New Zealand Food Safety
Haumaru Kai Aotearoa

Risk Profile Update: Norovirus in bivalve molluscan shellfish (raw)

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Prepared for New Zealand Food Safety
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Cover Image: 3D graphical representation of a number of norovirus virions.
Credit: Centers for Disease Control and Prevention (CDC)/ Jessica A. Allen

Scientific Interpretative Summary

This SIS is prepared by New Zealand Food Safety (NZFS) risk assessors to provide context to the following report for NZFS risk managers and external readers.

Risk Profile Update: Norovirus in bivalve molluscan shellfish (raw)

This document is an update for the risk profile of Norovirus in bivalve molluscan shellfish (BMS) consumed raw in New Zealand. The report reviews the most recent information, focusing on studies detailing attribution and risk management interventions to assess if the risk from norovirus in bivalve molluscan shellfish (BMS) has changed since the previous risk profile published in 2009.

Between 2009 and 2015, a total of 172 foodborne outbreaks caused by Norovirus infection have been reported in New Zealand. Shellfish was the suspected vehicle of infection for 13 outbreaks (8% of total), involving 104 cases. This rate is consistent with the New Zealand expert elicitation which estimated that 8% of all norovirus infections in New Zealand are due to transmission by seafood. Overseas attribution studies suggest that transmission of norovirus by seafood represents up to 11% of foodborne illnesses. It is important to note, however, that despite being the most frequently reported agent of foodborne disease in New Zealand, Norovirus infections are still considered to be underreported.

Commercially harvested oysters were implicated in 85% of norovirus foodborne outbreaks in New Zealand, with those from an imported origin implicated in 31% of outbreaks.

Baseline microbiological data on the prevalence of Norovirus in BMS commercially harvested in New Zealand are not currently available as food analysis only occurs during an outbreak investigation.

Data collected from sites known to be at risk from contamination between 2006 and 2011 have demonstrated the presence of norovirus in 50% of recreationally harvested BMS, with concentrations > 1000 genome copies per gram of guts for approximately 25 % of the samples. However, the sampled BMS may not have been destined for human consumption.

From 2012, norovirus testing of oysters has been added to the Imported Food Requirements. The absence of reported outbreaks since this date suggests this measure is effective in contributing to a decreased risk associated with BMS.

The risk associated with commercially harvested BMS in New Zealand seems to also have decreased although this finding is questionable as cases are underreported and seafood consumption has decreased in in New Zealand. Generating additional prevalence data would be needed to confirm this risk assessment is accurate.

Finally, the two most recent outbreaks reported in 2013 and 2015, were associated with recreationally harvested BMS, supporting that the risk remains for consumption of recreational shellfish.

Numerous data gaps remain on exposure, detection methods and virus removal techniques. However, the most important knowledge gap is the lack of prevalence data in New Zealand BMS. Future microbiological surveys of raw or lightly cooked BMS available to New Zealand consumers, with a focus on commercially and recreationally harvested shellfish other than oysters will be considered by MPI to address this data gap.

RISK PROFILE (UPDATE): NOROVIRUS IN BIVALVE MOLLUSCAN SHELLFISH (RAW)

Client Report FW16008

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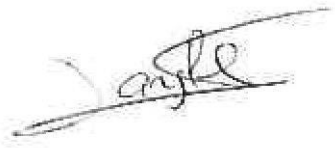

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

1997NNS	National Nutrition Survey conducted in 1997
2002CNS	Children's National Nutrition Survey conducted in 2002
2009ANS	Adult Nutrition Survey conducted in 2008-2009
BMS	Bivalve molluscan shellfish
BMSRCS	BMS Regulated Control Scheme
CAC	Codex Alimentarius Commission
CEN	European Committee for Standardization
CI	Confidence interval
CrI	Credible interval
DALY	Disability adjusted life year
E. coli	*Escherichia coli*
EFSA	European Food Safety Authority
ESR	Environmental Science and Research Limited
EU	European Union
FUT2	1,2-fucosyltransferase
GI	Genogroup I (norovirus)
GII	Genogroup II (norovirus)
GIV	Genogroup IIV (norovirus)
GII.4	Genogroup II, genotype 4 (norovirus)
HBGAs	Histo-blood group antigens
HPP	High pressure processing
HRI	High Regulatory Interest
IANZ	International Accreditation New Zealand
ID_{50}	50% infectious dose
IFR	Imported Food Requirement
ISO	International Organization for Standardization
L	Litre
NIWA	National Institute of Water and Atmospheric Research
NMDS	National Minimum Data Set
NZFSA	New Zealand Food Safety Authority[1]
MAF	Ministry of Agriculture and Forestry (New Zealand)[1]
MPa	Megapascal

[1] On 1 July 2010, NZFSA and MAF were amalgamated. On 30 April 2012, MAF was renamed as MPI. This document uses the names NZFSA and MAF for documents produced during the existence of these organisations.

MPI	Ministry for Primary Industries (New Zealand)[1]
MPN	Most probable number
MMWR	Morbidity and Mortality Weekly Report
MSC	Male-specific coliphages
ORF	Open reading frame
PCR	Polymerase chain reaction
ProMED	Program for Monitoring Emerging Diseases
QMS	Quota Management System
RASFF	Rapid Alert System for Food and Feed
RMP	Risk Management Programme
RT	Reverse transcription
RTE	Ready-to-eat
RT-PCR	Reverse transcription polymerase chain reaction
RT-qPCR	Reverse transcription real-time polymerase chain reaction
STEC	Shiga toxin (or shigatoxigenic) producing *E. coli*
TAC	Total allowable catch
TACC	Total allowable commercial catch
UI	Uncertainty interval
UK	United Kingdom
US	United States (of America), shortened version often officially used
USFDA	US Food and Drug Administration
VLP	Virus-like particles
WHO	World Health Organization

SUMMARY

This Risk Profile considers norovirus in bivalve molluscan shellfish (BMS) harvested from aquaculture or wild stocks and sold to New Zealand consumers shucked or whole in the shell, fresh or frozen, and consumed raw. The risk is also assessed for BMS collected non-commercially (customary or recreational gathering). BMS are filter-feeding shellfish such as oysters, clams, mussels and scallops, which can accumulate bacteria and viruses in their bodies as they feed. The noroviruses considered are only those that infect humans.

This is an update of a Risk Profile published in 2009 (Greening *et al.*, 2009), which was itself an update of a Risk Profile published in 2003 (Greening *et al.*, 2003a). The purpose of this update is to critically review new information to answer the following risk management question:

Has the risk from norovirus in bivalve molluscan shellfish (BMS) changed since the previous Risk Profile in 2009?

The literature on norovirus in BMS is extensive. The focus of this update has been on studies that have been performed in New Zealand, and overseas studies that inform on attribution and risk management interventions.

Noroviruses belonging to genogroups I, II and IV (GI, GII and GIV) cause gastroenteritis in humans of all ages. While the norovirus genotype GII.4 is currently the major cause of norovirus gastroenteritis outbreaks worldwide, other genotypes have the potential to emerge as the predominant norovirus. Compared to person-to-person outbreaks, food and waterborne outbreaks are more often associated with GI and non-GII.4 genotypes rather than GII.4.

Humans are the only known reservoir of the noroviruses that infect humans. Norovirus is primarily transmitted person-to-person and to a lesser extent via food, water or the environment. BMS are exposed to noroviruses when their growing waters are contaminated with human faeces, primarily from wastewater effluent. Norovirus GI and GII have been detected in wastewater treatment plant effluents, estuaries and rivers in New Zealand. Noroviruses can resist depuration processes and studies have shown that norovirus can persist inside BMS for weeks, and even months. As a human host is required for its replication, human noroviruses cannot replicate in shellfish during production or storage. Norovirus can readily survive under a variety of conditions including refrigeration and freezing, as demonstrated by outbreaks associated with frozen products.

There has been no comprehensive monitoring programme in New Zealand to investigate the presence of norovirus in commercially harvested BMS from New Zealand waters, or in BMS at retail. Analysis of commercially harvested BMS for norovirus is only generally performed as a part of a norovirus outbreak investigation or foodborne illness case.

BMS collected from non-commercial sites in New Zealand show a norovirus prevalence of approximately 50% (254/485). This prevalence may not necessarily be representative of non-commercial sites within New Zealand, as sampling was based on risk rather than through a comprehensive monitoring programme of representative New Zealand sites. Norovirus GI and GII were detected at concentrations of >1,000 genome copies per gram of guts in approx. 25% of positive samples.

Norovirus infection is underreported in New Zealand; sporadic cases are not necessarily notifiable and the symptoms of the disease do not usually require an infected person to seek medical attention. Despite this, norovirus is the most frequently reported agent for outbreaks in New Zealand, in terms of both numbers of outbreaks and numbers of associated cases.

For the period 2009-2015 there were 13 reported outbreaks of norovirus infection in New Zealand, involving 104 cases, where the vehicle of infection was likely to be shellfish. This represents 9% of foodborne outbreaks caused by norovirus during this period, and 5% of cases. Various genotypes of norovirus GI and GII were identified in these outbreaks. Commercially harvested oysters were implicated in 85% (11/13) of these outbreaks (imported oysters were the vehicle of infection four of these outbreaks). The other two outbreaks were the only outbreaks reported since 2012, and non-commercially harvested shellfish were implicated in both. From October 2012, norovirus testing of raw, cooked, dried and ready-to-eat (RTE) oysters was added to the Imported Food Requirements (IFR). There were two mandatory recalls of oysters in New Zealand due to presence or potential presence of norovirus during the period 2008 to 2015. Both related to reported cases of norovirus illness. There have been no New Zealand recalls for imported oysters contaminated with norovirus since the change to the IFR.

The 2003 Risk Profile had identified oysters as important vehicles of norovirus infection and concluded that the presence of norovirus in shellfish was largely a result of faecal contamination of the growing environment. The 2009 Risk Profile concluded: “It is unclear whether the risk of norovirus infection from commercial shellfish for the New Zealand population has changed since the previous Risk Profile was completed in 2003. However the risk has been better characterised as a result of surveys including the multi-site and Tauranga Harbour surveys, and evidence for widespread norovirus contamination of shellfish, particularly feral shellfish, has been obtained.”

The information presented in this current Risk Profile shows that BMS available in New Zealand from local and overseas sources can potentially be contaminated by norovirus, and that contamination events have led to illness in this country.

The available information suggests that:

- Norovirus testing of imported oysters has contributed to a decreased risk from this food since the 2009 Risk Profile. Control measures (testing for norovirus) on imported oysters have been effective, as indicated by there being no reported outbreaks from imported oysters since the change in the IFR in October 2012.
- There may be decreased risk from commercially harvested BMS, as suggested by the absence of outbreaks linked to this food since 2009, but baseline microbiological data are needed to validate this finding.
- BMS gathered for recreational or customary purposes present an ongoing risk for norovirus infection as they are more likely to be exposed to faecal contamination from point and non-point sources. Norovirus outbreaks connected with recreationally harvested BMS have now been reported.

Oysters continue to be the species of most concern with regard to norovirus infection from commercially harvested BMS. Mussels and scallops have not been implicated as the vehicle of infection for norovirus outbreaks in New Zealand. Raw BMS are an infrequently consumed food in New Zealand. A comparison of data from 1997 and 2009 suggests that adult New Zealanders are eating less shellfish, so exposure to BMS contaminated with norovirus is potentially less. Mussels account for the majority of shellfish consumed (and an estimated 40% of mussel servings are raw) and oysters are most likely to be consumed raw (estimated 50% of servings). Research suggests that Māori consume shellfish more frequently than the general population and so may be more at risk.

1. INTRODUCTION

This document updates a Risk Profile completed in 2009 that considered norovirus in mollusca (raw) (Greening *et al.*, 2009). The 2009 Risk Profile was itself an update of a Risk Profile completed in 2003 (Greening *et al.*, 2003a).

The risk is assessed for bivalve molluscan shellfish (BMS) harvested from aquaculture or wild stocks and sold to New Zealand consumers shucked or whole in the shell, fresh or frozen, and consumed raw. The risk is also assessed for BMS collected non-commercially (customary or recreational gathering). This Risk Profile includes all species of filter-feeding BMS including oysters, clams, mussels and scallops. Molluscs that are not bivalves and do not filter feed present a much lower risk from norovirus, and so are excluded.

This update is not a stand-alone document and refers to information presented in the 2009 document, which can be accessed from:

http://www.foodsafety.govt.nz/elibrary/industry/Risk_Profile_Norovirus-Science_Research.pdf

The purpose of this update is to critically review new information to answer the following risk management question:

- Has the risk from norovirus in BMS changed since the previous Risk Profile in 2009?

Risk Profiles provide scientific information relevant to a food/hazard combination for risk managers and describe potential risk management options (NZFSA, 2010).[2]

[2] Risk Profiles commissioned by MPI and its predecessors can be viewed at: http://www.foodsafety.govt.nz.

2. HAZARD AND FOOD

2.1 THE PATHOGEN: NOROVIRUS

Appendices A.1 - A.3 contain additional information on norovirus.

Key findings

Noroviruses belonging to genogroups I, II and IV (GI, GII and GIV) cause gastroenteritis in humans of all ages. While the norovirus genotype GII.4 is currently the major cause of norovirus gastroenteritis outbreaks worldwide, other genotypes have the potential to emerge as the predominant genotype. Compared to person-to-person outbreaks, food and waterborne outbreaks are more often associated with GI and non-GII.4 genotypes rather than GII.4.

A unified naming system for norovirus was proposed in 2013 in response to the need for nomenclature harmonisation and the increasing recognition of molecular recombination within this viral group. The proposed system fits with the nomenclature system used in New Zealand since 2007.

Human susceptibility to norovirus depends on the virus strain and a person's genetics. No specific studies have been carried out to determine norovirus susceptibility within the New Zealand population.

The current evidence does not support zoonotic transmission of norovirus. Norovirus is primarily transmitted person-to-person and to a lesser extent via food, water or the environment.

2.1.1 Nomenclature and classification

Noroviruses in the family *Caliciviridae* are now classified genetically into at least six genogroups (I-VI) (Green, 2013). There is also a proposed tentative seventh genogroup, (GVII) associated with infection in dogs (Tse *et al.*, 2012; Vinjé, 2015). Norovirus belonging to genogroup I (GI), II (GII) and less commonly IV (GIV) infect humans and are causative agents of human gastroenteritis. Certain norovirus genogroups are associated with animal infections including in cows, sheep, dogs and cats (Table 1).

TABLE 1: Norovirus genogroups

GENOGROUP	KNOWN HOST(S)
I	Humans
II	Humans, pigs
III	Cows, sheep
IV	Humans, dogs, cats
V	Mice
VI	Dogs, cats
VII (tentative)	Dogs

Noroviruses are highly diverse and genogroups are further divided into genotypes or genetic clusters. To date, there are nine GI and 22 GII capsid genotypes. There are three genotypes

in GII (GII.11, GII.18 and GII.19) that are only associated with infection of pigs (Vinjé, 2015). Unless otherwise indicated, the term norovirus or noroviruses used in this document refer to viruses belonging to GI, GII and GIV that infect humans.

Noroviruses belonging to genotype 4 in the GII group (i.e. GII.4) have predominated globally since the mid-1990s. This genotype is currently the major cause of norovirus gastroenteritis outbreaks, particularly in the healthcare sector. GII.4 viruses are further divided into 'variants'. GII.4 variants commonly emerge every 3-4 years and may cause global gastroenteritis pandemics (Siebenga *et al.*, 2009). In late 2012, the GII.4 variant Sydney_2012 emerged in several countries, including New Zealand, Australia, Europe, the United States (US) and Japan. This replaced the previous predominant GII.4 variant, New Orleans_2009, in less than a year (Eden *et al.*, 2014; van Beek *et al.*, 2013). It is possible that other norovirus genotypes will emerge as the predominant type. GII.17 was reported as the predominant genotype in regions of China in the winter of 2014-15 (Gao *et al.*, 2015) and outbreaks from this genotype have been reported in New Zealand (de Graaf *et al.*, 2015).

Due to the increasing recognition of the importance of recombination in the evolution and diversity of noroviruses (Eden *et al.*, 2014) and the need for harmonisation in the nomenclature used due to naming inconsistences, a unified system was proposed in 2013 (Kroneman *et al.*, 2013). The proposed system utilises dual genotyping results from both the Open Reading Frame (ORF)1 (that encodes for the viral polymerase) and ORF2 (that encodes for the major capsid protein VP1). For norovirus GI and GII, at least 47 ORF1 genotypes and 37 ORF2 genotypes have been described. New norovirus strains that result from the recombination of two viral genomes, most frequently around the ORF1/ORF2 junction of the genome, can result in a virus for which the ORF1 and ORF2 genotypes are different. For example, norovirus GII.4 Sydney_2012 is a recombinant with a GII.e ORF-1 and a GII.4 ORF2 (i.e. GII.Pe/GII.4).

