hypothesis a weight of 'weak', 'moderate', or 'strong' as likely to be a cause of norovirus contamination in BC oysters and in BC oyster growing areas;
- Create and manage a shared space for research papers, documents and minutes accessible by invitation to members and guests of the working group;
- Summarize findings and recommendations into a report.

Timeline:

- Meetings will be held on a biweekly basis during the national outbreak period, and less frequently thereafter as determined by the working group
- A report containing the summary of findings will be prepared by BCCDC in collaboration with working group members by December 2017.

Chair and Secretariat: BCCDC Environmental Health will chair and their staff will provide secretariat support.

Frequency: Meetings will be held as required, once every two weeks. Frequency may be adjusted if there is no new material to discuss, or additional information emerges that must be discussed immediately between scheduled meetings. Important issues arising between meetings will be communicated to working group members via email. If members feel there is a need for additional meetings they can request that such a meeting is scheduled by contacting the working group chair.

Actions arising from discussions: the intent of this working group is to discuss and evaluate evidence in a transparent manner. The working group may identify evidence gaps and make suggestions or recommendations on information requirements needed for evaluation of plausible hypotheses. Members should share recommendations within their agency/association for consideration.

The working group will report findings to Outbreak Investigation Coordination Committee during the national outbreak investigation.

* *Outbreaks will be managed as per the BC Foodborne Illness Outbreak Response Protocol (FIORP) or national FIORP by a Coordinating Committee with membership as described in the FIORP.*

Appendix 2. Role and responsibilities of agencies participating in the working group

The **Canadian Shellfish Sanitation Program (CSSP)** seeks to ensure that bivalve shellfish harvested in Canada is safe to eat. The CSSP is jointly run by three federal government agencies: Environment Climate Change Canada, Canadian Food Inspection Agency and Fisheries and Oceans Canada (DFO).

Canadian Food Inspection Agency:

- regulates the import and export, processing, packaging, labelling, shipping, certification, storage, repacking of shellfish to protect against contamination and product quality degradation and to maintain source and lot identity and integrity;
- suspends operations or decertifies shellfish processors on the basis of unacceptable operating and sanitation conditions;
- regulates the depuration (i.e., controlled purification) of shell stock, verifies product quality and purification effectiveness, maintains production and product quality records;
- maintains a biotoxin surveillance program of shellfish growing areas in support of DFO and CFIA activities;

Environment and Climate Change Canada:

- identifies safe shellfish harvest areas in Canada, which includes ongoing water quality monitoring of fecal contamination, in accordance with the CSSP Manual of Operations criteria;
- conducts comprehensive sanitary and bacteriological water quality surveys in shellfish harvest areas in Canada;
- identifies and assesses sources of point and non-point pollution that would impact harvest areas, such as municipal sewage, industrial wastes and agriculture runoff;
- recommends classification of shellfish harvest areas based on the results and analyses of these activities to Fisheries and Oceans Canada for regulatory implementation;

Fisheries and Oceans Canada:

- controls the harvesting of shellfish from areas which are classified as contaminated or otherwise closed;
- patrols growing areas, apprehends and prosecutes persons violating restrictions;
- regulates and supervises relaying, transplanting and replanting;
- restricts harvesting of shellfish from actual and potentially affected growing areas in a public health emergency;
- regulates licenses, harvesting locations and times and minimum harvest sizes for stock management purposes.

Health Canada

- establishes policies, regulations and standards related to the safety and nutritional quality of food, including seafood.
- conducts health risk assessments in order to inform and protect Canadians from the health risks associated with food.

BC Ministry of Agriculture.

BC Ministry of Agriculture is responsible for the production, marketing, processing and merchandising of agricultural products and food. In BC, all commercially harvested bivalve shellfish are required to be processed and inspected in a federally registered fish processing facility where bivalves are checked for potential contamination (e.g., marine toxins, *Vibrio*, etc.). Provincially licensed seafood processors can only obtain bivalves that have been processed at a federally registered fish processing facility handle or process shellfish and must meet regulatory requirements (e.g. written sanitation and food safety plans, constructional, operational and record keeping requirements) under the Provincial Fish and Seafood Licensing Regulation.

