Fisheries New Zealand

Tini a Tangaroa

A quantitative assessment of mussel nursery site performance in four geographical regions

New Zealand Aquatic Environment and Biodiversity Report No. 368

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PLAIN LANGUAGE SUMMARY

A single batch of mussel spat from Ninety Mile Beach was split among 15 marine farms across four regions (Banks Peninsula, Golden Bay, Coromandel, Marlborough Sounds) to measure differences in the retention (i.e., the number of mussel spat remaining on the farm) and growth of the mussel spat during a 5 month deployment.

By splitting a single batch of spat we reduced some of the variability that can make it hard to determine which are good farms for growing spat.

We found that some regions performed better than others although sometimes the performance of spat was highly variable within a region.

The next steps will be to assess the performance data alongside environmental data to try to understand what drives spat performance in New Zealand's mussel farming regions.

EXECUTIVE SUMMARY

South, P.M.; Delorme, N.J.; Ragg, N.L.C.; Thompson, K.; Wells N.; Taylor, D.I. (2025). A quantitative assessment of mussel nursery site performance in four geographical regions.

***New Zealand Aquatic Environment and Biodiversity Report No. 368.* 13 p.**

The results presented in this report detail the second of three major mussel spat-deployment experiments in Objective 2 of the Fisheries New Zealand project AQU2023-05 as undertaken by the Ahumoana o Aotearoa Spat Research Collective. The experiment was designed to assess variation in mussel spat performance among mussel farms across New Zealand to help determine optimal nursery farm sites and allow a characterisation of the environmental conditions that may affect the retention, growth and condition of the spat.

By deploying a single batch of spat collected from Ninety Mile Beach Te Oneroa-a-Tōhē into 15 mussel farms across four regions (Banks Peninsula, Golden Bay, Coromandel, Marlborough Sounds) using standardised seeding techniques, we aimed to reduce the background variability in spat size, age, condition and handling history that often confounds assessments of spat retention among mussel farms. This approach is unique in the research around spat retention both in its industry-relevant methodology and in the number of farm sites assessed. After deployments of 163 – 192 days depending on site, spat were sampled (10 × 50 cm samples per farm) and the number of spat per metre, the size of the spat, condition index (CI) and proximate composition (lipid, protein, carbohydrates, moisture and ash content) were quantified and analysed using routine methods. The number of blue mussels and the biomasses of animal (e.g., ascidians, hydroids) and seaweed biofouling were also quantified.

All metrics varied among sites, with some sites having better spat retention whereas others performed better in terms of the size and condition of the spat. Farms at Wainui in Golden Bay and Squally Point in Banks Peninsula had the greatest numbers of spat at the end of the experiment, while Pigeon Bay in Banks Peninsula had the largest mussels. Generally, the farms in Hauraki Gulf and one farm in Golden Bay had the poorest performance, especially in terms of the numbers of spat retained. Farms in Marlborough Sounds, the country's largest marine farming region, had significant levels of biofouling by blue mussels, seaweeds and ascidians, although the abundances of these varied from farm to farm, and often relatively poor retention, even in farms that have historically been considered to be good for farming spat.

By splitting a single batch of spat we reduced some of variability in spat condition and seeding practices that can make it difficult to determine good farms for growing spat. We found large differences among farms that suggest regional patterns in spat retention and growth. Further deployments of spat and predictive modelling will be used to verify and test these findings. Subsequent experiments and the incorporation of remotely sensed and locally collected environmental data, which is being analysed in Objective 3 of this programme, will allow for a fuller investigation of the drivers of mussel spat performance.

1. INTRODUCTION

Significant losses of spat during the first 4–6 months (nursery stage) of mussel aquaculture production are a major issue constraining the production and growth of the New Zealand mussel farming industry (Skelton et al. 2022; South et al. 2022). Identifying optimal spat nursery farms has therefore become a key priority for mussel farmers. Some mussel farms have historically been considered better than others for seeding and growing spat and have been favoured for spat deployments (South et al. 2022). While a few previous studies have suggested that factors including water motion and food availability are likely important determinants of spat performance, a detailed understanding of what factors or conditions are important for successful spat farms is yet to be achieved (Alfaro 2006; Hayden & Woods 2011; South et al. 2022). This understanding is hampered by high variability in the size and abundance of spat being seeded onto mussel farms, and in the methods (e.g., emersion duration, seeding density) used to deploy them among mussel-farming companies (Jeffs et al. 2018; Reyden et al. 2024). Furthermore, industry spat-seeding practices have possibly biased appraisals of mussel farms, because high quality batches of spat are more frequently seeded onto favoured farms, whereas poor quality spat can be assigned to perceived sub-optimal farms. It is therefore challenging to identify consistently good mussel farms for spat, let alone determine what it is about them that is beneficial for the spat.