This dual typing approach has been used in New Zealand since 2007 (Greening *et al.*, 2012) but most norovirus sequences in the international database GenBank, for example, show that this approach has not been used. Typing is further described in Appendix A.2.

2.1.2 Disease and transmission

Human norovirus is a leading cause of outbreaks and sporadic cases of gastroenteritis worldwide and infect all age groups (Siebenga *et al.*, 2009). In the US, norovirus is now the leading cause of medically-attended acute gastroenteritis in young children (Payne *et al.*, 2013). The common understanding is that immunity to norovirus is short-lived at between six months to two years (Parrino *et al.*, 1977). More recent studies have shown that the mean duration of immunity may be longer at 4.1 (95% confidence interval (CI) 3.2-5.1) to 8.7 (95% CI 6.8-11.3) years (Simmons *et al.*, 2013).

As infection with one particular norovirus genotype does not confer life-long immunity, and new variants and recombinants are always emerging, humans can expect to be infected with noroviruses many times throughout their life (Debbink *et al.*, 2012; Simmons *et al.*, 2013). Host susceptibility to infection is also affected by genetic makeup (see Section 2.1.3). Frequent exposure to noroviruses is supported by seroprevalence studies that show rates reaching >90% worldwide in adults (Son *et al.*, 2013). There are currently no approved norovirus anti-virals, vaccines or small molecule therapeutics available for norovirus prevention, treatment or prophylaxis, although there are a number of candidates that have shown promise (Herbst-Kralovetz *et al.*, 2010).

The routes of norovirus transmission are multiple and complex. Person-to-person is still considered to be the most common transmission route of human norovirus. Studies have indicated that children aged <5 years are much more infectious than older children and adults, and are thought to have a key role in transmission to other age groups (Simmons *et al.*, 2013). This is possibly due to young children having higher rates of physical contact and lower standards of hygiene compared to older people. Foodborne, waterborne and environmental routes are also important (Mathijs *et al.*, 2012; Verhoef *et al.*, 2015).

Foodborne and waterborne outbreaks are more frequently associated with GI and non-GII.4 types than GII.4, which is more commonly associated with person-to-person outbreaks, particularly in healthcare settings. Using data from between 1999 and 2012 from multiple surveillance systems including data from New Zealand, 10% (range 9-11%) of all GII.4 outbreaks were attributed to foodborne transmission compared to 27% (25-30%) of non-GII.4 outbreaks (Verhoef *et al.*, 2015; Verhoef *et al.*, 2010). Of outbreaks caused by mixtures of GII.4 and other noroviruses, an estimated 37% (24-52%) were foodborne (Verhoef *et al.*, 2015).

2.1.3 Human susceptibility to norovirus infections

Human susceptibility to norovirus is linked to the expression of highly polymorphic human histo-blood group antigens (HBGAs). Expression of HBGAs on human cells is genetically determined. HBGAs contain the ABH (A, B, O groups) and Lewis carbohydrate antigens that are thought to be present on human host cells in the gut. The precise role of HBGA is still poorly understood but it is thought that these carbohydrates serve as (co-) receptors or ligands for norovirus attachment (with the hypervariable P2 domain of the norovirus VP1 capsid protein binding to HBGAs). The FUT2 gene (encoding for 1,2-fucosyltransferase) controls the expression (secretion) of ABO HBGAs at the gut surface. Individuals that express a functional FUT2 gene and so express the ABH antigens in saliva or on epithelial cells are known as "secretors". Individuals that do not express the FUT2 gene as a result of a non-sense mutation ('non-secretors') show resistance, but not absolute protection (Carlsson *et al.*, 2009), to norovirus infection. While persons with a non-secretor gene represent approximately 20% of the populations in Europe and the US, the proportion is dependent on ancestry/ethnicity and so norovirus susceptibility within populations is variable (Currier *et al.*, 2015; Han *et al.*, 2013; Le Pendu *et al.*, 2006). For example, while persons of Meso-American and many of Asian descent are rarely non-secretors (Ferrer-Admetlla *et al.*, 2009), up to 50% of persons in the Philippines, Tanzania and Saudi Arabia have a non-secretor status (reviewed in Nordgren *et al.* (2016)).

Noroviruses are highly diverse in the HBGAs that they recognise. To date at least nine different HBGA antigens have been shown to bind with noroviruses. The interactions of norovirus with HBGA antigens are also strain-dependent (Ruvoen-Clouet *et al.*, 2013; Tan and Jiang, 2010). This means that populations with a large HBGA diversity would support the circulation of a wide range of norovirus genotypes. Indeed studies have shown the norovirus diversity in children in Africa (where there is a high diversity of HBGA) is higher than in other countries (reviewed in Nordgren *et al.* (2016)).

No specific studies have been carried out to determine the secretor status (i.e. FUT2 status) within the whole New Zealand population. This information may aid in the understanding of norovirus susceptibility and disease burden at the New Zealand population level.

As the predominate genotype, the interactions of GII.4 with HBGA is of particular importance. Norovirus GII.4 has been shown to interact with a wider range of HBGA types than other norovirus genotypes, so can potentially infect people with different (rather than just a specific) HBGA statuses (Singh *et al.*, 2015). This partly explains the global predominance of this genotype. Norovirus GII.17, predominant in China since 2014, has also been shown to interact with numerous HBGA types. As with GII.4, non-secretors and Lewis-negative individuals were non-symptomatic following exposure to GII.17, presumably because they were not susceptible to infection (Zhang *et al.*, 2015).

2.1.4 Cross-species or zoonotic transmission

The 2009 Risk Profile reported that zoonotic transmission of norovirus was not considered a significant pathway for human infection. Studies published since continue to support this view. Noroviruses are generally considered to be host species specific and although theoretically there is potential for zoonotic transmission, there are no confirmed reports of cross-species

transmission to humans. To date, no norovirus types that infect animals have been detected in humans. Based on this information, an animal reservoir for human norovirus is considered unlikely. Noroviruses that infect humans have been detected in animal faecal samples. In addition to the studies described in the 2009 Risk Profile, a 2012 paper reported that three of the 92 pet dog faecal samples tested positive for human norovirus GII.4 or GII.12 (Summa *et al.*, 2012). As virus replication in these animals could not be confirmed, the significance with respect to potential zoonotic transfer remains unclear. Studies have shown that bovine norovirus (belonging to genogroup III) binds to a carbohydrate motif not present on human cells, but canine noroviruses (genogroups IV and VI) interact with HBGA from human cells in a similar way to human noroviruses (Caddy *et al.*, 2014). Indeed, Caddy et al. suggested that it may be possible for canine norovirus to infect humans.

2.2 THE FOOD: MOLLUSCA (RAW)

Key findings

Landings data indicates that cockles and Foveaux Strait dredge oysters (Bluff oysters) are commercially harvested from wild stocks in the largest amounts, by weight. New Zealand green-lipped mussels and Pacific oysters are commercially farmed in New Zealand. The estimated number of BMS harvested by recreational fishers during 2012 were 1.7 million scallops, approximately 1 million mussels, and lesser numbers of tuatua, cockles, pipi and oysters.

The main BMS species imported into New Zealand is Pacific oysters, predominantly (96%) imported from the Republic of Korea. A large amount of frozen scallops are also imported, mainly from China.

For the most recent year for which information is available (2011), an estimated 13,000 tonnes (meat weight) of shucked BMS were available to New Zealand consumers, with green-lipped mussels accounting for 96% of this amount.

The molluscs considered in this Risk Profile are the same as those in the 2009 document, i.e. BMS: Clams (cockle, pipi, toheroa, tuatua), mussels, oysters and scallops. BMS are filter-feeders and can readily accumulate norovirus, primarily in the digestive glands. Both commercial and non-commercial stocks of BMS are considered. Other non-BMS mollusca such as paua, abalone, squid or snails are not included as they are not filter-feeders and present lower risk.

A variety of BMS inhabit New Zealand marine and estuarine environments (wild stocks) or are farmed (aquaculture). These include clams (e.g. cockles, pipi, toheroa, tuatua), oysters, mussels and scallops. Figure 1 explains the sources of BMS available to New Zealand consumers.

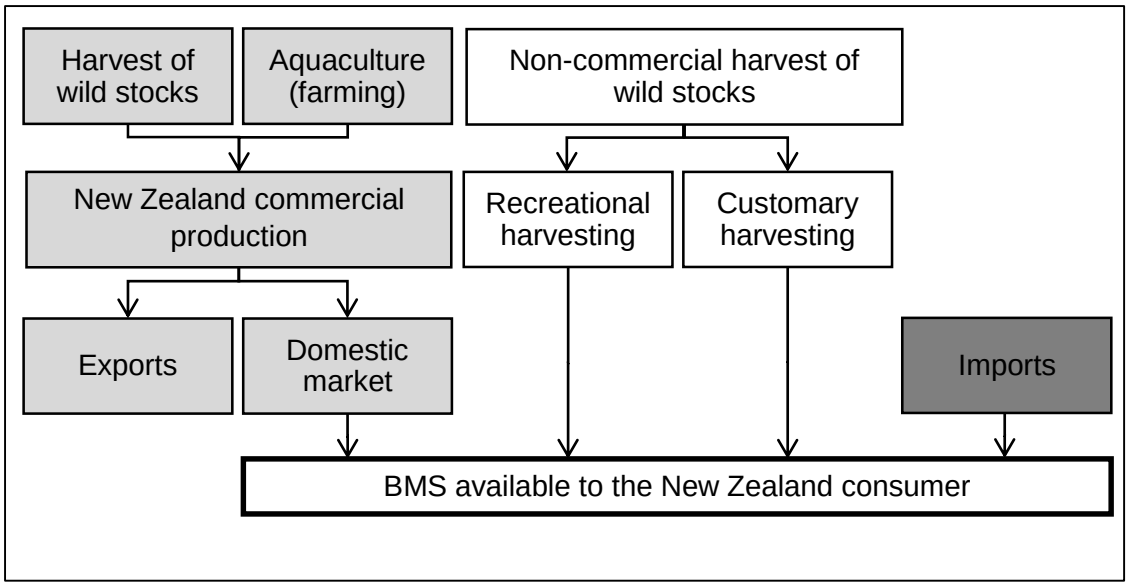

Figure 1: Sources of BMS available to New Zealand consumers (reproduced from King and Lake 2013)

2.2.1 BMS production and harvesting in New Zealand

Harvesting of many wild BMS stocks is managed under the Quota Management System (QMS) for New Zealand. Table 2 lists the weight of reported commercial shellfish landings for the 2014/15 fishing year and the permitted landings (quota) under the QMS.[3] The amounts listed represent a summation of data for specific areas (Quota Management Areas) around New Zealand.[4] As well as managing the QMS, the New Zealand Ministry for Primary Industries (MPI) sets limits on the number and size of BMS that can be gathered by individuals under customary or recreational allocations.[5]

The Total Allowable Commercial Catch (TACC) allocations may vary from year to year. Since the previous version of this Risk Profile TACCs for dredge oysters and deepwater tuatua have increased, while the TACC for scallops has decreased.

Scallops and cockles have been assigned the largest TACC allocations (by weight), while scallops, cockles, pipis, green-lipped mussels, and tuatua are the species with the greatest amounts set aside for customary and recreational gathering (Table 2). Landings data indicates that cockles and Foveaux Strait dredge oysters (Bluff oysters) are commercially harvested in the largest amounts, by weight, followed by scallops, triangle shells, green-lipped mussels and deepwater tuatua.

[3] Quota are the same for the 2015/16 fishing year but full data on reported landings are not available until October 2016.
[4] Not all quota management areas for a single species are managed under the QMA so additional harvesting may have occurred that was not reported.
[5] http://www.mpi.govt.nz/travel-and-recreation/fishing/fishing-rules/ (accessed 6 November 2015).

TABLE 2: Reported commercial landings and quota management amounts for BMS managed under the QMS (2014/15 fishing year, ending September 2016)[A]

NAME	SPECIES	REPORTED COMMERCIAL LANDINGS (TONNES)	TACC[B] (TONNES)	CUSTOMARY (TONNES)	RECREATIONAL (TONNES)
Cockle	*Austrovenus stutchburyi*	1078	3214	161	221
Dredge oyster (Foveaux Strait)[C]	*Ostrea chilensis*	1020	1526	0	0
Scallop[C]	*Pecten novaezelandiae*	360	4576	652	652
Triangle shell	*Spisula aequilatera*	307	2437	10	0
New Zealand green-lipped mussel	*Perna canaliculus*	207	1720	467	310
Deepwater tuatua	*Paphies donacina*	131	890	69	68
Large trough shell	*Mactra murchisoni*	69	744	10	0
Ringed dosinia	*Dosinia anus*	8	384	10	0
Deepwater clam/geoduck	*Panopea zelandica*	4	32	0	0
Dredge oyster	*Ostrea chilensis*	3	623	13	13
Frilled venus shell	*Bassinia yatei*	2	16	0	0
Queen scallop	*Zygochlamys delicatula*	2	380	0	0
Tuatua	*Paphies subtriangulata*	2	43	137	137
Pipi	*Paphies australis*	0	204	242	242
Trough shell	*Mactra discors*	0	160	0	0
Horse mussel	*Atrina zelandica*	0	29	9	9
Silky dosinia	*Dosinia lambata*	0	8	0	0

Source: http://fs.fish.govt.nz/Page.aspx?pk=16&tk=114 (accessed 6 November 2015).

[A] Data extracted from shellfish catch data provided by MPI and available from http://fs.fish.govt.nz/Page.aspx?pk=87&tk=287&ey=2015 (accessed 31 May 2016).
[B] Total Allowable Commercial Catch.
[C] Under QMA, Foveaux Strait oysters are reported as number of individual shellfish landed, and scallops are reported as meatweight (shucked). Conversion factors to standardise values to greenweight in tonnes were: 1 dredge oyster = 102 g (MPI, 2016c) and a multiplier of 8.00 for scallops (MPI, 2014).

Pacific oysters (*Crassostrea gigas*) and New Zealand green-lipped (Greenshell™) mussels are farmed commercially as aquaculture in New Zealand. Pacific oysters are grown on racks, or in baskets, mesh trays or bags attached to racks in the intertidal zone, or sometimes on subtidal long-lines (Castinel *et al.*, 2015). The oysters grown in the subtidal zone are usually transferred to the intertidal zone for some time before harvest to harden the shells. Green-

lipped mussels are grown on ropes permanently submerged in subtidal waters. During 2015, 80,000 tonnes of New Zealand green-lipped mussels and 1,910 tonnes of Pacific oysters were harvested (C. Johnston, Aquaculture New Zealand, pers. comm.). A large proportion of this amount is exported but there are no robust data on the tonnage available to New Zealand consumers (estimates have been calculated, see Section 2.2.4).

The most recent recreational fisher survey was completed in 2012 and estimates for the number of shellfish harvested by recreational gatherers during the 2011/12 year have been published (Wynne-Jones *et al.*, 2014). Scallops were harvested in the largest amount (an estimated 1.7 million), followed by mussels (approximately 1 million), tuatua (0.9 million), cockles (0.7 million), pipi (0.6 million) and oysters (0.3 million).

Using conversion factors from King and Lake (2013), the weights non-commercially harvested BMS can be roughly estimated, although the size and weight of non-commercially harvested BMS will vary greatly, and will also differ by species (e.g. green-lipped mussels vs. blue mussels). Estimates are 174 tonnes of scallops, 23 tonnes of tuatua, 17 tonnes of mussels, 7 tonnes of pipi and 6 tonnes of cockles.

2.2.2 Imported shellfish

New Zealand imports some BMS and BMS meat.[6] In the year ending December 2015, 2.4 million Pacific oysters were imported and all were shucked and frozen. This is approximately 22 tonnes meatweight and 160 tonnes greenweight.[7] Most (73%) of these imported oysters were from the Republic of Korea and the remainder were from China. In 2009, the Republic of Korea was also the source of most (83%) imported oysters but the overall quantity imported appeared to be much less (0.6 million oysters, 7% of which were whole and half-shell).[8]

There were 465 tonnes of scallops, mussels, cockles and other clams imported as meat, half-shell or whole shell during the year ending December 2015. This is more than the 299 tonnes imported in 2009. The majority by weight was frozen scallops, both in 2009 (99.99%) and 2015 (97%), thus importation of other BMS species is very small in comparison. In 2015 most (86%) of these frozen scallops came from China compared with 2009 when the weight imported from China was fairly similar to that from Japan and Peru. Frozen scallops traded as adductor muscle only, i.e. eviscerated with the guts and roe (gonads) removed are not subject to border testing.[9] Norovirus is mainly localised in the guts of BMS (Le Guyader *et al.*, 2006; McLeod *et al.*, 2009) so adductor muscle scallops present a lower risk to humans from norovirus compared with whole or roe-on scallops.

