9.17 Faecal indicator bacteria in shellfish

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Preamble: Bivalve molluscan shellfish (BMS) including oysters and mussels are filter feeders and are known to concentrate pathogenic microorganisms from the surrounding water. Grazing shellfish like paua, kina and pupu (catseyes) generally pose a lower human health risk compared to filter feeding BMS. To minimise the risk of human health disease from consumption of commercially grown or recreationally harvested shellfish, shellfish safety continues to revolve around two categories a) the quality of waters in which shellfish grow and, b) the flesh conditions of harvested and processed shellfish. Both these categories use levels of faecal indicator bacteria to minimise the risk of human health disease from consumption of shellfish. Discarding the gut (hua) from shellfish before cooking and eating them further reduces the risk[1]. Criteria for commercial shellfish are driven by multiple market standards with exported shellfish needing to comply with a standard based on *E. coli* in shellfish flesh (e.g., in the EU), and a standard based on faecal coliforms used to classify growing areas (e.g in the USA) [1]. For recreational harvesting of shellfish, guidelines refer only to the use of faecal coliforms to determine the quality of waters and assess the risk of faecal pollution of shellfish harvesting areas [2].

Information regarding the attribute of FIB in shellfish is considered in a wider sense of FIBs in the environment because the presence of faecal microbial contaminants in shellfish reflects the microbial quality of shellfish growing waters.

State of knowledge of attribute: Faecal indicator bacteria in shellfish (estuary/coastal): Medium / unresolved – some studies/data but conclusions do not agree.

While FIB provide valuable information about the faecal contamination status of shellfish harvesting waters and flesh, evidence relating FIB in shellfish to human health is moderate at best as their presence does not always reliably predict the presence of pathogens, nor do they relate to non-faecal derived pathogens or marine biotoxins which can present a significant risk to shellfish consumers. In addition, the relationship between water and shellfish flesh contamination is often poor, especially when the samples are taken contemporaneously, so a guideline based on microbes in water does not always provide assurance of shellfish safety in regards to flesh. Monitoring of

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[1] https://www.mpi.govt.nz/dmsdocument/1058-Food-safety-for-seafood-gatherers

shellfish safety for recreational or cultural consumption is not routinely carried out and monitoring of growing water quality is spatially and temporally limited leading to a lack of national-scale data and reference sites for comparison.

Part A—Attribute and method

A1. How does the attribute relate to ecological integrity or human health?

There is medium to good evidence from New Zealand and international studies that Faecal Indicator Bacteria (FIB) in shellfish are a weak indicator of the risk to human health from consuming raw or lightly cooked shellfish that have been exposed to faecal contaminated water. FIBs are generally not used to assess ecological integrity, but they can be used in combination with other indicators to assess overall water quality [3]. Faecal matter, particularly from humans, but also from warm-blooded animals such as birds and domestic animals (cows and sheep), may contain pathogens which are harmful to human health. These faecal microbial contaminants can enter estuarine and coastal environments through agricultural runoff, discharge of treated effluent from wastewater treatment plants into freshwater or marine environments, direct deposition into water (by birds), accidental sewerage overflows, and/or discharge from boats [4, 5], [6-8]. Shellfish, such as Bivalve Molluscan Shellfish (with two shells), can accumulate indicator bacteria and pathogens through their filter feeding activities. When consumed raw or lightly cooked, the contaminated BMS can make people ill.

Given the impracticality of routinely monitoring pathogens in shellfish, due to technical difficulties and costs, the use of faecal indicator bacteria FIB as a proxy for risk is a traditional approach. But it has limitations. There is only a moderate but positive correlation between norovirus, a common shellfish-associated pathogen, and indicator organisms [9]. Individual observations with low levels of FIB in shellfish do not imply low risk, and sanitary surveys, water quality monitoring, and the analysis of historical data should be used to assess risk. Not all health risks from the consumption of shellfish are associated with pathogens; biotoxins are a significant hazard, and FIBs do not provide any insight into these risks.

A2. What is the evidence of impact on (a) ecological integrity or (b) human health? What is the spatial extent and magnitude of degradation?

There is good evidence of widespread but intermittent faecal contamination of New Zealand shellfish growing waters and flesh particularly for norovirus [10, 11] [12] . Despite regulations to mitigate microbial contamination, outbreaks of disease linked to shellfish consumption continue in New Zealand [13] and elsewhere [14].

