9.16 Faecal indicator bacteria in water

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State of knowledge of the "Faecal Indicator Bacteria in estuary/coastal water" attribute: Medium / unresolved – some studies/data but conclusions do not agree.

Part A—Attribute and method

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

Faecal Indicator Bacteria (FIB) indicate (fairly recent) faecal contamination of water by faeces of warm-blooded animals. The preferred FIB for freshwaters in NZ is *Escherichia coli* (*E. coli*) and for marine waters is enterococci. This is primarily because *E. coli* are more persistent in sunlit freshwaters, with enterococci being more persistent in saline waters – because of salt toxicity to sun-damaged *E.* coli [1]. The 'best' FIB in intermediate salinity ('brackish') estuarine waters is either (or both) depending, not so much on salinity per se, as on flushing time [2].

The main influence on NZ's coastal microbial water quality is river inputs from adjacent land [3]. McBride et al. [2] showed that *E. coli* is the more appropriate FIB In rapidly flushed estuaries, particularly near inflowing rivers. Recognising the complexity of their advice, these authors recommend *both* indicators be monitored in estuaries.

NZ health-based guidelines for enterococci in marine waters are established from epidemiological studies encompassing the overall gastrointestinal and respiratory risk from a variety of pathogens. In contrast, the guideline for *E. coli* in freshwater relies on numerical modelling to estimate the risk of infection from just one pathogen – *Campylobacter.* Consequently, the enterococci guideline actually has a sounder basis for protection of human health. NZ does not have threshold levels of *E. coli* in coastal waters for risk protection, so we are stuck, for now, with enterococci for routine coastal surveillance monitoring – despite that the change in indicator from fresh to saline water complicates potential modelling of coastal faecal pollution from land sources.

FIB per se are not relevant to ecological integrity. However, faecal pollution as indicated by FIB may well have ecological impacts due to organics, oxygen demand and other contaminants accompanying FIB in faecal matter. For example faecal pollution has a detrimental effect on aquatic microbial community structure and correlates with reduced microbial diversity [4]. This would affect microbial processing within ecosystems and hence ecosystem functioning.

Conversely ecological integrity can compromise FIB as reliable indicators for health-based water quality monitoring. FIB can persist or even grow within estuarine plankton and on seaweeds [5] [6] whilst blooms of cyanobacteria may inactivate FIBs [7].

FIB are rather tenuously related to human health – because the actual hazard to human health is (infection by) a number of enteric pathogens that *may* be present (episodically) in faecally-contaminated water. FIB themselves do not normally cause disease [2] although there are some types such as *E. coli* 0157 that are pathogenic.

Correlation of FIB with risk to human health is at best only moderate for several reasons including that different animal and bird sources have very different risk 'profiles', ranging from low-risk for bird contamination to high risk (similar to that for sewage containing human wastes) for cattle sources [8].

Significant correlations between FIB and health risk are often detected following wet weather events and at locations impacted by recent faecal contamination [9]. Poorer relationships exist with multiple sources and some pathogens (e.g., viruses due to differential fate and behaviour) because health risks from mixed sources are not necessarily driven by the source(s) with the greatest load of FIB [10]. Certain strains of FIB can persist or even grow in the environment, further complicating risk relationships [11].

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

Several overseas studies of bather health after swimming at coastal beaches have shown a weak to moderate correlation of human health effects (gastroenteritis, respiratory problems...) with faecal contamination of the bathing water – as reviewed by McBride et al. [2].

The correlations in such studies are at best moderate because of the variety of pathogens that may be (episodically) present in faecally-contaminated water and the different type and severity of health effects. Additionally, FIB concentrations in marine waters can vary widely over time due to various inactivation or removal processes and coastal hydrodynamics. Resuspension of beach sands by wave action can remobilise stores of FIB [12]. Nevertheless, while FIB may not reliably predict the presence of specific faecal pathogens, they indicate an increased potential for pathogens to be present.

