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Living Filters pilot project: summary

Cawthron Report 4060

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REVIEWED AND APPROVED FOR RELEASE BY: Roger Young

PROJECT NUMBER: 18606

ISSUE DATE: 27 June 2024

RECOMMENDED CITATION: Crossett D, Ericson J, Vignier J. 2024. Living Filters pilot project: summary. Nelson: Cawthron Institute. Cawthron Report 4060. Prepared for Sustainable Seas and partners: Moananui, Port Nelson and MacLab.

Living Filters pilot project: summary

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Prepared for Sustainable Seas National Science Challenge (funder) and partners: Moananui, Port Nelson, and MacLab

Executive summary

This document reports on a pilot project to investigate the ability of Greenshell™ mussels to survive in Port Nelson. The project also focused on:

- structural integrity testing, i.e. mussel frames, Hall sensor cabinet, and instrumentation etc
- data gathering techniques
- quantifying the use of mussels as a bioremediation tool in an urban coastal environment.

Lessons from this pilot project inform functional knowledge of mussels as a bioremediation tool and provide a business case to scale-up across larger urban coastlines. If funding is secured to scale-up, a long-term goal is to raise awareness of collaborative, nature-based solutions to environmental problems that affect coastal habitats.

1. **Key lessons**

- Mussels survived and had significant growth in Port Nelson.
- Mussel retention was high on frames in Port Nelson.
- Growing frames, set up by MacLab, were fit for purpose, and there were no incidents when deploying and retrieving mussels.
- Based on Hall sensor data, mussels showed no evidence of undergoing detrimental stress due to the growing environment.
- Bioavailable trace metals, such as lead (Pb) and zinc (Zn), had similar or lower concentrations than those found in the Marlborough Sounds.
- This pilot project was well received by the community and industry, with multiple high-visibility outputs.[1,2] Connecting these groups is important for successful research.

2. **Reflections**

- Nothing is as simple in practice as in theory. For example, scientific gear was stolen and having an adaptable team was essential for coastal research.
- Appropriate funding to analyse mussel flesh / gut content would have advanced this project because, without further funding, we are unable to compare mussel filtration to historical sediment data (i.e. quantify trace metals or pollutants).
- The ability to be 'in the water' to sample was effective and proved fruitful for in situ imagery of mussels in action. However, more risk and cost is associated with 'diving' for fieldwork, especially in a port environment. Here again, an appropriately skilled team is necessary, and keen partners (i.e. port staff) helped to navigate the health and safety paperwork.
- Permitting is an important first step that can take time. Appropriate council, government, and iwi engagement is necessary in this process.
- Understanding questions for data is important. For example, Hall sensor data produced more than 47 million data points. Appropriate questions will help direct data investigations.

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[1] Port Nelson Community Open Day 2024
[2] NEWSLETTER - May 24 (marinefarming.co.nz)

- This project would not have been possible without countless in-kind staff hours and resources. Keen researchers and partners are also key; however, appropriate funding would remove the challenges associated with in-kind funding in the business or economic environment.

3. **Project length and funding**

- Project ideation and permitting was approximately six months.
- Pilot project was six months.
- In-kind funding and support – $5k Port Nelson, $10k MacLab (includes mussels), $20k Cawthron (includes leveraging parallel research: DGTs and Hall sensors) =$40k total.
- Sustainable Seas funding of $50k activated this project and allowed current results.
- An extra $35k would allow for mussel flesh / gut analysis and increase project impact.

1. Background and project aim

Bivalve molluscs, such as Greenshell™ mussels (GSM), are filter-feeders that play a crucial role in aquatic ecosystems. They have a considerable filtering capacity (hundreds of litres per adult per day; Burge et al. 2016) and can actively remove suspended material from the water column, including excess nutrients and pollutants, and so contribute to improving water quality and clarity. Bivalves are effective in taking up and accumulating many pollutants in high concentrations. For these reasons, bivalves – notably mussels – have been extensively used as bioindicators (tissue concentration measurements) and sentinel (biomarker measurements) species to assess coastal contamination (Goldberg et al. 1978; Lacroix et al. 2015).

In 2023, partners from Port Nelson, MacLab, Moananui, and Cawthron Institute outlined a project to investigate the use of Greenshell™ mussels as a bioremediation tool in Port Nelson. The first aim was to seed GSM into the port and evaluate their ability to improve water quality and water clarity (e.g. Rose et al. 2015).

Another important outcome of the pilot phase was to understand mussel biometrics and survival in the port environment. This step was critical because there was low survival of GSM in a similar project in Port of Auckland[3]. The long-term goal was to raise awareness of collaborative, nature-based solutions to the environmental problems created by human activities across the community. The project also aimed to demonstrate how similar solutions in other regions could be led by commercial partners.

[3] Seeded mussel lines filter seawater from beneath Te Wānanga - OurAuckland (aucklandcouncil.govt.nz)

2. Approach

Our project was originally divided into three phases:[4]

Phase 1: pilot testing (January–June 2024)

The pilot phase focused on structural integrity testing (i.e. mussel frames, Hall sensor cabinet, and instrumentation etc.), data gathering techniques, and quantifying the potential benefits of filtering contaminants and suspended solids to the wider ecosystem. The pilot provided foundational knowledge and a business case for scale-up across a larger area of Port Nelson.

Phase 2: scale-up

Pending successful pilot testing, the project's approach will be rolled-out to other areas of Port Nelson for further validation via testing, analysis, refinement, and identification of key attributes for replicability. Phase 2 will also include further testing of material collected during the Phase 1 pilot project.

We will use key lessons and reflections from this pilot project to inform best practice for Phase 2. We will also use knowledge gained from Phase 1 to seek funding to activate Phases 2 and 3. If funding is secured, we aim to explore more collaborators or partners to scale-up Living Filters across Aotearoa New Zealand.

Phase 3: community engagement and regional replicability

Once fully operational, the project will expand to include engagement with the wider Nelson community, through public displays and outreach activities with local colleges (living-lab) and uptake by other regions.