Areas used for commercial shellfish production and recreational harvesting in New Zealand are often located in shallow estuarine and coastal systems and would be vulnerable to extreme spatial and temporal variability in faecal microbial contaminant concentrations [15] [16]. However, not many estuarine or coastal areas near large river outflow are monitored for microbial contaminants[1] so understanding of the spatial extent of faecal contamination in water and shellfish is limited. The use of FIB as surrogates for human health assumes that FIB consistently correlates with pathogen

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[1] https://www.stats.govt.nz/indicators/coastal-and-estuarine-water-quality/

presence. There is strong evidence that many potential pathogens co-occur with high densities of faecal coliform bacteria in shellfish harvesting waters following rainfall events [17]. However, FIB often show poor correlation with viral pathogens such as norovirus during other times [12] or with autochthonous pathogens like *Vibrio* sp. [18].

Shellfish habitats are highly susceptible to runoff or discharge from adjacent catchments and river inputs which transport and disperse faecal microbial contaminants downstream into shellfish growing waters [4]. The nature and extent of this contamination are significantly influenced by land use practices such as urban development and agriculture, which determine the types and quantities of microbial contaminants entering these waters. Additional contaminant sources include direct defecation into the water by birds and the discharge of ballast or sewage from ships [8].

Enteric viruses occur frequently in non-commercial shellfish, especially near sewage outfalls following accidental sewage discharge events [12]. In contrast, sites impacted by diffuse sources such as agricultural runoff are more likely to be contaminated with bacterial pathogens. Consequently, multiple sources of faecal contamination can be present in shellfish areas and the health risks from shellfish consumption vary depending on these sources [19].

The extent to which FIB indicate the presence of waterborne pathogens and associated health risks in New Zealand is currently under review with the revision of MfE/MoH freshwater recreational guidelines [20]. This will have implications for the suitability of using FIBs to evaluate public health risks in downstream estuarine waters.

A3. What has been the pace and trajectory of change in this attribute, and what do we expect in the future 10 - 30 years under the status quo? Are impacts reversible or irreversible (within a generation)?

Faecal bacteria such as faecal coliforms and *E. coli* have been used as surrogates for excreted microbial pathogens for many years to assess the faecal contamination and microbiological quality of BMS and their growing waters [14].

At estuarine and coastal sites in NZ with substantial freshwater inputs, a large proportion of FIB are land-derived consistent with international understanding of susceptibility of coastal zones to land-based activities [16]. But there is progress in improving estuarine and coastal water quality. Between 2006 to 2020, 50% of NZ estuarine and coastal sites showed improving trends in FIB water quality[5] inferring improved conditions for shellfish growing waters and reduced potential contamination of shellfish.

However, challenges remain. While efforts to improve land management practices and reduce microbial losses from agricultural sources are underway (refer Section C2), aging urban infrastructure poses a threat of point source pollution from human sources with a high risk profile [21].

Faecal contamination of estuarine and coastal waters remains a major concern in New Zealand. Urban pollution, coastal development, land use intensification and climatic events considerably influence the faecal microbial quality of shellfish growing waters presenting ongoing challenges to managing microbial contamination and ensuring shellfish safety in New Zealand. Reducing the influx of faecal microbial contaminants into shellfish areas will assist in their recovery. Water quality can also rapidly improve after contamination events aided by factors like sunlight inactivation, sorption, sedimentation and hydrodynamic dispersion [22]. However, tidal currents and wave exposure can resuspend contaminants back into the water [23] prolonging the persistence of microbial contamination in shellfish waters and flesh. Variability in environmental conditions, sources of pollution, and hydrometeorological conditions further complicate efforts to maintain shellfish safety [8].

There is a growing range of methods that can be used to assess human health risks including phenotypic differentiation between enteric (fresh and aged faecal sources) and non-enteric sources of FIB [24], alternative viral indicators and faecal source tracking to identify the likely source and risks from faecal contamination [25] as well as improved pathogen monitoring techniques [26].

A4-(i) What monitoring is currently done and how is it reported? (e.g., is there a standard, and how consistently is it used, who is monitoring for what purpose)? Is there a consensus on the most appropriate measurement method?