BC Shellfish Growers Association is a non-profit industry stakeholder group comprised of shellfish farmers (growers), shellfish processors, suppliers, distributors and service providers. The industry participates with CSSP and other government agencies in monitoring and managing bivalve shellfish.

BC Centre for Disease Control

- provides health promotion and prevention services,
- analytical and policy support to government and health authorities, and
- diagnostic and treatment services to reduce communicable & chronic disease, preventable injury and environmental health risks

The Centre for Coastal Health

The Centre for Coastal Health (CCH) is an independent, non-profit organization. CCH conducts independent academic research into the interactions of human, animal and environmental health by undertaking problem-oriented research, risk assessments, research planning, policy development, field investigations, program evaluations, and education.

First Nations Health Authority

First Nations environmental public health services provide advice, education, inspections and recommendations to First Nations and their leadership to help them manage public health risks associated with the environment. They collect data and observations to determine whether a public health risk exists, and determine what steps can be taken to improve conditions. Chief and Council are responsible for addressing the recommendations provided.

Indigenous Services Canada

Indigenous Services Canada (ISC) works with First Nation governments and communities to support adequate and sustainable housing, clean drinking water and community infrastructure such as schools, roads, and wastewater systems, which are essential to healthy, safe and prosperous communities.

Ministry of Environment

The Ministry of Environment is responsible for the effective protection, management and conservation of B.C.'s water, land, air and living resources.

Ministry of Health

The Ministry of Health ensures that quality, appropriate, cost effective and timely health services are available for all British Columbians.

Public Health Agency of Canada

- Promote health;
- Prevent and control chronic diseases and injuries;
- Prevent and control infectious diseases;
- Prepare for and respond to public health emergencies;
- Serve as a central point for sharing Canada's expertise with the rest of the world;
- Apply international research and development to Canada's public health programs; and

- Strengthen intergovernmental collaboration on public health and facilitate national approaches to public health policy and planning.

Vancouver Island Regional Health Authority

The health authority role is to minimize environmental risks to the public under the following programs: food safety, drinking water, recreational water, communicable disease control, land use and healthy built environment.

Washington State Department of Health

Programs and services help prevent illness and injury, promote healthy places to live and work, provide information to help people make good health decisions and ensure Washington state is prepared for emergencies.

Appendix 3. List of events, speakers and meetings

Date(s)	Meeting / Event	Speaker	Topic Discussed
Jan 18, Jan 26, Feb 2, Feb 9, Feb 16, Feb 24	Intersectorial Norovirus Stakeholder		Outbreak investigation
Mar 2, 2017	Invited speaker	Dr. Curtis Suttle, University of British Columbia (UBC)	Marine virus
Mar 16, 2017	Formation of ETNO working group		Terms of reference for group, data privacy, data share point site
Mar 30, 2017	ETNO	Trevor Hamelin, Ministry of Environment	WWTP in Victoria and Vancouver
Apr 13, 2017	ETNO	Greg West (PhD candidate), Earth Ocean and Atmospheric Sciences (EOAS), UBC	Climate impacts during 2016 / 2017 and previous outbreak years
		Blair Holmes, Environment Climate Change Canada (ECCC)	Overview of WWTP sources
May 11, 2017	ETNO	Dr. Rich Pawlowicz, EOAS, UBC	Ocean current patterns
		Blair Holmes, Sarah Bartnik, ECCC	Summary of pollution sources document and WWTP table
		Aroha Miller, BCCDC	Survey results
May 25, 2017	ETNO		Creations of gaps and barrier table
June 5, 2017	Genome BC	ETNO presented (Eleni Galanis, Lorraine McIntyre, Natalie Prystajecky)	Assessment of research needs for norovirus detection
Jun 15, 2017	ETNO		Survey results and evaluation for plausible hypotheses
Jun 29, 2017	Environmental Health Policy Advisory Committee	ETNO presented (Lorraine McIntyre)	Group activities
Jun 29, 2017	BC Medical Journal and press arising from article	L. McIntyre, E. Galanis, N. Prystajecky, Tom Kosatsky	Publication commentary on outbreak
Jul 6, 2017	ETNO		
Jul 18, 2017	Invited speaker	Dr. Abraham Deng, Louisiana State University	Modelling to forecast oyster norovirus outbreaks
Aug 17, 2017	ETNO	Ron Hein, Registered Onsite Wastewater Practitioner, Coast Mountain	Onsite sewage systems in BC
		Aroha Miller, BCCDC	Environmental factors literature review
Sep 7, 2017	ETNO	Emma Cumming, BCCDC	Sewage source literature review
Sep 28, 2017	ETNO		Mapping needs (for gaps table)
Oct 19, 2017	ETNO		Review of gaps table
Nov 9, 2017	ETNO	Lorraine McIntyre, BCCDC	Septic operators expert opinion results; WWTP literature review
Nov 30, 2017	ENTO (presented in person at CFIA laboratory as invited guest of K. Eloranta)	Tom Howell, Owner, Spinney Creek Oysters	Male-specific coliphage testing
		Ryan Powell, Nanaimo Pollution Control Centre	Description of WWTP and testing of influent and effluent discharge
		Marsha Taylor, BCCDC	Situational outbreak map of WWTP sources