The extent to which FIB indicate the presence of waterborne pathogens and associated potential health risks in New Zealand is currently being assessed with a revision of the MfE/MoH [13] freshwater recreational guidelines [14]. The outcome of this assessment will have implications for the suitability of FIBs for assessing public health risk and for comprehending contamination in freshwaters and implications for 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)?

The FIB, *E. coli* and enterococci, and similar or related FIB (e.g., faecal coliforms) have been used for many decades (nearly a century for faecal coliforms).

Despite that these attributes (FIB) do not *directly* measure health-impacting pathogens, they are hard to improve upon short of measuring actual pathogens. That is very challenging and usually too expensive for surveillance monitoring because particular pathogens (which must be individually tested for) are usually absent (only episodically present) and typically require technically sophisticated methodology for detection.

The problem of faecal contamination of coastal waters remains a fairly major concern in NZ. Fortunately, faecal contamination of coastal waters is self-correcting once sources are cut off (e.g., inflowing contaminated river floodwaters abate) because of fairly rapid natural disinfection (primarily by sunlight) [1] combined with sorption and sedimentation and hydrodynamic dispersion. These natural processes of attenuation of faecal contamination should be recognised as a major ecosystem service.

In the future we may expect to see increasing measurement of

- Certain actual pathogens (e.g., *Campylobacter* in NZ where campylobacteriosis is a major reportable disease and is endemic in our dairy herds)
- Microbial source tracking (MST) by genetic markers to identify animal sources with different risk factors (e.g., low risk from avian sources versus high risk from bovine sources)
- Phenotypic differentiation between enteric (fresh and aged faecal sources) and non-enteric sources of FIB
- Proxy instrumental monitoring (e.g., turbidity and visual clarity often correlate roughly-but-usefully with – co-mobilised – FIB),
- On-site automatic portable laboratory monitors (e.g., Coliminder) for high-frequency analysis of biochemical proxies of FIB in waters, and
- Modelling of FIB concentrations based on high-frequency monitoring, particularly in inflowing rivers combined with hydrodynamic modelling and satellite (optical) remote-sensing of covarying water tracers.

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 routinely measured in NZ as part of two main categories of monitoring:

- SoE water quality monitoring (usually monthly) as one of a broad suite of variables, and
- Bathing beach surveillance (usually weekly) over the summer bathing season. (This monitoring also contributes to beach grading.)

Sampling and laboratory methods for FIB are (have to be) very well standardized in order to achieve reliable (comparable) results. This does have the advantage, however, in permitting data aggregation across waters and monitoring agencies in NZ. For example, the LAWA website 'hosts' FIB data on NZ waters obtained mainly by regional councils in both types of FIB monitoring.

Current monitoring and reporting fail to fully meet public health objectives for several reasons including retrospective microbial risk information (laboratory tests for FIB typically take at least 24 hours to culture the organism), information on risk is spatially and temporally limited, and reporting of human health risk is limited in scope – primarily focusing on FIB while risks presented by cyanobacteria and hazards posed by poor water clarity are overlooked [15]. There are also no guidelines or standards specifically for the microbial quality of estuarine waters.

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

There are no substantial practical or logistical barriers to monitoring FIB in coastal waters – *except* that a boat is usually needed for access for SoE monitoring (as is common to coastal water quality more generally). Once on-site, sampling is quick and easy (although care is needed to prevent contamination) and can be cost-effectively combined with sampling for a variety of other variables and attributes (as is routinely done in SoE monitoring in NZ (NEMS2019 – Part 4 Coastal waters) [16]. Monitoring of bathing beach water quality is usually by wading from the shore, so a boat is not normally needed.

An insulated bin ("chilly bin") is mandatory with FIB sampling to prevent inactivation by sunlight during (prompt – typically within 24 hrs is often specified) transfer to the laboratory. Chilling water samples to slow biochemical reactions is also advised [16].

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).