FIB are monitored to assess faecal contamination and potential health risks associated with shellfish consumption. However, monitoring differs for commercial and non-commercial shellfish harvesting purposes and among different regulatory agencies monitoring for recreational harvesting. These differences include the species of FIB monitored, whether water or flesh is tested, the sampling and testing method used, the locations and frequency of testing, data analysis and information reporting. Inconsistences in data collection and limited spatial and temporal coverage presents challenges for aggregating and comparing data at a national level. This complicates efforts to obtain a comprehensive understanding of faecal contamination and the safety of shellfish for consumption.

Monitoring requirements for the commercial harvest of BMS, are set out in the Animal Products Regulations and Notice for Bivalve Molluscan Shellfish administered by MPI [27] [1]. BMS harvested from areas classified for human consumption are monitored for faecal coliforms in water (MPN/100mL) and *E. coli* in shellfish flesh (MPN/100g) [28] to ensure shellfish safety for consumption. Monitoring frequency is prescribed for each classification area, but most areas are only sampled 5 times per year. Results are reported to MPI annually to demonstrate compliance with regulations against bacteriological standards for that classified area. Measurement methods are specified by MPI but there is provision for seeking approval to use equivalent methods.

Councils may monitor across several different programmes to provide information on the safety of shellfish for consumption e.g., as part of weekly surveillance monitoring of recreational waters, monthly SoE water quality monitoring or for compliance monitoring for resource consents [29] [30]. Water samples are typically collected but sampling methods are not standardised e.g depth of sampling, tidal state (and bias towards high or low salinity conditions). The microbial quality of shellfish gathering waters is compared to the guidelines for recreational harvesting included in the MfE and MoH Microbiological Water quality Guidelines for Marine and Freshwater Recreational Areas [2]. These guidelines specify thresholds for faecal coliform levels in water over the shellfish gathering season. These criteria align with those for approved growing waters for commercial shellfisheries for which shellfish are expected to have suitable microbiological quality for safe public consumption [1]. Guidelines should be applied alongside a sanitary survey to confirm the absence of point sources of contamination. This precaution is necessary because water meeting faecal coliform criteria may still pose a risk if a contamination source is identified.

There are no specific microbiological guideline criteria for routine flesh testing of recreationally or customarily harvested shellfish which would provide greater confidence in shellfish safety for consumption. Few councils appear to consistently monitor shellfish flesh. Council monitoring for consent compliance may include pathogen testing and FIB especially for wastewater discharges, to better understand the relationship between microbial concentrations in water and flesh and associated health risks.

IANZ-accredited multi-tube MPN methods are recommended for determining faecal coliforms in shellfish gathering water and *E. coli* in flesh [2] [28]. However, other methods, such as those reporting results as CFU, are used by councils. This discrepancy complicates data aggregation across monitoring agencies particularly where recreational and commercial shellfish monitoring overlap.

There is no national monitoring for faecal microbial contaminants in recreationally harvested shellfish unlike for biotoxins[1]. Available FIB information collected as part of SoE monitoring of estuarine waters or other focused monitoring programmes (e.g., see [30], and which may overlap with recreational shellfish locations, is not included on LAWA for estuary health[2] but could be to provide a broader understanding of estuary conditions for shellfish harvesting.

A4-(ii) Are there any implementation issues such as accessing privately owned land to collect repeat samples for regulatory informing purposes?

Monitoring for FIB such as faecal coliforms and *E. coli* is practical and feasible; however, FIB do not differentiate the human health risks associated with various faecal sources. This limitation means that while FIB provide an indication of faecal contamination, they do not specify the origin or potential pathogenicity of the contamination.

Monitoring deeper coastal waters poses logistical challenges, often requiring the use of boats, unlike the more accessible shallower estuarine waters. This can impact the frequency and coverage of monitoring efforts. Monitoring sites are not necessarily representative at a national level due to the omission of suitable monitoring sites that are inaccessible or where access is prohibited, and differences in resourcing and capability across councils. This restricts the understanding of the extent and magnitude of FIB in shellfish and how this attribute relates to human health risks.

Monitoring frequency for shellfish gathering waters may be insufficient, as monthly monitoring for SoE purposes often fails to capture temporal variations in water quality due to hydrometeorological effects like rainfall and tides. In addition, regulatory monitoring might only monitor shellfish gathering waters during the summer bathing period to align with marine water surveillance or during a “shellfish-gathering season”. However, this approach should recognise local practice and a season defined according to local usage and in consultation with the community or even year-round.