The target audiences for project outputs are:

1. key sustainability and investment decision-makers within collaborating organisations — to continue development of blue economy restoration activities
2. local students and community — to share knowledge and profile the blue economy
3. commercial partners seeking regenerative and restorative projects that demonstrate and contribute to a regional blue economy — for commercial uptake.

[4] Wording from Sustainable Seas Impact Project – Living Filters proposal document.

3. Methods

On 11 January 2024, 28,800 mussels were seeded onto two frames at Layup 3 in Port Nelson (Figures 1 and 2). Alongside these mussels, duplicated Diffuse Gradients in Thin-film (DGT® Research Ltd, Lancaster, UK) passive samplers were deployed in a cage to measure trace metals concentrations in the water column and seawater temperature, respectively (Figure 3). These samplers accumulate trace metals over time and provide a time-integrated average labile / bioavailable concentration, and one temperature logger (Onset® HOBO 64k temperature / light logger). Cages containing the DGTs and the logger were deployed for 21 days, after which they were recovered, rinsed with deionised water, and sent to the lab for extraction and chemical analyses. The process was repeated every three weeks (French et al. 2021).

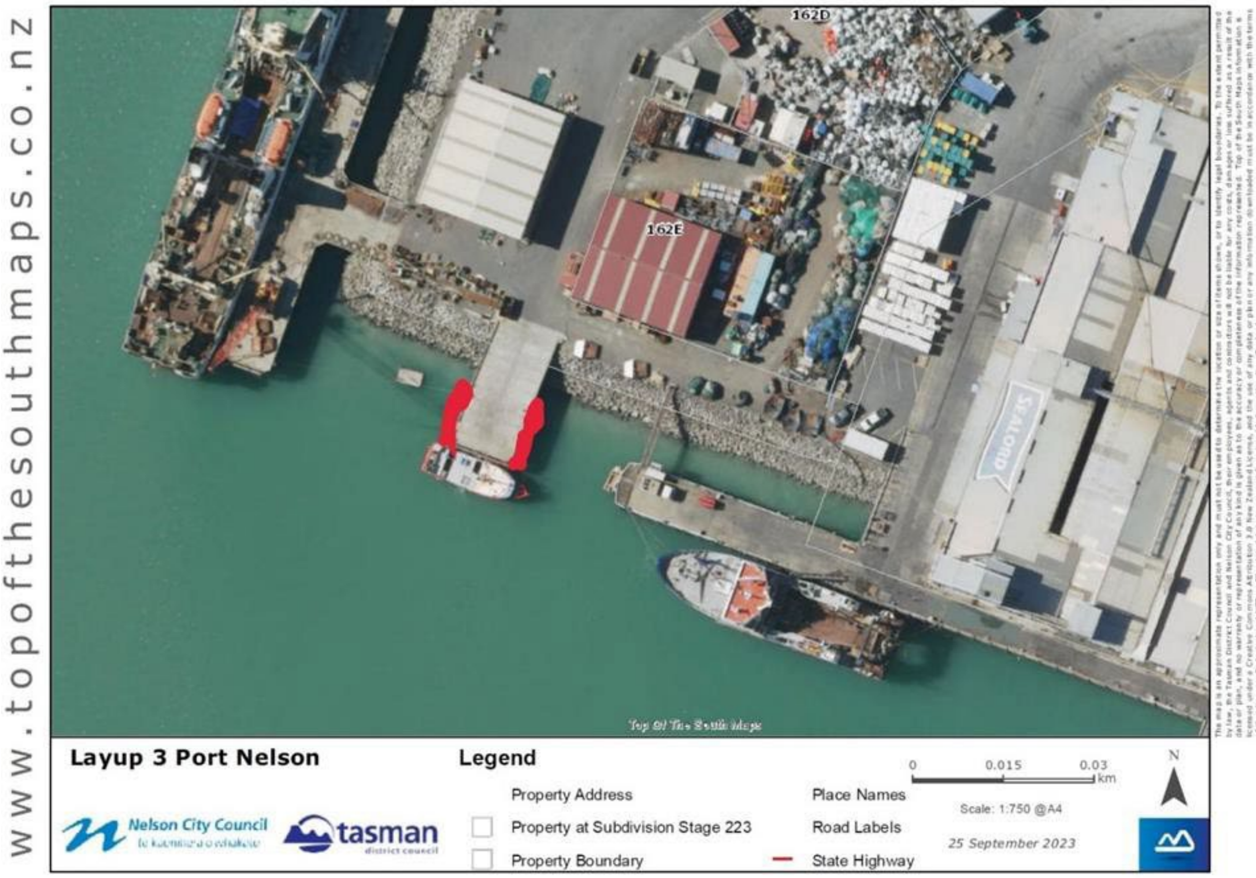


Figure 1 Site details of Layup 3 at Port Nelson.

Figure 2 Original deployment of juvenile mussels at Layup 3 in Port Nelson. (A) The MacLab team put the mussels into cotton socks before wrapping the socks around the frames; from left: Callan Kotua (MacLab), Dan Crossett (Cawthron), Julien Vignier (Cawthron), Mark Burnaby (MacLab), Shannon Holroyd (Port Nelson), Brent Shone (MacLab). (B) Frames were then deployed offshore on lines using *Vanguard's* (MacLab vessel) davit.

Figure 3 Diffuse Gradients in Thin-film (DGTs) passive samplers (round white samplers) and one temperature logger (Onset® HOBO 64k temperature / light logger, green pendant) contained in cages deployed along mussel frames.

On three occasions (11 January, 27 March, 15 May), 30–50 mussels were sampled from the frames and analysed at Cawthron Aquaculture Park for measurements of biometric parameters (shell length and whole weight). In addition, samples of mussel gut / flesh were dissected and frozen (archived) for later analysis if / when funding was secured for this additional work. Baseline sediment data were also investigated from previous long-term monitoring within the studied area of Port Nelson (Sneddon 2019). Further interrogation of these baseline data is advised if appropriate resources are secured.