Appendix 4. Supplementary materials from the ETNO working group

The following list of supplementary materials were developed during the working group or received by the ETNO working group. These PDF of all documents are available on request. With permission of the authors these will be made available in the future on the BCCDC web-site. Links to documents already on the web are shown.

- *Literature review of environmental factors and major sources of sewage affecting norovirus*. November 2017. Results of literature reviews were presented to the working group in a series of installments. This document summarizes the work done by Aroha Miller, Emma Cumming, Lorraine McIntyre and others. It outlines the literature search and review into norovirus, environmental and sewage sources, and provides a summary of shellfish outbreaks from enteric viruses.

- *Norovirus outbreak stakeholder survey results*. June 2017. This report summarizes the results of the first stakeholder survey into plausible hypotheses of norovirus contamination of shellfish.

- *Time series of environmental factors for four oyster growing areas in BC from 2002 to April 2017*. This report presents the methods and results of the following environmental factors: rainfall, salinity, sea surface temperature, upwelling (wind force on the ocean) and sunlight. Norovirus illnesses are overlaid onto plots.

- *Onsite Sewage System Background – Coast Mountain*. August 15, 2017. This summary from Mr. Ron Hein, ROWP/RULT was prepared for the working group members to explain the types of sewage systems covered under the sewerage system regulation, and describe systems in BC.

- Associated Engineering Ltd. Comox valley regional district south region LWMP. Feasibility of continuing to use private septic systems as primary wastewater strategy. . 2015. https://www.comoxvalleyrd.ca/sites/default/files/docs/Projects-Initiatives/1-2015_feasibility_study_continuing_to_use_private_septic_systems_as_primary_wastewater_strategy.pdf

- Canadian Council of Ministers of the Environment (2009). Canada-wide Strategy for the Management of Municipal Wastewater Effluent. 2014 Progress Report. http://www.ccme.ca/files/Resources/municipal_wastewater_efflent/cda_wide_strategy_mwwe_final_e.pdf

Appendix 5. Shellfish farm closures for 2016 and 2017 norovirus outbreaks

A search of the page link below "Fishery Notices - Search by Keywords" using the search terms shellfish AND land registry yields 5 notices for 2016 and 28 notices for 2017. Many of the notices are revokes of previous notices, or amendments. FN notices associated with the twelve 2016-17 shellfish farms closed as part of the outbreak cluster and the reason for the closure are shown below.

http://notices.dfo-mpo.gc.ca/fns-sap/index-eng.cfm?pg=keyword_search&ID=all&CFID=33009767&CFTOKEN=71a54d12089a9b3b-DC5A4C92-0C52-0482-56DCB02F087A379A