Current monitoring and reporting practices fall short of fully meeting public health objectives. Microbial risk is retrospective, spatially and temporally limited, and human health risk is constrained by the limitations of using FIB to detect faecal pathogens in shellfish growing waters or in flesh.

Detection and quantification methods for pathogens like norovirus in shellfish exist [13], but there are not established microbiological standards for norovirus or other pathogens in BMS. Proposed enteric virus concentrations in commercial shellfish growing waters [31] are yet to be included in NZ legislation. There is a reluctance in implementing viral testing due to uncertainty about regulatory response if positive results are found. The absence of clear guidelines for viral pathogens complicates microbial contamination management and assurance of shellfish safety in New Zealand.

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[1] https://www.mpi.govt.nz/fishing-aquaculture/recreational-fishing/where-unsafe-to-collect-shellfish/shellfish-biotoxin-alerts/

[2] https://www.lawa.org.nz/explore-data/estuaries#/tb-national.

A4-(iii) What are the costs associated with monitoring the attribute? This includes up-front costs to set up for monitoring (e.g., purchase of equipment) and on-going operational costs (e.g., analysis of samples).

Shallow intertidal waters can be effectively sampled using a pole sampler whilst deeper waters require a boat. Sampling for FIB in water can be integrated with other attributes for SoE assessments or routine monitoring during the summer bathing season and thus included within survey costs. This approach optimises resources and streamlines sampling efforts. Shellfish sampling requires collection by hand from inter-tidal or sub-tidal areas and is more labour intensive. Thus, main survey costs are related to field staff labour costs.

In contrast to pathogen testing which can be more complex and time-consuming, the enumeration of FIB using culture-based assays offers a relatively quick and cost-effective method for assessing water quality [32] and shellfish. Laboratory charges are approximately NZ$40 per sample for both membrane filtration (CFU) and multiple-well (MPN) methods [33]. However, most costs are associated with personnel time spent on data collection, analysis and reporting results.

A5. Are there examples of this being monitored by Iwi/Māori? If so, by who and how?

Shellfish species have significant customary value as taonga for Māori and faecal contamination of water is a particular concern for iwi regarding the potential contamination of kai moana. Methods to enable tangata whenua to measure FIB in estuarine waters have been developed for the “Ngā Waihotanga Iho – The Estuary Monitoring Toolkit [34] but we are not aware of whether it has been implemented by iwi. Similar low-cost methods have been evaluated for detecting FIB in shellfish and could be similarly used by iwi and communities [35].

There are examples of the development of cultural health indicators and indices that have been used at local scale and/or to provide baseline measures in estuarine management [36]. Cultural health assessments have been used to assess the cultural health of the Te Ihutai (Avon-Healthcote Estuary) using the State of the Takiwa system developed from Ngāi Tahu values [37, 38] which included laboratory analysis for *E. coli* in water. Iwi-led observations included catchment land use, visual clarity and silt deposits that all influence suitability for safe shellfish harvesting.

It is important to highlight that, the level of bacteria in shellfish for consumption, is only part of the baseline of health that is considered by Tangata Whenua when considering harvesting kaimoana for consumption. For instance if there site and wider catchment health has a history of contamination and there is degradation within a site, kaimoana won’t be collected from that area. The standard of health considers a whole suite of indicators that are already assessed by whānau, hapū and iwi that suggest an area is environmentally unsafe for interacting with [74]. Second, the local government includes bacteria in their suite of monitoring protocols. Today there are numerous areas of significance to tangata whenua that have been restricted from harvesting due to the impacts of contaminants on mahinga kai and overall cultural environmental health.

A6. Are there known correlations or relationships between this attribute and other attribute(s), and what are the nature of these relationships?

Establishing useful local correlations between FIB with other attributes in coastal water can assist in determining periods when harvesting of shellfish is most likely unsafe. The dominant source of faecal contamination in most estuarine and coastal waters in NZ is river flow. Strong correlations between salinity and FIB occur within faecally contaminated coastal plumes produced by river floods [39]. These plumes result in an influx of microbial contaminants due to runoff from adjacent catchment areas resulting in contamination of shellfish with FIB after rainfall events often from ruminant sources [40].

