National SCIENCE Challenges

SUSTAINABLE SEAS

Ko ngā moana whakauka

Kohunga Kūtai: Creating a sustainable supply of seed mussels using mātauranga Māori

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Report

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About this report

This report outlines results from the final part of a project to apply mātauranga Māori to develop an effective product for capturing and on-growing mussel spat on mussel farms using biodegradable fibres from native plants.

The results from this research show that natural fibre ropes produced from harakeke and the tī kōuka can catch spat and sustain long-term deployment at sea. With improvements to manufacturing processes, and design characteristics (e.g., increased physical complexity of natural fibre ropes) these natural fibre ropes, particularly the tī kōuka, could replace plastic mussel ropes for processes such as spat catching in the Greenshell™ production cycle.

Cover image: Taura (rope) woven woven from muka by Ngāti Whātua o Ōrākei weavers who have harvested their harakeke to use for holding kuku for experimental restoration deployments in their rohe at Ōkahu Bay

Introduction: Biodegradable alternatives could exist to plastic ropes on Greenshell™ mussel farms

Greenshell™ mussels (kuku or kūtai) are grown in sheltered coastal locations throughout New Zealand, where they dominate the country's aquaculture sector and serve as an important source of kaimoana. To begin production, each year the Greenshell™ industry deploys thousands of kilometres of fibrous plastic ropes into the sea to catch and on-grow the juvenile seed mussels (also known as "spat") that are used to stock their farms (Figure 1). However, in recent years, concern has increased about the fate of lost plastic ropes, and the small fragments of plastic fibres that are shed from the ropes into the sea, which may contribute to the accumulation of microplastics in coastal waters (Arantzamendi et al., 2023). There is growing scientific evidence of the persistence and negative environmental effects of plastic particles in marine ecosystems.

Figure 1 Photograph of cut loop spat catching rope that is often deployed by Greenshell™ farmers to catch the seed mussels used to stock their farms. The physical characteristics of the spat rope that are known to attract mussel larvae (i.e., fine, fibrous strands) can be replicated using natural fibres, which do not shed plastic fragments into the environment.

A possible solution to this problem is to develop biodegradable alternatives as a replacement for the plastic ropes currently used on Greenshell™ mussel farms (Paul-Burke et al., 2018). In this instance, it appears that mātauranga Māori may have a ready solution. Greenshell™ mussel larvae are known to be attracted to settle and attach strongly to native plant fibres, such as harakeke and tī kōuka, when placed in the sea. Plant fibres with a range of qualities are highly prized by Māori, for their wide range of uses, from finger weaving of fine fabric to the production of heavy-duty anchor ropes and waka lashings. Individual plants with unique fibre properties are prized and often replanted into protected areas for safe keeping, such as in flax gardens (pā harakeke). This unique botanical resource and its associated mātauranga Māori is a valuable resource with outstanding potential to provide a uniquely Indigenous solution as an alternative to plastic for catching and on-growing spat for mussel aquaculture.

To this end, the goal of this project is to apply mātauranga Māori to develop an effective product for the capture and on-growing of mussel spat on mussel farms using biodegradable fibres sourced from native plants. The first component of this research was to pre-screen a wide variety of available plant fibres to compare their extraction, preparation, characterisation, and durability when submerged in seawater, so that the best performing fibres could be identified and used for further trials on their spat-catching performance. The results from this initial research (Skelton et al., 2021) demonstrated that fibres extracted from harakeke, tī kōuka, and pampas were the best performing plant fibres, and so the fibres from these three species were progressed for further testing.

The final component of this project was to determine the relative spat-catching performance of these two natural fibres in two different formats, and then to subsequently determine the performance of these fibres when seeded alongside plastic mussel rope onto a mussel farm in the Coromandel.

Methods: multiple trials tested potential of natural fibre ropes

Fibre extraction, rope manufacturing, and deployment

Initial work handling harakeke, tī kōuka, and pampas to fabricate mussel settlement structures found that pampas was difficult to work with because the fibres once separated rapidly, became brittle, and would break easily if folded, unlike both harakeke and tī kōuka, which remained flexible. Consequently, the work focused solely on harakeke and tī kōuka as the pampas would be unsuitable for any further development for large scale processing for an applied product.