2.2.3 Exported shellfish

Export data for the year ending December 2015 shows exports of approximately 28,000 tonnes of tonnes of mussel products, which made up 92% of BMS exports by weight.[10] Smaller weights of product from oysters (1,900 tonnes), cockles (192 tonnes), tuatua (93 tonnes), scallops (39 tonnes) and other clams (318 tonnes) were also exported. Together, these

[6] Import data obtained from Statistics New Zealand Infoshare, http://www.stats.govt.nz/infoshare/ (accessed 13 April 2016 and 1 June 2016). Updated data for Pacific oysters, for 2012-2015 directly provided by Statistics New Zealand (September 2016). Updated data differs from published official statistics.

[7] Greenweight is the weight of the whole, unshucked shellfish. Meatweight is the weight of the shucked shellfish (minus the shell and any liquid in the shell). Conversion factors applied were those reported in King and Lake (2013) and are for New Zealand, so may not be suitable for Pacific oysters produced in other countries.

[8] This may be an artefact of reporting as classification codes have changed since 2009.

[9] Imported Food Requirements: Bivalve Molluscan Shellfish (March 2015). Kindly provided by the New Zealand Ministry for Primary Industries.

[10] http://www.seafoodnewzealand.org.nz/publications/export-information/export-statistics/item/january-december-2015/ (accessed 1 June 2016). Data are for exports in all forms – fresh, frozen, processed.

shellfish products represent approximately 10% of the total 290,000 tonnes of seafood product exported from New Zealand in the year ending December 2015.

2.2.4 Amount available to the New Zealand consumer

An estimated 68,000 tonnes greenweight (13,000 tonnes meatweight) of BMS were estimated as being available to New Zealand consumers for the year 2011 (King and Lake, 2013). This analysis took into account commercial production and harvesting, non-commercial harvesting and international trade. Most (99%, by weight) of the available BMS were commercially harvested. Mussels, mostly New Zealand green-lipped mussels, accounted for 96% of the total available BMS by meatweight.

2.3 CONTAMINATION OF BMS WITH NOROVIRUS

Key findings

There is no change to the information on sources of norovirus contamination in BMS. Humans are the only known reservoir of the noroviruses that infect humans. BMS are exposed to noroviruses when their growing waters are contaminated with human faeces, primarily from wastewater effluent.

There is new information on the presence and quantitation of norovirus in the New Zealand aquatic environment. Norovirus GI and GII have been detected in wastewater treatment plant effluents, estuaries and rivers in New Zealand.

Both specific (via HBGA-like receptors) and non-specific binding of norovirus to BMS explain its prolonged persistence in this food. There are limited data on norovirus persistence and depuration rates for BMS but recent data has shown that human noroviruses persist longer (6 weeks) in cooler (15°C) water temperatures than in warmer ones (25°C, 2-4 weeks).

2.3.1 Sources

Humans are the only known reservoir for noroviruses that infect humans. Faecal pollution from inadequately treated wastewater discharges, septic tank leachates and boat discharges can cause norovirus contamination of shellfish growing water. Since 2009 Risk Profile, there is no change to the information on sources of norovirus contamination in BMS.

Additional information on the prevalence and quantitation of norovirus in wastewater and receiving waters in New Zealand is now available. The presence of norovirus was found to be sporadic in influent and effluent wastewater in a study of ten treatment plants. Concentrations of norovirus GI and GII ranged from 2.1 to 5.5 $\log_{10}$ genome copies/L in influent to 2.2 to 5.5 $\log_{10}$ genome copies/L in effluent. Irrespective of wastewater treatment, human enteric viruses, including presumably noroviruses, are likely to be present in non-disinfected effluent (Hewitt *et al.*, 2011). In another New Zealand study, of estuarine waters, noroviruses were detected at a higher frequency (all 15 samples positive) than other enteric viruses. Although the reasons for this was not known, their persistence in these waters presents a potential food safety risk if shellfish growing nearby are eaten by people (Hewitt *et al.*, 2013). Noroviruses are also frequently present in other New Zealand environmental waters including rivers receiving wastewater effluent (Hewitt *et al.*, 2013; Williamson *et al.*, 2011).

BMS could also become contaminated via infected food handlers, which is a common cause of foodborne norovirus transmission (Mathijs *et al.*, 2012), and potentially water used for depuration or cleaning shellfish harvested from growing areas.

2.3.2 Survival and persistence

Noroviruses can resist depuration processes in BMS and so depuration is not a permitted post-harvest treatment for potentially contaminated shellfish in New Zealand. Relaying is permitted.[11] However, as described in the 2009 Risk Profile, norovirus RNA can be detected up to 8-10 weeks post-bioaccumulation using molecular methods (i.e. reverse transcription (RT)-polymerase chain reaction PCR, RT-PCR) for detection (Greening *et al.*, 2003b; Ueki *et al.*, 2007). While the presence of norovirus RNA indicates a potential risk, it does not confirm presence of infectious viruses.

A mathematical model, based on experimental data with hepatitis A virus and a norovirus surrogate (murine norovirus) with clams and mussels (Polo *et al.*, 2014), has been developed to characterise the kinetics of enteric virus removal during depuration (Polo *et al.*, 2015a). The model predicts that following a two phase kinetic decay in the number of viruses, a residual viral load (those viruses unable to depurate) remains in BMS, but further work is required to enumerate this residual load for noroviruses. This partly explains the prolonged periods of virus retention with BMS. These data may need consideration by regulatory authorities in terms of the time required to remove noroviruses following a contamination event and/or for relaying purposes.

Norovirus persistence is dependent on many factors including BMS species, virus genogroups/genotypes, initial virus concentration and seawater temperatures.

Lower temperatures favour persistence, most likely because the pumping rate of BMS slows with reducing temperature (Choi and Kingsley, 2016). For example, norovirus GI.1 was shown to persist for at least six weeks in oysters held at 7 and 15ºC in seawater, compared to 2-4 weeks at 25ºC, with a predicted reduction in norovirus concentration of 1 $\log_{10}$ in a period of 2.3 weeks at 15ºC (Choi and Kingsley, 2016). Depuration of a GII norovirus strain from oysters was observed at 16ºC but not at 8ºC when monitored for 14 days (Neish, 2013).

The ability of noroviruses to bioaccumulate and persist in BMS can be explained through both non-specific norovirus binding, and by specific binding between noroviruses and structures similar to the HBGA in BMS (Le Guyader *et al.*, 2006; Maalouf *et al.*, 2010). The degree of specific binding helps to explain why noroviruses, unlike bacteria, persist well after the commercial post-harvest depuration process. Different binding patterns can be observed between norovirus genotypes and different shellfish species which may have different HBGA ligands, as discussed in the 2009 Risk Profile. In one study, the bioaccumulation efficiency of three genotypes in oysters were compared. Norovirus GI.1 was more efficiently concentrated in oysters than both the GII.3 and GII.4 strain used, with GII.4 being poorly bioaccumulated compared to the others (Maalouf *et al.*, 2011). A New Zealand study described that binding of norovirus was stronger with oysters than mussels, and for those genotypes tested, the combination of GI.3 and oysters showed the highest binding affinity (Langlet *et al.*, 2015).

2.3.3 Potential for growth of noroviruses

As a human host is required for its replication, human noroviruses cannot replicate in shellfish during production or storage. However, norovirus readily survive under a variety of conditions including refrigeration and freezing, as demonstrated by outbreaks associated with frozen products (Simmons *et al.*, 2007). Although this Risk profile concerns BMS consumed raw, it was noted in the 2009 Risk Profile that norovirus can survive and retain infectivity after light cooking (e.g. at 60°C for 30 min).

[11] Relaying is the transfer of shellfish from one growing area to another and can be used to relocate shellfish away from a contaminated growing area.

2.4 EXPOSURE ASSESSMENT

Key findings

There has been no comprehensive monitoring programme in New Zealand to investigate the presence of norovirus in commercially harvested BMS from New Zealand waters, or in BMS at retail. Analysis of commercially harvested BMS for norovirus is only generally performed as a part of a norovirus outbreak investigation or foodborne illness case.

Data from BMS collected from non-commercial sites in New Zealand show a norovirus prevalence of approximately 50%. However this may not necessarily be representative of non-commercial sites within New Zealand, as sampling was based on risk rather than through a comprehensive monitoring programme of representative New Zealand sites. Concentrations of >1,000 genome copies per gram of guts were detected in approx. 25% of positive samples.

There were two recalls of oysters due to presence or potential presence of norovirus during the period 2008 to 2015. From October 2012, norovirus testing of raw, cooked, dried and ready-to-eat (RTE) oysters was added to the Imported Food Requirements (IFR). There have been no New Zealand recalls for imported oysters contaminated with norovirus since the change to the IFR.

There is evidence to suggest that the frequency of shellfish consumption by the New Zealand population decreased during the period 1997-2009. Mussels account for the majority of shellfish consumption, while oysters are the shellfish most likely to be consumed raw. A recent study suggests that shellfish are more frequently consumed by Māori than by the general population.

Noroviruses cannot be cultured in the laboratory so virus quantitation is based on molecular techniques that measure the number of genome copies (using RT real-time quantitative PCR, RT-qPCR for example). RT-qPCR does not necessarily indicate whether the noroviruses are infectious or not, but instead indicates potential risk. The use of molecular methods that provide information on nucleic acid and capsid integrity, with digital PCR for absolute quantitation for example, may aid in providing more accurate data in the future.

There are limited data on the quantity of norovirus in shellfish, both for commercially or recreationally harvested samples, or BMS associated with gastroenteritis outbreaks. Until recently, a reliable standard detection method was not available. A method standardised by the International Organization for Standardization (ISO) is nearly complete (refer to Appendix A.1).

2.4.1 Presence and quantitation of norovirus in BMS available in New Zealand

Norovirus presence and quantitation in New Zealand shellfish samples (pre-2009, *n* = 257) from commercial and non-commercial sites were summarised in the 2009 Risk Profile. Norovirus levels of norovirus GI and GII varied from low (< 80 genome copies per gram guts in most of the samples that tested positive) to extremely high (> 10,000 genome copies per gram guts). It was noted that shellfish from a few recreational gathering areas contained extremely high levels.

Data on norovirus presence and quantitation in BMS submitted to the Institute of Environmental Science and Research (ESR) and collected between 2006 and 2011 (*n* = 639) was reanalysed specifically for this Risk Profile. Approximately 90% (n = 566) of samples originated from New Zealand (J. Hewitt, pers. comm.), with other samples originating from China and South Korea (most associated with norovirus outbreaks), and from Australia. Of the 566 New Zealand BMS samples, most (n = 485) were from non-commercial sources of which 52.4% (n = 254) tested positive for norovirus GI and/or GII. This prevalence may not

represent non-commercially harvested BMS in New Zealand since samples were often selected from sites where water quality or BMS contamination was of concern.

Norovirus GI and GII were detected at concentrations of >1,000 genome copies per gram of guts (classed as very high or extremely high levels) in 34/151 (22.5%) and in 81/306 (26.5%) norovirus positive samples respectively. Most of these (33/34, 97.1% GI and 75/81, 92.6% GII) positive samples were from non-commercially harvested BMS from New Zealand. The remaining samples were from overseas shellfish associated with outbreaks.

Of the BMS samples (*n* = 72) associated with notified New Zealand outbreaks between 2006 and 2011, norovirus was detected in 66.7% (48/72). Norovirus GI and GII concentrations in these samples ranged from very low (<80 genome copies/gram guts) to extremely high (>10,000 genome copies/gram guts), with most results below 80 genome copies/gram.[12] No New Zealand commercially harvested BMS samples associated with a notified norovirus outbreak contained levels of norovirus >1000 genome copies/gram guts (J Hewitt, pers. comm.).

Non-commercially harvested BMS

Since the 2009 Risk Profile, there have been few studies on the presence of norovirus in wild shellfish in New Zealand.

The Northland Regional Council monitored viruses in BMS (oysters, pipis and cockles) from four sites in the Bay of Islands area until 2012. These results are not publically available.

As part of monitoring the effect of diverting treated sewage away from the Avon-Heathcote estuary, Christchurch City Council commenced a shellfish sampling plan for the estuary in March 2008, with samples collected quarterly (Mar-Jun-Sep-Dec) for monitoring of *Escherichia coli* (*E. coli*) from eight sites and five sites for norovirus analysis (Greening *et al.*, 2009). The concentrations of norovirus and *E. coli* decreased following the commissioning of an ocean outfall, thus confirming sewage as a major source of contamination in the area. However, earthquakes in February and June 2011 caused substantial damage to the city's sewerage infrastructure. Following the February earthquake, norovirus was detected at extremely high concentrations (>10,000 genome copies/g shellfish guts) with *E. coli* concentrations in the BMS flesh increasing to 16,000 most probable number *(*MPN)/100 grams. This clearly compromised the safety of shellfish in the estuary for recreational gatherers (Hewitt and McMurtrie, 2013) and resulted in the local Medical Officer of Health issuing health warnings including signage and publicity.[13]

New Zealand commercially harvested BMS

There has been no comprehensive monitoring programme to evaluate the presence of norovirus in commercially harvested shellfish from New Zealand waters. Analysis of BMS for norovirus is only generally performed as a part of a norovirus outbreak investigation or foodborne illness case.

Overseas-sourced BMS for the New Zealand market

There has been no comprehensive monitoring programme to evaluate the presence of norovirus in shellfish imported from overseas into New Zealand. The testing of oysters under the IFR is discussed in Section 2.4.3.

[12] Levels were reported as low (<80), moderate (<320), high (<1,000), very high (<10,000) and extremely high (>10,000) genome copies/gram guts.

[13] http://www.stuff.co.nz/the-press/news/5567490/Extreme-norovirus-risk-from-Estuary-shellfish (accessed 11 April 2016).

2.4.2 Product recalls

There were two mandatory product recalls of BMS in New Zealand due to the presence or potential presence of norovirus during the period 2008 to 2015. Both were related to reported cases of norovirus illness:

- Frozen oysters imported from China (2012): Associated with an outbreak (see Section 3.3.1); and
- Half-shell and pottled oysters sourced from New Zealand (2008): Associated outbreaks discussed in 2009 Risk Profile.

2.4.3 Imported food testing for norovirus

The IFR that was amended on 1 October 2012[14] included an additional requirement for norovirus testing for oysters under certain circumstances (MPI, 2016a, 2016d). Between October 2012 and March 2016, 16 oyster samples destined for importation to New Zealand were tested for norovirus GI and GII by RT-qPCR. Five samples (31.5%) tested were norovirus positive, either for GI and/or GII.[15]

Details of the requirements for norovirus testing under the revised IFR are described in Section 5.1.3.

2.4.4 Food consumption: Mollusca (raw)

The following information is taken from analyses (Cressey, 2013; Cressey *et al.*, 2006) of data from the 24-hour dietary recall components of the New Zealand Adult Nutrition Survey conducted in 2008-2009 (2009ANS) (University of Otago and Ministry of Health, 2011) and the 2002 Children's National Nutrition Survey (2002CNS) (Ministry of Health, 2003). For the adult population some general comments about trends in shellfish consumption can be made by comparison with data from the National Nutrition Survey conducted in 1997 (1997NNS) (Russell *et al.*, 1999). It should be noted that these data do not distinguish between commercial or non-commercial sources of shellfish, and that 'paua' and 'paua fritters' were included in these analyses. Prawns and lobsters were excluded.

Proportion of population consuming shellfish

For the adult New Zealand population, 1.5% of survey respondents reported consuming shellfish in the previous 24-hour period, compared to 2.4% in 1997. Those aged over 65 years of age are approximately as likely (1.3%) to consume shellfish than those aged under 65 years of age (1.5%). This is a change from the 1997NNS, which found that those aged over 65 years of age were less likely (1.7%) to consume shellfish than those aged under 65 years of age (2.6%). None of the pregnant participants in the 2009ANS (n = 64) reported consuming shellfish. Children aged 5-15 years are infrequent consumers of shellfish, with only 0.5% of respondents in the 2002CNS reporting consumption of shellfish in the previous 24-hour period.

A study lead by the National Institute of Water and Atmospheric Research (NIWA) investigated the kai moana consumption patterns in two Māori populations; Te Arawa, living around Lake Rotorua in the North Island, and Arowhenua, living in the South Canterbury region of the South Island (NIWA, 2014). In the Te Arawa cohort, 21% of respondents reported eating mussels at least weekly, with half of those respondents eating mussels 3-4 times each week. In the Arowhenua cohort, a similar proportion of respondents (20%) reported consuming mussels at least weekly, but none reported mussels more frequently than twice per week.