Since FIB sampling of coastal waters is typically combined with other attributes in routine SoE monitoring, the costs of access (notably travel time and boat deployment) are distributed. The only costs of sampling specific to FIB is for sterile sample containers (e.g., 100 mL vials).

Bathing beach sampling is routinely done by wading from the shore, ideally using a pole sampler.

Laboratory charges are currently about NZ$40 per sample for both membrane filtration and multiple-well methods (Colilert, Enterolert) [17].

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

Faecal contamination of waters is a particular concern for iwi as regards swimming exposure and contamination of moana kai. Iwi groups are currently using the Petrifilm® method in the NIWA-designed SHMAK kit to measure *E. coli* in NZ river waters. Methods to enable community measurement of FIB in coastal waters have been developed for Estuary-SHMAK by Rebecca Stott (NIWA-Hamilton) [19].

Examples of hapū and iwi monitoring include use of the SHMAK faecal indicator tools, the Murihiku Cultural Water Classification System by Ngāi Tahu ki Murihiku [27,28], and the assessment of river health input into estuaries for the State of the Takiwā [29].

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

Yes – very often useful (local) correlations of FIB with other attributes in coastal water can be established, notably with visual clarity and salinity [2].

The dominant source of faecal contamination of most coastal waters in NZ is river inflow. For example, Dudley et al. [3] showed that coastal water quality varied strongly inversely with salinity which is reduced by river inflow. FIB in rivers sometimes exhibit rough but useful correlations with flow and visual clarity, and these correlations are expected to translate into coastal receiving waters. In pastoral catchments, the correlation of *E. coli* and visual clarity can be relatively strong due to co-mobilisation of FIB and fine sediment by livestock activities. Correlations of FIB with visual clarity are usually stronger than flow correlations in such catchments [18].

Fairly strong correlations between salinity, visual clarity and FIB occur within faecally-contaminated coastal plumes produced by river floods [20].

Part B—Current state and allocation options

B1. What is the current state of the attribute?

We have a broad understanding of faecal contamination of NZ coastal waters at the national scale from monitoring by regional councils for SoE and marine recreational bathing sites.

Faecal contamination of NZ coastal waters is extremely variable over time – mainly with varying river inputs. This reflects rivers being the main source of the FIB in coastal waters and that rivers have extremely variable fluxes (cfu/s) to the coast. As a consequence, the state of faecal contamination in coastal waters varies very widely over time. Most estuaries and almost all embayments are typically clean and clear of faecal contamination (except when subject to wind-wave disturbance) but may become heavily contaminated for a few hours or days by flood plumes from rivers that are contaminated by livestock pasture or urban drainage [20]. Additionally, resuspension of FIB populations in beach sands and decaying vegetation may contribute to inputs into coastal waters [21] [22].

Although hydrodynamics plays a major role in determining coastal FIB levels, the faecal inputs of rivers appears to be the single largest influence. NZ rivers vary widely in characteristic faecal contamination. For example, Davies-Colley et al. [18] reported median *E. coli* concentrations ranging from (about 1 cfu/100 mL in the near-pristine upper Motueka River at the Gorge, to 310 cfu/100 mL in the predominantly pastoral Mataura River at Seaward Downs. Rivers, and therefore downstream coastal recieving waters, also vary greatly in FIB concentration with state-of-flow.

As a consequence, only those estuaries and embayments with adjacent land catchments in near-pristine condition (lacking pastoral agriculture or urban development) can be expected to have swimmable FIB levels after heavy rain.

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

A relatively few NZ estuaries with near-pristine catchments might be useful as references as regards faecal contamination status, such as Whanganui Inlet and Okarito Lagoon (Westland).

Given that coastal water faecal contamination is most strongly affected by river inputs, we can infer general coastal contamination levels based on the condition of adjacent land. Faecal contamination levels are expected to be relatively high (particularly after rain events) where FIB are mobilised from catchments in adjacent land by certain activities, particularly livestock agriculture and urban runoff.

