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**Pātangaroa: Co-developing management strategies for a starfish outbreak in Ōhiwa Harbour**

A thesis
submitted in fulfilment
of the requirements for the degree
of
**Doctor of Philosophy in Environmental Sciences**
at
**The University of Waikato**
by
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THE UNIVERSITY OF
WAIKATO
*Te Whare Wānanga o Waikato*

2025

# Abstract

The management of marine environments often prioritises scientific information to address complex marine social-ecological issues. However, there is a wealth of learning to be gained from Indigenous people who have generated place-based intergenerational understandings and cultural ethics and practices. Consequently, Indigenous knowledge alongside science can offer better insights, holistic understanding, sustainable management strategies and greater sources of evidence. This research is located in Aotearoa New Zealand and engages in mātauranga Māori (Māori knowledge) alongside marine ecology as an appropriate method for contemporary marine research and management. The thesis study focused on Ōhiwa Harbour, aiming to co-develop a starfish management action plan (SMAP) with local iwi (tribe) Ngāti Awa and other affiliated iwi, district councils and regional council to address the overabundant starfish (species: *Coscinasterias muricata* and *Patiriella regularis*). By engaging in transdisciplinary research and collaborative decision-making, this study sought to bridge the gap between Indigenous knowledge and mainstream science, offering lessons for inclusive marine management practices.

To achieve this, I developed and prescribed a co-developed framework actively promoting a mixed-methods approach, inclusive of kaupapa Māori research methodologies, tikanga, participatory design, applied mātauranga ā iwi, quantitative marine scientific field methods and experimental study design. Through the collaborative process, I identified areas of appropriate research aims and methods. This included co-developing a novel starfish trapping methodology sensitive to local ecology and cultural values and an experimental starfish removal study to assist decision-makers in implementing an efficient and effective starfish removal regime as an approach to management.

Results from the field studies showed the efficacy of starfish traps is dependent on environmental conditions, physical characteristics and soaking time (the length of time the trap is left in the water). A soaking time of 48 h maintained the highest starfish catch per unit effort (CPUE) while minimising time to re-bait and reset traps. Observations also indicated an open trap design had less bycatch than a semi-enclosed box trap and could withstand the tidal currents for a longer period. The findings found that bait type did not impact on CPUE. In the starfish removal study, the combined effort of diver removals and trapping produced higher daily catch rates than the single treatments (i.e., diver removals only or trapping only), therefore was the

most efficient removal method. The empirical information gathered from the field studies was then used to inform the SMAP and was accepted unanimously at the highest local/regional co-management level. Furthermore, through the findings I identified future research opportunities that would further close gaps in our knowledge around the best management approaches for a starfish outbreak. These included investigation into the predation impacts of *P. regularis* on mussel recruitment, identification of alternative restoration sites less susceptible to starfish predation pressures and investigation of potential drivers of the starfish outbreak.

Overall, the acceptance of the SMAP by local iwi/hapū and government authorities underscores the success of the collaborative approach. The collaborative process not only addresses the immediate concerns of starfish infestation but contributed to the broader goal of supporting kaitiakitanga (active guardianship) responsibilities and promoting Indigenous perspectives in marine management. This thesis demonstrates and recommends a new approach to starfish management in coastal marine areas using both marine science and mātauranga Māori understandings, practices and ethics, furthermore, it demonstrates the commitment to the inclusion of multiple knowledge systems and involvement of communities.

# Mihi—Acknowledgements

First, I would like to thank my chief supervisor, Professor Kura Paul-Burke. Your contribution to marine research, which intentionally and respectfully situates mātauranga Māori alongside science as a significant contributor to managing our moana, is admirable. Thank you for your continuous support and encouragement throughout this thesis, from demonstrating what true, respectful co-development looks like in practice to providing invaluable technical advice and feedback in study design, field work planning and writing. I am forever grateful to you for going above and beyond in your duties as a supervisor and creating work opportunities and connections that supported me while undertaking this thesis. Secondly, I would like to thank my secondary supervisor, Professor Conrad Pilditch. Your enthusiasm and openness in approaching challenging marine social-ecological issues are inspiring. Your technical advice, attention to detail and ongoing support helped me immensely. Thank you both for being so patient with me as I navigated the interface between mātauranga Māori and marine science.

To Te Rūnanga o Ngāti Awa iwi advisors, practitioners and mātauranga Māori experts Chairperson, Tūwhakairiora O'Brien and Manager of Customary Fisheries, Charlie Bluett: your guidance, support and willingness to share your mātauranga and feedback are greatly appreciated. To the Ōhiwa Harbour Implementation Forum and the Ōhiwa Harbour Strategy Coordination Group: your continuous positive support and feedback throughout the co-development of this research have been deeply felt. To Rokahurihia Ngarimu-Cameron and Kerri Cameron: thank you for generously sharing your wisdom, tikanga and practices when it came to developing the starfish traps.

Joe Burke, the ultimate skipper, dive buddy, technical advisor and rope untangler: your dedication to your work and to Ōhiwa Harbour is truly inspiring. Thank you for your novel ideas and advice in ensuring that we could execute and complete the field work effectively and safely. I would also like to thank Greg Rackham, our other amazing skipper: your dedication to safety on the water instilled the confidence in me that I could get the job done and return home safely; thank you. Also, thank you to Mike Scott, for helping me lift and reset the starfish traps with a smile on your face.