An initial set of experimental natural fibre ropes made from harakeke and tī kōuka were hand manufactured by Ngāti Manuhiri. These ropes consisted of two traditional weaving designs for each of harakeke and tī kōuka, including a three-way plait with splayed loose fibre ends and a three-way plait for which the surface was combed with a wire carding brush to generate additional fibre attachment points for settling mussels (Figure 2). Ten metres of each design of rope was prepared and the ropes were then deployed by looping each rope over a polyethylene holding rope and lashing three replicates of each design along a single backbone line on the spat catching farm in Aotea Harbour in late September 2022. Unfortunately, these natural fibre ropes were deployed too late in the spat settlement season and failed to catch any useful quantity of mussel spat. The ropes were held in place into summer in the hope they would catch spat at the start of the summer spat catching season. However, with the warmer summer water temperatures they began to disintegrate, precluding their use for any further testing.

Figure 2 Photographs of the natural fibre ropes manufactured by Ngāti Manuhiri before being deployed on the spat catching farm in Aotea Harbour (left – harakeke, right – tī kōuka).

A second set of experimental natural fibre ropes were prepared with the Muriwhenua aquaculture class at Northtec in Kaitaia on 7 March 2023. These consisted of fibres separated from harakeke and tī kōuka using traditional methods of combing and scraping the leaves to release the fibres. The fibres were then fabricated into two different designs, hand twisted and plaited, producing three replicates of 3m length for each design. These ropes were deployed at a commercial spat catching site in Whangapē Harbour on 11 March 2023. Individual replicate ropes were lashed as 0.5m spacings along a weighted subsurface line that ran 1 m below the surface. Upon checking the lines two weeks later, all the ropes were found to have been shredded, with observations from staff at the spat catching site indicating the ropes had been attacked by fish (parore) and pulled apart, possibly as they attempted to feed on spat settling on the ropes. Parore are known to actively feed on mussel farm dropper ropes after being seeded out with spat on mussel farms in the Hauraki Gulf.

A third set of experimental natural fibre ropes made from harakeke and tī kōuka were manufactured by the University of Auckland and deployed on the mussel spat farm in Aotea Harbour in April 2023. These fibres consisted of fibres separated from harakeke and tī kōuka using the traditional methods described above. The fibres were then fabricated into the two different designs, a thin twine, and a thick plaited rope, producing three replicates of 3m for each fibre and design. Each replicate of thin twine was then wrapped around individual rectangular plastic frames (10 × 30 cm), which had a 2.5kg lead dive weight tied to one end. The individual replicate frames were then lashed to the backbone line of the spat catching farm in February 2023, along with the 3m replicate lengths of thick plaited rope, each of which were weighed down with a 2.5kg dive weight. Unfortunately, despite catching mussels these fibres were destroyed in a storm in early May, with only small, unusable fragments remaining (Figure 3), and were therefore, not used in subsequent testing.

Figure 3 Photograph of fragments of thick plaited fibres remaining after the storm in May 2023 showing they successfully caught and retained mussel spat (left) and a photograph of the remains of a large plastic frame that was used to deploy the thin twine fibre ropes that was destroyed by the storm in early May 2023 (right).

A fourth set of natural fibres ropes made from harakeke and tī kōuka were manufactured by the University of Auckland and deployed on the mussel spat farm on 20 May 2023. These ropes consisted of a 10m length of polypropylene rope (5mm diameter), with small bundles of each fibre twisted into the rope at 10cm intervals, producing three replicates for each fibre. Each of these replicate ropes were then lashed directly to the backbone lines of the spat farm, with a 2.5kg lead dive weight tied to one end. The natural fibres that were twisted into the polypropylene rope did not remain attached to the rope and were likely washed away in the high current of Aotea Harbour, with only a few small clumps remaining. As a result, there was insufficient natural fibre material remaining twisted into the ropes to enable further testing.

A fifth set of natural fibre ropes were manufactured by the University of Auckland and deployed on the mussel spat farm in Aotea Harbour on 1 June 2023. Four different natural fibre ropes were manufactured using two types of fibre and two designs: harakeke plain, harakeke “fluffy”, tī kōuka plain, and tī kōuka “fluffy”. Each rope was manufactured by first extracting green fibres from harakeke or tī kōuka leaves by combing them with a dog hair comb, before passing the separated fibres into heavy duty wool carding machine which further separated and aligned the plant fibres. The carded fibres were then twisted into a single strand using as repurposed wool spinner, to form a single strand of twisted rope. Two of these single strands were then fed back through the spinner with a reversed twist, to produce a two-strand twisted rope. The “fluffy” rope designs were prepared by running a serrated knife along the ropes to loosen strands to ensure the rope more closely resembled spat-catching rope used by the Greenshell™ industry. In total, over 10m of rope was produced for each plant species and each of the two designs.