The results presented in this report are from the second of three major spat-deployment experiments designed to assess variation in spat performance among mussel farms to determine optimal nursery sites and facilitate a wider assessment of their environments. By deploying single batches of spat into multiple mussel farms using standardised seeding techniques, we aimed to reduce the background variability that can confound assessments of relativity among mussel farms. This approach is unique in the research around spat retention both in its industry-relevant methodology (i.e., deployments of continuous dropper ropes) and in the number of farms assessed. Previous work has typically been at much smaller scale (2 – 3 farms), has typically addressed farms that were perceived to be good for spat, and has used experimental approaches such as frames, or small sections of rope making the results difficult to interpret in an industry-relevant context (South et al. 2019; Skelton & Jeffs 2021). This report focuses on variations in metrics of spat performance among farms and includes analyses of the number of spat per metre (retention), the size of the spat and two measures of condition: their meat to shell ratio (condition index [CI]) and their proximate composition (lipid, protein, carbohydrates, moisture and ash content). The data generated by this, and the subsequent experiments, will be coupled with remotely-sensed and locally collected environmental data (water temperature, chlorophyll, nutrients, currents) to develop a predictive model of spat retention as the programme progresses.

2. METHODS

2.1. Spat deployment

Fifteen spat farms across four spat growing regions (Table 1) were identified by the industry delegates of the Ahumoana o Aotearoa Spat Research Collective. Spat farm performance was determined using a single batch of spat obtained from Ninety Mile Beach Te Oneroa-a-Tōhē on 02/10/2024 and seeded onto the fifteen marine farms in accordance with industry best practices on 4/10/2024 (Banks Peninsula, Hauraki Gulf, Marlborough Sounds) and 05/10/2024 (Golden Bay) by the industry operators in the Ahumoana o Aotearoa Spat Research Collective. Three hundred metres of dropper rope were seeded at each spat farm with two 10-kg bags of seaweed and spat. Five samples (~100 g each) of seaweed and spat were assessed from ten of the fifteen sites to determine whether the spat resource was likely to have varied among sites. The seaweed and spat samples were frozen and sent to the laboratory where they were defrosted and a 10-g subsample was taken from each of the five bags. For each sample, the spat were washed from the seaweed using vigorous jets of water over a 100-micron sieve. The spat were then vacuum filtered onto a 45-µm glass fibre gauze and weighed immediately. Five subsamples (0.1 g) were then taken from each sample of spat and enumerated under a dissecting microscope with the mean abundance of these being used to estimate the total number of spat per sample. Temperature loggers were stowed with the spat from the packing shed to the mussel farm to assess temperature fluctuations during transit. Temperature loggers were deployed at 1 and 8 metres at each farm for the duration of the spat deployment.

Table 1: Farm details including their location, deployment date and sampling date.

Region	Site	Deployed	Time	Retrieved	Days	Months
Golden Bay	AMA 1 (d)	05/10/2024	08:30	17/03/2025	163	5.4
Golden Bay	AMA 2 (q)	05/10/2024	07:30	17/03/2025	163	5.4
Golden Bay	Wainui	05/10/2024	09:30	17/03/2025	163	5.4
Marlborough Sounds	Croisilles	04/10/2024	11:00	14/04/2025	192	6.4
Marlborough Sounds	Anakoha	04/10/2024	13:50	01/04/2025	179	6.0
Marlborough Sounds	Clova Bay	04/10/2024	12:05	01/04/2025	179	6.0
Marlborough Sounds	Schnapper Point	04/10/2024	10:20	01/04/2025	179	6.0
Marlborough Sounds	Saratoga	04/10/2024	15:45	01/04/2025	179	6.0
Marlborough Sounds	Port Underwood	04/10/2024	19:00	26/03/2025	173	5.8
Hauraki Gulf	Li.310E / Area 614-2	04/10/2024	07:45	27/03/2025	174	5.8
Hauraki Gulf	Pe.364W / Area 616-1	04/10/2024	09:15	27/03/2025	174	5.8
Hauraki Gulf	Li.402 / Area 617-1	04/10/2024	10:15	27/03/2025	174	5.8
Hauraki Gulf	Li.524 / Area 619-1	04/10/2024	11:20	27/03/2025	174	5.8
Banks Peninsula	Squally Bay PE740	04/10/2024	13:50	24/03/2025	174	5.8
Banks Peninsula	Pigeon Bay PE383	04/10/2024	20:40	24/03/2025	174	5.8

2.2. Sample collection and processing

Samples of spat were collected between 17/03/2025 and 14/04/2025 with deployment durations ranging between 163 days in Golden Bay to 192 days in Croisilles, Marlborough Sounds (Table 1). Most spat are typically lost in the first few weeks after they are deployed onto a marine farm (South et al. 2019), therefore variations in deployment duration were not likely to confound our tests of differences among sites. The spat were sampled by removing dropper ropes from the water and stripping replicate 50-cm lengths of rope of all organisms, which were retained for analysis (Figure 1). Five samples at one and five metres depth were taken at each farm, totalling 10 samples per farm for 150 samples in total. An additional 20 spat were sampled from the dropper rope directly above or below where the 50-cm sample was taken to provide spat for size, condition and proximate analysis.