Year	Date	FN#	Tenure	Reason[1]
2016	Dec 15	1355	1405436	PC
	Dec 23	1383	1401533	NV
2017	Feb 1, Mar 31	70, 312	1411213	PC
	Feb 10	83	1407063	EC
	Feb 16, Mar 31	113, 310, 311	1402060	PC
	Feb 17	118	354967	PC
	Mar 9	195	1400036	PC
	Mar 9	196	278774	PC
	Mar 10	203	2401589	PC
	Apr 3	322	1401824	PC
	Apr 11, 13	357, 371	278757	EC
	Apr 18	376, 377	1402975	PC

[1]EC=E.coli; PC=potential contamination; NV=norovirus

Appendix 6. Evidence gaps, research needs, and barriers discussed that would inform plausible hypotheses for norovirus contamination in oysters and oyster growing areas

Summary: The working group identified 30 evidence gaps that hindered the ability to fully assess plausible hypotheses. Evidence gaps and associated barriers arose in norovirus and indicator methods, mapping, information about norovirus behaviour in marine environments, epidemiological assessments, and during assessments of various sewage sources. Overarching barriers to evidence included inaccessibility of information for a variety of reasons: institutional privacy concerns where data could not be shared, format and storage of information making accessibility and interpretation difficult (e.g., PDF reports), or the information was not collected. A status evaluation of evidence gaps demonstrates 18% of the evidence gaps are completed, i.e. the working group collected information from a variety of sources, and was able to assess the related hypotheses. A status indication of in progress was assigned to 38% of the evidence gaps. However, the majority of evidence gaps, 43%, have an unexplored status, i.e. no agency is planning to address this gap, has the mandate to address the gap, or the working group does not know how to request action for the evidence gap.

How to interpret the information provided in this section.

1. Evidence gaps and barriers are divided into the following tables:
    - Table 1. **Mapping** gaps and barriers
    - Table 2. Evidence gaps and barriers concerning **how norovirus behaves in the marine environment** in BC
    - Table 3. **Epidemiological assessment gaps** and barriers concerning the BC outbreak
    - Table 4. Evidence gaps and barriers concerning **sewage sources from land** in BC
    - Table 5. Evidence gaps and barriers concerning **sewage sources from vessel traffic** in BC
    - Table 6. **Methodological** gaps and barriers
2. Research needs are determined by priority and barriers to accessing evidence are indicated where required on each summary table.
3. Research priority of an item is listed as either
    a. 1 = high
    b. 2 = medium
    c. 3 = low
4. Status of an item is listed as either
    a. Completed: information or gap is addressed
    b. In progress: information of gap is being evaluated
    c. Unexplored: no-one is collecting information on this gap or issue

Unless explained, the status description Unexplored can additionally be interpreted as a barrier, as there is no agency collecting information on the gap or issue

Table 1: Mapping gaps and barriers

Overarching gaps and barriers for all items that would be useful to map: it is unclear whether the information collected at the agency level can be made publicly available, or is publicly available on-line. If on-line, does the information require interpretation (cleaning) before it can be used? Is there an available platform or access point to the information? The barriers in Table 1 are itemized for each item as:

A. information is mapped but either lack of permission to share publicly or no platform to share i.e. an institutional barrier;
B. information is collected but not formatted or able to be mapped without extensive interpretation;
C. information has not been collected

Information that would be useful to map:	Research Priority	Who has done work or plans to do work to address this gap?	Is this information publically available? Yes or No. Barrier category A, B, C	Status
1. Shellfish farms • All tenures • Those implicated in 2016-17 outbreak	1	• BCCDC has mapped all tenures • BCCDC also mapped tenures associated with the 2016-17 outbreak, using public DFO notice closures	Yes: all tenures Link[16] No: outbreak associated tenures. Barrier A.	Completed
2. Sewage sources (locations and/or density):	1			
• Wastewater treatment plants and sewage outfalls	1	• ECCC has GIS information related to the location of all actual and potential sources of fecal contamination. This was given to BCCDC for mapping. • MOE has publicly available spreadsheets of all authorized sewage discharges in the province.	ECCC and MOE. [17]Barrier A & B Yes (MOE), but requires interpretation, and is not complete Link[18] Barriers B and C	Completed In progress (under consideration as a future student project)

[16] http://maps.bccdc.org/shellfish

[17] ECCC provided information for internal use. This info was shared with the WG, however, for public consumption the owner of the data (MOE) must provide the link as this is not ECCC information. It was obtained through communication and surveys with individual WWTP.

