

Peer review of Assessment of Seabed Effects report provided to Ngai Tahu Seafoods in support of the Hananui proposal to farm salmon off northern Stewart Island (Cawthron Report 4188).

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Focus areas for the benthic model and effects assessment review as requested by Environment Southland (e-mail on 9/9/2025):

Question 1: Review of relevant information provided by the applicant and commentary on whether you consider the information provided to be commensurate with the scale and magnitude of potential effects, and accurately assesses potential adverse impacts.

Question 2: is the seabed across the site sufficiently characterised to conduct an appropriate assessment of the potential effects of the proposed activity?

NB: The two above questions are closely aligned, so I will address them together

The proposed site has been repeatedly surveyed by the Cawthron institute over a span of 7 years (2018 to 2025). Extensive sampling has been conducting, including wide spatial coverage with side-scan sonar, visual surveys (numerous drop-camera inspection, and some focussed ROV dives), and sediment sampling grid in 31 locations using a grab to assess benthic macrofauna and sediment physical chemical characteristics. In Feb 2022 the site was also mapped at high spatial resolution using multibeam, which was a very informative and useful addition to the survey efforts and superseded the sidescan data.

With respect to this application, one of the more critical aspects concerns the exact spatial extent and characteristics of the bryozoan-sponge habitats, and its whereabouts in relation to the proposed activity and associated footprint. The sampling effort appears well aligned with respect to where the enrichment effects are predicted to occur and, importantly, extends out to and beyond the expected outer limit of effects. One exception being that the NE area within the proposed area was not grab sampled for macrofauna or sediment characteristics. It is apparent from the drop camera videos that the flat area between the elongated ridges in that region is predominantly soft-sediment and of comparable depths to grab stations 16, 20 and 29, and therefore presumably compositionally similar. However, given the size of the area, I think it would have been prudent to confirm as much by taking some sediment samples from this 'outer' region. I note that those three stations (16, 20 and 29) were also considerably richer and more abundant (in MDS group e) than those in the main farming area to the south. However, I also gather that this is a 'back-up' location and will not be used initially, so the information can presumably be collected in due course.

The sampling arrangement benefits from the more recently obtained multibeam data, which allowed Cawthron to revisit the site to focus on ground-truthing the map that was produced from that survey. The repeated survey also presented an opportunity to visually assess temporal stability and variability of these habitats, and increased sampling coverage in the process. However, I note that there is no comment relating to any temporal changes that may have been observed; this may be because the sampling arrangement wasn't suitable for such observations? Unclear as Fig. 2 does not differentiate these sites.

In my opinion, the overall approach taken to characterising the sites physical and biological characteristics (of soft sediments as well as mixed and hard habitats) were appropriate and sufficient given the proposed activity. The methods used are suitable and contemporary would be difficult to improve upon, aside from possibly increasing spatial resolution. The sampling intensity is more than satisfactory in most areas, aside from the NE area (as listed below) and possibly a missed opportunity to assess temporal stability.

I do however have a few questions and suggestions for the authors. I will divide these into those that are pressing (i.e., should be addressed before application) and those that are more 'useful to have' and / or can be obtained either during baseline surveys or during development.

Incorporate into report prior to submission:

- The elongated ridges, especially in the NE area of the site appear from the backscatter data to be more reflective and therefore harder in composition, yet these have not been recognised as such? Is it the case that the solid material is subsurface? Some clarification or comment on this would be informative.
- On Fig. 2, it would be informative for the reader to colour code the video survey sites according to when they were obtained, i.e. which survey. Gives an idea of temporal comparability.
- Regarding the pronounced NE-SW elongated ridges in NE area, which are potential capture points for waste. Have you given any thought to discerning: a) whether these ridges are mobile and constantly burying or resuspending sediments (promoting decay and metabolization) or b) whether they are stable and waste may accumulate along fringes, potentially causing hotspots?

Useful to have going forward

- Why no grab samples in NE area? Might the macrofauna be different due to greater depth and potentially increased stability? It appears that it will be more fauna rich (probably due to increased stability) which may have implications for the monitoring and management approach. Given this is a back-up area, this can perhaps be planned as part of baseline?

- It would have been useful to revisit a selection of the previous grab sites to evaluate temporal stability, especially in the macrofauna communities, which appears variable and naturally depauperate at this site. Is it possible to make any comment on this now? Has relevance to temporal stability for planning monitoring etc.