Figure 1: Spat sampling. (A) removing the spat from the water at Port Underwood. (B) the spat at Port Underwood prior to sampling, (C) measuring the 50-cm length of dropper rope to be sampled, (D) sampling the mussel spat, (E) the sampled 50-cm length of dropper rope, and (F) a dropper rope showing bare rope where samples were taken at 1 and 5 metre depths.

Samples were processed to determine the number of green-lipped mussel spat per sample (then scaled to number per metre) and the size of the spat (shell length in millimetres). Ten spat per sample were measured when sufficient spat were present). Spat were processed for condition (proximate analysis, condition index [CI]) and biofouling abundance (dry weight fouling organisms). CI was calculated as the ratio of the dried tissue to dried shell-weight ratio, multiplied by 100 with greater values indicating more tissue and 'better' condition (Andrisoa et al. 2019). Proximate composition was analysed at 1 m only. Mussel spat for proximate composition analysis were shucked and the tissue was freeze-dried. Detailed methods for the laboratory analyses can be found in Delorme et al. (2020). There were insufficient mussels at AMA1 to assess their size, condition and biochemical composition.

Data were analysed using either permutational (number, size, condition), conventional (proximate composition) analyses of variance (ANOVA) or Kruskal-Wallis one way analysis of variance on ranks where data failed to meet assumptions of the statistical tests (proximate analyses). We analysed the effects of farm and depth on number, size, and condition of spat whereas we only tested for the effects of farm on the proximate composition of the spat. Permutational analyses were used because they have no assumption of normally-distributed data, despite yielding similar results to conventional ANOVA. Equality of variances among groups was tested with the permutations of dispersion (PERMDISP) function in PRIMER v6/PERMANOVA or with a Bartlett's test. Post hoc pairwise t-tests or Tukey's tests were used to assess differences among levels of important factors or their interactions. Spearman's Rank Correlation analysis was used to assess relationships between biofouling organisms (number per metre of *Mytilus galloprovincialis*, dry weight of animal fouling, and dry weight of seaweed fouling) and the number of *Perna canaliculus* per metre. Conventional ANOVAs and Spearman's Rank correlations were done in Sigma Plot 14.0.

3. RESULTS

The numbers of spat per 10 g of seaweed range from 16 816 to 64 349 with a mean value of 33 899 ± 15 481 SE per 10 g across samples (n = 49). There were no differences among samples detected by a one-way analysis of variance ($F_{9,42}$ = 2.0731, P = 0.057; Figure 2).

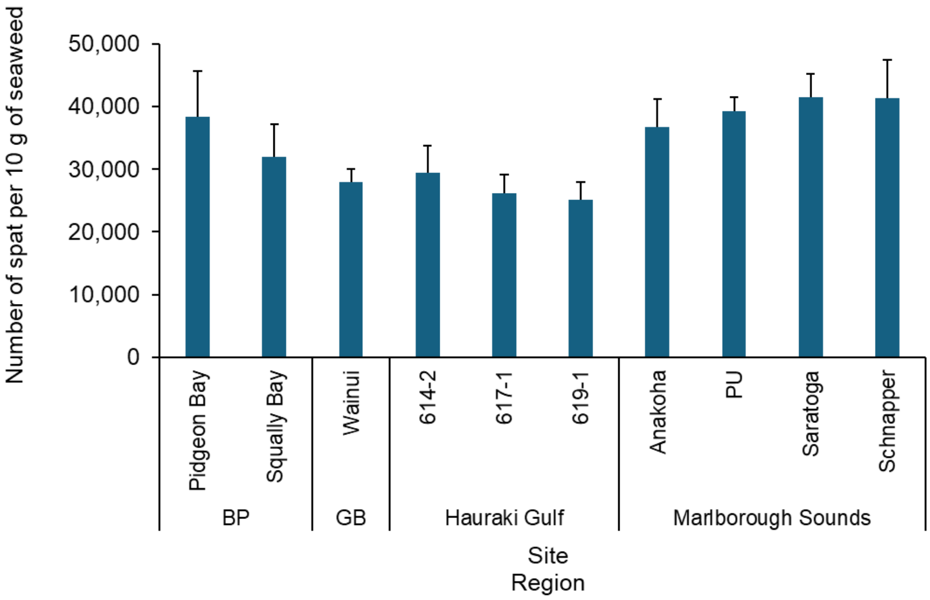

Figure 2: Mean (± SE) estimated number of spat per 10 g of seaweed deployed on 10 mussel farms.

The mean number of spat per metre (across depths) ranged from 26.2 (± 14.1 SE) to 1447.6 (± 65.3 SE) spat per metre at AMA1 and Wainui, respectively and was highly variable among farms (Figure 3A). The greatest numbers of spat were at Wainui, which was similar to that at Squally Bay in Banks Peninsula, which in turn was similar to the number of spat per metre at Pigeon Bay, AMA2 and Port Underwood in Banks Peninsula, Golden Bay and Marlborough Sounds, respectively. The sites with the lowest numbers of spat per metre were AMA1, all four of the sites in the Hauraki Gulf, followed by Saratoga and Clova Bay in Marlborough Sounds. There was also an overall effect of depth with more spat at 1 m, with significantly greater numbers of spat at 1 m in Pigeon Bay and Port Underwood.