Each of the four natural fibre ropes were then wrapped around four strong rectangular plastic frames (10×30cm) and the ropes secured in place on the frames with cable ties ready for deployment at the spat catching farm in Aotea Harbour on 1 June 2023. Each frame was then lashed to the backbone lines of the spat catching farm and weighed down with a 2.5kg lead dive weight (Figure 4). A corresponding 7m length of new looped plastic spat-catching rope (Quality Equipment Ltd,

R50QE#LS#3L) was deployed at the same time and weighed down with a 2.5kg lead dive weight. After 66 days in the water, the natural fibre ropes were retrieved from the mussel spat catching farm and transported to the Coromandel for seeding out. At the time of retrieval, the harakeke fluffy rope had disintegrated leaving only enough material to estimate the number of spat that had settled onto the rope in Aotea Harbour, and not enough material for seeding in the Coromandel. The ropes made from tī kōuka appeared to be in better condition than the harakeke rope and retained their tensile strength, whereas the harakeke ropes were able to be teased apart more easily.

Figure 4 Photograph of a replicate of "fluffy" harakeke natural fibre rope wrapped around a plastic frame before being deployed on the mussel spat farm in Aotea Harbour.

Seeding of natural fibres

Following their retrieval from the spat catching farm in Aotea Harbour on 17 August 2023, the natural fibre ropes and plastic mussel rope were loaded into a cool, damp insulated container and transported to the Coromandel overnight for seeding out the following day. The seeding process involved wrapping 0.5m lengths of the natural fibre rope around 0.25m sections of new plastic mussel growing rope (R50QESL#MBB, Quality Equipment Ltd), before being encased in a protective cotton stocking (i.e., mussock) and cable tied at each end. In total, nine replicate lengths of seeded plastic mussel rope were prepared for each of the remaining fibre and design combinations (i.e., harakeke plain, tī kōuka plain, and tī kōuka fluffy) as well as nine replicate 0.25m lengths of spat-covered plastic mussel rope to serve as a control. Three replicates of each fibre and design as well as three replicates of spat-covered plastic mussel rope were then attached at random positions along each of three 5m polypropylene dropper ropes using stainless-steel shark clips. The three dropper ropes were then lashed to the backbone lines of a mussel farm south of Whanganui Island, in the Coromandel Harbour (Figure 5), each weighed down by a 2.5kg lead dive weight tied to one end.

An additional 1.5m of each natural fibre rope and mussel spat rope was retained at the time of seeding out and analysed to determine the initial number of spat that had settled onto the ropes in Aotea Harbour and the dry weight of the fibres using the methods described below.