Commercial shellfisheries have established specific criteria for each growing area that trigger closures for harvesting. These criteria rely on threshold values for environmental indicators of contamination such as rainfall in growing area catchments and salinity levels at the shellfish farm. By implementing harvest closures e.g during high rainfall events, the risk of exposure to potentially contaminated shellfish is mitigated. Harvest closures are also instigated in response to notification of wastewater discharge events such as overflows.

Part B—Current state and allocation options

B1. What is the current state of the attribute?

In New Zealand, there is a broad understanding of faecal microbial contamination of waters as these are routinely monitored for FIB either weekly during summer season surveillance of recreational bathing sites, or monthly for SoE monitoring. The preferred FIB for freshwaters in NZ is *Escherichia coli* (*E. coli*), while enterococci are used for marine waters. In estuarine waters, with intermediate salinity ('brackish'), either or both indicators may be used depending more on flushing time than salinity itself [41]. However, guidelines for shellfish harvesting use faecal coliforms.

While some councils assess water quality at coastal and estuarine locations to determine suitability for shellfish gathering, not all councils monitor waters specifically for this purpose. If faecal coliforms are included in their SoE monitoring programmes, the data might only be used to determine the overall health status of the estuary rather than explicitly addressing shellfish contamination. Periodic monitoring of microbial contaminants in recreationally harvested shellfish has been done by councils [42, 43]. As a result, the understanding of shellfish FIB contamination is spatially and temporally limited at the national scale.

Estuarine and coastal waters receive multiple inputs from point and diffuse sources of contamination with the potential to impact on water quality. River flows are the primary influence on downstream water quality with extremely variable fluxes (#/s) of FIB [44]. The extent and nature of this influence varies between seasons and years. Most estuaries and nearby coastal areas are heavily contaminated by flood plumes from rivers polluted by livestock runoff or urban drainage – the effect of which may last hours or days [39]. Through monitoring, some councils identify unacceptable health risks to recreational shellfish gatherers and erect warning signage while investigating problematic sites. However, only shellfish harvesting areas in remote areas with adjacent land catchments free from pastoral agriculture or urban development are likely to have safe-to-eat shellfish after heavy rain.

B2. Are there known natural reference states described for New Zealand that could inform management or allocation options?

Given the strong influence of river inputs on the faecal contamination status of downstream estuarine and coastal water quality, the general contamination levels in these areas can be inferred from land use practices in adjacent catchments. A few NZ estuaries with near-pristine catchments would serve as useful reference sites regarding faecal contamination status. Some councils have identified high-quality and typically “unimpacted” areas in their coastal environmental plans e.g., [45].

Establishing background contamination levels at these pristine sites would be particularly valuable for benchmarking viral markers such as F-specific RNA bacteriophage , crAssphage and pepper mild mottle virus (PMMoV) and their use in indicating the potential risk of viral contamination of human origin in shellfish [25] [46] [47] . Most commercial shellfish growing areas are located in remote regions away from large population centres, and consequently, the risk of contamination from domestic wastewater is perceived to be low [48]. However, testing from non-commercial sites near polluted urban areas has shown a high prevalence of norovirus highlighting the potential risks associated with proximity to human settlements [12].

Shellfish can serve as valuable bioindicators, bioaccumulating contaminants and providing a means to evaluate the effectiveness of management strategies in maintaining or improving water quality suitable for various purposes including shellfish harvesting and recreational activities. The use of shellfish as sentinels also allows for the detection of changes in environmental conditions over time and provide insights into how these changes affect water quality.

B3. Are there any existing numeric or narrative bands described for this attribute? Are there any levels used in other jurisdictions that could inform bands? (e.g., US EPA, Biodiversity Convention, ANZECC, Regional Council set limit)

New Zealand has established numeric guidelines for recreational shellfish harvesting that use faecal coliforms as an indicator of water quality and the suitability for gathering shellfish [2]. These guidelines specify that the median faecal coliform level over the shellfish gathering season should not exceed 14 MPN/100mL, and no more than 10% of samples should exceed 43 MPN/100ml. These numeric thresholds have also been incorporated into regional council coastal environment plans where they manage for shellfish gathering waters [45]. Current recreational harvesting guidelines assess compliance at the end of the season potentially posing health risks during the season. To enable a short-term health risk assessment, McBride et al (2019) recommended using a single sample maxima for surveillance criteria, changing the 90th percentile to a maximum where no sample should exceed 43MPN/100mL[41].