The mean size of the spat varied among farms and depths (Figure 3B) with the mussels with the largest shell lengths (across depths) at Pigeon Bay (42.1 mm ± 0.3 SE) and the smallest at Croisilles (26 mm ± 0.7 SE). Overall, the mussels were generally larger at 1 m compared to at 5 m, although this pattern was not consistent among farms (Figure 2. For example, spat were smaller at 1 m in Wainui and Port Underwood. The greatest difference in shell length between depths was found at 619-1 in Hauraki Gulf where the spat were 44.4 mm (± 0.9 SE) at 1 m compared to 34.7 mm (± 1 SE) at 5 m.

The mean condition index (CI, tissue: shell ratio) values ranged from 9.6% (± 0.1.4 SE) to 18.9% (± 0.2.7 SE) at Saratoga and Pigeon Bay, respectively (Figure 3C). CI was highly variable among sites with mussels in better condition at Pigeon Bay and Squally Bay in Banks Peninsula and in Port

Underwood in Marlborough Sounds. Spat from 617-1 in Hauraki Gulf and Saratoga in Marlborough Sounds were in the poorest condition. There were occasional effects of depth on CI values although there were no consistent patterns across farms. At Farms 616-1 and Schnapper Point there was high variability in CI at 5 m.

Proximate composition of the mussel spat varied among the farms for all metrics (Figure 4). Protein content was greater at Saratoga than at 619-1 and Pigeon Bay. Carbohydrates were greater at Pigeon Bay compared to Saratoga and Clova Bay. Lipid contents were greater at Pigeon Bay, Squally Bay, and Clova Bay than they were at AMA2 and Wainui (Figure 4). Water content was greater at 617-1 than at Anakoha whereas ash-free dry weight was greater at Port Underwood than at 617-1, Saratoga, Wainui, and Clova Bay.

The mean number of blue mussels that had settled onto the dropper ropes at the end of the nursery period ranged from 0 at 614-2 to 1801.4 (± 384.6 SE) in Croisilles (Figure 5A). All of the farms in Marlborough Sounds, except for Port Underwood, had significantly more blue mussels than in the other regions. All sites outside of the Marlborough sounds had around or fewer than 100 blue mussels per metre. In Croisilles, there was a significant effect of depth with greater numbers of blue mussels at 1 m compared to at 5 m. Across all farms there was a significant positive correlation (r = 0.2, $p < 0.05$) between the numbers of green and blue mussel spat per metre. However, this pattern was not consistent when the region with the greatest numbers of blue mussels (Marlborough Sounds) was analysed separately, as there was a weak, non-significant (r = -0.002, $p > 0.05$) relationship between the numbers of blue and green spat. There was also a significant negative correlation between the number of blue mussels and the mean size of the green spat in each sample across all farms although the relationships were not significant when the region and farms with the most abundant settlement of blue mussels were analysed separately.

The mean biomass of animal biofouling that had settled onto the dropper ropes at the end of the nursery period ranged from 0 g DW (dry weight) at Schnapper point to 5.06 g DW (± 1.8 SE) in Port Underwood (Figure 5B), where most of this animal fouling was found at 5 m. The type of animal fouling varied among farms and regions with the animal fouling community being dominated by hydroids in Banks Peninsula, a mixed assemblage of worms, hydroids and ascidians in Golden Bay and Hauraki Gulf, and colonial ascidians in Port Underwood. There was a weak but positive correlation (r = 0.02, $p < 0.05$) between the number of green mussel spat and the dry weight of animal biofouling across all farms. At Port Underwood there was a significant negative correlation (r = -0.66, $p < 0.05$) between the abundance of animal biofouling and the number of green mussel spat per metre. Across all farms, there was a significant positive correlation (r = 0.29, $p < 0.001$) between the dry weight of animal biofouling and the mean size of the green mussel spat.

The mean biomass of seaweed biofouling that had settled onto the dropper ropes at the end of the nursery period ranged from 0 g DW at AMA1 to 9.8 g DW (± 2.5 SE) in Clova Bay, where the seaweed biomass was consistent between depths (Figure 5B). Biofouling seaweeds were generally small red algae such as *Polysiphonia* spp., *Ceramium* spp. and *Laurencia distichophylla,* small amounts of bubble weed *Colpomenia* spp. or *Ulva* spp. However in Clova Bay and Saratoga in the Marlborough Sounds the seaweed assemblage was dominated by *Cladophora ruchingeri* (horsehair). There was a significant negative correlation (r = -0.38, $p < 0.01$) between the number of green mussel spat and the dry weight of seaweed biofouling across farms in the Marlborough Sounds although there were no significant correlations between the number of green mussel spat and the dry weight of *C. ruchingeri* at Clova Bay and Saratoga where this green seaweed was highly abundant. There was a significant relationship (r = -0.2, $p < 0.05$) between seaweed biofouling across all farms and the mean size of the green mussel spat in each sample, although this relationship weakened when farms in the Marlborough Sounds were analysed separately (r = -0.2, $p > 0.05$).