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 existing numeric guidelines for coastal water contact recreation (also for recreational shellfish harvesting) [13]. These guidelines have been more recently reviewed and endorsed by McBride et al. [2]. Note, however, that these guidelines should not be used where wastewater discharges dominate, because the relationship between indicator and pathogens may be substantially changed during wastewater treatment particularly with technical disinfection.

NZ now has new standards ("target attribute states") for *freshwaters* in the National Policy Statement for Freshwater Management- Tables 9 and 22 [23]. These standards may be expected to contribute strongly to achieving swimmable conditions in downstream *coastal* receiving waters that are strongly degraded (albeit episodically) by contaminated river flood plumes.

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

No, the concept of tipping points does not really apply to human health effects of exposure to faecally-contaminated water. So far as we know, human health risk increases monotonically, although not necessarily *linearly*, with FIB concentration – without inflexion points, let alone singularities associated with change to a new stable state. Target attribute states and guidelines ("thresholds") are therefore based on somewhat arbitrary levels of estimated health risk.

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?

The main legacy effect of faecal contamination of both rivers and coastal receiving waters is uptake by the bed sediments in which natural dieoff of FIB (and pathogens) is greatly slowed compared to overlying water due to screening from sunlight. For example, Drummond et al. [24] modelled uptake of *E. coli* by river beds (the hyporheic zone) during declining flows and subsequent mobilisation of these faecal stores due to accelerating water currents on flood fronts. Similarly, faecal microbes stored in coastal bed sediments or beach wrack during quiescent conditions may be mobilised by currents or waves [12].

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.

Contamination of ecosystems is, understandably, of great concern to tangata whenua.

Practices such as rāhui on environments, including the activity of shellfish harvesting, demonstrate the importance for preventing risks, however it is just one of a suite of tools.

There are examples of mātauranga a-iwi, and multidiscplinary approaches given above (e.g., [27]) that provide insight into more culturally appropriate approaches towards answering this query. Engagement with the mana whenua, with Māori researchers, and those who engage with appropriate methodology is fundamental.

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?

The main pressure on faecal contamination status of coastal waters is mobilisation of FIB from adjacent land with conveyance to the coast via rivers, notably during high flow events. However, the relationship between the *pressure* (FIB mobilisation on land) and coastal faecal contamination status is highly complex because of:

- Displacement in space of land sources from coastal receiving waters
- Variation in time, particularly with river flow conditions and coastal plume hydrodynamics
- Dieoff of FIB (and pathogens) in waters, often referred to as 'natural disinfection', depending most strongly on sunlight exposure
- Uptake and storage of FIB (and pathogens) in the hyporheic zone of rivers and coastal bed sediments (that are subject to hydraulic disturbance), and
- Poor wastewater infrastructure

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?

Because most faecal contamination of coastal waters comes from adjacent land the interventions must focus on land. Interventions are underway in NZ, focussed mainly on general water quality (including fine sediment and nutrients as well as FIB) of *rivers* rather than coastal waters.

C2-(i). Local government driven

Regional councils are the agencies most actively intervening to improve water quality in NZ, including faecal contamination status – by promoting stream fencing (to reduce direct livestock pollution – cattle have a known attraction to waters) and riparian setbacks (to trap FIB in land runoff – reducing indirect livestock pollution). Such riparian management has been shown to improve stream water quality with reductions in *E. coli* observed in relatively flat pastoral land [26]. However, effectively managing FIB losses in hill country sheep and beef farming poses challenges especially on steep slopes. Improving sewage infrastructure should also reduce faecal contamination.

Regional councils are also keen to inform the recreating public of faecal contamination status – based currently, mainly on so-called beach-grading. In future, modelling of FIB status informed by high-frequency monitoring of flow and FIB proxies such as salinity and turbidity [2] could, in principle, be used to warn swimmers in near real-time of the likelihood of contamination. NIWA currently has 'Smart Idea' funding of a project (WaiSpy MBIE contract: C01X2204) that is attempting to develop a system for informing swimmers of 'swimmability' of rivers, and potentially, also downstream coastal receiving waters, based on monitoring of contributing rivers.