On 15 February, a solar powered cabinet containing appropriate instrumentation for powering, collecting and sending Hall sensor data was installed at Layup 3 by Cawthron scientific engineers and technicians. Hall sensors were attached to 12 mussels and deployed at the site on 27 February (Figure 4). These Hall sensors measure the distance between mussel half-shells, whereby a magnet is glued to one shell and a Hall effect sensor on the opposite shell. The distance between the Hall sensor and the magnet is measured in mV and describes 'gaping' behaviour. Gaping behaviour can indicate stressful environmental conditions such as high freshwater input or sedimentation (Vereycken and Aldridge 2023). When investigating gaping behaviour in mussels, incidences of synchronised behaviour are of particular interest (e.g. synchronised closing or wide gaping). Closing for extended periods indicates avoidance of potential threats in the water column (e.g. predators, pollution, etc.), and wide gaping may indicate compromised health or death.

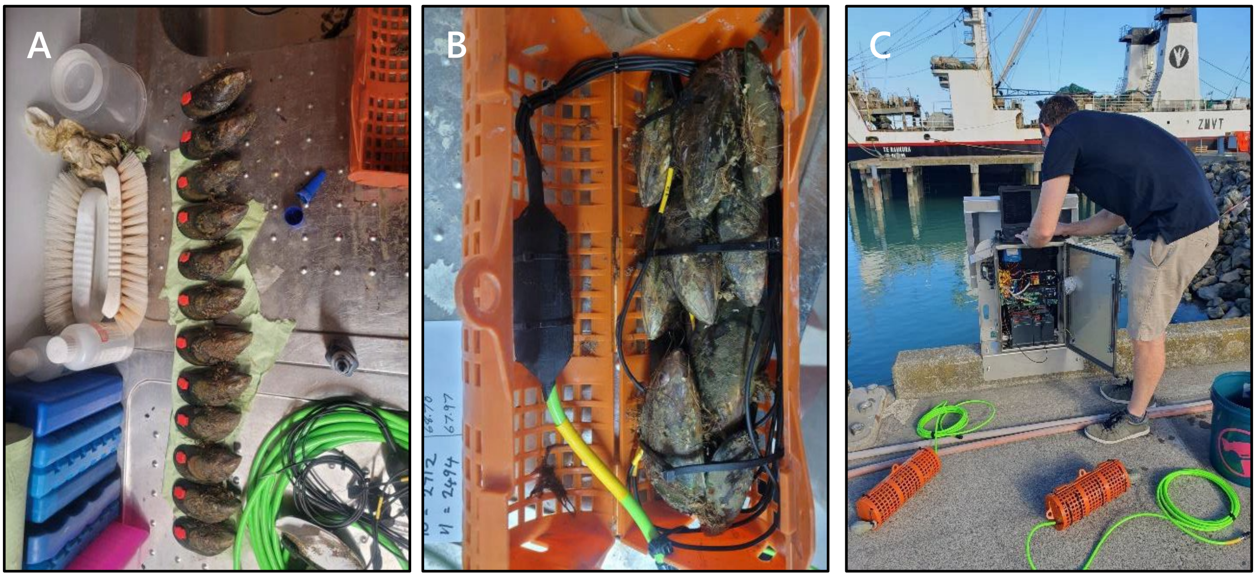


Figure 4 (A) Mussels primed for attachment of Hall sensors. (B) Hall sensors attached to mussels in cage. (C) Shaun Graham (Cawthron) wiring up Hall sensors and deploying them at Layup 3.

4. Summary

Mussels have not only survived the Port Nelson environment, but they have also thrived. Mark Burnaby (MacLab) observed that survival in the port has been greater than at farm sites offshore. He noted that compared to Port Nelson, there is generally reduced retention of mussels shortly after deploying spat or juveniles onto mussel lines at farm sites. Mark also remarked on the strength of byssal threads of mussels deployed in the Port, which likely increased survival and reduced the number of mussels 'dropping off' frames. There has been predation of mussels, mainly from the eleven-armed sea star (*Coscinasterias calamaria*), which is common on mussel reefs, but generally only on the lower regions of the frames. To mitigate this predation, lines holding the frames were tightened to increase their distance from the seafloor. This also likely reduced the amount of sediment smothering these filter-feeding organisms.

Our Living Filters pilot project also featured at Port Nelson's 2024 Open Day[5] and in the Marine Farming Association autumn 2024 newsletter.[6]

Trace metals in the water column and seawater temperature

To date, eight deployments of DGT/HOBO have taken place. However, we were unable to analyse the second and third deployment in February–March because gear was stolen or lost. Data from sampling events 1, 4, and 5 are shown in Figure 5, and data from sampling events 6 and 7 are still being analysed. We found that some specific metals were more prevalent than others. For instance, bioavailable aluminium (Al), iron (Fe), manganese (Mn), nickel (Ni) and copper (Cu) were relatively elevated, with maximum concentrations measured during deployment 1 (January) for most of these elements (Figure 5). When comparing these levels with those measured in the Marlborough Sounds between 2021 and 2022, they are generally higher or similar, whereas concentrations of zinc (Zn), lead (Pb), chromium (Cr) or cadmium (Cd) tended to be lower than those found in the Marlborough Sounds (Figure 5; Vignier et al. 2023). Interestingly, we also found high concentrations of sulfur (S), a non-metallic element, which are likely the result of anoxic mud abundant under the frame. Future analyses of mussel tissue will confirm the trends of metals present in the water column.