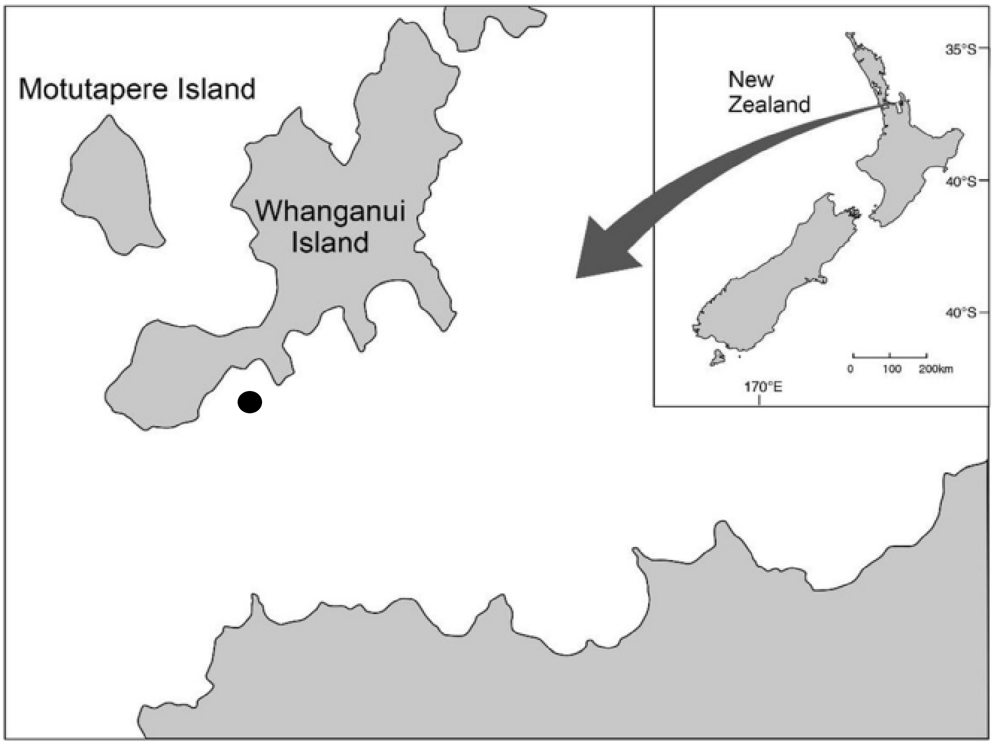

Figure 5 Map showing the location of the Coromandel Peninsula and the sheltered coastal location of the mussel farm located to the south of Whanganui Island, near the entrance to the Coromandel Harbour where the spat lines were deployed.

Sampling

After 32 days in the water at the mussel farm at Whanganui Island, the three dropper ropes were retrieved from the mussel farm and transported to the laboratory in Auckland for analysis.

Spat counts and size

The 1.5m sections of rope retained after deployment in Aotea Harbour were cut into short (0.25m) sections for analysis. Spat that had settled onto the ropes were washed off and onto a 200 µm sieve. The spat were then spread evenly in a large petri dish (14cm diameter) and counted in five randomly selected 4cm2 subsamples. The resulting counts were then multiplied to estimate the total number of spat remaining per metre of rope.

For each dropper that was recovered from the mussel farm at Whanganui Island, each short section of seeded rope was detached, and the stocking material and any remaining natural fibre rope removed. Any remaining mussel spat were then carefully washed off the plastic mussel rope, the stocking material and the natural fibre rope and onto a 200µm sieve. The spat were then spread evenly in a large petri dish (14cm diameter) and counted in five randomly selected 4cm2 subsamples. The resulting counts were then multiplied to estimate the total number of spat remaining per metre of plastic mussel rope. In addition, a random sample of 25 spat from each natural fibre species and design, and from the control plastic ropes, were photographed under a dissecting microscope and measured using image analysis (ImageJ Software). The remaining natural fibre ropes that were recovered from the droppers were then dried in a drying oven at 50◦C for 24h and subsequently weighed.

Statistical analyses

The mean number and size of spat attached per each metre of rope was compared among sampling events, species of fibres, and designs using separate three-way analyses of variance (ANOVA). The mean dry weight of fibre remaining was compared among sampling events, fibres, and designs using a three-way ANOVA.

The assumptions for ANOVA were checked by examining the distributions of residuals, and plots of individuals versus means, and where necessary, data were transformed appropriately prior to analysis. For each ANOVA, where there were significant main effects detected, pairwise Tukey HSD post hoc tests were used to identify differences among means.

Results: Natural fibre ropes are suitable for catching Greenshell™ mussel spat

Spat retention

After being deployed in Aotea Harbour for 77 days, the mean number of spat that had settled onto the ropes was 56 spat m-1 (± 24 SE), 51 spat m-1 (± 24 SE), 87 spat m-1 (± 19 SE), 35 spat m-1 (± 22 SE), and 1,349 spat m-1 (± 233 SE) in the harakeke plain, harakeke fluffy, tī kōuka plain, tī kōuka fluffy, and control spat ropes, respectively (Figure 6). By the end of the experiment, after 32 days in the water in the Coromandel, the mean number of spat remaining attached to each short section of rope had increased to 478 spat m-1 (± 74 SE), 605 spat m-1 (± 178 SE), 571 spat m-1 (± 174 SE), and 2,357 spat m-1 (± 326 SE) in the harakeke plain, tī kōuka plain, tī kōuka fluffy, and control spat ropes, respectively.