[14] Imported Food Requirements: Bivalve Molluscan Shellfish (March 2015). Kindly provided by the Ministry for Primary Industries.

[15] The protocol specifies that five 300 gram samples of flesh per lot are submitted and that the samples may be composited by the laboratory. Product is rejected if either norovirus GI and/or GII is detected. There is no threshold limit.

Mean daily consumption of shellfish

Analysis of all (raw and cooked) shellfish serving data from the 2009ANS gave a mean daily intake for consumers of shellfish of 85.1 g/person/day (1997NNS 105.5 g/person/day) and a mean across the whole study population (consumers and non-consumers) of 1.2 g/person/day (1997NNS 2.5 g/person/day). Daily consumption by consumers less than 65 years (91 g/person/day) is markedly higher than consumers 65 years and older (66 g/person/day). The corresponding data for the child population (5-15 years) gave a mean daily consumption for consumers of 49 g/person/day and for all respondents of 0.2 g/person/day.

A 2011 analysis of the amount of raw, shucked shellfish available to New Zealanders estimated 8 g/person/day for the total New Zealand population, and 407 g/person/day for shellfish consumers (King and Lake, 2013). These values were compared with data from the 1997NNS and 2002CNS because results from the 2009ANS were unavailable at the time. While these values are around three times that reported in the nutrition surveys for adults and children combined, they are for raw shucked shellfish available for consumption', while the nutrition survey figures represent shellfish reported to have been consumed. The differences between these two figures are not unusual, particularly considering the weight lost with cooking prior to consumption.

Analyses of data from the adult nutrition surveys suggest Māori consumers, on average, consume larger amounts of shellfish. From the 1997NNS, the average daily consumption of shellfish by Māori was 139 g as compared to 99 g for non-Māori. These figures from the 2009ANS were 135 g and 69 g, respectively, suggesting decreased daily consumption by non-Māori. These data represent a national average; consumption is likely to vary between regions and be influenced by access to kai moana harvesting areas (rohe moana). The NIWA study derived estimates for mussel consumption of 16.9 g/person/day for the Te Arawa cohort and 11.1 g/person/day for the Arowhenua cohort.

While comparisons in shellfish consumption between difference countries should be conducted with caution, some general observations can be drawn from examination of the GEMS/Food cluster diets, derived by the World Health Organization, from a synthesis of country food balance sheets.[16] New Zealand is grouped with mainly European and North American countries and developed Asian countries (Japan and the Republic of Korea). Of the 17 GEMS/Food cluster diets, only three report higher consumption of molluscan shellfish than the cluster containing New Zealand: cluster G09, including mainly South-East Asian countries, cluster G07, including mainly developed countries such as Australia, the United Kingdom and France, and cluster G17, including Pacific and Caribbean island nations.

Serving sizes of shellfish

Analysis of data from the 2009ANS gave mean, median and 95th percentile serving sizes for shellfish of 79.3, 65.5 and 164.4 g. Child servings, as reported in the 2002CNS are smaller, with corresponding values of 49.4, 43.5 and 108.0 g. These values are derived from all shellfish servings, whether raw or cooked. There are insufficient data to differentiate raw versus cooked servings, and serving size is probably independent of cooking status.

A comparison of serving sizes between the 1997NNS and 2009ANS shows that mean and 95th percentile serving sizes have decreased, but the median serving sizes are similar. The difference in mean serving sizes between 1997 and 2009 is not statistically significant (Cressey, 2013).

In deriving daily consumption estimates for kai moana mussels in the Te Arawa cohort, NIWA used a 'meal size' of 144 g for kākahi (freshwater mussels), mussels and pipi.

In an assessment of heavy metal contaminant exposure from consumption of Green-lipped mussels in the Bay of Islands, a mean serving size of 78 g was used (Whyte *et al.*, 2009).

[16] http://www.who.int/nutrition/landscape_analysis/nlis_gem_food/en/ (accessed 30 November 2016).

While the source for this figure was not identified, it is very close to the mean adult serving size derived from the 2009ANS.

Types of shellfish consumed and cooking method used

Of 74 servings of shellfish identified in the 2009ANS 24-hour dietary recall records, 45 (61%) were mussels, 12 (16%) were oysters and 5 (7%) were scallops. The balance was paua, pipis, tuatua or recipes in which the shellfish was not specifically identified.

Compared to the 1997NNS, a greater proportion of shellfish servings were mussels (61% compared to 46%), about the same proportion were oysters (16% compared to 17%) and fewer servings were scallops (7% compared to 12%).

Oysters were the shellfish most commonly consumed raw (6/12 – 50% of servings). Mussels were consumed raw (7/45) or marinated (11/45) for 40% of servings. These results are proportionally similar to those from 1997NNS (59% of oyster servings and 47% of mussel servings eaten raw or marinated).

There is a data gap concerning exposure assessment from shellfish, in that while recreational gathering of wild shellfish is acknowledged to be widespread, there are few quantitative consumption data. The NIWA study has provided some information. An analysis of data from the 2012 recreational fisher survey (Wynne-Jones *et al.*, 2014) using the weight conversion methods of King and Lake (2013) would provide additional information.

2.5 PREVALENCE OF NOROVIRUS IN BMS IN OVERSEAS STUDIES

Overseas data on the prevalence on norovirus in BMS between 2009 and 2015 are summarised in Appendix A.4.

Key findings

As would be expected from geographically diverse studies (and as found in the 2009 Risk Profile), the prevalence of norovirus in BMS in overseas studies is highly variable ranging from 1.7-76.2% for commercial BMS and 0-96% for non-commercial BMS.

For example, reported norovirus-positive rates for commercially harvested oysters were 1.7% in Australia, 4% in the US, 9% in South West France, and 76% in the United Kingdom (UK). The prevalence of noroviruses in commercial BMS from China and South Korea were 12-13% and 14-22% respectively. This is of relevance as BMS are imported into New Zealand from these countries, although not necessarily from the same growing areas surveyed.

Viral contamination is strongly dependent on factors such the proximity of growing areas to the plume from wastewater treatment effluents, effectiveness of virus removal during wastewater treatment processes, environmental factors and on the laboratory methods used for recovery and detection. Consequently, overseas data cannot be used as an indicator for the virus prevalence expected in domestically produced New Zealand shellfish.

3. EVALUATION OF ADVERSE HEALTH EFFECTS

3.1 DISEASE CHARACTERISTICS

Key findings

There has been no change in the norovirus disease characteristics since the 2009 Risk Profile. Outbreaks and sporadic cases of norovirus gastroenteritis continue to occur globally, including in New Zealand. All age groups are affected.

3.2 DOSE RESPONSE

Key findings

Since the 2009 Risk Profile, additional dose-response models using results from human challenge trials or outbreak data have been published. The 50% infectious dose is dependent on the matrix, virus genotype and host factors – including their HBGA secretor (FUT2) status. The studies support the notion that noroviruses have a low infectious dose, are highly infectious to those that are secretor positive and that there is no known safe level of exposure.

Studies from New Zealand and overseas show that concentrations detected in BMS linked to norovirus illness vary from less than 100 to more than 10,000 copies per gram of guts (EFSA, 2012; Greening *et al.*, 2009). However, there is no threshold infectivity limit established for noroviruses as determined by PCR and the relationship between the genome copies as detected by PCR and the number of infectious viruses is not constant. The ratio will vary depending on environmental conditions that the virus has been exposed to such as temperature, salinity, ultraviolet light, presence of bacteria and source (for instance the wastewater treatment type the virus has been exposed to). Hence, PCR can only provide an indirect measure of risk, and may overestimate risk.

Dose-response models may assist in predicting likely outcomes of illness when consuming norovirus contaminated shellfish (Campos and Lees, 2014). Several human volunteer challenge trials with noroviruses have been conducted to assess the dose response and likelihood of becoming infected when exposed to a certain dose as determined by PCR (Atmar *et al.*, 2014; Frenck *et al.*, 2012; Teunis *et al.*, 2008). Dose-response models based on these trials have been published (Atmar *et al.*, 2014; Messner *et al.*, 2014; Teunis *et al.*, 2008). However, assumptions made on virus aggregation (i.e. assuming either a disaggregation or aggregated dose) and host status in these models differed (Schmidt, 2015). For example, Teunis et al. (2008) assumed subjects who were 'secretors' had no immunity to norovirus (i.e. GI.1 Norwalk virus).

The dose-response model published in 2008, and discussed in the 2009 Risk Profile (Teunis *et al.*, 2008), estimated that the 50% infectious dose (ID_{50}) ranged from 18 (95% CI 1.03-4350) for disaggregated viruses, to approximately 1000 genome equivalents. The study showed that the likelihood of becoming infected was partly dependent on the norovirus dose i.e. there was an increasing probability of infection with increased dose. A dose-dependent probability of becoming ill was 0.1 at a dose of 10^3 norovirus genome copies, increasing to 0.7 at a dose of

10^8 virus genome copies (Teunis *et al.*, 2008). This model made adjustments for virus aggregation and assumed that the study population would have no immunity.

A dose-response model published in 2014 (Atmar *et al.*, 2014) estimated a similar ID_{50} of approximately 1320 genome equivalents, but this was just for susceptible populations (based on host HBGA 'secretor' status'). The norovirus ID_{50} increased to 2800 genome equivalents when non-susceptible populations were included. As the Atmar model did not address the issue of aggregation, this may partly explain differences with the earlier model. The importance of allowing for virus aggregation for the dose-response models was discussed in 2014 (McBride, 2014).

An infection dose-response model was also generated using data from norovirus (GI.1, G1.4, GII.4, GII.8 and GII.9) outbreaks associated with consumption of raw oysters (Thebault *et al.*, 2013). Information on the host HBGA status and genotype was used to determine norovirus infectivity based on genome copies determined by PCR. For secretor positives (i.e. susceptible persons) the estimated median ID_{50} ranged from between 1.6 and 7.5 genome copies per oyster consumed. The probability of infection at a mean dose of one genome copy was estimated at 0.29 (95% CI 0.015-0.61) for norovirus GI and 0.4 (95% CI 0.04-0.61) for GII (Thebault *et al.*, 2013). The probability of infection was much lower for secretor negative populations (non-susceptible).

Despite the varying assumptions made in the dose response models, target populations and the wide variances determined (as shown by the 95% CI), all the models support the notion that noroviruses have a low infectious dose and are highly infectious to those that are secretor positive (Atmar *et al.*, 2015; Kirby *et al.*, 2015; McBride, 2014).

3.3 NEW ZEALAND HUMAN HEALTH SURVEILLANCE

Key findings

For the period 2009-2015 there were 13 reported outbreaks of norovirus infection, involving 104 cases, where the vehicle of infection was likely to be shellfish. This represents 9% of foodborne outbreaks caused by norovirus during this period, and 5% of cases. Various genotypes of both norovirus GI and GII were identified in these outbreaks. Commercially harvested oysters were implicated in 85% (11/13) of these outbreaks (imported oysters were the vehicle of infection four of these outbreaks). The other two outbreaks were the only outbreaks reported since 2012, and non-commercially harvested shellfish were implicated in both.

Norovirus infection is underreported in New Zealand; sporadic cases are not necessarily notifiable and the symptoms of the disease do not usually require an infected person to seek medical attention. Despite this, norovirus is the most frequently reported agent for outbreaks in New Zealand, in terms of both numbers of outbreaks and numbers of associated cases. During the period 2009-2015, there were 1,539 reported outbreaks of norovirus infection involving a total of 38,391 cases. Of the 1,539 outbreaks reported during the period 2009-2015, 146 were foodborne outbreaks involving 2,076 cases. The genotype most commonly identified between 2009 and 2015 was GII.4.

Norovirus infection is not a notifiable disease in New Zealand. However a suspected common source (i.e. an outbreak) or a 'high risk' person identified as being ill, e.g. a food handler or an early childhood service worker (signalling potential for an outbreak) is notifiable and reported in New Zealand's communicable disease database EpiSurv (Ministry of Health, 2013). Cases of norovirus infection in New Zealand are underreported as illness is usually of short duration, usually without complications requiring medical attention, and testing of norovirus is usually only performed in those cases associated with reported outbreaks, or food/waterborne illness. Samples referred to the ESR norovirus reference laboratory from reported outbreaks are typed

for norovirus. ESR is the only laboratory in New Zealand that analyses shellfish associated with sporadic cases or outbreaks of norovirus infection.

3.3.1 BMS consumption as a risk factor for norovirus infection in New Zealand

The 2009 Risk Profile reported on the norovirus outbreaks linked to BMS consumption from the early 1990s to 2008. A more recent publication summarises ESR laboratory outbreak data reported from 2002 to 2009 (Greening *et al.*, 2012). During this period there were 34 laboratory-confirmed norovirus outbreaks in New Zealand that were attributed to the consumption of imported or domestically harvested shellfish. Norovirus was identified in both human faecal samples and the implicated shellfish in 13 of these 34 outbreaks. In 2008, eight of nine outbreaks were linked to the same oyster growing area (and are discussed in the 2009 Risk Profile).

EpiSurv outbreak data, ESR Laboratory data and annual surveillance reports for the period 2009-2015 have been analysed for reporting in this Risk Profile. There were 146 outbreaks classified as foodborne during the period 2009-2015. Using epidemiological and microbiological evidence, shellfish were identified as the likely vehicle of norovirus infection in 13 of these outbreaks, with 104 associated cases (Table 3).

TABLE 3: Norovirus outbreaks and related cases in New Zealand where epidemiological or microbiological evidence implicated BMS as the vehicle of infection (2009-2015)

YEAR	NUMBER OF OUTBREAKS		NUMBER OF CASES (FROM OUTBREAKS)	
	IMPORTED SHELLFISH	DOMESTICALLY HARVESTED SHELLFISH	IMPORTED SHELLFISH	DOMESTICALLY HARVESTED SHELLFISH
2009	0	7	0	41
2010	1	0	15	0
2011	0	0	0	0
2012	3	0	41	0
2013	0	1	0	5
2014	0	0	0	0
2015	0	1	0	2
Subtotals	**4**	**9**	**56**	**48**
TOTAL	**13**		**104**	

Details of these outbreaks have been included in Table 4. Where available, norovirus typing information is included in the table.

The outbreaks associated with imported BMS were associated with BMS from South Korea, China and another country that was not reported.

No norovirus outbreaks associated with imported BMS have been reported since MPI added norovirus testing to the IFR for oysters.

Domestically-harvested BMS were implicated in nine outbreaks (2009, 2013 and 2015).

- Commercially harvested shellfish from New Zealand growing areas have only been implicated in outbreaks during 2009. Two of these 2009 outbreaks were associated with the same New Zealand growing area and wastewater was the probable source of contamination. The *E. coli* levels in the shellfish were below 230 MPN/100 grams. The BMS Regulated Control Scheme (BMSRCS) measures lead to the closure of the growing

area, recall and remediation of the contamination source (Wall *et al.*, 2011). There were two other linked outbreaks (outbreak numbers 2009-6 and 2009-7, Table 4).

- Two outbreaks were associated with the consumption of non-commercially harvested BMS (2013 and 2015).

TABLE 4: Details of BMS-associated norovirus outbreaks in New Zealand (2009-2015)

YEAR	OUT-BREAK NUMBER	REPORT DATE (d/m/y)	FOOD	CASES	LAB CON-FIRMED CASES	SOURCE	EVIDENCE	POSSIBLE FAILURE(S)/ NOTES
2009	2009-1	22/07/09	Oysters	17	5	NZ, commercial	Epidemiological. Faecal samples positive for GI (GI.4). Oysters consumed positive for GI. Same source as outbreak 2009-3.	Leakage of wastewater discharged into stream adjacent to growing area. Product recall. Raw oysters consumed (Wall *et al.*, 2011).
2009	2009-2	29/07/09	Oysters	2	1	NZ, commercial	Epidemiological. Faecal sample positive for GII (GII.4). No other illnesses reported from premises.	Consumed raw oysters.
2009	2009-3	07/08/09	Oysters	3	3	NZ, commercial	Epidemiological. Faecal samples positive for GI (GI.4). Oysters consumed positive for GI. Same source as outbreak 2009-1.	Leakage of wastewater into stream adjacent to growing area. Raw oysters consumed. Product recall (Wall *et al.*, 2011).
2009	2009-4	17/9/09	Oysters	12	7	NZ, commercial	Epidemiological. Faecal samples positive for GI (GI.4).	Consumed raw oysters.
2009	2009-5	05/11/09	Oysters	2	1	NZ, commercial	Epidemiological. Faecal sample positive for GII (GI.2).	Consumed raw oysters.
2009	2009-6	10/11/09	Oysters	2	0	NZ, commercial	Epidemiological. Same source as outbreak 2009-7.	Consumed raw oysters.
2009	2009-7	11/11/09	Oysters	3	3	NZ, commercial	Epidemiological. Faecal samples positive for GI (GI.4). Same source as outbreak 2009-6.	Consumed raw oysters.
2010	2010-1	12/07/10	Oysters	15	1	South Korea	Epidemiological. Faecal sample positive for GII (GII.5). Second bag of oysters purchased at same time (unopened) positive for GI and GII.	Packaging states product should be cooked before consumption. Consumed raw oysters.
2012	2012-1	20/04/12	Oysters	11	2	Overseas (unidentified)	Epidemiological. Faecal samples positive for GII.	
2012	2012-2	22/05/12	Oysters	2	1	China	Epidemiological. Faecal sample positive for GI (untyped) and GII (GII.13). Shellfish positive for norovirus GI and GII.	Purchased commercially, cooked (battered) oysters at home. Oysters may not have been cooked properly.