[18] http://www2.gov.bc.ca/gov/content/environment/waste-management/waste-discharge-authorization/search-status-and-documents

Information that would be useful to map:	Research Priority	Who has done work or plans to do work to address this gap?	Is this information publically available? Yes or No. Barrier category A, B, C	Status
• Catchment size[19]	1	• This information is required to estimate norovirus risk.	No. Barrier A and B	Unexplored
• CSOs and areas where sewers not separated	1	• Some, but not all, CSOs are indicated on MOE discharge authorization list. This information is derived from Liquid Waste Management Plans (LWMP). LWMP are voluntary so not all communities have one.	Yes (MOE, as above). Barriers B and C	Unexplored
• Septic tanks	1	• Some septic tanks are indicated on MOE discharge authorization list. MOE has information on small septic tank discharges to marine and freshwater through outfalls for most flows, and septic tank discharges to ground for flows greater than 22.7 cubic metres per day.	Yes (MOE, as above). Barriers B and C	Unexplored
• Float homes	1	• DFO/ECCC are aware of all sites.[20]	No. Barriers A and B	Unexplored
• Other sewage sources	1	• ECCC has GIS information related to the location of known actual and potential sources of fecal contamination. [21]	No. Barriers A and B	Unexplored
3. Benthic sediment composition around: • Shellfish farms • Outfalls & WWTPs	3	• PHSA labs (Natalie Prystajecky) has limited sediment composition information from another (viral adhesion) project. • MOE has benthic information for site specific outfalls.	No. Barriers A and B	In progress (data can be made available if required for modelling)
4. Environmental data	2	• Expert (Rich Pawlowicz, EOS at UBC) has mapped	Publication in progress.	In progress

[19] Areas within a defined catchment size are expected to have norovirus present at all times, this may be available from census data

[20] This information is mapped by ECCC but requires on-site interpretation to assess actual level of risk. Also, under MCFR (Fisheries Act regulations), all float homes (floating living accommodation) have an automatic 125m harvesting prohibited zone. The location of float homes are fluid and do not remain constant.

[21] This information is mapped by ECCC but requires on-site interpretation to assess actual level of risk. Also, under MCFR (Fisheries Act regulations), all sewage outfalls have an automatic 300m harvesting prohibited zone at outfall point.

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Information that would be useful to map:	Research Priority	Who has done work or plans to do work to address this gap?	Is this information publically available? Yes or No. Barrier category A, B, C	Status
including ocean currents, watersheds, etc.		ocean currents for WG. • ECCC also collects oceanographic data, available via search in the Federal Science Library.[22] This source (PDF) would require data to be re-entered. • Currents and tides information is available on-line.[23] • Oceans Networks Canada also collects citizen science data through an agreement with U.Vic.[24]	Barriers B and C Link Link Link	(data is being compiled by BCCDC for modelling)

Table 2: Evidence gaps and barriers concerning norovirus behaviour in the marine environment in BC

Evidence gaps:	Research Priority	Who has done work or plans to do work to address this gap? Describe barriers.	Status
5. We don't have baseline/background levels or ongoing surveillance of **norovirus** concentration and diversity for BC in:	1		
• Oysters (in both outbreak-affected and unaffected areas)	1	• CFIA is conducting a survey of norovirus in domestic oysters – this data collection is ongoing. This is a market survey at retail – 150 samples collected per year.	In progress
• Marine waters	2		Unexplored
• Sediment	3		Unexplored
• WWTP effluent and influent	1		Unexplored
6. We don't have baseline/background levels or ongoing surveillance of **norovirus indicators (e.g., MSC)**	1	• CFIA plans to conduct method validation for MSC enumeration in Pacific oysters, as a necessary first step for future MSC testing. Testing starting 2018.	In progress: to start 2018