The mean number of spat attached to the ropes was not consistent between sampling events ($F_{1, 52} = 25.2$, $P < 0.01$) or between species of fibres ($F_{2, 52} = 55.7$, $P < 0.01$), but was consistent between designs ($F_{1, 52} = 0.03$, $P = 0.85$). Post-hoc Tukey tests indicated that the mean number of spat attached to the ropes was significantly higher at the end of the experiment than it was at the outset ($P < 0.01$), and that the control plastic mussel ropes had higher numbers of spat attached than both the harakeke ($P < 0.01$) and tī kōuka ($P < 0.01$) ropes. The interaction between sampling event, species of fibre, and design was not significant ($F_{1, 52} = 0.43$, $P = 0.51$).

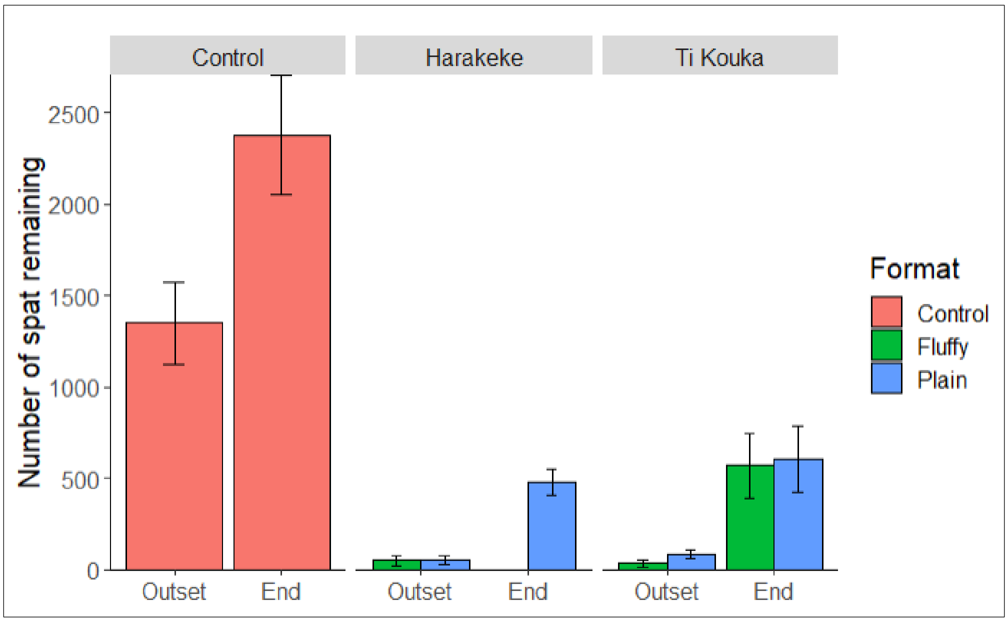

Figure 6 Mean (± SE) number of spat remaining per metre of rope for each fibre and format at the outset and end of the experiment.

Spat size

After 32 days in the water at the mussel farm near Whanganui Island, the mean size of spat had reduced from an initial size of:

- 1.78mm (± 0.12 SE) to 0.82mm (± 0.05 SE) mm on the harakeke plain ropes
- 1.65mm (± 0.15 SE) to 0.8mm (± 0.07 SE) mm on the tī kōuka plain ropes
- 1.82mm (± 0.2 SE) to 0.82mm (± 0.08 SE) on the tī kōuka fluffy ropes.

In contrast, the mean size of spat on the control plastic mussel ropes increased from 1.46mm (± 0.12 SE) to 1.74mm (± 0.1 SE). The mean size of spat caught on the harakeke fluffy ropes in Aotea Harbour was 1.35mm (± 0.08 SE) (Figure 7).

The mean size of spat attached to the ropes was not consistent among species of fibres between sampling events (sampling event × fibre interaction, $F_{2, 191} = 35.5$, $P < 0.01$), or between designs among fibres (format × fibre interaction, $F_{1, 191} = 12.1$, $P < 0.01$). Post-hoc Tukey tests indicated that the mean size of spat remaining attached to the control ropes at the end of the experiment were significantly larger than those attached to the harakeke ropes ($P < 0.01$), and tī kōuka ropes ($P < 0.01$). Furthermore, there was no difference in the mean size of spat attached to the control ropes at the outset and end of the experiment ($P = 0.27$), but the mean size of spat attached to the ropes at the end of the experiment was significantly smaller than at the outset for both the harakeke ($P < 0.01$) and tī kōuka ropes ($P < 0.01$). Post-hoc Tukey tests also indicated that at the end of the experiment the mean size of spat attached to the plastic mussel spat ropes was larger than those attached to harakeke plain ($P < 0.01$), harakeke fluffy ($P < 0.01$), tī kōuka plain ($P < 0.01$) and tī kōuka fluffy ($P < 0.01$) ropes. The interaction between sampling event, species of fibre, and design was not significant ($F_{1, 191} = 2.76$, $P = 0.09$).