C2-(ii). Central government driven

C2-(iii). Iwi/hapū driven

There are examples of mātauranga a-iwi, and multidiscplinary approaches given above (e.g,. [27]) that demonstrate culturally appropriate approaches. Tikanga Māori are well known to prevent risks to contamination, however whānau and hapū have long advocated for more holistic approaches that prevent contamination, and improved the health of catchments, ki uta ki tai [28]. Implementation of tikanga Māori is difficult given the legislative barriers to mātauranga preventing the implementaiton of hapū and iwi decision-making within waterway management [30,31].

C2-(iv). NGO, community driven

Community-driven initiatives such as 'Mountains to Sea' mobilize community interests in stream fencing, restoration planting and water monitoring. These efforts should reduce the burden of faecal pollution of rivers and downstream coastal waters. We are not aware of improved coastal water quality in NZ being explicitly linked to land management, however such connections have been made overseas. Improved faecal contamination status of coastal waters is difficult to attribute to land management because of the complexity of land-coastal connections (Refer C1).

C2-(v). Internationally driven

Part D—Impact analysis

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

Not managing faecal contamination of coastal waters is likely to lead to increased disease burden on recreational swimmers [2] and downgraded perception of NZ as 'clean and green' among tourist visitors. It would also have severe implications for shell fisheries and exports as well as cultural impacts for kai moana (e.g., rāhui on shellfish harvesting, and the healthy reciprocal relationship between Tangata and their Whenua/Moana).

Managing faecal contamination of coastal waters requires, mainly, management of faecal contamination of inflowing rivers – in turn by reducing faecal mobilisation from land. So, land activities that mobilise FIB (and potentially pathogens, episodically), primarily livestock agriculture and urban land use, need to be isolated so far as possible from waters. Important controls on FIB mobilisation in waters are:

- In livestock pasture: fencing to exclude livestock and riparian set-backs to entrap FIB in runoff water,
- In semi-rural areas: improved operation and maintenance of on-site wastewater systems, and

- In urban areas: maintenance of foul sewers (reducing wet weather surcharging and overflows) plus street-sweeping to reduce stormwater contamination by domestic and feral animals.

To manage faecal contamination status of coastal waters requires its measurement – which, currently, is deficient in NZ because of necessarily discrete sampling for FIB and sparse distribution of sites. What is needed for improved management is *modelling* to fill in the measurement gaps in time and space – ideally informed by high-frequency instrumental monitoring of proxy variables like turbidity (in contributing rivers as well as coastal receiving waters) or new modelling approaches using satellite remote sensing – integrated within an artificial intelligence framework (refer 'Coastwatch' currently proposed by NIWA to the MBIE Endeavour fund.)

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 main economic impact would be on NZ's tourist industry – which trades strongly on NZ's image as a 'clean green', environmentally responsible country.

The general public of NZ would be impacted in a difficult-to-quantify way if our coastal waters were increasingly perceived by NZ citizens as contaminated, resulting in reduced recreational opportunity and sporting activities for fear of illness.

A decline in the microbial quality of coastal waters would also be expected to have economic impacts on bivalve shell fisheries, especially oyster farming.

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

Increased variability of river flows due to global warming may be expected to increase variability of water quality of coastal water, including faecal contamination status. More frequent large floods can be expected to cause more over-land runoff, resulting in more faecal contamination being conveyed episodically to coastal waters via rivers with associated increased risk of waterborne faecal-related diseases [2].

Higher summer temperatures may be expected to drive people to swim and recreate more often in coastal waters despite frequent contamination, further increasing the disease burden from swimming exposure with children being typically identified as being at higher risk than adults.

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