[22] http://science-libraries.canada.ca/eng/home/
[23] http://www.waterlevels.gc.ca/eng/info/Webservices
[24] http://dmas.uvic.ca/home?TREETYPE=1&LOCATION=58&TIMECONFIG=0
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Evidence gaps:	Research Priority	Who has done work or plans to do work to address this gap? Describe barriers.	Status
concentration and diversity for BC in: • Oysters • Marine waters • Sediment • WWTP effluent and influent		• Dr. Lilly (Xiao-Li) Pang has conducted study in Edmonton rivers impacted by WWTP • Washington State will be conducting a study this winter on WWTP effluent (Mark Toy). • Global project testing WWTP in progress, looking at AMR, considering virus (Dr. Yost). • FoodNet program will include retail oysters in their sampling plan next year.	Published. Link[25] In progress
7. We don't have a metagenomics assessment of virome (i.e. not only norovirus) for BC in: • Oysters • Marine waters • Sediment • WWTP effluent and influent • Marine wildlife (potential carriers/reservoirs)	3	• To date, sea lions have not been demonstrated to carry human norovirus. They do carry a diverse virome, including non-human norovirus strains. • No artificial infection done. • A study on noroviruses in porpoises has been done in The Netherlands. Link.[26]	Unexplored

8. We don't know how the following environmental parameters impact the dispersion, survival, and infectivity of norovirus in seawater and oysters in BC	1	• Modeling
		  • A. Deng's work in Gulf of Mexico and Puget Sound. Link[27].
		  • Exploratory work at BCCDC for BC context (E. Cumming).
		• Expert speakers presented to WG re: currents and rainfall (R. Pawlowicz and G. West)
			Completed (See Descriptive Time Series Report)

• Sea surface temperature • Water depth/gage height • Rainfall	• Salinity • Currents	• Wind speed and direction • Solar radiation • Wave action	

[25] https://www.ncbi.nlm.nih.gov/pubmed/26473649
[26] https://wwwnc.cdc.gov/eid/article/23/1/pdfs/16-1081.pdf
[27] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4858391/pdf/ehp.1509764.pdf

Evidence gaps:	Research Priority	Who has done work or plans to do work to address this gap? Describe barriers.	Status
9. We don't know **how long norovirus can survive** in the BC marine environment, either in sea water or bound to sediment or microorganisms.	1	• Washington State is conducting a growing area study this winter that may inform this question.	In progress in WA Unexplored in BC
10. We don't know **how far norovirus can travel** and disperse from both:	1	• Washington State is conducting a growing area study this winter that may inform this question.	In progress in WA Unexplored in BC
• Point sources of sewage, such as WWTPs and other sewage outfalls in BC i.e., how does norovirus behave in sewage plumes in BC waters. (related to #4)	1	• Sewage plumes have been mapped by ECCC with respect to fecal coliforms and E. coli, and modelling does include virus reduction but not specifically for norovirus. There is no work planned for norovirus or MSC at this time. • There has been no sampling of oysters in plumes of WWTP in BC.	Completed (Modelling work) Unexplored
• Non-point source runoff e.g., septic tank seepage, urban rainfall runoff, etc. This depends on soil type and other site specific factors.	1		Unexplored
11. We don't know for certain that no **wildlife carrier/reservoir** exists, such as sea lions or birds. We also don't know the mechanism by which norovirus would be transmitted from sewage to animals to oysters.	3	• PHSA labs, in collaboration with DFO and Vancouver Aquarium, have tested a small number of mammal fecal samples for norovirus this year. No human norovirus detected. One sample was positive for norovirus, but had only 70% homology to human calicivirus. Sea Lions (n=38) and Harbour Seals (n=14)	Completed (no further testing planned)

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Table 3: Epidemiological assessment gaps and barriers