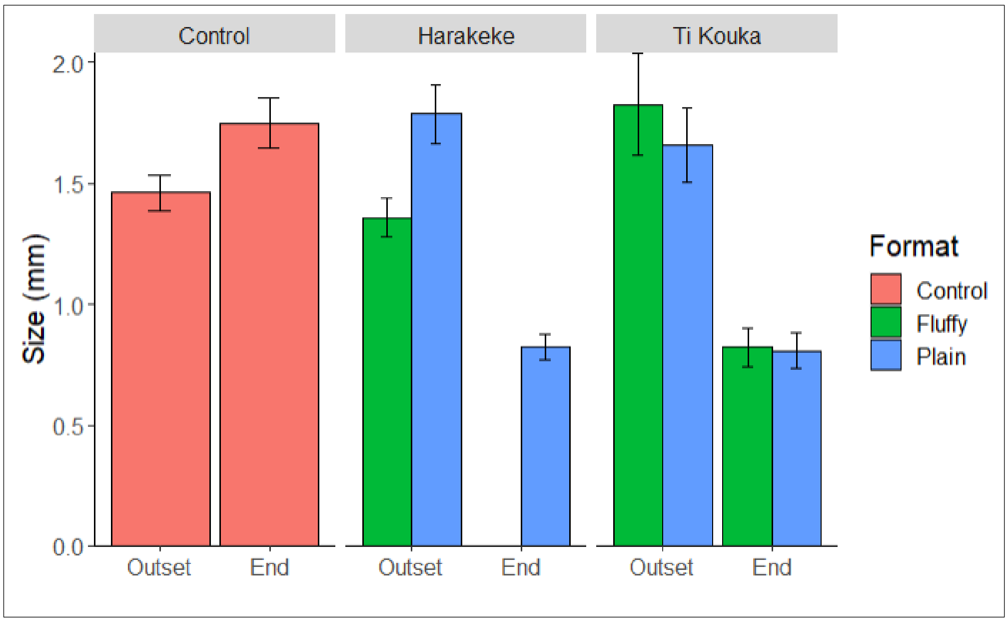

Figure 7 Mean size (mm ± SE) of mussel spat attached to each type of rope at the outset and end of the experiment.

Fibre breakdown

After 32 days in the water on the mussel farm at Whanganui Island, the mean dry weight of fibre remaining had increased from an initial dry weight of 8.6g m-1 (± 0.88 SE) to 9.2g m-1 (± 0.34 SE) in the tī kōuka plain ropes, and reduced from 12.7g m-1 (± 0.70 SE) to 10.5g m-1 (± 0.35 SE) for the tī kōuka fluffy ropes, and from 7.0g m-1 (± 0.2 SE) to 5.0g m-1 (± 0.30 SE) in the harakeke plain treatment. The mean dry weight of the harakeke fluffy fibres at the outset of the experiment was 9.4g m-1 (± 0.87 SE) (Figure 8).

The mean dry weight of fibre remaining was not consistent between designs within sampling events (design × sampling event interaction, $F_{1, 40} = 4.89$, $P = 0.03$), or between designs within fibres (design × fibre interaction, $F_{1, 40} = 4.67$, $P = 0.03$). Post-hoc Tukey tests indicated that at the end of the experiment, the mean dry weight of remaining fluffy ropes was significantly higher than that of the plain ropes ($P < 0.01$), and that in the case of the tī kōuka fibres, fluffy formats weighed significantly more than plain designs ($P < 0.01$). The three-way interaction between sampling event, fibre, and design was not significant ($F_{4, 40} = 2.14$, $P = 0.15$).