Councils are concerned about overly conservative numeric indicator bacteria values without a technical explanation correlating them with actual human health risks [49]. In response, reformulating the use of faecal coliforms as the indicator for recreational shellfish gathering waters has been suggested based on a risk assessment approach, potentially replacing faecal coliforms with enterococci with a requirement that the median is less than 7 enterococci/100 ml and the maximum does not exceed 22 enterococci per 100 mL [41].

Levels of faecal coliforms in water and *E. coli* in flesh used to classify commercial shellfish growing waters into 6 categories, could be used to determine bands for recreational shellfish harvesting waters.

B4. Are there any known thresholds or tipping points that relate to specific effects on ecological integrity or human health?

It is generally regarded that as the concentration of FIB in water or shellfish increases, the presence of pathogens becomes more likely, thereby increasing the probability of experiencing adverse health effects from the consumption of shellfish. Although the relationship between FIB concentration and health risk is unidirectional, it is not necessarily linear nor indicative of a change to a new state. Hence tipping points do not generally apply for human health exposure.

To manage risk, regulatory agencies monitor recreational shellfish areas against threshold levels for FC in waters. These thresholds are based on median concentrations and a proportion of samples not exceeding a specific criterion. If these criteria are exceeded, there is no formal requirement to conduct a further specific risk assessment in the MfE/MoH (2003) guidelines.

B5. Are there lag times and legacy effects? What are the nature of these and how do they impact state and trend assessment? Furthermore, are there any naturally occurring processes, including long-term cycles, that may influence the state and trend assessments?

A legacy of faecal contamination in estuarine/coastal receiving waters is the uptake of faecal microbial contaminants by sediments and beach sands. These environments provide protection for faecal microbes from various biotic and abiotic stressors allowing them to persist [50]. These sediments act as reservoirs for microbes such as FIB which can be resuspended back into the water column by wave action and tides, significantly impacting microbial water quality and intertidal exposure of shellfish to microbial contaminants in the absence of fresh inputs [51] [52]. Additionally, the resuspension of FIB populations from decaying vegetation can contribute to the contamination of coastal waters and uptake by shellfish [53].

Shellfish bioaccumulate microbial contaminants from the surrounding water, creating a lag between the contamination of the water and the contamination of shellfish flesh. This has severe implications for pathogens such as norovirus which can persist and remain in shellfish for extended periods (weeks to months) and is not effectively removed by depuration practices [13].

B6. What tikanga Māori and mātauranga Māori could inform bands or allocation options? How? For example, by contributing to defining minimally disturbed conditions, or unacceptable degradation.

Estuarine and coastal areas are highly valued by tangata whenua, as their papa kāinga, and including mahinga kai (sites, species, and practices) [54] [55]. Faecal contamination of these areas impacts environmental safety, including the safety to gather kai, thus impacting long term relationships with place, and practices [56]. Several kaupapa Māori frameworks have been developed for estuarine/coastal assessments in NZ [57, 58] and may provide indicators to benchmark perspectives of shellfish safety for harvesting and consumption. Integrating tikanga and mātauranga Māori regarding cultural practices around collecting and processing of shellfish with scientific approaches (e.g attribute states) may provide a more holistic assessment of safety of shellfish for consumption.

The State of the Takiwā is a complementary monitoring framework that integrates mātauranga Māori and science to gather environmental data and takes into account Māori cultural values. The approach has been used to establish baseline conditions for assessing the health of estuaries [38]. The Marine Cultural Health Index[1] has been added to provide a protocol where kaitiaki can assess the health of their mātaitai, taiāpure or area where a temporary closure has been imposed. Recently, a

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[1] https://www.mahingakai.org.nz/community-tools/marine-cultural-health-index/

marine cultural health index (MCHI) has been developed as part of the Marine Cultural Health Programme, to monitor the health of the marine environment e.g., for mahinga kai in the Ahuriri/Napier area [59,]

Part C—Management levers and context

C1. What is the relationship between the state of the environment and stresses on that state? Can this relationship be quantified?