Epidemiological assessment gaps:	Research Priority	Who has done work or plans to do work to address this gap? Describe barriers.	Status
12. During the period of the outbreak, the outbreak team did not have access to sewage sources such as authorization discharges from WWTP, or other possible sites of contamination	1	• Onus is on treatment plants to report to the emergency reporting line.[28] ECCC called plants to check for this outbreak. • **Barrier:** information collection is not automated and is not accessible or available during times of crisis (i.e. outbreak).	Unexplored
13. We don't have **tenure history for oyster harvesting** in BC. Tenure history should identify the full movement history of the shellfish, including the length of time grown at all tenures (i.e. shellfish farm locations). At present only the final tenure is recorded by law. Potential contamination occurs prior to wet storage at final recorded tenure site.	1	*Note: the illness criteria closure model for landfills will not be based on production volumes, farming techniques, or water temperature and other data as these are not necessary for norovirus assessment (in comparison to Vibrio assessments).* These gaps were removed from table. DFO is examining tenure history in a new WG. The priority is to address this concern in future outbreaks, as this information cannot be ascertained retroactively. Concern is that shellfish tag information did not / does not accurately describe the full movement history and origin of shellfish.	In progress
14. We don't know how the BC outbreak of 2016-17 compared to the one in **Washington State**.	1	• A. Deng has looked at this with modeling project. • Washington State has shared outbreak reports to inform this gap.	Completed
15. We don't know genotyping of all the **community outbreaks** of norovirus to compare to genotypes found in oysters	1	• PHSA labs has genotyping for community outbreaks in some health authorities, but not in areas that conduct their own presence/absence testing for norovirus. Estimate 70% of activity in province is captured by PHSA labs. • PHSA is trying this season to get in-patient samples. Will ask VIHA to send representative samples for this season. • **Barrier:** sample collection, submission and reporting across the province of	In progress

[28] http://www2.gov.bc.ca/gov/content/environment/air-land-water/spills-environmental-emergencies/report-a-spill

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		BC is not standardized for norovirus community outbreaks differing by regional health authority.	

Table 4: Sewage sources from land gaps and barriers

Evidence gaps:	Research Priority	Who has done work or plans to do work to address this gap? Describe barriers.	Status
16. We don't know when WWTPs use **secondary treatments** that effectively inactivate virus. • Residence time of influent in lagoons • If the plant uses UV treatment or chlorine treatment for wastewater discharges to the environment.	1	• ECCC table and MOE discharge authorizations give some idea of locations with secondary treatment processes involving use of chlorine, but not when they are implemented. Disinfection timing would be in the permits and site specific authorizations. Disinfection is typically year round, with exceptions • **Barrier:** information about when treatment processes are implemented is not accessible	Unexplored
17. We don't know **when WWTPs implement seasonal changes** in their treatment plans. For e.g., decisions to chlorinate effluent discharge during summer bathing season, but not during winter norovirus season.	1	• Only aware of Metro Vancouver changing treatment mid-season due to E. coli at beaches. Disinfection timing would be in the permits and site specific authorizations. Disinfection is typically year round, with exceptions. • **Barrier:** information about when treatment processes are implemented is not accessible	Unexplored
18. We don't know how **quality targets differ across WWTPs**, what criteria are used, and whether virus levels are measured or if plans exist to implement viral monitoring. • We don't know what regulations exist re: viral concentrations.	1	• There are no federal or provincial regulations for NoV levels in WWTP effluents and norovirus is not included in regulatory monitoring	Unexplored
19. We don't know the **catchment size** of WWTPs and how this affects norovirus levels in discharges	1	• Census data is publicly accessible, but it is not mapped to WWTP. Municipal governments also have this data, and MOE has information through voluntary LWMP and site specific authorizations.	Unexplored