Sea temperatures have been on the rise globally, and coastal temperatures around Port Nelson and within Tasman Bay / Te Tai-o-Aorere are not immune to this trend and have been increasing. Sea temperature was recorded during this project because adult mussels may experience decreased health and / or survival at summer seawater temperatures ≥ 22 °C (Ericson et al. 2023; Venter et al. 2023). A point of interest in this project was to identify the temperature range of Port Nelson, particularly during the warm summer months. Seawater temperature is also critical for modelling and calculating trace metal concentrations from the DGTs (French et al. 2021; Vignier et al. 2023). Due to gear being stolen or lost during deployments 2 and 3, we gathered seawater temperature from just outside Port Nelson using a global model network[7] for this period. We also extended these data until the end of May to compare against data that were collected on site with HOBO temperature loggers for deployments 1, 4

[5] Port Nelson Community Open Day 2024
[6] NEWSLETTER - May 24 (marinefarming.co.nz)
[7] https://home.oceanum.io/ – ECMWF ERA5 global 2 m temperature hindcast

and 5 (Figure 6). There is greater range in seawater temperature data gathered from global models, likely because it was modelled from data at 2m depth and offshore of the Port Nelson coast. Here, we use these data only as a reference for what summer seawater temperatures were in proximity to Port Nelson because on site seawater temperature at Lay up 3 was unavailable.

Mussel biometrics

From 11 January to 15 May 2024, mussels grew significantly in weight (Figure 7; $p < 0.001$) and length (Figure 7; $p < 0.01$). On average, mussels weighed 16.22 g and were 62.125 mm long on 11 January 2024. Five months later, on average, mussels weighed 19.756 g and were 64.51 mm long. On 20 June 2024, we were also able to sample mussels from the same spat source at MacLab's Tasman Bay farm. This sampling point was a month later than our final sampling point in Port Nelson, and Tasman Bay farm mussels were larger (~25.25 g) and longer (~75.56 mm) than those in the port (compared to 15 May). The mussels at the farm site were expected to show better growth, but this project did demonstrate a good comparison for mussels grown at Layup 3 in Port Nelson.

Hall sensors

Hall sensors were attached to 12 mussels and were deployed at Layup 3 on the 27 February. Data were sent back to Cawthron via telemetry from the cabinet installed at Layup 3 on 15 February.

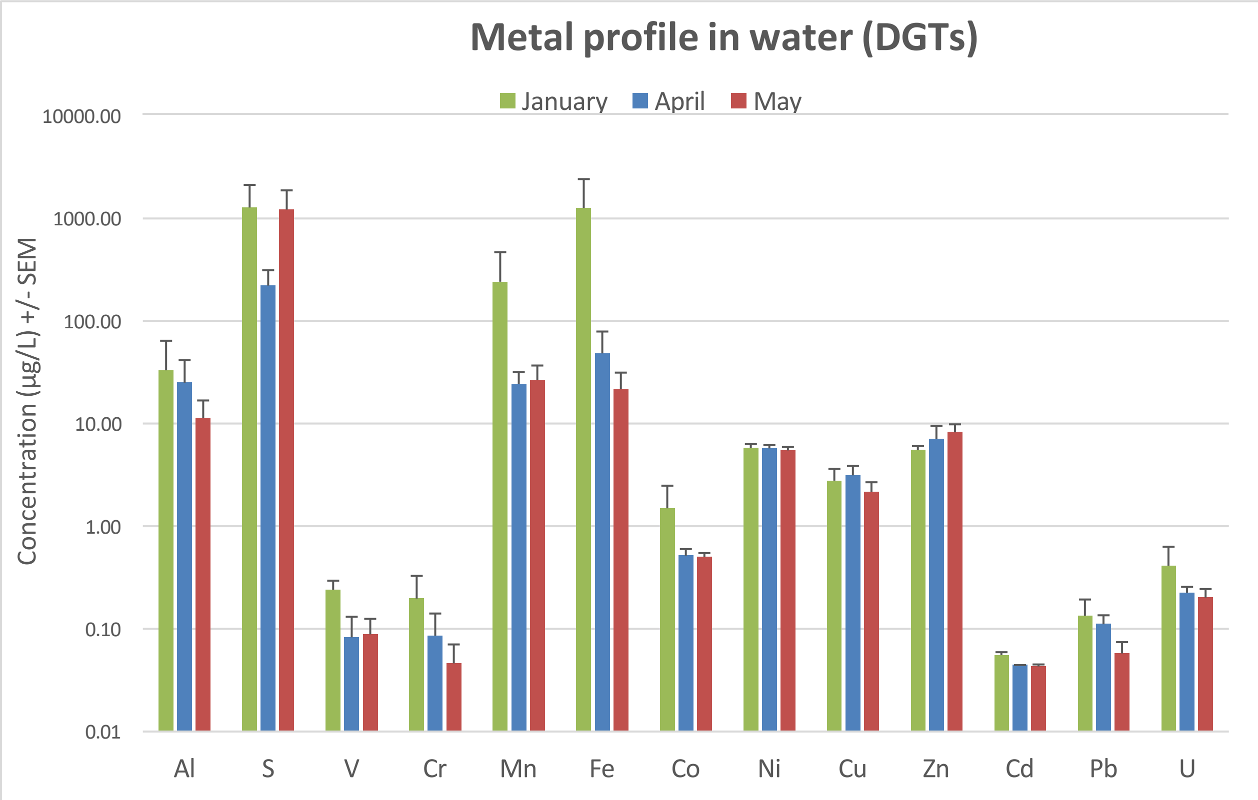
Due to the necessity to capture fine-scale gaping behaviour, data must be collected every second. The final datasets are, therefore, very large and present computing challenges. Cawthron's data science team helped develop statistical code to clean and analyse sensor data. Due to the nature of these large datasets (> 40 million data points), we can only display data from particular periods of interest. For example, we investigated gaping behaviour before, during, and after the heavy rain event in April 2024 by plotting the mean gape (%) for every 1-hour period for each mussel. Gape percentages were calculated for each mussel based on their largest and smallest gape values throughout the study (0% gaping is closed, 100% gaping is fully open; Figure 8a).