Contamination of shellfish with faecal microbes is influenced by the quality of overlying waters in growing areas. The state of faecal contamination of estuarine and coastal waters with FIB is strongly affected by land-derived contaminants delivered by contaminating river flows to downstream locations notably during high flow events. Potential sources of contamination include runoff from agriculture, stormwater, treated wastewater discharges, leaking septic tanks and /or liveaboard vessels and other marine craft and wildfowl. There is clear evidence that agricultural and urban land use pressures negatively impact the microbiological quality of freshwater systems [60] [61] and that estuarine water is generally of poorer quality than at coastal sites [30]. However, the relationship between pressure variables and faecal contamination status of estuarine/coastal water and shellfish is complex and a challenge to understand due to;

- the simultaneous presence of multiple sources of contamination – FIB do not provide information on the source of faecal contamination so distinguishing between multiple sources is difficult,
- spatial displacement of land use sources from estuarine/coastal receiving waters,
- temporal variability as a result of river flow conditions and contaminating plume hydrodynamics in estuarine and coastal waters,
- tidal movements affecting the distribution and resuspension of faecal microbial contaminants in water,
- uptake and storage of FIB (and pathogens) in estuarine/coastal sediments or other habitats (e.g wrack) that may be released back into the water column by hydraulic disturbance,
- inactivation and die-off of FIB (and pathogens) in water – depending strongly on sunlight exposure,
- bioaccumulation within shellfish and differential persistence of pathogens – rate and extent of bioaccumulation can depend on the type of shellfish, filter feeding rates, and local environmental conditions. This makes it difficult to correlate levels of FIB in shellfish directly with those in the surrounding water,
- poorly maintained wastewater infrastructure.

Uncertainty about the source and causes of degradation presents a risk that management interventions will target pressures that have little effect on the impact of safe shellfish for consumption. Interventions should be tailored to the specific sources of contamination identified in shellfish (guided by sanitary surveys) with regular testing of waters and implementing temporary harvesting closures when bacterial (or proxies) levels exceed safety thresholds.

C2. Are there interventions/mechanisms being used to affect this attribute? What evidence is there to show that they are/are not being implemented and being effective?

C2-(i). Local government driven

Since most faecal contamination of coastal waters originates from land-based sources in New Zealand, efforts to improve water quality are primarily focussed on the water quality of rivers rather than coastal water quality. Intensive pastoral agriculture is a significant contributor to faecal microbial degradation of waterways; reducing FIB loss to surface waters also reduces the downstream delivery of zoonotic pathogens (disease causing organisms transmitted between humans and animals). Council promotion of measures such as stream fencing to exclude livestock from water bodies, and establishing riparian buffers to attenuate FIB in land runoff, mitigate contaminants entering river networks leading to evidence of water quality improvements under base and elevated flow conditions [62] [63] [64]. Various interceptive mitigations are available across a range of farmed landscapes to reduce contaminant losses to surface waters although managing FIB losses on steep slopes presents challenges [65]. Implementing a package of mitigation measures for erosion-sediment control at multiple locations within a region can produce valuable co-benefits including improved microbial water quality on a regional scale though upgrading point source discharges provides stronger evidence of regional water quality improvements [66].

C2-(ii). Central government driven

Contamination of surface waters with pathogens is a national water quality issue. Policies and targets for human health are part of the NPS-FM 2020 [67] which provides attribute states (standards) for *E. coli* as the preferred faecal indicator bacteria for freshwaters, to manage the average level of health risk for contact recreation. Management to ensure risks to human health are within an acceptable limit is a statuary requirement of the NPS-FM and requires regional councils to set limits on resource use to achieve this outcome. A recent study estimated that a mean reduction of 73% of current load of *E. coli* was required across NZ to meet minimum bottom lines for contact recreation [68]. The NPS-FM does not have attributes for estuaries, but measures taken to reduce loss of *E. coli* into rivers are expected to contribute strongly to reduction of other FIB and faecal pathogens into downstream shellfish areas.

C2-(iii). Iwi/hapū driven

To safeguard the sustainability of shellfish populations, rāhui and/or temporary closures are employed by iwi, effectively prohibiting the harvesting of shellfish during designated periods [69]. These customary practices not only protect shellfish populations but can also prevent and protect communities from consuming contaminated shellfish. By restricting access to shellfish beds known to be affected by faecal contamination, rāhui and temporary closures help mitigate health risks. Given that Māori may be more likely to consume shellfish more frequently than the general population and thus have a higher risk of exposure [13], these protective measures are important for minimising exposure to potential faecal microbial contaminants from cultural practices.