YEAR	OUT-BREAK NUMBER	REPORT DATE (d/m/y)	FOOD	CASES	LAB CON-FIRMED CASES	SOURCE	EVIDENCE	POSSIBLE FAILURE(S)/ NOTES
2012	2012-3	26/06/12	Oysters	28	5	China	Epidemiological. Faecal samples positive for various GI and GII genotypes. Surrogate' oyster sample were positive for norovirus GII.	Packaging states product should be cooked before consumption. Consumed raw oysters.
2013	2013-1	31/01/13	Not reported	5	2	NZ, non-commercial	Epidemiological. Faecal samples positive for GI (GI.4).	Recreationally gathered shellfish consumed raw.
2015	2015-1	14/10/15	Pipis	2	2	NZ, non-commercial	Epidemiological. Faecal samples positive for GI and GII.	Recreationally gathered.

3.3.2 Norovirus infection in New Zealand

Norovirus is the most frequently reported agent for outbreaks in New Zealand, in terms of both numbers of outbreaks and numbers of associated cases. This pattern, as reported for the period 2001-2007 in the 2009 Risk Profile, has continued.

During the period 2008-2015, there were 1,691 reported outbreaks of norovirus infection involving a total of 42,308 cases (Table 5). Of these, there were 172 foodborne outbreaks associated with 2,676 cases. These data are taken from the ESR Annual Outbreak Summaries, from surveillance data recorded in the database EpiSurv[17] and from the ESR Norovirus Reference Laboratory. The ESR Laboratory, in addition to analysing faecal specimens, consolidates information on outbreaks, which can provide a more detailed picture of the epidemiology. The number of outbreaks reported to the Norovirus Reference Laboratory differs from the number recorded in Episurv because not all norovirus outbreaks reported in EpiSurv provide human samples that are sent to ESR for analysis. The number of hospital discharges for ICD-10 code A08.1 (acute gastroenteropathy due to Norwalk agent[18]), taken from the National Minimum Data Set (NMDS), are also included in Table 5.

TABLE 5: Number of outbreaks, associated cases, hospital discharges and deaths due to norovirus infection (2008-2015)

YEAR	OUTBREAKS (FOODBORNE OUTBREAKS)[A]	ESR LAB CONFIRMED OUTBREAKS[B]	OUTBREAK-ASSOCIATED CASES (FOODBORNE CASES)	HOSPITAL DISCHARGES	DEATHS (FOODBORNE DEATHS)
2008	152 (26)	142	3917 (600)	200	6 (0)
2009	270 (29)	199	7116 (349)	319	17 (0)
2010	152 (19)	123	3223 (215)	159	1 (0)
2011	181 (20)	160	4014 (206)	160	1 (0)
2012	249 (26)	221	6097 (549)	363	7 (0)
2013	169 (16)	157	3685 (172)	104	2 (0)
2014	322 (18)	312	9363 (373)	105	4 (0)
2015[C]	196 (18)	184	4893 (212)	290	4 (0)

[A]Episurv data; [B]based on laboratory data only (the mode of transmission is not reported); [C]Preliminary data.

The majority of norovirus outbreaks reported in EpiSurv are laboratory confirmed by the ESR Norovirus Reference Laboratory. In 2015, 90% of reported norovirus outbreaks were laboratory-confirmed by ESR (J. Hewitt, pers. comm.). The remaining norovirus outbreaks are confirmed by community or hospital laboratories.

Of all norovirus genotypes, GII.4 variants are the most commonly reported, at least in the last two decades. From 2002 to 2009, GII.4 variants were identified in 68% (825/1206) of reported norovirus outbreaks in New Zealand where a genotype was identified (Greening *et al.*, 2012). For the period 2010-2015, this figure was 62% (670/1085).

The number of reports of both outbreaks and cases of norovirus infection were significantly lower from 2001 to 2007 compared to the period 2008 to 2015 ($p < 0.05$). As norovirus specific

[17] http://www.surv.esr.cri.nz/surveillance/annual_outbreak.php (accessed 2 April 2015).
[18] Refers to norovirus.

RT-PCR assays have been available since 1995 (and RT-qPCR since 2006) at ESR, the increase may be mainly due to increased awareness and compliance in reporting outbreaks (Greening *et al.*, 2012; Greening *et al.*, 2001) rather than improvements in testing. Although outbreaks of norovirus are notifiable, there will be underreporting to the New Zealand Public Health Units by affected parties. In addition, no samples are submitted for testing for some gastroenteritis outbreaks reported in Episurv, so the causative agent is not identified. These outbreaks are recorded in EpiSurv as 'Gastroenteritis', and a proportion are likely to be caused by norovirus.

Mortality recorded for reported outbreak cases of norovirus infection is highly variable from year to year, ranging from one (2010 and 2011) to 17 (2009). The 17 deaths in 2009 were residents/patients of rest homes (n = 16) or hospitals (n = 1), which suggests that there were other contributing factors as well as the norovirus infection. This compares to figures from 1997 to 2005 where there was a total of 6 reported deaths, and to 2006 and 2007 where there 5 and 10 reported deaths respectively. All of those who died in the 2006 and 2007 norovirus outbreaks were also residents of rest homes or hospitals.

Norovirus infection is popularly referred to as 'winter vomiting disease' in the Northern Hemisphere as they have a winter seasonality in those regions (Rohayem, 2009). iSO, there is no clear seasonality in New Zealand. While an increase in outbreaks is often observed in the spring (October-November), peak months can vary year to year. For example, in 2011 and 2014, most norovirus outbreaks were reported in May and March respectively (Eden *et al.*, 2014; Greening *et al.*, 2012; Hewitt, 2014).

3.4 NOROVIRUS ILLNESS ASSOCIATED WITH BMS CONSUMPTION IN OTHER COUNTRIES

Overseas data on norovirus outbreaks associated with BMS between January 2009 and March 2016 are summarised in Appendix B.1

Key findings

Outbreaks of norovirus infection associated with BMS continue to be reported from a number of countries including Australia, China, European Union countries, Japan, South Korea, the US and the UK. The reports of outbreaks overseas indicate the importance of raw oysters as the most commonly implicated type of shellfish, which is consistent with New Zealand data. The Rapid Alert System for Food and Feed (RASFF) database revealed 44 alert notifications on norovirus in BMS and/or norovirus food poisoning associated with the consumption of BMS between March 2009 and January 2016. These incidents were commonly associated with oysters. Mussels were also implicated in one outbreak of norovirus infection.

4. EVALUATION OF RISK

4.1 EXISTING RISK ASSESSMENTS

Key findings

There are no new risk assessments considering norovirus in BMS in New Zealand or overseas. A joint risk assessment for the US and Canada is in preparation.

An expert elicitation process estimated that 8% of all norovirus infections in New Zealand were due to transmission by seafood (BMS were not specifically considered). Attribution studies for other countries have estimated between 1 and 11% of norovirus infections are due to transmission by seafood.

4.1.1 New Zealand risk assessments and related activities

The 2009 Risk Profile described a preliminary quantitative risk model for norovirus in shellfish (Greening and Lewis, 2007). This model has not been developed further.

A joint New Zealand/Australian paper evaluated eight case studies drawn from New Zealand and New South Wales where a norovirus illness event had been associated with the consumption of oysters contaminated with norovirus before harvest (Hay *et al.*, 2013). Some of the conclusions drawn from this study were:

- *E. coli*/faecal coliform indicators failed to consistently predict the risk of viral contamination in shellfish harvested for market;
- Infrequent sanitary surveys conducted as part of the Shellfish Quality Assurance programme did not provide an adequate assessment of the risk of virus contamination of shellfish in the growing area and incorrectly assumed little change would occur in the risk of viral contamination in the growing area through time; and
- There was a failure to manage re-occurring viral contamination risks.

The report made multiple recommendations under the themes of managing growing areas, science/technical issues and environmental policy issues.

A New Zealand expert elicitation process estimated the proportion of norovirus infections that were due to foodborne transmission and also estimated the proportion of foodborne norovirus infections that were due to “seafood” (BMS were not specifically considered). Of the 32.7% of norovirus infections that were considered to be due to foodborne transmission, 24.4% (95th percentile (95%) credible interval (CrI) 3.9-54.7%) were considered to be due to transmission of the virus by seafood (Cressey and Lake, 2013). Overall, these estimates would imply that approximately 8% of all norovirus infections were due to transmission by seafood. The expert elicitation also concluded that person-to-person transmission of norovirus was the primary contributor to the overall burden of disease, but did not quantify the proportion of infections due to this transmission route (Cressey and Lake, 2013).

Data from New Zealand were used to determine norovirus genotype profiles associated with foodborne transmission. This is described in Appendix B.2.

4.1.2 Risk assessments and risk-related activities from other countries

No risk assessments published since 2009 considering norovirus in shellfish were located. The US Food and Drug Administration (USFDA) and Health Canada are in the process of completing a joint risk assessment of norovirus in BMS but this is not yet available.[19]

The results from recent overseas attribution studies for norovirus have been summarised in Appendix B.2. Considered together, the information suggests that somewhere between 1 and 11% of illness due to norovirus is due to transmission of the organism by seafood. While the studies reviewed did not further subdivide the seafood category, shellfish are probably the major contributors to norovirus infections from this category, due to their potential for growth in waters polluted with human wastewater effluent and their ability to bioaccumulate norovirus.

The estimated proportion of norovirus infections that were due to foodborne transmission recently derived from the New Zealand expert elicitation (32.7%; Section 4.1.1) is consistent with estimates from the US (26%) (Scallan *et al.*, 2011) and Canada (31%) (Thomas *et al.*, 2013). Lower estimates have been derived for Australia (18%) (Vally *et al.*, 2014) and the Netherlands (17%) (Havelaar *et al.*, 2008).

4.2 EVALUATION OF RISK FOR NEW ZEALAND

Key findings

BMS available in New Zealand from local and overseas sources can potentially be contaminated by norovirus and contamination events have led to illness in this country.

The available information suggests that:

- Norovirus testing of imported oysters has contributed to a decreased risk from this food.
- There may be decreased risk from commercially harvested BMS but baseline microbiological data are needed to validate this finding.
- BMS gathered for recreational or customary purposes present an ongoing risk for norovirus infection.

4.2.1 Risk associated with BMS consumption

This Risk Profile considers BMS harvested both commercially (from aquaculture and wild sources) and non-commercially (customary and recreational gathering). Although many of the BMS species considered in this Risk Profile are usually consumed cooked, the light cooking often used for the preparation of BMS may not be sufficient to inactivate any norovirus present. 'Adequate' cooking will inactivate norovirus but such cooking makes BMS less desirable. Oysters and mussels are often consumed without any cooking. The risk is discussed for BMS consumed raw.

The 2003 Risk Profile had identified oysters as important vehicles of norovirus infection and concluded that the presence of norovirus in shellfish was largely a result of faecal contamination of the growing environment. The 2003 document also included an estimate for the rate of norovirus infection due to BMS (52/100,000 population), but this figure was based on multiple assumptions and is not considered reliable.

The 2009 Risk Profile concluded: "It is unclear whether the risk of norovirus infection from commercial shellfish for the New Zealand population has changed since the previous Risk Profile was completed in 2003. However, the risk has been better characterised as a result of

[19] http://www.fda.gov/Food/FoodScienceResearch/RiskSafetyAssessment/default.htm (accessed 21 March 2016).

surveys including the multi-site and Tauranga Harbour surveys, and evidence for widespread norovirus contamination of shellfish, particularly feral shellfish, has been obtained."

Some of the findings from the 2009 Risk Profile were:

- There are data to indicate frequent contamination of New Zealand shellfish with norovirus both in commercial and recreational settings;
- There have been reported outbreaks of norovirus infection in New Zealand from commercially harvested and imported oysters, and these suggest ongoing risk;
- Mussels and scallops have not been identified as causing outbreaks, possibly because commercially harvested populations grow in deeper waters in New Zealand;
- Cockles have not been identified as the cause of a norovirus outbreak in New Zealand but shellfish monitoring programmes have found contamination in this type of shellfish;
- Despite widespread norovirus contamination of BMS in non-commercially harvested sites in New Zealand, there is no evidence of illness associated with their consumption; and
- Raw molluscan shellfish are an infrequently consumed food in New Zealand, but consumption is likely to be concentrated in certain regional and ethnic populations.

Risk Management Question: Has the risk from norovirus in bivalve molluscan shellfish changed since the previous Risk Profile in 2009?

The available information indicates that BMS available in New Zealand from local and overseas sources can potentially be contaminated by norovirus and that contamination events have led to illness in this country:

- Norovirus is frequently present and often at high concentrations in New Zealand effluent wastewater.
- Norovirus is frequently present in sewage receiving waters including estuarine waters.
- If BMS are contaminated by norovirus, the virus can persist and remain potentially viable for prolonged periods (weeks, months) and are not effectively removed by depuration.
- Norovirus has been detected in commercially harvested BMS associated with outbreaks of norovirus infection (although no such outbreaks have been reported since 2009).
- Norovirus continues to be detected in BMS harvested from non-commercial sites, albeit from sites known to be at risk from contamination, and two norovirus outbreaks from recreationally gathered BMS (pipi and an undefined species) have been reported.
- Norovirus outbreaks have been associated with imported oysters although controls over this food have been tightened.

In reference to the findings of the 2009 Risk Profile, the available information suggest that norovirus contamination of non-commercially harvested sites in New Zealand is still widespread and continues to represent a risk to consumers of BMS from these sites. Outbreaks connected with recreationally harvested BMS have now been reported. In contrast, there have been no reported outbreaks of norovirus infection in New Zealand from commercially harvested or imported BMS since 2012. This suggests a decrease in risk from these sources, but the underreporting of norovirus infection in New Zealand creates uncertainty over this finding. Oysters continue to be the species of most concern with regard to norovirus infection from commercially harvested BMS. Mussels and scallops have not been implicated as the vehicle of infection for norovirus outbreaks in New Zealand.

There is no change to the finding that raw BMS are an infrequently consumed food in New Zealand, and that consumption is likely to be concentrated in certain regional and ethnic populations. More recent data suggest that adult New Zealanders are eating less shellfish so exposure to BMS contaminated with norovirus is potentially less. Mussels account for the majority of shellfish consumed (and an estimated 40% of mussel servings are raw) and oysters are most likely to be consumed raw (estimated 50% of servings).

Research suggests that Māori consume shellfish more frequently than the general population and so may be more at risk.

Overall the available information suggests that:

- Control measures (testing for norovirus) on imported oysters have been effective, as indicated by there being no reported outbreaks from imported oysters since the change in the IFR in October 2012. This suggests that the risk from commercial oysters imported from overseas has decreased since the 2009 Risk Profile.
- There may be decreased risk from commercially harvested BMS, as suggested by the absence of outbreaks linked to this food since 2009, but baseline microbiological data are needed to validate this finding.
- BMS gathered for recreational or customary purposes continue to present a risk for norovirus infection as they are more likely to be exposed to faecal contamination from point and non-point sources.

4.2.2 Risks associated with other foods

Norovirus is easily spread by an infected person to foods during preparation and this is believed to be a major contributor to foodborne norovirus infections. Contamination of foods by infected food handlers means that the variety of foods implicated in norovirus outbreaks is wide. It can be difficult to determine whether foods were contaminated prior to handling by an infected person, and also to distinguish between outbreaks where a food handler was infected through contact with the food, or vice versa.

Data from recent norovirus outbreaks in New Zealand, where the mode of transmission was reported as foodborne, provide very little information on risks associated with other foods in this country. For example, of the 18 foodborne norovirus outbreaks reported during 2014 a suspected food vehicle was reported in only three, and only one outbreak had strong evidence to support the food as the vehicle of infection (a berry trifle) (Horn *et al.*, 2015). In 2013 a suspected food vehicle (or multiple suspected foods) were reported in only 2 of 16 reported foodborne norovirus outbreaks, one of which was associated with BMS (Horn *et al.*, 2014). In 2012 this proportion was 8 of 26 reported outbreaks (Lopez *et al.*, 2013). Lopez *et al*. (2013), reported that of these eight outbreaks, there was strong evidence linking the food to the cases for only three outbreaks. The implicated foods were pasta salad (food handlers also positive for norovirus infection) and oysters (two outbreaks), but additional laboratory evidence identified an additional oyster outbreak with strong evidence (see Section 3.3.1) giving a total of four outbreaks.