Question 3: Are there logical connections between model outputs and reported environmental effects.

The primary method that was used to infer environmental effects from the model is by using an established relationship between predicted flux and observed ecological effects. I am obviously familiar with this because I developed the underpinning relationships that are used back in 2013. The authors have applied them to the solids flux estimates, which is the correct thing to do in this situation. This is because the relationships were developed from 'no-resuspension' prediction in DEPOMOD, which is the approximate equivalent approach, albeit much less sophisticated than what has been used here. They have also appropriately used the high flow (dispersive) site relationships. To my knowledge, there is very little in the way of alternative approaches and it is therefore still probably the best and most relevant relationship to use.

I expect that the Hananui site may in-fact be even more dispersive than the sites where those relationships were developed, which may mean that the Hananui site is more assimilative and resilient. I suspect this will be primarily due to 2 processes, altered and intensified hydrodynamics during storm events ('storm set-up') and wave orbitals from long-period waves. If so, the flux thresholds that have been applied will prove to be conservative, i.e., higher fluxes may be required to induce comparable levels of effects in the near-field. But to my knowledge, the dispersal processes induced by such long-period wave events, is yet to be effectively documented, and so the only way to know for sure is to undertake the activity and to observe (i.e., effects-based management). While this does amount to a degree of uncertainty, I note that the assessment is based on the precautionary side of that uncertainty, meaning that the degree to which enrichment effects manifest could be less, and probably not worse. I also note that the authors have taken an additional precautionary step of halving the established threshold for 'measurable effects' ($< 0.5 \text{ kg m}^{-2} \text{ mo}^{-1}$, as opposed to $1 \text{ kg m}^{-2} \text{ mo}^{-1}$). In light of the highly dispersive nature of this site and the tendency for waste to be widely dispersed, I support this relatively conservative measure. What it means in effect is that level and extent of measurable enrichment may be over-predicted, but the spatial influence (at a very diffuse level, detectable only by sensitive tracers) may be larger. This should be carefully monitored to inform future management and monitoring decisions.

The approach to using residual solids is also advanced and essentially best practice, integrating the most up to date parameters relating to particle dynamics and how seabed roughness is handled. Utilising a combination of 'residual' solids with solids flux, is still the best way to evaluate what are complex processes. To my knowledge there is no single model that accommodates both concepts in a more interpretable way.

The approach to running the simulations, i.e., targeting peak feed periods, a 3-month spin up period to reach a stable state, and capturing multiple cycles over a 24-month period, is robust and sensible. Figure 13 is useful, but I suggest considering including an accumulated total Feed line, which would require extending the y-axis? That would indicate how the feed inputs to the wider area ramp up with time and when the overall peak occurs. But perhaps this would suppress the detail for the individual farms too much?

As far as I can see the approach to inferring effects from the model outputs is appropriate and utilises best available information and methods. The approach also has some conservative elements built in such that, if anything, the effects are more likely to have been overestimated than underestimated.

Specific questions or recommendations.

Incorporate into report prior to submission:

- I would like to see a bit more information about:
 - a) how the forcing conditions used in the model runs incorporated storm surge (and what the events look like, I don't see this clearly in Zingfogel et al), and
 - b) what the exposure is to long-period waves and how that might affect particle distribution.
- If possible, give some consideration to how the particles on the seabed might behave around the elongated ridges, especially toward the NE area where they seem to be most pronounced (even if it is necessarily speculative).
- Consider showing total accumulated feed input on Fig 4.
- NB: Some details missing on P54 (highlighted text). Delete first use of 'Table 8' at start of second paragraph on P54

Useful to have going forward

- A better understanding of what the driving forces (and climatic conditions) are that control dispersion and sediment movements at the site
- Site-specific validation of model outputs

Question 4: A statement on whether you agree/disagree with the applicant's conclusions on the potential ecological effects of the fish farm (with evidence to support your conclusions where appropriate).