We did not observe any particularly notable synchronised behaviour during this period, which suggests that the mussels continued filtering throughout the rain event. We also investigated whether there were any 'closing events' where mussels were closed for more than five minutes for any period throughout that week (Figure 8b). Although some closing events were observed for each mussel, there were not any events where all mussels were closed at the same time. These data suggest that the mussels continued filtering during the rain event, and the freshwater run-off was likely not significant enough to promote prolonged valve closure.

In summary, a vast amount of gaping data were collected during this project. It was extremely valuable to road-test the Hall sensor cabinet and learn that we could successfully collect and transmit gaping data back to our network. In future, the current data can be further interrogated to answer specific research questions, and any new data collected will be extremely valuable to extend our knowledge on mussel gaping behaviour and the potential for real-time biomonitoring in the port (e.g. see molluscan-eye).

Timeline

A full summary of the timeline of this pilot project can be found in Figure 9.



Metal	Mean	SEM
Pb	207.5	191.6
Mn	29.0	8.8
Zn	21.0	8.6
Cr	9.2	9.9
Fe	5.7	2.5
Cd	5.3	4.8
Al	4.4	2.1
Ni	2.5	0.5
Cu	0.9	0.2
U	0.3	0.3
Co	0.3	0.1
As	0.1	0.0

Figure 5 Trace metal profile in seawater, expressed in µg/L (± SEM). Data collected via Diffuse Gradients in Thin-film (DGTs) passive samplers during deployment 1 (January), deployment 4 (April) and deployment 5 (May 2024) (left figure). For comparison, mean concentrations of trace metals, in µg/L, measured via DGTs in the Marlborough Sounds over the course of 18 months from Vignier et al. (2023) – Climate change exacerbates marine pollution impacts (right table)

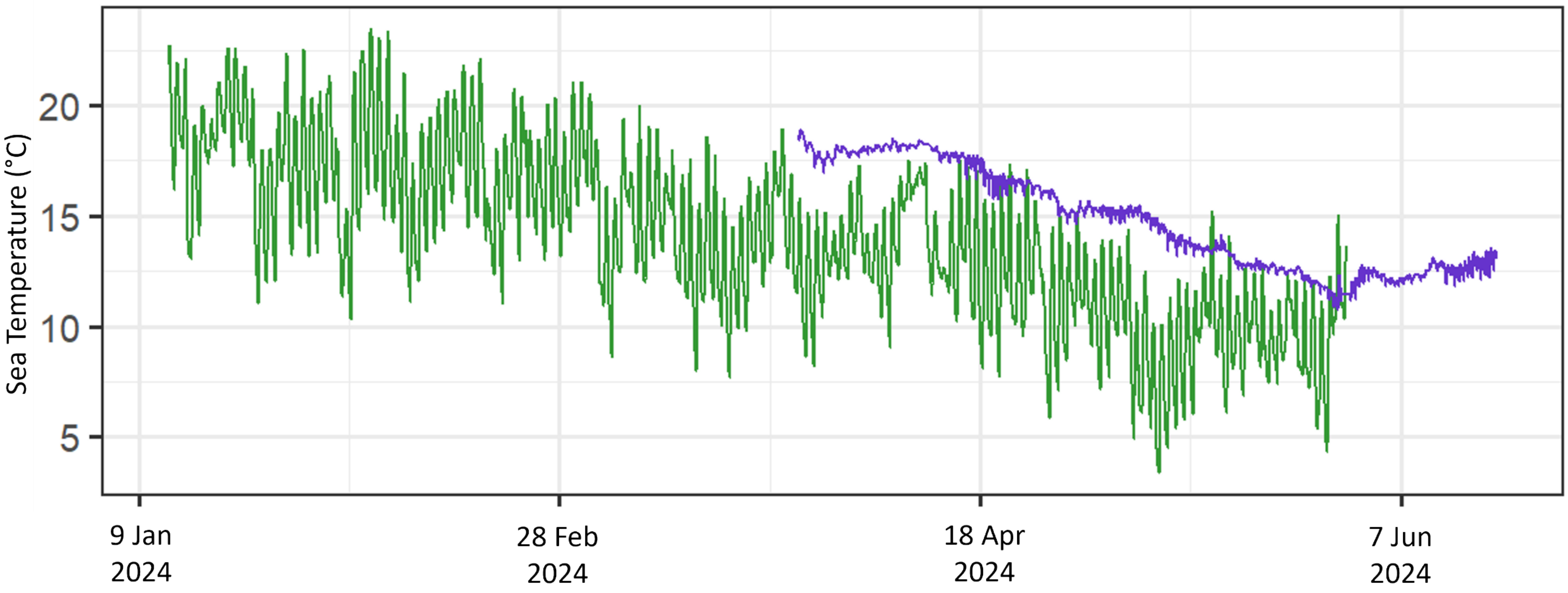


Figure 6 Seawater temperature just offshore of Port Nelson collected using https://home.oceanum.io/ – ECMWF ERA5 global 2 m temperature hindcast (solid green line) and seawater temperature collected at Layup 3 using Onset HOBO temperature loggers (solid purple line).