Information from other countries suggests that fresh vegetables and fruit (particularly berries) are important contributors to the burden of norovirus infection (King *et al.*, 2016) (Appendix B.2). Norovirus may be introduced to these foods prior to the food preparation stage through contamination with irrigation water or from infected harvesters or packers. For example, during 2014 there were 76 foodborne norovirus outbreaks in the European Union with strong evidence linking cases to a food, and fresh fruit or vegetables (or products thereof) were implicated in 21% (16/76) of these. This was the third highest proportion behind mixed foods (22%) and “crustaceans, shellfish, molluscs and products thereof” (37%) (EFSA and ECDC, 2015). A notable outbreak was reported in Germany in 2012, where 10,950 cases were infected with norovirus from frozen, imported strawberries (EFSA and ECDC, 2014). An

analysis of 67 foodborne norovirus outbreaks reported during 2009-2012 in the US, in which specific food categories were implicated, found that vegetable row crops were implicated in 30%, fruits in 21% and molluscs in 19% (Hall *et al.*, 2014).

4.3 BURDEN OF DISEASE

Key findings

Nationally, on the basis of existing information, the burden of disease from BMS contaminated with norovirus appears to be low relative to other risk factors for norovirus infection, particularly contact with another sick person or consuming food contaminated by an infected food handler.

The burden of disease from foodborne norovirus infection in New Zealand was either first or fourth (after foodborne campylobacteriosis, listeriosis and STEC infection) in a risk ranking of potentially foodborne diseases, depending on the approach taken.

Globally, norovirus causes approximately 700 million illnesses per year and is the leading cause of foodborne illness with an estimated 125 million (95% UI 70–251 million) cases per year. In New Zealand, there are an estimated 211,000 norovirus cases per year, equating to a population rate of 4750 per 100,000.

4.3.1 Burden of disease from BMS contaminated with norovirus

There is insufficient information to quantitatively assess the burden of disease in New Zealand from BMS contaminated with norovirus relative to other foods contaminated with norovirus.

On a national scale, based largely on indications from public health surveillance data, the burden of disease from BMS contaminated with norovirus appears to be low relative to other risk factors for norovirus infection, particularly contact with another sick person or consuming food contaminated by an infected food handler. Food handlers are not considered to be a major factor in the contamination of raw shellfish.

4.3.2 Burden of disease from all norovirus infections

Norovirus infection cases associated with reported outbreaks are considered to represent only a proportion of the total norovirus infection cases that occur in New Zealand. Using estimates of community rates of norovirus infection, determined for the UK (Tam *et al.*, 2012), it has been estimated that approximately 211,000 (95th CrI 180,000-245,000) cases of norovirus infection occurred in New Zealand in 2013 (Cressey and Lake, 2014). Based on a mid-year population estimate for New Zealand of 4,442,100 in 2013[20] this equates to a crude population rate of 4750 per 100,000. These cases of disease were estimated to represent a burden of 2195 disability adjusted life years (DALYs); the greatest burden associated with any of the microbial pathogens considered.

Alternatively, the number of community cases of norovirus infections can be determined by applying a multiplier (288, 95th CI 239-346; Tam *et al*., 2012) to the number of notified cases. This approach results in a much lower estimate of the number of norovirus infection cases, of 21,900 (95th CrI 18,000-24,500), with associated DALYs of 253 (Cressey and Lake, 2014). The smaller number is due to the low rate of reported infections, for reasons discussed in Section 3.3. This estimate of case numbers is probably less reliable than the estimate based on community rates, as it is unlikely that the reporting of norovirus infection cases is similar in New Zealand and the UK and, consequently, the UK-derived multiplier may be of dubious relevance to New Zealand.

[20] http://www.stats.govt.nz/~/media/Statistics/browse-categories/population/estimates-projections/erp-2013-sources-methods/est-res-pop-2013-data-methods.pdf (accessed 9 April 2015).

An expert elicitation, conducted in 2013, estimated the most likely proportion of norovirus infection cases that would be due to foodborne transmission was 32.7% (95th CrI 10.0-66.4%) (Cressey and Lake, 2013). When applied to the total burden of disease due to norovirus infection (2195 or 253 DALYs, see above), this provides a mean estimate of 758 or 87 DALYs for foodborne infections, depending on the approach taken to estimate the number of cases (Cressey and Lake, 2014). These DALY values placed norovirus infection either first or fourth (after foodborne campylobacteriosis, listeriosis and Shiga toxin producing *E. coli* (STEC) infection in a risk ranking of potentially foodborne diseases.

The burden of disease to the health system and society in general has also been considered, through a cost of illness estimate (Cressey and Lake, 2008). This study estimated the total cost for norovirus infections as NZ$7.6 million/year, with foodborne infections costing NZ$3.0 million/year. This was the second highest burden estimate, but much lower than the highest estimate, for foodborne campylobacteriosis, of NZ$74 million/year. A more recent cost of foodborne illness study included costs associated with personal and lifestyle costs incurred by households and individuals in connection with private disbursements (where no recourse to government subsidy exists) and pain, suffering and disruption, including the possibility of premature death (Applied Economics, 2010). Using this approach an annual cost of NZ$50.1 million was derived for foodborne norovirus infections.

In the US it has been estimated that norovirus infection accounts for 58% of domestically-acquired foodborne illnesses, 26% of hospitalisations due to domestically-acquired foodborne illness and 11% of deaths (Scallan *et al.*, 2011). Norovirus infections were estimated to be substantially domestically acquired (>99%), with foodborne transmission accounting for 26% of cases. This US model was also applied to foodborne disease in New Zealand (Cressey and Lake, 2011). It was estimated that norovirus was the cause of 39% of all cases of domestically-acquired foodborne disease, caused by known pathogens, in New Zealand. Norovirus accounted for 99.7% of foodborne viral infections.

A Dutch study estimated that community-acquired norovirus infection caused 610,000 (95th CrI 418,000-878,000) cases of gastroenteritis per annum (Verhoef *et al.*, 2013). Given that the population of the Netherlands is almost four times the population of New Zealand, this estimate is similar to New Zealand estimates, based on population rates. Based on a foodborne proportion of 17% (Havelaar *et al.*, 2008), the burden of foodborne norovirus infections in the Netherlands in 2009 was estimated to be 305 (95th CrI 135-480) DALYs.

An Australian study estimated that (circa 2010) 1,550,000 (90 percentile (90th) CrI 1,220,000-1,940,000) cases of norovirus infection would occur per annum (Kirk *et al.*, 2014). Of these, 276,000 (90% CrI 78,100-563,000) cases (18%) were considered to be due to transmission by food. Norovirus accounted for 93.6% of foodborne viral illnesses. The analysis also included consideration of astrovirus, adenovirus, rotavirus and sapovirus. A second Australian study, conducted in a similar timeframe, estimated a higher number of norovirus infection cases (2,180,145), equating to 1109 DALYs (Gibney *et al.*, 2014). It should be noted that this Australian study used disability weight for gastroenteritis taken from the Global Burden of Disease 2010 study (Salomon *et al.*, 2012) to calculate DALYs, while the New Zealand study summarised above used disability weights taken from a Dutch study that developed weights specific to foodborne gastroenteritis (Haagsma *et al.*, 2008).

A meta-analysis of 175 studies worldwide concluded that the prevalence of norovirus infection amongst cases with acute gastroenteritis was 18% (95% CI 17-20%) (Ahmed *et al.*, 2014). The prevalence of norovirus infections was higher in low-mortality developing and developed countries compared to high-mortality developing countries and higher in community and outpatient cases of acute gastroenteritis than inpatient cases.

The World Health Organization (WHO) published estimates of the global burden of foodborne diseases in December 2015 (WHO, 2015). Of the approximately 600 million cases of illness caused by the 31 foodborne hazards studied (circa 2010), norovirus accounted for the largest

proportion (21%). It was estimated that norovirus caused 124,803,946 (95% uncertainty interval, UI 70,311,254-251,352,877) foodborne illnesses, 34,929 (15,916-79,620) foodborne deaths, and was responsible for 2,496,078 (1,175,658-5,511,092) foodborne DALYs (Kirk *et al.*, 2015; WHO, 2015). When all routes were considered, Kirk et al. (2015) identified norovirus as causing 684 million (95% UI 491–1,112 million) illnesses worldwide per year - the largest number of cases for the 22 pathogens studied. This figure is similar to an estimated 699 million (95% UI 489–1,086 million) cases norovirus illness for all ages per year reported in another study with over 219, 000 deaths globally - the majority (213,000) in low and middle income countries (Bartsch *et al.*, 2016). It was also estimated that the global economic burden of norovirus gastroenteritis was US$60.3 billion (95% UI: US$44.4–93.4 billion) per year, equating to US$86 per illness globally.

4.4 DATA GAPS

Key findings

There are very limited data on the prevalence of norovirus in commercially harvested shellfish. Quantitation of norovirus from outbreak-related BMS samples would aid in assessing the infectious dose.

Data gaps identified in the 2009 Risk Profile and updated commentary on these are presented in Table 6.

TABLE 6: Data gaps identified in the 2009 Risk Profile

DATA GAP	COMMENTARY
Surveillance	
Improved surveillance to link norovirus cases and outbreaks to a particular food source, in particular BMS consumption.	No longer a significant data gap. Surveillance systems and laboratory services adequate to assist with epidemiological investigation. Good contacts between public health units and ESR laboratories exist.
The prevalence of the norovirus in key growing/recreational shellfish gathering areas, including the seasonal and geographical distribution of viral contamination.	Limited studies since 2009. - Recreational BMS (cockles) tested for norovirus in Christchurch (2008-2012). - Recreational Tuatua testing ongoing for Christchurch City Council but only tested for enteroviruses. - MPI study proposed to commence in the vicinity of a commercial BMS harvesting area in mid to late 2016.
Exposure assessment	
Recreational gathering of shellfish is acknowledged to be widespread. There is little quantitative data to assess norovirus exposure from both recreational and commercially grown shellfish. No information on the current level of shellfish consumption per person, per meal, per age group, cultural group, etc. in New Zealand	Analyses of National Nutrition Surveys are available, as is recent information on recreational harvesting and New Zealand consumption (King and Lake, 2013; NIWA, 2014; Wynne-Jones *et al.*, 2014).
The role of post-harvest food handlers in the transmission of norovirus in shellfish is unknown.	No further information available.

DATA GAP	COMMENTARY
Information on the minimum infective dose in shellfish and how it relates to norovirus RNA levels detected by RT-PCR, and also information on dose response.	There is an increasing probability of infection with increased norovirus dose as determined by PCR. A 'safe' threshold has not been determined.
Presence and distribution of genetic susceptibility factors for the different norovirus strains in the New Zealand population.	No information.
Information on the survival rates of norovirus in boat and domestic sewage to define the contamination process.	No information.
Information on the survival and persistence of norovirus in the environment and in shellfish. Efficiency of sewage and wastewater treatment processes for removal of norovirus and hepatitis A virus.	New Zealand studies inform on the removal of noroviruses from wastewater treatment plants. It can be expected that effluent would contain infectious noroviruses (Hewitt *et al.*, 2011).
Role and value of microbial and viral source tracking tools for predicting occurrence of viral contamination, especially norovirus contamination	Literature review on the use of faecal source tracking tools carried out in 2014 (Hewitt and Williamson, 2014). Several tools available in New Zealand but further validation for use in shellfish growing areas and/or in BMS required.
Quantitation methods for infectious norovirus in shellfish and the environment.	Molecular approaches to assess virus integrity have been developed but none have proved adequate in terms of sensitivity and useful for risk evaluation (Knight *et al.*, 2013; Wolf *et al.*, 2009). Uncertainties remain in assessing the risk to human health from samples detected as positive in PCR assays. Cell culture methods using 3D cell culture techniques have so far been shown to be unsuitable for norovirus culture (Papafragkou *et al.*, 2014). Other approaches of informing on potential infectivity using molecular techniques have been published. One approach (Langlet *et al.*, 2012) includes a three-step protocol to remove non-encapsidated genome using RNAse, then to select non-damaged capsids, and finally to use a modified RT-qPCR to detect long genome fragments. Following treatment of murine norovirus with free chlorine, this molecular approach reflected the culture assay but further validation is required for other viral inactivation mechanisms.
Detection Methods	
Improved, efficient norovirus recovery, detection and quantitation methods from shellfish. Current norovirus recovery methods from shellfish are frequently of variable efficiency, which may relate to shellfish type. Accurate estimation of the quantity of virus present in a sample is problematic.	Methods for the detection and quantitation of norovirus have been validated and it is likely that the methods will be issued as an ISO protocol in late 2016/early 2017 (ISO/DIS 15216). The methods include the standard RT-qPCR assay for detection and quantitation of viral RNA. Suitability of digital PCR for absolute quantitation is an option.

DATA GAP	COMMENTARY
Effectiveness of methods for virus removal from shellfish and control strategies	
Efficiency and effectiveness of virus removal or natural depuration from shellfish in the environment and in post-harvest treatment. Information on the effectiveness of depuration and relaying processes pre-harvest prior to putting shellfish on market.	Additional data on persistence under different temperatures show that noroviruses are retained longer in BMS at cooler rather than at warmer temperatures (Choi and Kingsley, 2016).
Value of testing shellfish for norovirus at intervals following sewage spills and discharges.	No new information.
Inactivation mechanisms for norovirus and other pathogenic viruses in shellfish. Data are required on stability and persistence, effect of temperature, pH, time, matrix/organic material, disinfection by chemicals, ultraviolet light and radiation.	Information obtained through the use of norovirus surrogates, which is useful but cannot be applied to human noroviruses with certainty (Araud *et al.*, 2016).
Effectiveness of ultra-high pressure processing of shellfish for inactivation of human norovirus.	Using GI.1 and human feeding trials, a high pressure processing (HPP) treatment of 600 megapascal (MPa) for 5 minutes at 6ºC was sufficient to inactivate norovirus in oysters (Leon *et al.*, 2011). Treatments of 400 MPa for 5 minutes at either 6 or 25ºC were not. This may be a potential intervention to inactivate infectious viruses in oysters, but oysters treated at this high pressure and served without cooking may not be organoleptically acceptable to consumers. Other studies using virus-like particles (VLP) show that compared to norovirus surrogates, human norovirus capsid appears highly resistant to HPP - with 500-600 MPa for up to 60 minutes being insufficient to inactivate the virus (Lou *et al.*, 2012).
Virus recombination	
Significance of norovirus recombination in New Zealand shellfish harvested from contaminated areas.	No new information.
Role of animal viruses	
Information on potential zoonotic transmission of noroviruses between animals and humans through dual contamination events in shellfish.	No evidence of zoonotic transmission. Ongoing genotyping of circulating noroviruses to monitor is recommended.

A review of eight norovirus illness events in New Zealand and Australia associated with norovirus-contaminated oysters (Hay et al. 2013) also identified several data gaps as being important for managing risk in the future. These data gaps are covered by the table above.

The gaps identified were the following:

- A norovirus test method that distinguishes between infective and non-viable viruses;
- The effectiveness of F-RNA bacteriophages (referred to as MSC) as indicators of risk of viral contamination in oyster growing areas in New Zealand conditions;
- Sensitive and specific markers for human faecal contamination able to be reliably detected in a medium that captures information about water quality over a period of time (e.g. in shellfish, adsorbent media);

- The length of time noroviruses remain infective within the marine environment;
- The length of time noroviruses remain infective in shellfish; and
- The effectiveness of various wastewater treatment processes in reducing the level of infective norovirus.

The following other areas of required research identified in the review were:

- Development of a norovirus culture assay;
- Anti-viral drugs for norovirus;
- Development of a norovirus vaccine; and
- A better understanding of host genetics, immunity, and environmental factors.

5. AVAILABILITY OF CONTROL MEASURES

5.1 CURRENT CONTROL MEASURES

Key findings

There are no microbiological standards for norovirus in commercially harvested BMS in New Zealand. General food safety controls required for BMS growing, harvesting and post-harvest activities will help prevent contamination by norovirus. Depuration for the control of viruses is not allowed in New Zealand, but the relocation of BMS to other sites ("relaying") is permitted. No post-harvest treatments are recommended for inactivating norovirus.

Hazard-based controls are in place to avoid placing norovirus-contaminated oysters from overseas on to the New Zealand market. Where testing is required for importation, norovirus must not be detected. There is no threshold limit. There are no microbiological standards for norovirus in other imported BMS species.