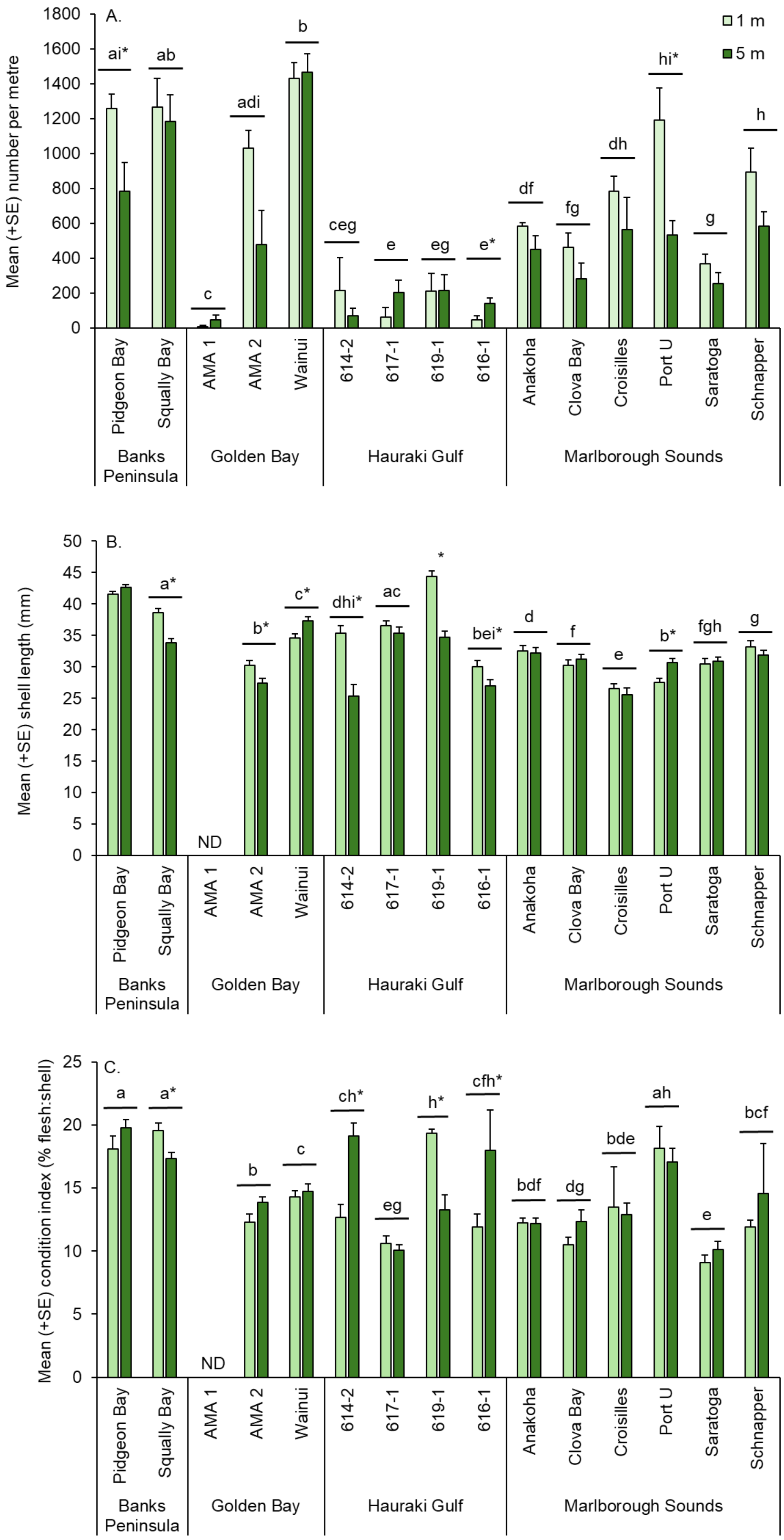

Figure 3: A: Mean (+SE) number of green-lipped mussel spat per metre at 15 farms, B: size (shell length in mm) and C: condition index of spat at two depths (1 m and 5 m) after a nursery deployment (5.4 – 6 months depending on farm). ND indicates farms for which there are no data due to low numbers of mussels. Asterisks indicate differences between depths within a farm. Different letters above bars indicate significant differences among farms (pooling across depths) indicated by post-hoc pairwise t-tests.