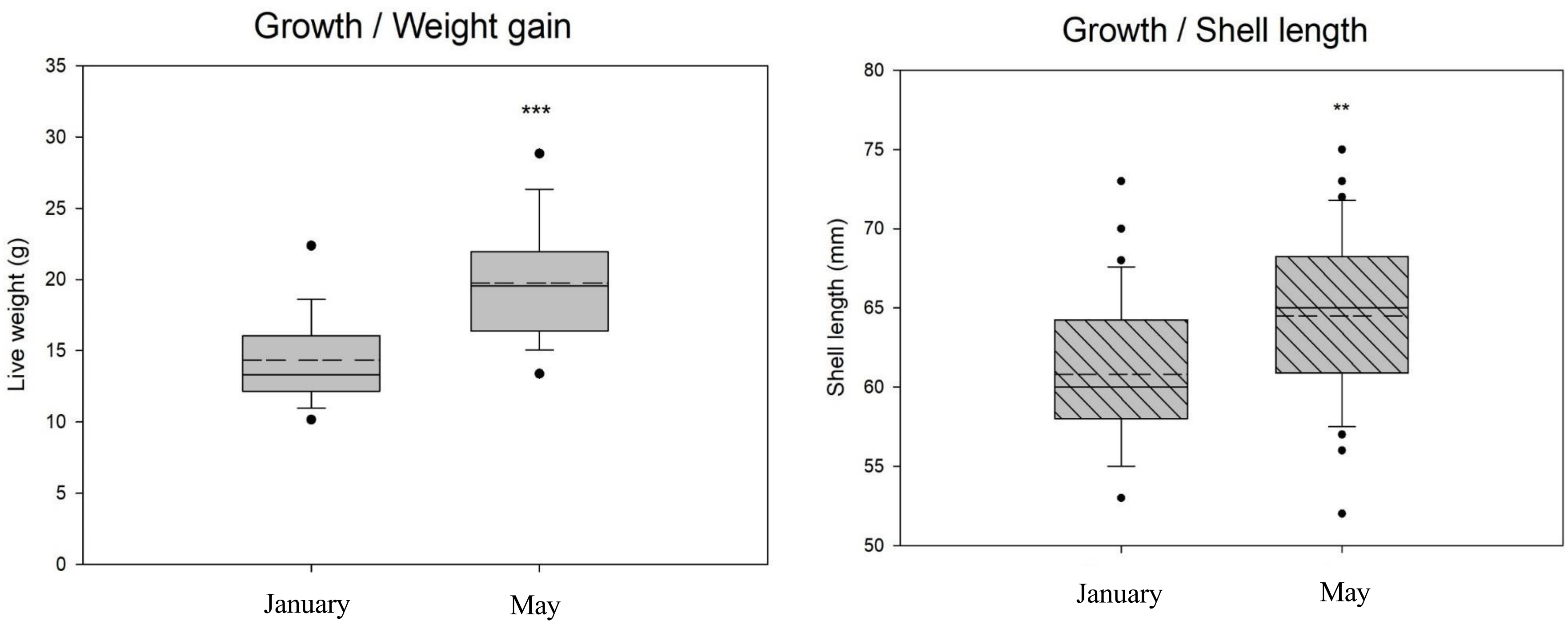


Figure 7 Biometric parameters of live Greenshell™ mussels. Growth / weight gain (left figure) and growth / shell length (right figure) of mussels from start of pilot (11 January 2024) to final sampling point (15 May 2024). A total of 30–50 mussels were sampled at each point. Grey boxplots represent interquartile range (25–75 % of measurements), solid line represents median, dashed line represents mean, min, and max, 'whiskers' represent 95% confidence interval of data, and solid dots are outlier measurements compared to 95 % confidence interval. ** and *** above June boxplots denote < 0.01 and < 0.001 significant levels. Note that the March mid-sampling point is not displayed because mussels had to be frozen before sampling, and thus were not live biometrics.