5.1.1 Regulatory controls

Businesses that grow, harvest, process, store or transport BMS for human consumption are subject to the *Animal Products Act 1999* and associated regulation and notice.[21] This includes shellfish harvested from aquaculture areas or wild stocks.

The Animal Products (Regulated Control Scheme-Bivalve Molluscan Shellfish) Regulations 2006 and Animal Products (Specifications for Bivalve Molluscan Shellfish) Notice 2006 (both forming the BMSRCS) were both described in the 2009 Risk Profile. These apply to BMS harvesters and those involved in transport and storage, and have not changed. The microbiological monitoring requirements do not include standards for norovirus. All BMS commercially grown or harvested in New Zealand must come from a shellfish growing area that is registered with MPI and classified for harvest for human consumption, and such areas are monitored for faecal coliforms (water) and generic *E. coli* (shellfish).[22] Prior to classifying a growing area a sanitary survey is completed which includes an evaluation of all actual or potential pollution sources in the growing area catchment. The human sewage risk, and hence norovirus potential risk, is therefore evaluated during this process. Where necessary, prohibited zones are placed around potential sewage input sources.

Pursuant to the BMS RCS, if a growing area is a confirmed source of a norovirus illness outbreak, the growing area is closed and kept closed until, the source has been mitigated, and a contaminant reduction study undertaken to ensure no norovirus is present in the BMS.

Businesses that process BMS, including depuration and land-based wet storage, must operate under a registered Risk Management Programme (RMP).[23] General food safety controls in place as part of a RMP will help control norovirus contamination after harvesting (e.g. from sick workers). A generic model RMP for oysters is available and lists norovirus among the possible microbiological hazards to be considered.[24] A BMS processor may choose

[21] http://www.foodsafety.govt.nz/industry/sectors/seafood/bms/ (accessed 21 March 2016).
[22] A list is maintained by MPI. Version as at 1 February 2016 available at: http://www.foodsafety.govt.nz/elibrary/industry/bms-shellfish-growing-areas.pdf (accessed 21 March 2016).
[23] http://www.foodsafety.govt.nz/industry/sectors/seafood/bms/processors.htm (accessed 21 March 2016).
[24] http://www.foodsafety.govt.nz/elibrary/industry/code-practice-seafood/generic-rmp-model.pdf (accessed 21 March 2016).

to include norovirus-specific monitoring as part of their RMP. BMS processors must also comply with the Animal Products (Specifications For Products Intended For Human Consumption) Notice, and the most recent version of this notice came into effect on 1 April 2016. Sections 14.12-14.34 set out the requirements; none are specific to norovirus.

A revised Australia New Zealand Food Standards Code came into effect on 1 March 2016.[25] Schedule 27 of Standard 1.6.1 (microbiological limits in food) specifies a microbiological standard for *E. coli* in BMS (excluding scallops). No microbiological limits have been established for norovirus in BMS.

Based on the number, BMS source and types of outbreaks reported since 2010, appropriate management controls seem adequate for norovirus control in BMS.

5.1.2 Post-harvest treatments

Relaying and depuration were discussed in the 2009 Risk Profile and there have been no changes. Options for post-harvest treatment of potentially norovirus contaminated shellfish remain limited and the focus should be to avoid growing and harvesting BMS in the vicinity of wastewater effluent or other faecal sources (CODEX, 2012).

Depuration is not permitted by MPI as a post-harvest treatment for norovirus contaminated BMS as it may be ineffective (Savini *et al.*, 2009), but BMS can be relayed to other sites. Depending on the time period and water temperature, this may not be an effective post-harvest measure in removing noroviruses.

Without a reliable culture method for human noroviruses (Papafragkou *et al.*, 2014), the effects of post-harvest treatment aimed at decreasing norovirus viability is difficult to assess (Refer to Appendix A). As this Risk Profile consider raw mollusc, cooking is not relevant as a post-harvest treatment but further information on heat treatments is covered elsewhere (EFSA, 2015).

As viruses can withstand freezing, this process is unlikely to inactivate noroviruses. Indeed, many documented norovirus outbreaks have occurred following the consumption of pre-frozen BMS (Brucker *et al.*, 2012; Simmons *et al.*, 2007). Following a systemic review of the scientific literature, 3% of the 359 shellfish-borne viral outbreaks between 1980 and 2012 (most of which resulted from the consumption of norovirus-contaminated oysters), were as a result of consuming frozen (raw) product (Bellou *et al.*, 2013).

5.1.3 Imported shellfish

BMS imported into New Zealand must have been shelled and either cooked, dried or frozen (MAF Biosecurity, 2008). Unshelled molluscs are permitted for importation from the European Union but need an import permit (shelled molluscs do not need this permit) (MAF Biosecurity, 2004).

Regardless of country of origin, BMS and products containing BMS are classified as a food of "High Regulatory Interest (HRI)" because they are known to present an increased risk to human health. As such BMS always require food safety clearance before being imported into New Zealand (MPI, 2016a). Schedule 1 of the Importing Food Notice describes the IFR for BMS and products containing BMS (MPI, 2016d).

As MPI uses a risk-based approach for managing food safety, the clearance requirements for BMS are determined on the basis of an assessment of a country's BMS programme against the sanitary outcomes of the New Zealand production system. To meet clearance requirements, evidence required for BMS importation from Australia, Canada, Chile, countries

[25] http://www.foodstandards.gov.au/code/Pages/default.aspx (accessed 21 March 2016).

of the European Union, Japan, Republic of Korea, Peru, Thailand, the US (not Gulf States) and Vietnam are as follows:

- Official Certificate (accepted for clearance issued by the countries relevant issuing bodies),
- Sample and Test (MPI will decide on the frequency of testing), or
- New Zealand Importer Assurance (previously known as a Multiple Release Permit).

For China, there is no pre-clearance agreement. Instead the evidence required is either 'Sample and Test' or a 'New Zealand importer Assurance'. Importation to New Zealand is not permitted from countries or geographic regions not listed in Food Notice:Importing food (Schedule 1) (MPI, 2016d).

There is one food safety clearance limit for norovirus, "not detected in 300 g". This only applies to oysters and was introduced in October 2012 (MPI, 2016d). An International Accreditation New Zealand (IANZ) accredited (against ISO 17025) method is used for the detection of norovirus (Greening and Hewitt, 2008; ISO, 2013b).

Results from norovirus testing completed under the IFR from October 2012 to March 2016 are given in Section 2.4.3.

Food imports requiring inspection and testing are identified by their import tariff codes, and the imported foods are selected for testing subject to a 'switching rule'. Under this rule, the number of tested consignments of a specific food from a specific exporter, and belonging to an importer, reduces with continued compliance with import standards. This rule means that the proportion of consignments tested is usually small in relation to the total consignments arriving at the New Zealand border. Oysters arriving without recognised certification will be subject to norovirus testing starting at the 'tightened' testing rate under the switching rule. Oysters arriving under recognised certification will be subject to norovirus testing at the time of their next scheduled verification.

From 1 March 2016, seafood importers are required to be registered with MPI or import using a registered agent (MPI, 2016b). The registered importer must be a New Zealand resident. There is a transition period for food importers to become registered that expires on 30th June 2017. The list of registered importers can be found on the MPI website.[26]

5.1.4 Consumers and food handlers

In June 2013, MPI updated resources that promote food safety for seafood gatherers.[27] MPI advise only to collect "shellfish from areas where the seawater is not contaminated in any way" and advise to cook the shellfish properly.

Some products imported into New Zealand considered 'high risk' (by the producers) were labelled with phases such as "cook before consumption". However, such labelling was not effective and did not prevent illness as shown by the occurrence of outbreaks, including in New Zealand (Simmons *et al.*, 2007). These instructions can be easily ignored or the interpretation of the extent of cooking required unclear.

[26] The steps required for the importation of seafood can be found at: http://www.mpi.govt.nz/importing/food/seafood/steps-to-importing/ (accessed 21 March 2016). The list of importers at http://www.foodsafety.govt.nz/registers-lists/food-act-2014-registered-food-importers/index.htm?setup_file=fa2014-food-importers-ssi.setup.cgi&rows_to_return=20000&submit_search=Search (accessed 12 September 2016).

[27] http://www.mpi.govt.nz/food-safety/community-food/wild-foods/food-safety-when-fishing-or-gathering-seafood/, http://www.mpi.govt.nz/document-vault/1058 (accessed 22 March 2016).

5.1.5 International guidelines

The Codex Alimentarius Commission (CAC) publishes food standards that support safe food production and fair trade.[28] In 2012 the CAC published Guidelines on the Application of General Principles of Food Hygiene to the Control of Viruses in Food (CAC/GL 79-2012). Annex I of these guidelines specifically considers control of hepatitis A virus and norovirus in bivalve molluscs. The main focus in the annex is controls over environmental hygiene. Cooking and high hydrostatic pressures are discussed as post-harvest treatments but the annex emphasises that validation of these treatments is required, and they should not be relied on to protect consumer health.

CAC/GL 79-2012 also refers to The Code of Practice for Fish and Fishery Products (CAC/RCP 52-2003) that was first published in 2003 and most recently updated in 2013. This latter document lists norovirus as a hazard that can be introduced pre-harvest but does not specifically consider controls for norovirus, rather it includes general controls that will help prevent microbial contamination.

5.2 OPTIONS FOR ENHANCED CONTROL MEASURES

The impact from human recreational activities, boating, septic tank leachates, and sewage spills on shellfish growing areas requires stringent management strategies to reduce the risk of viral contamination. As faecal indicator bacteria are depurated more rapidly than noroviruses, they are not necessarily considered good indicators of viral presence (Lees, 2000) and so other approaches should be considered in assessing possible norovirus contamination sources of BMS.

Increasingly, F-RNA bacteriophages (referred also as male-specific coliphages, MSC) are being considered for use in shellfish sanitation programmes as the assay is cheaper and less labour intensive than virus pathogen detection. While F-RNA bacteriophages have shown potential as viral indicators in certain circumstances and as a risk management tool, further work is required to understand the correlations between noroviruses, F-RNA bacteriophages and health risk.

Faecal source tracking tools are potentially useful in the management of shellfish growing area as they can assist in differentiating between sources of indicator bacteria (i.e. *E. coli*, faecal coliforms) (Greening and McCoubrey, 2010). A review of faecal source tracking tools available in New Zealand (Hewitt and Williamson, 2014) identified the following data gaps:

- Lack of knowledge of the relationship between the risk of enteric virus contamination and presence of human Faecal source tracking markers, including bacteriophages, in shellfish growing waters and shellfish;
- Lack of knowledge of the persistence of human faecal source tracking markers compared to enteric viruses in shellfish growing waters and shellfish;
- Lack of validation of faecal source tracking molecular markers, particularly human-specific, from shellfish tissue.

The determination of an exact source of faecal contamination of growing areas can be a complex process, and so for optimal results a polyphasic approach, using a tiered approach and multiple faecal source tracking methods are required (Hewitt and Williamson, 2014). It was recognised though that there is currently no universal approach to source tracking, methods have no regulatory approval and research techniques and applications are rapidly changing.

[28] Standards are available from http://www.fao.org/fao-who-codexalimentarius/standards/en/ (accessed 22 March 2016).

After an assessment of post-harvest control measures to reduce noroviruses in oysters in the European Union, the European Food Safety Authority (EFSA) concluded “The most effective public health measure to control human NoV [norovirus] infection from oyster consumption is to produce oysters from areas which are not faecally contaminated, particularly given the ineffectiveness of current control regimes.” (EFSA, 2012). The depuration and relaying measures used by industry did not adequately reduce norovirus contamination of oysters. Another key recommendation was for risk managers to consider establishing an acceptable limit for norovirus in oysters to be harvested and placed on the market. The need for more data was also highlighted. Specifically, a European Union baseline survey to establish the prevalence of norovirus in oysters was suggested and further work was required to investigate the norovirus infectious dose in shellfish. The baseline study is planned to commence late 2016 (EFSA, 2016).

An investigation of eight norovirus illness events associated with oysters contaminated with norovirus before harvest (Hay et al. 2013) identified the frequency of viral testing as an issue for risk management. The investigators found a reluctance from the industry to sample shellfish for viruses in commercial shellfish growing areas and that such testing was only occasionally undertaken. They commented that “This reluctance arises from an uncertainty as to the regulatory response if the results are positive. (Anonymised harvest area and product surveillance would not provide the area-specific data required to improve risk management in specific growing areas). The interpretation of virus test results within the context of other concurrent factors (such as other indicators) could overcome this problem.” The report makes additional recommendations on managing the risk of shellfish being contaminated with norovirus.

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APPENDIX A: HAZARD AND FOOD

A.1 NOROVIRUS DETECTION AND QUANTITATION

Following a 2007 report describing human norovirus culture (Straub *et al.*, 2007), attempts to replicate the researchers findings proved difficult (Papafragkou *et al.*, 2014; Takanashi *et al.*, 2014)[29], and to date there is no reliable and reproducible culture system available for the noroviruses that infect humans (i.e. GI/GII/GIV). Norovirus infection of B cells has been reported though, most likely with norovirus infection facilitated by a co-factor derived from commensal microbiota (Jones *et al.*, 2014; Jones *et al.*, 2015; Karst and Tibbetts, 2016). While not thought to be essential for infection (Brown *et al.*, 2016), this information aids better understanding norovirus cell tropisms and ultimately efforts towards developing a successful culture method.

As virus culture methods are challenging, there has been the development of methods aimed at assessing both the virus capsid and nucleic acid integrity, and which ensures the non-detection of 'free RNA' using molecular approaches. These have included pre-treatment of samples with propidium monoazide, RNase, and/or utilisation of porcine gastric mucin as HBGAs for virus capture (Escudero-Abarca *et al.*, 2014; Knight *et al.*, 2013; Wang and Tian, 2014). Results from studies using molecular approaches may aid understanding of survival and inactivation, and aid public health risk assessments.

In the context of this Risk Profile, the proteinase K digestion method used frequency for the recovery of noroviruses from BMS (ISO, 2015) is reported to be less likely to recover free viral RNA than are other virus recovery methods (Knight *et al.*, 2013). In addition, free viral RNA is not efficiently bioaccumulated by BMS (Dancer *et al.*, 2010). Although these observations need verification, these data suggest that subsequent PCR will predominately detect intact particles, although it is not known if those detected are infectious viruses. It is also unclear if the norovirus capsid is damaged during the proteinase digestion process of the recovery step. If so, any post-processing assessment of infectivity may be compromised by the recovery step.

Molecular methods are the only suitable approach for detecting norovirus from complex matrices such as BMS. RT-qPCR is commonly used for detecting norovirus (a RNA virus that requires a reverse transcription step prior to the PCR) from clinical, environmental and BMS samples. Method standardisation is lacking globally with laboratories and a variety of in-house protocols or one of several commercial kits available are used (for example, http://www.ceeramtools.com/, http://www.fast-trackdiagnostics.com/products/ftd-noro/, http://www.bc-diagnostics.com/products/kits/real-time-pcr/viruses).[30] Commercial kits targeted for rapid diagnostics from clinical samples may not be suitable for BMS. For example, rapid immunochromatographic tests and enzyme immunoassays often used for clinical samples are not sensitive enough for use with BMS.

The 2009 Risk Profile reported that the European Community and National Reference Laboratories were validating standard methods for norovirus detection in shellfish, foods and waters. In 2013, two ISO Technical Specifications were published. The documents were prepared by the European Committee for Standardization (CEN), in collaboration with Technical committee ISO/TC 34, *Food products*, Subcommittee SC 9 *Microbiology.* The documents are referred to as CEN/ISO TS 15126-1:2013 and 15216-2:2013 (ISO, 2013a,

[29] Of the norovirus group, only murine norovirus (belonging to norovirus genogroup III) can be cultured.
[30] Accessed 14 April 2016.

2013b). These describe the detection and quantitation of noroviruses (and hepatitis A virus) from a number of matrices including BMS.

Briefly, the procedure describes the recovery of viruses by proteinase K digestion followed by viral RNA extraction by lysis with guanidine thiocyanate and adsorption to silica. The extracted RNA is then converted to complementary DNA (in the RT step) and amplified using qPCR. Although the procedure specifies that primers and probes should target the genome conserved regions at the junction of the ORF1/ORF2, there is no specific recommended assay nor reagents. The method requires the use of a process control such as murine norovirus or mengovirus, and the use of appropriate positive and negative controls.