On the whole, I agree with the conclusions relating to potential ecological effects and how the different effects zones (AZE, OLE etc) are interpreted in relation to the proposed farm area and reef habitats. I have a couple of minor suggestions for the authors:

Incorporate into report prior to submission:

- Paragraph 4, P55: I see that you have acknowledged that outside of Zone 2 moderate enrichment in dispersive locations (and generally) can actually manifest as increased abundance and increased richness for 'outside of the proposed area', which is a valid point. But I think it should also be acknowledged as a scenario under Zone 2 - especially the early stages of the development.
- Last para P56: This is where you could acknowledge that some particles may get trapped by the uneven / 'rough' nature of the reef habitats, potentially creating very localised fringes or pockets of anoxia. But probably insufficient to impact the habitability of the habitat when at low levels?

Useful to have going forward / things to consider

- Top of P55: I would question the likelihood of 'some increase in organic content' beyond the ZME. Dispersive sites often have very little or variable responses with respect to accumulation of organic carbon (Keeley et al. 2019, Keeley et al. 2024). It tends to be readily metabolised and / or dispersed and exported where it occurs in dilute form and able to be assimilated without measurable consequences. But probably ok to give precautionary warning of this.

Question 5: A review of the management and monitoring recommendations, and comment on whether you believe that they are appropriate for managing the potential adverse ecological effects of the farm.

Review of Cawthron document titled 'Hananui Monitoring Plan Summary'.

The applicants have done a good job of positioning the site and associated footprint where it has negligible spatial overlap with the more ecologically valuable biogenic habitat.

Monitoring Soft-sediments

General design?

Effects-based management is a logical approach to take, especially in this case where the physical nature of the environment is relatively atypical and lacks close precedent. The only way to confidently understand how the system responds to such inputs is to initiate the activity in precautionary manner and then to undertake a carefully designed

effects monitoring program with management response requirements. The 2-stage development seems to be a sensible approach in this regard, permitting a sanity check of the predictions before moving to full development.

Appropriate environmental parameters and thresholds?

The monitoring program is underpinned by a 2-tier sampling strategy, whereby Tier 1 utilises four relatively cheap indicator variables that give instantaneous results. Tier 2 sampling is triggered when the Tier 1 variables exceed stated thresholds, and involves more comprehensive assessment based on the microbial and macrofaunal communities. If Tier 2 indicators are exceeded, then management actions are required. This is a sensible approach.

The Tier 1 indicators are the best currently available (S^2_{UV} , Redox/pH, near bottom DO and visual assessment of bacterial mats and outgassing). Tier 2 results are a combination of an established 'gold standard' (macrofauna indices) and a newly established and promising e-DNA-based microbial index: b-MBI. All of which are very appropriate for monitoring organic enrichment in soft-sediments. Noting that the b-MBI may require some refinement during the first year of operation to expand its base GeneCodeID library to include some regional specific ASV's.

EQS thresholds and associated indicator thresholds seem appropriate. ES5 is an established maximum enrichment level, ES4 is high for a big area like Zone 2, but suitable if it applies on a 'at any station basis'? To be clarified – see below. <ES3 is generally suitable for 'beyond Zone 2' – noting that it applies to any station. Also by implementing a definitive threshold it protects against 'creep' / accumulative enrichment at far field locations. However, under Tier 2, it is evaluated relative to reference stations - if this is point-in-time referencing then creep could still be an issue? (see comment below)

Appropriate sampling arrangement?

Spatial arrangement of sample stations with respect to zones seems appropriate.

Zone 1 peak and tiered monitoring design seems appropriate given the staggered way in which the farms will be stocked. It also provides a measure of short- and medium-term recovery, useful for future management decisions.

Beyond Zone 2: no more than minor enrichment = minor enrichment is permitted anywhere. Was that the best wording / really what is intended?

Appropriate sample timing and intensity?

Zone 2 monitoring stations – with so few sample stations there is a risk that they all fall in low influence areas. Did you consider constraining such that a percentage of the stations (50%?) are situated within the predicted residual solids footprint boundaries?

Also, 'haphazardly' I think it would be useful to get some context on that? i.e., Why haphazard and not random? What are the constraints?

Number of replicates and number of stations for Zone 2 and beyond are not given.

NB: The urgency of the below points depends a little on how tight and refined the monitoring plan needs to be at point of submission. Presumably a lot of these can be refined subsequently.