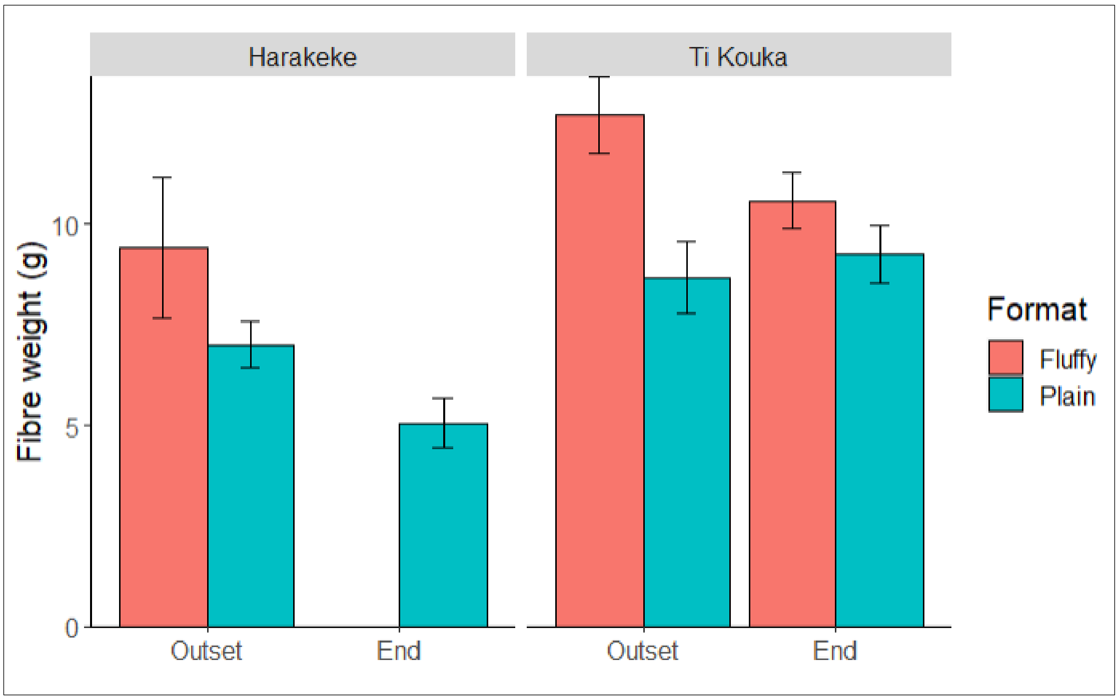

Figure 8 Mean dry weight (g m^{-1} ± SE) of fibres remaining at the outset and end of the experiment.

Discussion — natural fibre rope could be adopted by industry for sustainability or regulatory reasons

Spat catching in Aotea Harbour

The results from this study demonstrate that, although they caught fewer spat than plastic mussel spat ropes, natural fibre ropes are suitable for catching Greenshell™ mussel spat. This finding is consistent with work conducted elsewhere that has found that mussel spat will readily settle onto a range of natural fibres including cocoa fibre, esparto grass (Stipa tenacissima), sisal, and coir (Nayar & Mahadevan, 1980; Petrocelli et al., 2021; Paul-Burke et al., 2018; Paul-Burke et al., 2022; Ompi et al., 2023). The lower spat catches on the natural fibre ropes measured in this study are unsurprising given the differences in the overall rope diameter (i.e., 5 versus 12 mm core) and surface area, with the plastic mussel spat catching ropes having far greater overall surface area available for spat to settle. Furthermore, previous research has demonstrated that individual harakeke and tī kōuka fibres catch spat at similar rates to individual plastic fibres suggesting that if the natural fibre ropes had similar dimensions to the plastic ropes, it's possible that they could have caught spat at similar rates (Skelton et al., 2021).

Among the natural fibre ropes and designs, there were no differences in the number of spat caught, suggesting ropes manufactured from both harakeke and tī kōuka are equally suitable for catching mussel spat. Furthermore, the lack of a difference in spat catches among natural fibre ropes of different designs (i.e., plain, or fluffy) would appear to suggest that any differences in the structural complexity of the rope designs is insufficient to result in differences in spat settlement.

The similar size of spat caught on the ropes in Aotea Harbour suggests that each rope caught spat from the same cohort, and that the differences in physical complexity between rope formats were not great enough to catch spat of different sizes as might be expected. Greenshell™ spat display ontogenetic preferences for settlement substrate, preferring to settle on finely branching filamentous materials while small, before shifting to coarser substrates as they get bigger (Buchanan & Babcock, 1999; Skelton & Jeffs, 2020). Given that the size of spat attached to the ropes after being deployed in Aotea Harbour were of similar sizes, it's possible that the structure of the ropes was complex enough to catch primary settlers and retain them as they grew. It's also possible that only one pulse of mussel larvae entered Aotea Harbour and were available to settle onto the ropes during the period that the ropes were deployed.