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Evidence gaps:	Research Priority	Who has done work or plans to do work to address this gap? Describe barriers.	Status
seasonally		• **Barrier:** mapping of data	
20. We don't know how big of an impact **septic tanks, communal septic systems and small on-site systems with disposal fields** have on sewage contamination of the marine environment in BC, especially those in **performance failure** that need upgrading/replacement. • We don't know how difficult performance failures are to detect during shoreline surveys • There is no reporting requirement for performance failures	1	• Ron Hein (compliance inspector) of Coast Mountain Earth Services compiled three months of inspection data for WG suggesting 80% performance failure rate, but data was not based in shellfish growing areas. • Interviews of septic service agents (ROWP) in shellfish growing areas confirmed performance failure in areas with older systems and poor substrates are of concern. • **Barrier:** working group did not assess communal septic systems, small on-site systems or disposal fields in the literature review or discussions • **Barrier:** there is no reporting requirement for performance failures and information held by the health authority is in scanned PDF documents that are not able to be analysed.	In progress
21. We don't know how big of an impact **SSOs** & **CSOs** have on sewage contamination of the marine environment in BC: • How are overflows monitored, tracked, and alerted throughout BC, especially coastal communities.	1	• Greater Vancouver monitors its CSOs during overflow events and presents results in an annual report. Does this occur elsewhere? Greater Vancouver also monitors SSOs, and report out on annually. • Individual plants keep records of all events and there is some email notification to stakeholders regarding overflow events. Note; plants track bypasses of treatment works, no necessarily SSOs. • **Barrier:** plant records are not easily available or compiled into information that can be accessible and analyzed.	Unexplored

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Table 5: Sewage sources from vessel traffic gaps and barriers

Evidence gaps:	Research Priority	Who has done work or plans to do work to address this gap? Describe barriers.	Status
22. We don't know the volume of **recreational boat** traffic from October to April, or the risk of impact from such boats.	1	• Sewage discharge regulations. CSSP is working with Transport Canada and BCSGA for recreational boaters on an educational campaign to discharge waste appropriately per regulations. Educational poster created. • ECCC collects observations related to potential sewage sources, including recreational boats. In B.C. coastal waters, compared with the summer, the number of recreational active boats is reduced during the winter when norovirus is most prevalent in the community. Thus recreational boats are less likely to directly contribute to winter norovirus sources in shellfish growing areas.	Completed Completed
23. We don't know if the **cruise ship traffic** period overlaps with norovirus outbreak period.	3	• Cruise ship traffic is minimal October to April and unlikely to directly contribute to winter norovirus sources in shellfish growing areas.	Completed
24. We don't know the risk of **commercial fishery vessel traffic** prior to and during outbreak period.	1	• DFO is examining vessels associated with specific fisheries via a new working group. They have recognized this as a risk, and are attending commercial vessel sectoral meetings to provide education on this issue. • DFO provided this working group with a list of open fisheries during the outbreak period (one commercial boat during herring fishery did have active gastro illness with sewage discharge to marine waters).	In progress
25. We don't know the risk generated from **float homes and accommodation barges**, and whether sewage regulations are generally followed by such homes.	2	• DFO/ECCC examining this issue and level of compliance with regulations during field surveys. They do invoke closures and have zones of prohibition around homes to shellfish areas.	In progress

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Table 6: Methodological gaps and barriers

Methodological gaps:	Research Priority	Who has done work or plans to do work to address this gap? Describe barriers.	Status
26. We don't have culture methods that discriminate between human and animal sources of feces/MSC (similar to issues with *E. coli*).	2	• But better to have some data than no data. Screen with plaque assay, then if positive, could test. Should not wait for human/non-human indicator	Unexplored
27. We don't have MSC as a routine indicator in shellfish or baseline MSC data in shellfish	1	• This testing is available in the US on a routine basis	In progress
28. We lack an easy norovirus genotyping method.	1	• Genome BC may be able to assist.	In progress (discussion at this point)
29. Shellfish farmers have no way of testing for norovirus themselves.	1	• BCSGA, in collaboration with BC researchers from North Island College and the BC Centre for Aquatic Health Sciences, is developing an assay based on the ISO 15216-1 method. This will be a molecular based assay.	In progress
30. Current quantitative test (PCR) cannot distinguish between live and dead viral particles.	3		Unexplored

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