C2-(iv). NGO, community driven

Ki uta ki tai – from mountains to sea – is a philosophy that acknowledges the connectivity between the land-to sea and people with the environment. Given the land use pressures and mobilisation of

FIB from upstream to downstream waters, this approach would provide an improved management approach to shellfish safety for consumption. Participatory approaches are necessary for implementation and the efforts from iwi and community driven interests and initiatives (e.g restoration planting and water monitoring using community-based water monitoring methods) should reduce the burden of faecal contamination of rivers and downstream coastal waters. Attributing improved faecal contamination status of coastal waters is challenging due to the complex connections between land and coastal environments (see Section C1).

C2-(v). Internationally driven

For commercial enterprises, current criteria for determining when BMS are safe to harvest are driven by multiple international market standards which either require compliance with a standard based on *E. coli* in shellfish flesh (EU) or compliance with a standard based on faecal coliforms in growing waters (US).

Part D—Impact analysis

D1. What would be the environmental/human health impacts of not managing this attribute?

Changes in the attribute state will affect human health. Failing to manage faecal contamination of estuarine and coastal waters would likely lead to increased disease burden among shellfish consumers and harm shellfish exports. Managing the sources of contamination (e.g. human and animal faecal sources) is a priority to ensure the protection of public health. Recent estimates indicate that around 8% of all norovirus infections in New Zealand are due to shellfish consumption, with commercially harvested oysters implicated in 85% of these outbreaks [13]. Since shellfish, through their filter-feeding activities can bioaccumulate faecal microbes particularly viruses from water and the median infectious dose for norovirus (i.e. the infectious dose at which there is a 50% chance of becoming ill) is less than 30 genome copies, even minimal faecal contamination of overlying waters poses a significant public health risk.

D2. Where and on who would the economic impacts likely be felt? (e.g., Horticulture in Hawke’s Bay, Electricity generation, Housing availability and supply in Auckland)

The aquaculture industry particularly oyster farming, is highly susceptible to impacts from faecal microbial contamination. Oyster farms are typically located in shallow intertidal areas making them more vulnerable to episodic contamination from river plumes. In the event that a shellfish growing area is impacted by a wastewater pollution event, the area is generally closed for 28 days following the end of the event. The area can only reopen once evidence shows the contaminating event has ceased and microbial contaminant levels in water and flesh have returned to background levels [1]. Closure of shellfish farms has significant economic implications including revenue loss, increased operational costs, potential loss of market share, disruption of supply chains, reputational damage and additional regulatory compliance costs.

Recreational and cultural harvesting of shellfish would also be affected with associated socio-cultural impacts and impacts on cultural values.

D3. How will this attribute be affected by climate change? What will that require in terms of management response to mitigate this?

Climate change is likely to affect disease burden from exposure to pathogens though the direction of change may vary as environmental and climatic drivers of transmission differ among pathogens [70].

Key features of climate change expected are increased temperatures and variability in extreme rainfall events [71]. Runoff effects following short intense rainfall will increase the variability of river flows and expected variability in the faecal contamination status of estuarine and coastal waters. Bacteria indicator and pathogen concentrations can increase by 1 – 3 orders of magnitude during high flow conditions in pastoral streams [72] and can remain elevated. An increase in rainfall will also increase the chance of sewage overflows, and infrastructure damage [73]. Extreme weather events including more frequent flooding events, are expected to cause more land runoff resulting in episodic delivery of increased faecal contamination to coastal waters via rivers with an associated increased risk of waterborne faecal related diseases. Studies also suggest a decrease in FIB during summer months due to reduced runoff and increased temperatures that enhance bacterial die-off processes [8]. However, warming waters may also lead to increased persistence and survival of pathogenic bacteria including naturally occurring bacterial pathogens (eg *Vibrio* sp), posing additional risks.

The uptake and accumulation of FIB and pathogens by shellfish typically reflect the concentrations present in the overlying water. Temperature and salinity are key factors influencing shellfish filter-feeding activities and the rates of faecal microbe bioaccumulation. Warmer water temperatures increase shellfish clearance rates, while reduced salinity decreases feeding rates. Studies on FIB accumulation kinetics in shellfish show that they can respond quickly to environmental contamination with maximum concentrations accumulating within 30 minutes of exposure and persisting in flesh for at least a week after rainfall events.

Management responses to mitigate these impacts include developing climate-adaptive management strategies, such as adjusting harvesting times and locations, improving water quality monitoring, and enhancing shellfish treatment processes, e.g., depuration strategies to maintain shellfish safety.

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