Post-seeding increases in spat densities and decreases in spat size

Following their deployment in the Coromandel, all fibres caught additional spat. This result is unusual as in most instances, following seeding out, substantial losses of spat from their seeding substrate take place. These results indicate that there was a local settlement of mussel spat in the Coromandel while the experiment was deployed, which has been confirmed by anecdotal reports from farmers, and by industry monitoring of local spat settlement. Although it was not measured during this study, observations during the processing of samples indicated that most spat were attached to the natural fibres rather than the short sections of plastic mussel rope, demonstrating that even after prolonged deployment, these fibres continued to provide attractive settlement substrate for mussel spat.

The decrease in the size of spat attached to the natural fibres after seeding onto the Coromandel mussel farm suggests that many of the spat that were originally caught in Aotea Harbour were lost from the droppers following seeding out and were replaced with settlement by local spat. This suggestion is consistent with previous work throughout the Coromandel, where extremely high spat losses have often been measured shortly after seeding out (Skelton & Jeffs, 2021), and suggests that the natural fibres were not as effective as plastic ropes at retaining mussel spat. However, this does not preclude natural fibres from being a suitable replacement for plastic ropes for catching and sourcing mussel spat. Natural fibre ropes could still be used to catch mussel spat, which could then be removed and grown in nursery culture systems before seeding to reduce spat losses. Further research should investigate approaches for separating spat from natural fibre ropes to facilitate this approach. Further research should also focus on comparing spat catches on natural and artificial ropes with a similar diameter and surface area.

Practicalities of each fibre

Except for fluffy harakeke ropes, the breakdown of each of the fibres was minimal over the course of the experiment demonstrating that they are capable of being deployed for extended periods of time (i.e., up to 109 days between deployment in Aotea Harbour and collection from the Coromandel). However, by the end of the experiment, compared to the harakeke fibres, which were easily teased apart and fragmented, the tī kōuka fibres maintained their shape and strength, making them more suitable for long term deployment. This is despite previous work that demonstrated that fibres produced from both species had similar tensile strength (Skelton et al., 2021).

Practicalities of commercial scale fibre processing

From 1860 to the 1930s Aotearoa-New Zealand had a large number of harakeke mechanical processing plants in many parts of the country that were usually located near swampland with naturally occurring harakeke, which was harvested to supply the mill. For example, by 1870 there were 161 harakeke mills nationwide employing nearly 1800 workers (Te Ara Encyclopaedia of NZ). The processed harakeke fibres were exported and used locally for making sacking, carpet backing, fibrous plaster, twines, and ropes. The industry petered out from the 1920s because of the depression and the increasing replacement of natural fibres with plastic alternatives.

Today, the only harakeke processing plant remaining is in Foxton as a museum piece. In recent years, a resurgence of interest exists in the use of natural plant fibres as a more sustainable alternative to the use of plastic. For example, in Aotearoa-New Zealand there is current activity by New Zealand Natural Fibres around the use of locally grown hemp fibres for processing to be used in backing material for all natural fibre carpets. This activity has included importing specialised decorticating machinery from Europe to extract fibres from the hemp (Max Miles, Terry Textiles Ltd, pers. comm.). Such machinery is designed to process specific plant fibres with a commercial scale plant estimated to cost over NZ$1M. Growing, harvesting, transporting, and processing plant fibres would add significant additional costs on top of the processing cost. By way of contrast, existing plastic spat rope wholesales for around $1:50 a metre and will last for at least five spat catching seasons and usually ten (Quality Equipment, R50QECL0L2 QE CUT LOOP). One aquaculture rope manufacturer has experimented with using natural fibres for mussel ropes, including coir and hemp fibres, but not harakeke or ti kouka, with mixed success and experienced difficulties with fabricating rope designs that are equivalent to plastic spat ropes (Nick Franklin, Diamond Aquaculture Ltd).

The commercial development and use of natural fibre aquaculture ropes seems likely to rely either on the mussel aquaculture industry adopting natural fibre rope for sustainability reasons, and paying the premium for doing so, or being forced to through regulation on the use of plastic ropes.

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