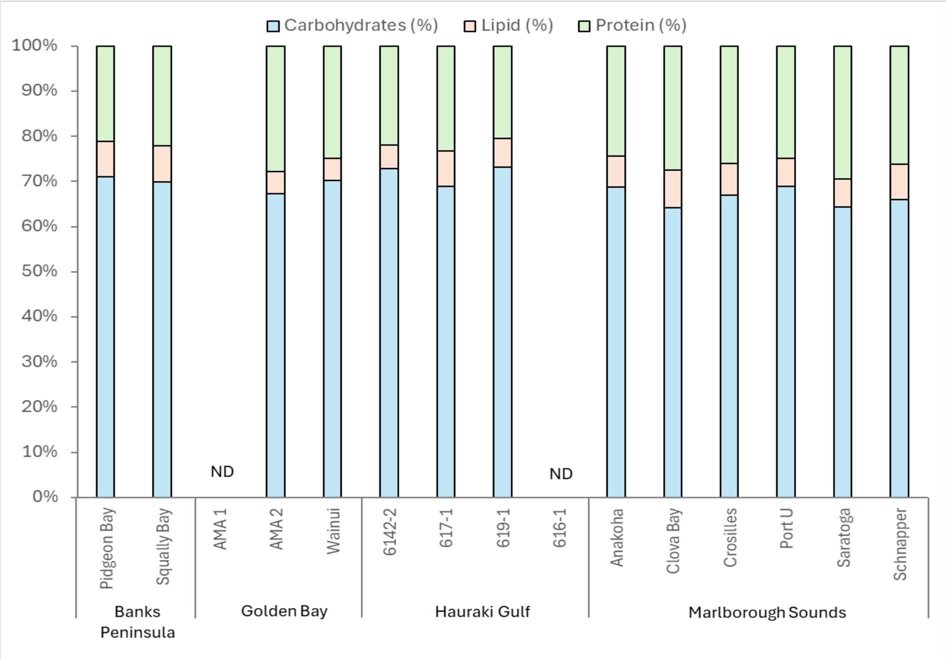

Figure 4: Mean proximate content (%) of carbohydrates, lipids and protein for spat at 1m depth from 15 farms across New Zealand. ND indicates farms for which there are no data due to low numbers of mussels.

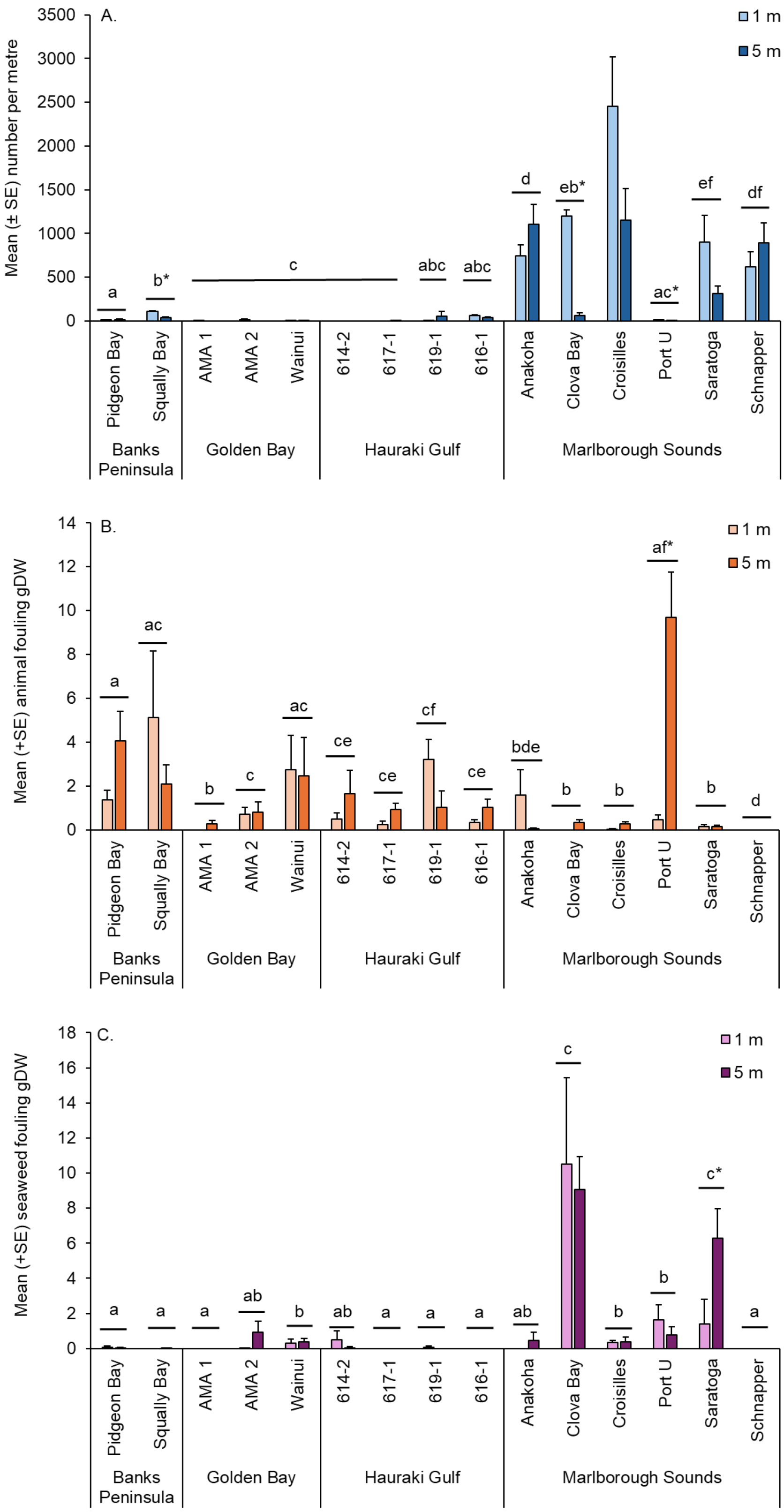

Figure 5: A: Mean (+SE) number of blue mussel spat per metre, B: dry weight biomass of animal biofouling, and C: dry weight biomass of seaweed biofouling at two depths (1 m and 5 m) after a nursery deployment (5.4 – 6 months depending on farm). Asterisks indicate differences between depths within a farm. Different letters above bars indicate significant differences among farms (pooling across depths) indicated by post-hoc pairwise t-tests.