Points for consideration / clarification:

- Clarify what constitutes non-compliance in Zone 2 – any station average for any indicator, at any one station? All stations? (very different threshold)
- Clarify if compliance trigger applies on a station-by-station basis for 'Peak production monitoring'? So any two (or more) indicators at any one of 4 PP stations?
- Likewise for Zone 2: Tier 1 -> Tier 2 triggered by any one station? (I see Beyond Zone 2 is explicit in this regard).
- Use of 'Redox / pH index > 3.0' needs context (presumably referring to the biplot in the Norwegian standards?)
- For beyond Zone 2 EQS, might want to clarify '...for relevant reference stations'. Assuming this means at any point in time? (ie from one survey). Not looking at a) baseline samples, or b) reference samples from all years?
- Any consideration given to 'creep' at reference sites under Teir 2 at 'Beyond zone 2'?
- Specify how many Zone 2 stations must be monitored? Is it 13 as shown on graph? If so, is that enough for the given area? (seems minimal). Perhaps there is a way whereby Teir 1 stations can be more numerous (for coverage) and triggering Teir 2 just applies to a portion of those samples somehow? (eg those at or near threshold?)
- Please give some consideration to what 'haphazard' means? If it was truly random, you run the risk of a small cluster in one corner, I presume hence 'haphazard', but what are the constraints? E.g., Consider distributing according to strata such that each farm has minimum 2 in general vicinity? I suspect you are planning to do this anyway but have not put it into words?
- Specify number of stations for Beyond Zone 2?
- You mention 'station averages' but the number of replicates is not given (some of these details probably in Newcombe et al but I think this document should be reasonably stand alone.

Monitoring Biogenic habitat

General design?

I agree in principle that there is little in the way of established methods upon which EQS's can be set for this type of habitat; that said, there is now a means of sampling benthic flocs directly from any substrate for deriving the b-MBI may provide an exception to this (see below). The dual investigative approach using broadscale and fine-scale visual methods with sediment tracer and waste indicators is sensible and I believe achievable. Together, this seems like a relatively robust approach.

Appropriate environmental parameters and thresholds?

The proposed environment parameters seem appropriate. The authors plan to assess the structure, distribution and composition of habitats (multibeam or sidescan – I would strongly recommend the former), in conjunction with finer-scale enumerating and percentage cover of key taxa from video surveys. They also propose establishing sentinel soft-sediment stations adjacent to the reefs (nearest to farms), which will be sampled for the same variables as for soft-sediment monitoring. Of these, the b-MBI should prove to be a fairly sensitive indicator, which is appropriate for this type of far-field locations. The other variables will be triggered once the enrichment is more pronounced.

It is not yet clear how sensitive the biogenic taxa are to the enrichment in relation to those established indicators, so I presume that these relationships be addressed through the early stages of the monitoring program.

A suggestion I have is that the b-MBI could be extracted directly from the surface of the biogenic reef structures using a SIBS sampler (Keeley et al. 2025), so the indicator could be relevant to any specific point over the reef, as opposed to the edge nearest the farm. This approach also permits visual assessments at the same time and has the potential to negate the need for 'sentinel' soft sediment sites in the future.

Appropriate sampling arrangement?

Takes a broadscale, medium-scale and fine-scale approach with sentinel sites on edge nearest farm. Comprehensive, but will probably need to be refined as more is learned about how the site is responding, what the best indicators are, and which methods are most effective.

Appropriate sample timing and intensity?

Propose 6-monthly sampling. Seems appropriate, especially in the first 2-3 years as the site is being developed and understood and effects footprints are validated. After which it should probably be revised; i.e., if there are no obvious effects and the waste is not being detected on the reefs in substantive quantities, then it could be reduced, e.g. annually.

Points for consideration / clarification:

- Consider using extracting floc samples directly off the biogenic reefs for b-MBI measurements.

Keeley N, Dunlop K, Laroche O, Hansen PK, Angell IL, Rudi K (2025) An approach for quantifying the influence of fish farm waste on hard-bottom habitats. *Marine Pollution Bulletin* 217:118039

Keeley N, SÆvik P, Woodcock S, Bannister R (2024) Tackling the elephant in the room – Large-scale salmon farming and the potential for far-field ecosystem effects. *Marine Pollution Bulletin* 209:117056

Keeley NB, Valdemarsen T, Woodcock S, Holmer M, Husa V, Bannister RJ (2019) Resilience of dynamic coastal benthic ecosystems in response to large-scale finfish farming. *Aquaculture Environment Interactions* 11:161-179