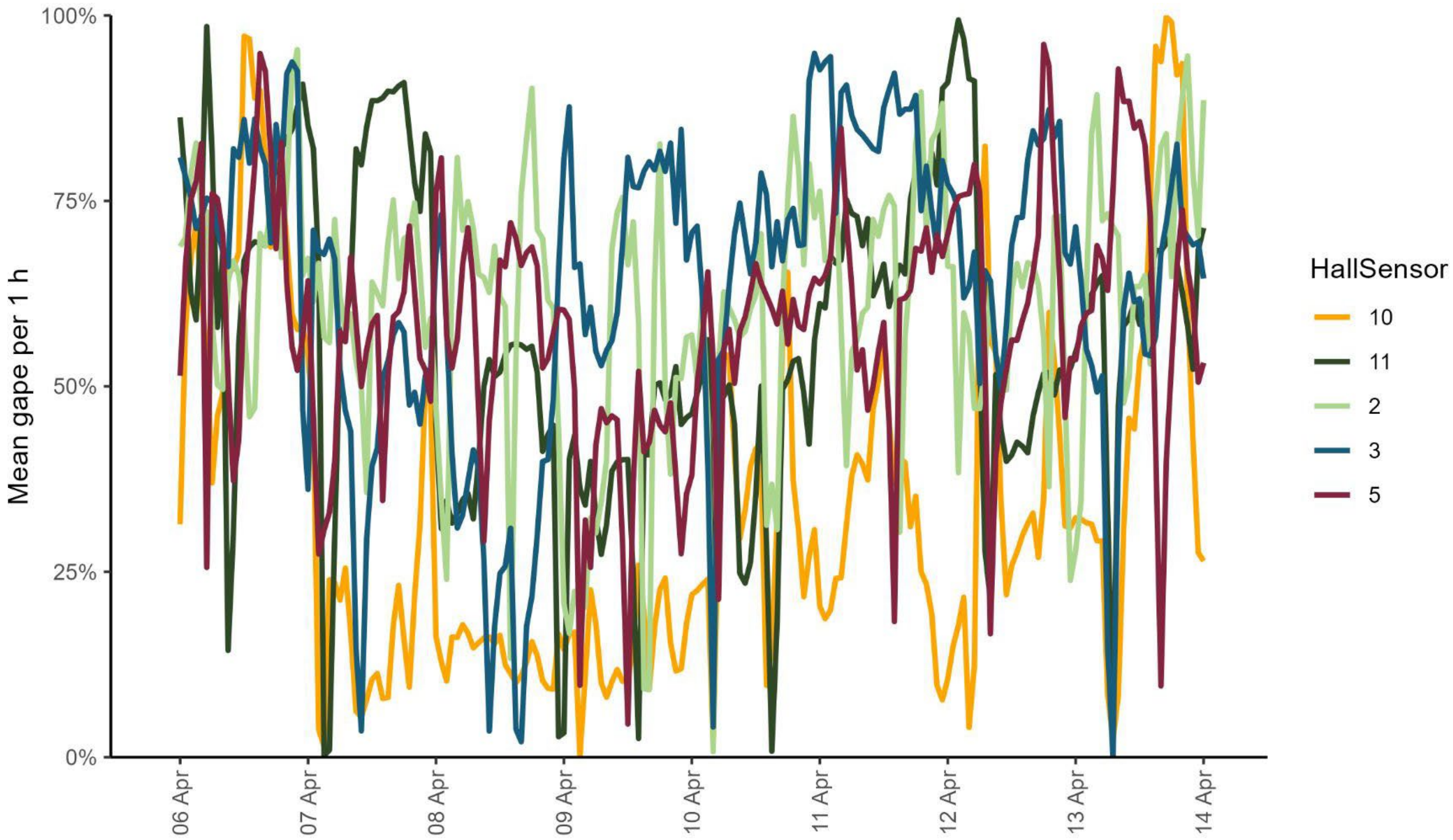


Figure 8a. Data from Hall sensors. Sensors were originally attached to 12 mussels but this figure displays data for five mussels during the period 6–14 April 2024. This period was chosen because there was a heavy rain event (11 April) that may have influenced mussel gaping behaviour.

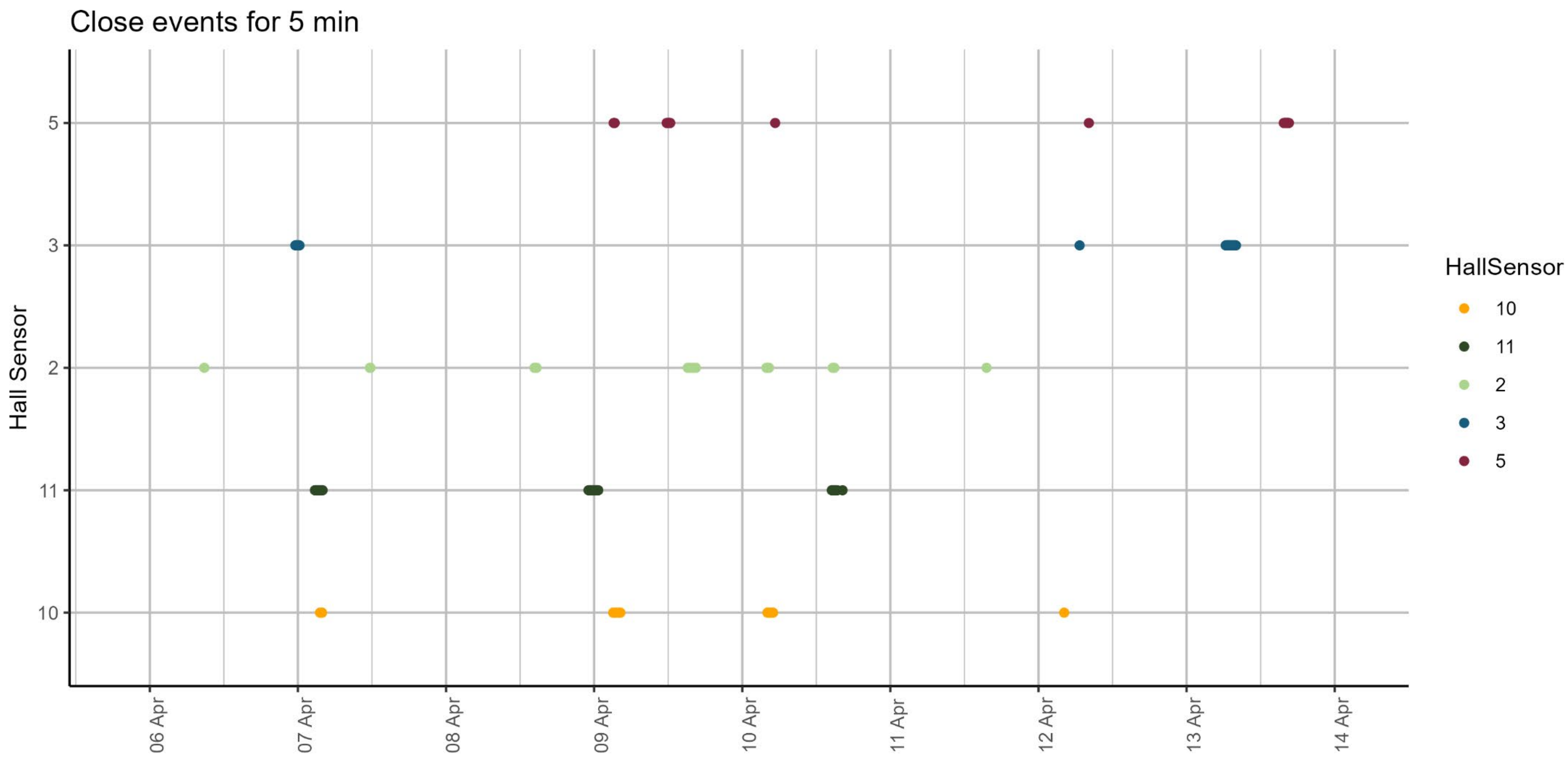


Figure 8b. 'Close events' when mussels were closed for more than 5 minutes during the period of 6–14 April. This period was chosen because there was a heavy rain event (11 April) that may have influenced mussel gaping behaviour if significant freshwater run-off had occurred. Each dot represents a five-minute period when a mussel with a Hall sensor (y-axis) was closed.