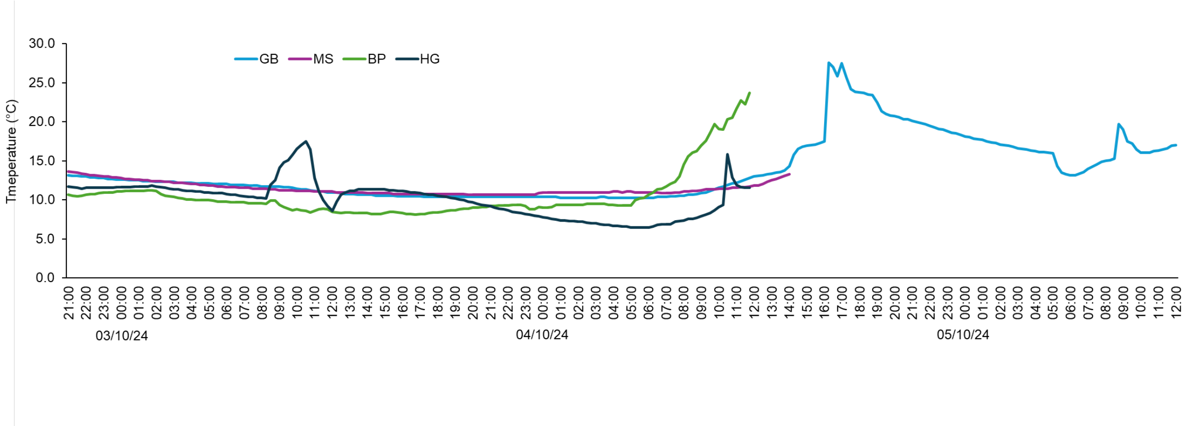

Figure 6: Temperature (°C) of containers containing spat during transit from Ninety Mile Beach to four mussel farming regions across New Zealand. GB: Golden Bay; MS: Marlborough Sounds; BP: Bay of Plenty; HG: Hauraki Gulf.

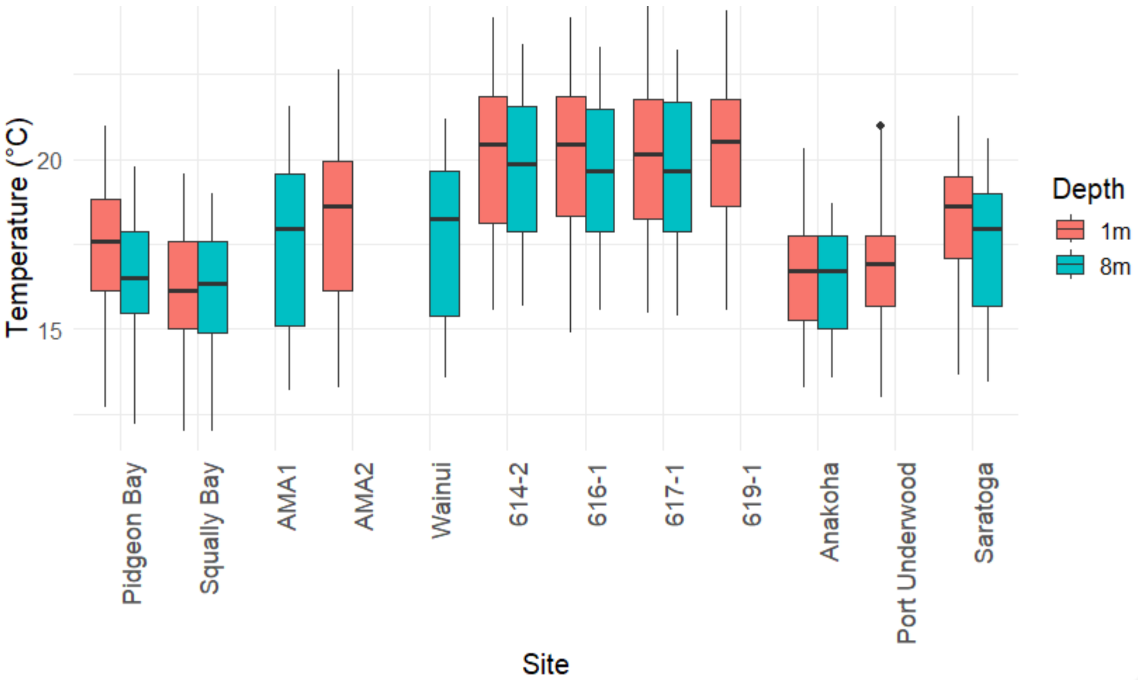

Figure 7: Temperature (°C) at 1 and 8 metres in 12 mussel farms across New Zealand. Note some loggers failed or were lost at some farms. Horizontal lines in boxes show the medians, box edges define the inter-quartile ranges, upper and lower whiskers represent the maximum and minimum temperatures, respectively.