As ISO T/S are reviewed after three years, the procedures are due for revision no later than 2016 and are eligible to become an International Standard. If confirmed, another review takes place after a further three years. Alternatively, they will be confirmed for a further three years, or withdrawn. After this time, it must either become an International Standard or be withdrawn. In November 2015, the CEN/ISO TS 15126-1:2013 was revised (with additional technical information added). The revision became the draft international standard ISO/DIS 15216-1 (ISO, 2015) and, as of March 2016, is under review. The standard describes the procedure for virus quantitation. In 2012, EFSA considered the use of the CEN method and concluded that it was suitable for use in a legislative context (EFSA, 2012).

Digital PCR is an alternative approach for detecting and quantifying nucleic acid at low concentrations, negating the use of an external standard curve to allow absolute quantitation (Racki *et al.*, 2014). However its use for detecting noroviruses in BMS has not been demonstrated and this process is not considered in the ISO/DIS 15216-1 standard as described above.

A.2 TYPING

Molecular typing of human noroviruses is important in public health surveillance purposes but selection of the genome to sequence is vital for identification and to allow sequence data comparisons (Verhoef *et al.*, 2012). In New Zealand, the norovirus genotype is routinely determined by sequencing both the partial polymerase (region B) and partial capsid (region C) of the genome. This allows alignment with sequence data both from the US (CaliciNet database) and Europe (Noronet database) but more extensive genome sequencing would provide better comparisons. The use of an automated web-based typing tool (http://www.rivm.nl/mpf/norovirus/typingtool) is used to aid genotyping. For a new genotype, this web based tool defines that the VP1 region of the capsid must differ with other known genotypes by a minimum of 15% pairwise difference (Kroneman *et al.*, 2013). For GII.4, there is approximately 5% divergence in the VP1 amino sequence between variants, and up to 2.8% within variants (Zheng *et al.*, 2006).Where possible, genotyping is carried out for noroviruses detected in BMS samples as this can inform source tracing, but this can be problematic due to the often low levels and a mixture of viruses present.

Next generation typing methods such as whole genome sequencing by massively parallel sequencing can offer an alternative approach for virus typing from clinical and food/environmental samples and can provide higher resolution to typing. For both clinical and food samples, extensive validation is required before it replaces the current PCR and Sanger-sequencing methods used for noroviruses. Sensitivity may be an issue not only for environmental and food samples including BMS, but for clinical samples too, so development and method harmonisation work will be required. The typing tool (http://www.rivm.nl/mpf/norovirus/typingtool) is not yet suitable for analysis of the whole genome by next generation typing.[31]

[31] http://www.compare-europe.eu/Library/Reference-Genomes/Norovirus (accessed 14 April 2016).

A.3 SURVIVAL AND INACTIVATION

Because of the historical lack of a culture system, there are limited data on survival and inactivation of human noroviruses.

Information on the known properties of human noroviruses are presented in a microbiological datasheet published in 2010 (available at https://www.mpi.govt.nz/document-vault/1362). Norovirus can retain infectivity following heat treatment at 60°C for 30 minutes (data is based on volunteer inoculation studies). As norovirus illness has been documented following the consumption of norovirus-contaminated BMS that had been heated/steamed, it is apparent that these common shellfish cooking methods do not readily inactivate noroviruses. The recommendation by the UK Ministry of Agriculture for commercial cooking operations is that the internal shellfish meat temperatures should reach 90°C and be held for 1.5 minutes. This was discussed in the 2009 Risk Profile.

Norovirus surrogates such as feline calicivirus, murine norovirus and Tulane virus have been used in heat inactivation studies. Surrogate viruses can be completely inactivated at 56°C within 20 minutes (Cromeans *et al.*, 2014). Shellfish tissue can have a protective effect to viruses during heating (Flannery *et al.*, 2014) but sufficient heating (e.g. 80°C, > 6 minutes) can inactivate most norovirus surrogates in oyster tissue (Araud *et al.*, 2016). However caution is advised when extrapolating such data to noroviruses.

A.4 OVERSEAS DATA ON PREVALENCE OF NOROVIRUS IN SHELLFISH

The 2009 Risk Profile listed overseas studies of the prevalence of norovirus in raw BMS from the 1990s to 2008. Overseas surveys of BMS for norovirus published from 2009 to 2015 are summarised in Table 7.

One of the most extensive study was commissioned by the UK Food Safety Authority to investigate the prevalence and concentration of norovirus in oyster harvesting areas. The study was carried out by Centre for Environment, Fisheries and Aquaculture Science in the UK (Lowther *et al.*, 2012). Key findings in that study were that:

- Norovirus was detected in 76% of oysters;
- 52% samples contained <100 genome copies/gram;
- 1.4% samples contained >10,000 genome copies/gram; and
- A higher norovirus prevalence was observed in the winter compared to summer.

TABLE 7: Prevalence of norovirus in raw BMS from overseas surveys (published 2009-2015)

COUNTRY	SURVEY PERIOD	BMS SPECIES	NO OF SAMPLES TESTED	NO OF POSITIVE SAMPLES	% POSITIVE	COMMERCIAL/ NON-COMMERCIAL BMS	REFERENCE
Australia	2010-2011	Oysters	120	2	1.7%	Commercial	Brake *et al.* (2014)
Belgium	2012-2013	Oysters, mussels and clams	65	21	32.3%	Commercial	Li *et al.* (2014)
Brazil	2008-2009	Mussels	11	0	0%	Non-commercial	Keller *et al.* (2013)
Canada	2004-2007	Mussels	13	0	0%	Non-commercial	Levesque *et al.* (2010)
China	2007	Clams, mussels, oysters and scallops	162	20	12%	Mainly Commercial	Ming *et al.* (2013)

COUNTRY	SURVEY PERIOD	BMS SPECIES	NO OF SAMPLES TESTED	NO OF POSITIVE SAMPLES	% POSITIVE	COMMERCIAL/ NON-COMMERCIAL BMS	REFERENCE
China	2009-2011	Oysters, mussels and others	840	112	13.3%	Commercial	Ma *et al.* (2013)
Europe (Finland, Greece, Spain)	2010	Mussels	153	18	11.7%	Commercial	Diez-Valcarce *et al.* (2012)
France	2010-2010	Oysters	387	35	9%	Commercial	Schaeffer *et al.* (2013)
Available in France (sources from EU & non-EU countries)	2008	Mussels	83	18	21.7%	Commercial	Loutreul *et al.* (2014)
Ireland	2005-2007	Oysters	167	62	37.1%	Commercial	Flannery *et al.* (2009)
Ireland	2007-2009	Oysters	23	22	95.6%	Non-commercial[A]	Rajko-Nenow *et al.* (2012)
Italy	No dates	Mussels	80	2	2.5%	Commercial	Serracca *et al.* (2010)
Italy	2005-2008	Clams, mussels and oysters	116	14	12.1%	Commercial	Terio *et al.* (2010)
Italy	2007-2010	Mussels and others	163	94	57.7%	Commercial	Pepe *et al.* (2012)
Italy	2003-2010	Clams, mussels, oysters and others	4463	182	4.1%	Commercial	Pavoni *et al.* (2013)
Italy	2011-2012	Mussels	51	7	13.7%	Commercial	Fusco *et al.* (2013)
Italy	2011-2012	Razor *(Solen marginctus)*	8	2	22.2%	Non-commercial	Fusco et al. (2013)
Italy	2008-2012	Clams, mussels and oysters	336	173	51.5%	Commercial	Suffredini *et al.* (2014)
Morocco	2006-2010	Oysters clams and cockles	77	23	30%	Unknown	Benabbes *et al.* (2013)
Poland	2010-2012	Mussels	120	GI 22 GII 28	GI 18.3% GII 23.3%	Non-commercial	Bigoraj *et al.* (2014)
Portugal	2008-2009	Oysters, mussels and others	49	18	37%	Commercial	Mesquita *et al.* (2011)
South Korea	2006	Oysters	156	22	14.1%	Commercial	Moon *et al.* (2011)

COUNTRY	SURVEY PERIOD	BMS SPECIES	NO OF SAMPLES TESTED	NO OF POSITIVE SAMPLES	% POSITIVE	COMMERCIAL/ NON-COMMERCIAL BMS	REFERENCE
South Korea	Not given	Oysters, mussels and clams	152	GI 9 GII 33	GI 5.9% GII 21.7%	Commercial	Seo *et al.* (2014)
Spain	2005	Mussels	24	14	58.3%	Commercial	Vilarino *et al.* (2009)
Spain	2005	Mussels clams and cockles	17	9	52.9%	Non-commercial	Vilarino *et al.* (2009)
Spain[B]	2004-2008	Mussels and clams	151	19	12.6%	Commercial	Rodriguez-Manzano *et al.* (2014)
Spain	2010-2012	Mussels	81	41	49.4%	Commercial	Manso and Romalde (2013)
Spain	2011-2012	Mussels, clams and cockles	168	GI 54 GII 43	GI 32.1% GII 25.6%	Commercial	Polo *et al.* (2015b)
Spain imported: Morocco, Peru, Vietnam and South Korea	2006-2009	Oysters clams and cockles	50	GI 12 GII 4	GI 24% GII 8%	Commercial	Polo *et al.* (2010)
Thailand	2005	Oysters	118	45	38%	Commercial	Kittigul *et al.* (2011)
UK	2009-2011	Oysters	844	643	76.2%	Commercial	Lowther *et al.* (2012)
US	2006-2007	Oysters	9	5	55%	Non-commercial	Gentry *et al.* (2009)
US	2007	Oysters	388	GI 4 GII 11	3.9%	Commercial	Woods and Burkhardt (2010) and DePaola *et al.* (2010)

[A] Area selected for testing was closed for harvesting due to previous incidents of norovirus contamination leading to illness outbreaks; [B] Imported (*n* = 34) and Spanish domestic (*n* = 117) product included.

APPENDIX B: NOROVIRUS INFECTION OVERSEAS

B.1 OUTBREAKS ASSOCIATED WITH BMS CONSUMPTION

Similarly to New Zealand, norovirus infection in many other countries is not notifiable so data on norovirus infection are largely derived from reported outbreaks. This section focuses on reported outbreaks associated with BMS overseas.

The 2009 Risk Profile gave examples of overseas norovirus outbreaks associated with the consumption of raw BMS. These included outbreaks from Australia, Canada, France, Italy, Singapore, the UK and the US. Table 8 summarises outbreaks of norovirus infection linked to the consumption of BMS reported in the scientific literature between January 2009 and March 2016.

TABLE 8: Overseas norovirus outbreaks associated with the consumption of raw BMS and reported in the peer-reviewed scientific literature (published January 2009-March 2016)

COUNTRY	YEAR OF OUTBREAK	MOLLUSC SPECIES IMPLICATED	NUMBER OF REPORTED CASES	OUTBREAK SETTING	EVIDENCE FOR FOOD IMPLICATED	REFERENCE
Australia	2013	Oysters	525	Various	Epidemiological, Norovirus in faeces.	Lodo *et al.* (2014)
Australia	2014	Oysters	8	Restaurant	Epidemiological, Norovirus in faeces and BMS.	Fitzgerald *et al.* (2014)
China	2014	Oysters	65	Food festival	Epidemiological, Norovirus in faeces and BMS.	Wang *et al.* (2015)
EU (UK, Norway, France, Sweden Denmark)	2010	Oysters	334 (65 clusters)	Various	Epidemiological, Norovirus in faeces and BMS.	(Rajko-Nenow *et al.* (2014); Westrell *et al.* (2010))
France	2012	Oysters	84	Nursing home	Epidemiological, Norovirus in faeces and BMS.	Loury *et al.* (2015)
Ireland	2012	Oysters	18	Restaurant	Epidemiological, Norovirus in faeces and BMS.	Rajko-Nenow *et al.* (2014)
Japan	2008	*Ruditapes philippinarum*	17	Restaurant	Epidemiological, Norovirus in faeces and BMS.	Iizuka *et al.* (2010)
South Korea	2013	Fermented oysters	8	School Restaurant	Epidemiological, Norovirus in faeces and BMS.	Cho *et al.* (2016)

COUNTRY	YEAR OF OUTBREAK	MOLLUSC SPECIES IMPLICATED	NUMBER OF REPORTED CASES	OUTBREAK SETTING	EVIDENCE FOR FOOD IMPLICATED	REFERENCE
Sweden	2007	Oysters	30	Restaurant	Epidemiological, Norovirus in faeces and BMS.	Nenonen *et al.* (2009)
US	2009	Oysters	>200	Restaurant	Epidemiological, Norovirus in faeces.	Alfano-Sobsey *et al.* (2012)
UK	2010	Oysters	11	Restaurant	Epidemiological, Norovirus in faeces and BMS.	Baker *et al.* (2011)
UK	2011	Oysters	>240	Restaurant	Epidemiological, Norovirus in faeces and BMS.	Smith *et al.* (2012)

Additional outbreaks have been reported in:

- The Program for Monitoring Emerging Diseases (ProMED)-mail database, e.g. 14 people reported ill after eating Louisiana oysters at a New Orleans restaurant (ProMED-mail, 2012b); 16 people reported symptoms in Vancouver following consumption of raw oysters produced on Vancouver Island, Canada and harvested in Sept 2010 (ProMED-mail, 2010); large outbreak across three different restaurants in Taiwan associated with the consumption of Korean oysters (ProMED-mail, 2012a);[32]
- The RASFF database revealed 44 alert notifications on norovirus in BMS and/or norovirus food poisoning associated with the consumption of BMS consumed between March 2009 and January 2016,[33] e.g. outbreak in the Netherlands in January 2016 associated with oysters, outbreak in France in February 2015 associated with oysters, outbreak in Denmark in March 2014 associated with oysters from France, outbreaks in France in April 2013 and April 2015 associated with mussels from Spain;
- Outbreak and annual surveillance reports made available by governmental agencies such as the US Centers for Disease Control and Prevention and the Public Health Agency of Canada, e.g. The Morbidity and Mortality Weekly Report (MMWR) website at:http://www.cdc.gov/mmwr/index.html; http://www.cdc.gov/foodsafety/outbreaks/multistate-outbreaks/reports.html (accessed 30 March 2016);
- US interstate shellfish sanitation informs on illness outbreaks and closures http://www.issc.org/closuresreopenings.aspx. e.g. Recall of Oregan oysters following

[32] http://www.promedmail.org/index.php (accessed 19 February 2016), The Program for Monitoring Emerging Diseases (ProMED) is an internet-based reporting system managed by the International Society for Infectious Diseases.

[33]Rapid Alert System for Food and Feed database (https://webgate.ec.europa.eu/rasff-window/portal/). Use the search parameters: Hazard = Pathogenic micro-organisms; Product = bivalve molluscs and products thereof; Type, Basis = Food poisoning, Keyword = norovirus; Date 2009 to January 2016 (accessed 19 February 2016).

norovirus outbreak investigation associated with the product (accessed 30 March 2016); and

- Foodborne outbreak online database available at: http://wwwn.cdc.gov/foodborneoutbreaks/Default.aspx, which informs on the US foodborne outbreaks.

B.2 NOROVIRUS ATTRIBUTION STUDIES FROM OVERSEAS

An international study used genotyping information to estimate the proportion of total norovirus outbreaks attributable to foodborne transmission (Verhoef *et al.*, 2015). Overall, using combined outbreak surveillance data from the US, Europe and New Zealand, it was estimated that 13.7% of norovirus outbreaks between 2009 and 2012 were attributed to foodborne transmission.

A US study used analyses of outbreaks and expert elicitation to derive attribution estimates to food groups for 14 pathogens including norovirus (Batz *et al.*, 2012). Based on foodborne outbreak analysis, 9.2% of norovirus outbreak events were attributed to seafood, including BMS. The largest proportion of norovirus outbreaks (45.5%) was attributed to 'complex foods', while a further 15.6% of outbreaks were attributed to produce. Expert elicitation was used to attribute the foodborne illnesses, rather than outbreaks, to specific food groups. Seafood was considered to account for 34.1% of norovirus illnesses, while produce accounted for a further 37.3%. The New Zealand estimate of the proportion of foodborne norovirus infections due to seafood (24.4%) falls between the two US estimates.

A Canadian expert elicitation concluded that the mean contribution of seafood to foodborne gastrointestinal disease due to norovirus was 34% (median 31%) (Davidson *et al.*, 2011). Produce (31%) was considered to be the other food group making a major contribution to the burden of foodborne norovirus infections.

An international study of food-associated outbreaks estimated that 13% of foodborne norovirus outbreaks could be attributed to seafood (Greig and Ravel, 2009). The food groups to which the largest proportions of norovirus outbreaks were attributed were multi-ingredient foods (40.2%) and produce (16.5%).

None of the attribution studies reviewed considered food handlers as a transmission route, independent of the foods they handle. An Australian expert elicitation estimated that 59% of illnesses due to norovirus infection resulted from person-to-person transmission (Vally *et al.*, 2014), while a Dutch expert elicitation estimated that 55% of the norovirus disease burden was due to person-to-person transmission (Havelaar *et al.*, 2008).

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