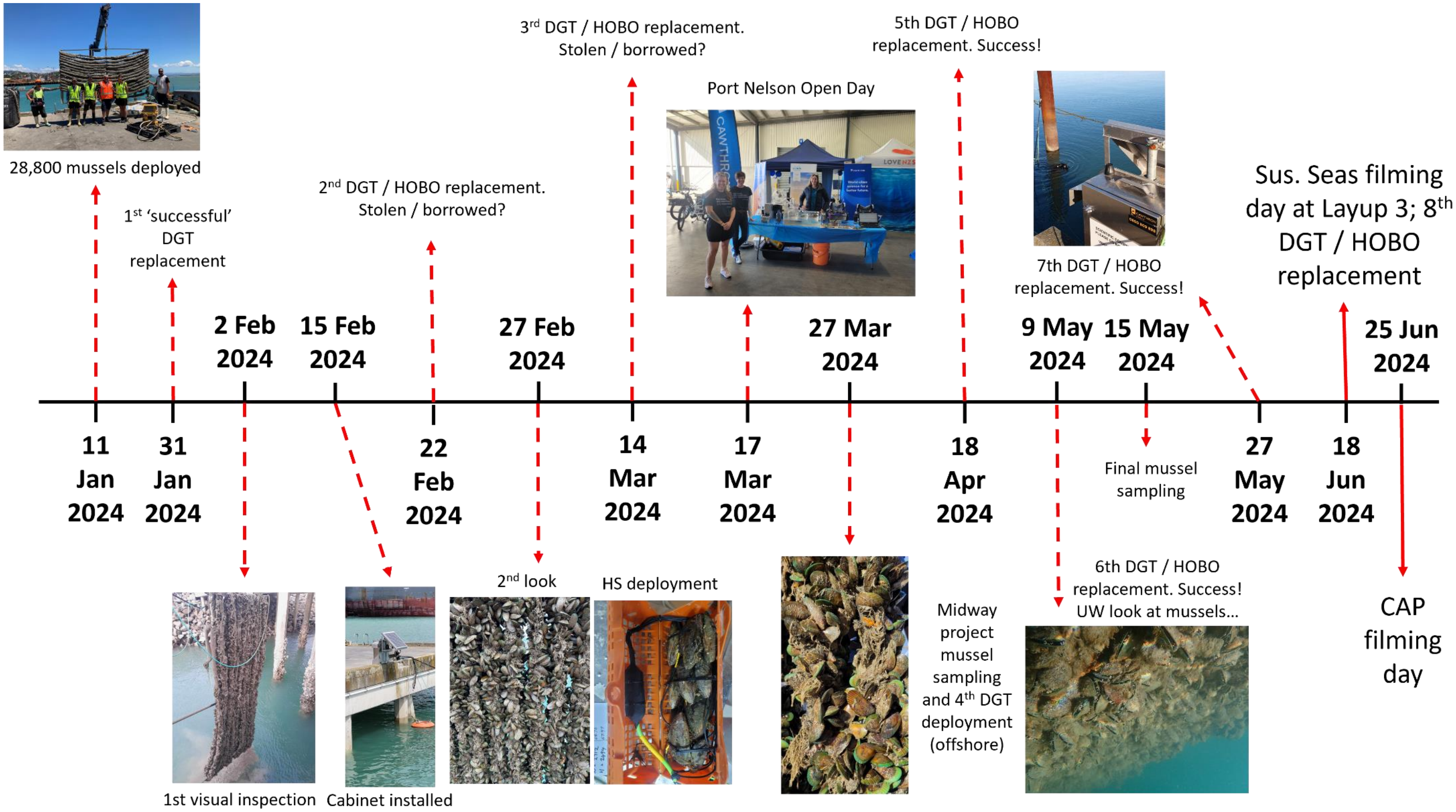


Figure 9 Timeline of Living Filters pilot project.

5. Next steps

Funding

We appreciate that Sustainable Sea National Science Challenge finishes in June 2024 and so other funding must be secured to progress our Living Filters project into Phases 2 and 3. We have identified a few alternative funding options but hope this summary will assist in resourcing the next steps of this important research and outreach.

A proposal has been submitted to Cawthon's MBIE Shellfish Aquaculture Programme (ShARP) to continue monitoring mussels / water quality. This funding opportunity may also include resources to analyse archived mussel flesh / gut content and compare the results to Port Nelson's long-term monitoring sediment data (Sneddon 2019). Port Nelson has also identified resources from its 2024–25 FY budget to extend this monitoring effort. We are also proposing an MBIE Smart Idea, which would leverage and continue the work done under the Living Filters pilot project. The title is 'Bioreporting from the frontlines: a novel nature-based integrative solution for biomonitoring connectivity in a changing environment'. The project will investigate connectivity between freshwater–coastal environments by combining biomonitoring and bioremediation tools such as eDNA, passive samplers and remote sensing, with Greenshell™ mussels as the central focus.

Phases 2 and 3

Phases 2 and 3 will follow the original Sustainable Seas proposal if funding can be secured:

Phase 2: Scale-up – Pending the successful pilot testing, the approach would be rolled-out to other areas of Port Nelson for further validation via testing, analysis, refinement, and identification of key attributes for replicability. Additional collaborators and funders may be sought.

Phase 3: Community engagement and regional replicability – Once fully operational, the project will expand to include engagement with the wider Nelson community through public displays and outreach activities with local colleges (living-lab), as well as uptake by other regions.

A video is currently being produced to increase the visibility of this project and help seek more funding as we work towards Phase 2. This video will also serve as an outreach tool and will be introduced to the Nelson community and schools in Phase 3.

MacLab spat from Layup 3

MacLab has obtained resource consent to collect spat from structures just off the seabed outside of Layup 3 — we have identified incredible research potential for this project. Although spat grown in this location cannot leave Port Nelson, we could deploy these mussels throughout the port. The data generated will likely be a good candidate for the toolbox mentioned earlier for the Smart Ideas bid. Also, an interesting comparison would be to investigate the growth / filtering / bioaccumulation metrics of mussels hanging on frames (i.e. aquaculture) vs mussels growing on intertidal / shallow subtidal rock (i.e. natural habitat). Another interesting research focus would be to compare the biometrics of mussel spat at a Tasman Bay farm vs spat grown in Port Nelson. This study could be done by a master's or PhD student, which would add another collaborative partner (university).

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