The temperatures of the containers holding the spat remained relatively stable during transit from the point of collection to the mussel farm sites although there was a temperature spike over around two hours on the 3/10/2025 when the spat were being transported to Hauraki Gulf (Figure 6).

A qualitative assessment of the water temperature data (Figure 7) indicated that water temperature was higher in the Hauraki Gulf compared to the other regions. In Hauraki Gulf, the median water temperature was around 20°C during the spat deployment, regardless of depth. The coolest farms were in Port Underwood, and Banks Peninsula where median water temperatures were around 16–17°C.

4. DISCUSSION

This is the first comprehensive assessment of spat performance among mussel farms across regions in New Zealand. The performance of this single batch of spat in terms of its abundance (number per metre), size (shell length in millimetres), condition (tissue: shell ratio) and proximate composition was generally variable among farms. The data indicate that there are strong regional differences in spat performance, for example, the number of spat per metre retained at farms in Hauraki Gulf was generally lower than that in other regions, while the spat at both farms in Banks Peninsula had high numbers of spat that were large in size and were in better condition than in most other farms and regions. In Golden Bay, and to a lesser extent in Marlborough Sounds, there was high variability within the regions. For example, there was a clear gradient in the number of spat per metre from AMA1 to Wainui, which had the least and greatest numbers of spat retained across all farms in this study.

Blue mussels were a conspicuous biofouling organism in Marlborough Sounds and were abundant at all farms except for at Port Underwood with their greatest abundance being around 2500 per metre at 1 metre depth in Croisilles. At Croisilles, green-lipped mussel spat were the smallest recorded across the study, perhaps due to competition for food with the significant numbers of blue mussels although there were no significant correlations to support this hypothesis. Another significant biofouling organism in this study was the green alga *Cladophora ruchingeri* which was highly abundant at Clova Bay and Saratoga in the Marlborough Sounds although there was no significant relationship between the biomass of this species and the number or mean size of the mussel spat at these farms. We also note that seaweed fouling was low at these farms in year 1 of the programme, when the spat also performed poorly in these locations. By contrast, it is possible that animal biofouling (*Aplidium* spp.) impacted spat retention at lower depths in Port Underwood given its high abundance, although an alternative possibility is that losses of spat at greater depths freed space for the ascidians to colonise the ropes.

Spat performance at nine of the farms in Golden Bay and the Marlborough Sounds in this study were also assessed in year 1 of AQU2023-05 (South et al. 2024) There were some similarities between years in that Port Underwood was the best performing Marlborough Sounds farm in terms of spat abundance although the mussels were generally smaller in both years. Schnapper Point also performed consistently well in both years, which is surprising given that industry delegates had considered this to be a poor site for farming spat. In both years, Schnapper Point had similar numbers of spat retained to Croisilles, which was considered to be a good site for growing spat. In year 1 of the programme, the seeded spat were lost at Wainui and Anakoha, both sites that were considered good for growing spat. Wainui was among the best performing farms in year 2 of this programme, where the abundance of spat was only equalled in Squally Bay in Banks Peninsula. Anakoha, however, had fewer spat per metre than Schnapper Point and Port Underwood, was similar to Clova Bay and Croisilles, and only had greater numbers of spat per metre than Saratoga, a site that has been deemed poor by the industry and was one of the worst performing sites in the year 2 deployment.

The results presented in this report pertain to Objective 2 of the Fisheries New Zealand project AQU2023-05. While they are not presented in this report and are currently being processed and analysed, the Ahumoana o Aotearoa Spat Research Collective has also collected environmental data (turbidity, temperature, chlorophyll-a) at a subset of the sites which are being coupled with satellite derived data, and the data collected in this and South et al. 2024 (e.g., biofouling abundance) to develop of a predictive model for spat performance in Objective 3 of this programme.

5. FULFILMENT OF BROADER OUTCOMES

Building Capacity & Capability

This programme has fulfilled its broader outcome of **building capacity & capability** in its second year due to the success of the highly collaborative and interactive engagement across aquaculture industry and research organisations leading to the Ahumoana o Aotearoa Spat Research Collective effectively carrying out the largest spat retention experiment done to date in this country. The committed and collaborative approach to deploying the spat in a highly standardised manner, sharing data, know-how and resources such as farm space, vessel time, and personnel has established an important precedent for collaborative research required to address the most significant production issues in mussel aquaculture. Ahumoana o Aotearoa Spat Research Collective continues to engage with its members and the wider aquaculture community as it develops workstreams for year three of this programme.

6. ACKNOWLEDGEMENTS

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