A mihi to our next generation of kaitiaki, Te Āmai Paul-Burke and Te Waikamihi Lambert. Thank you for giving up your time to help me in the field for lollies and ham buns in return. Your energy, enthusiasm and attitudes are inspiring and made the field work so much more fun.

To my remaining supervisors, Dr Richard Bulmer and Professor Shaun Ogilvie: you were both instrumental soundboards when I felt a little out of my depth. Your willingness to spend time explaining things and continuous reassurance made me feel more at ease. Thank you.

To my peers at the University of Waikato, Kiri Reihana and Kia Māia Ellis: you are both inspiring wāhine Māori in marine science, forging your own paths with grace. I would also like to thank Kiri (aka 'camp mum') for feeding us with good kai at our writing retreats. Thank you to my beautiful friend Natalie Prinz, who helped me on numerous occasions with field work and starfish trap making—thank you for being the most kind and generous human being I know, I appreciate you. Thank you also to Tim Thomson and Claire Shellem, for helping me in the field. Tim, your enthusiasm and appetite for life are inspiring—thank you for being a great friend and social event organiser (even though I never showed up). Thank you to the rest of the crew at the 184 Cameron Road office—Lizzy, Akuhata, Edo, Carolina and Sourajit. I loved sharing an office with you all; you made it enjoyable to show up to mahi, and I always looked forward to our lunchtime catch-ups.

A huge thank you to my tāne, Gemini. You really are my toka, my rock. Thank you for being a supportive and loving partner, for the ability to give sound and logical advice, even if I did not want to hear it. To my whānau, Glenda, Hawiki, Ngaire and Manaia: thank you for just being a loving family—your support does not go unnoticed. To my tīpuna, who are not with us today but have left a legacy of love and adoration for their whānau that is still felt every day- thank you.

Lastly, I want to show my appreciation to the Sustainable Seas National Science Challenge, which funded my PhD research. I am forever grateful for the financial support I received. I would also like to acknowledge Bay of Plenty Regional Council for the He Toka Tū Moana-Toi Moana scholarship, the Māori Education Trust Postgraduate STEM scholarship and Waikato-Tainui, Te Rūnanga o Ngāti Awa, Omataroa Trust Rangataiki No. 2 Trust and Nepia Hona Lands Trust for my tertiary education grants.

# Glossary and Acronyms

## Glossary

| | |
|---|---|
| Aotearoa | New Zealand |
| Atua | Deity |
| Hangarua | Recycle |
| Hapū | Subtribe(s) |
| Harakeke | New Zealand flax (*Phormium tenax)* |
| Hīnaki | Eel trap |
| Hui | Meeting |
| Hui-ā-iwi | Tribal meeting(s) |
| Iwi | Tribe(s) |
| Kai | Food |
| Kaimoana | Seafood |
| Kaitiaki | Guardian |
| Kaitiakitanga | Active guardianship |
| Kanohi kitea | A face seen |
| Karakia | Recite ritual chants, say grace |
| Kaumātua | Elder |
| Kaupapa Māori | Māori research approach |
| Komiti | Committee |
| Kotahitanga | Working or coming together |
| Kuia | Elderly woman |
| Kūtai | Green-lipped mussel (*Perna canaliculus)* |
| Māhanga pātangaroa | Starfish trap(s) |

| | |
|---|---|
| Mahinga kai/mātaitai | Traditional food gathering area |
| Mana | Prestige, authority, control, influence, status |
| Mana whenua | Territorial rights, group that exercises authority over a specific area |
| Manaakitanga | Nurture and care for others |
| Manuhiri | Visitors, guests |
| Marae | Traditional meeting place |
| Mātaki | Observe |
| Mātauranga Māori | Traditional Māori knowledge |
| Mātauranga-a-iwi: | Māori tribal knowledge and its relationship to its land base. |
| Moana | Ocean |
| Moumou | Wasteful |
| Muka | Prepared flax fibre |
| Ngahere | Forest |
| Ngāti Awa | Tribe of Eastern Bay of Plenty, from Mātaatua canoe |
| Pātangaroa | Eleven-armed starfish (*Coscinasterias muricata)* |
| Pepeha | Tribal introduction, greeting |
| Pirita | Supple Jack (*Ripogonum scandens*) |
| Pūkenga | Expert |
| Pūrākau | Ancient legend, story |
| Rāhui | Temporary closure restricting harvesting |
| Rangatiratanga | Sovereignty, right to exercise authority |
| Raranga | To weave, plait |
| Rāwaho | People who are not related to the hapū or whānau members |
| Rohe | Traditional tribal oceanic boundaries |
| Tangata whenua | People of the land |

| | |
|---|---|
| Taonga | Treasure |
| Tāruke | Crab trap |
| Taura | Mussel spat lines made from natural fibres |
| Te ao Māori | Māori world view |
| Te rōpū kairangahau | Māori advisory group |
| Te Ūpokorehe | Subtribe of Whakatōhea tribe in the Eastern Bay of Plenty |
| Teina | Younger sibling of same sex |
| Tikanga | Correct procedure, custom |
| Tīpuna | Ancestor(s) |
| Tohunga | Expert, Priest |
| Tuakana | Elder sibling of same sex |
| Tūhoe | Tribe of Eastern Bay of Plenty |
| Tunaroa | Eel god |
| Utu | Reciprocity |
| Wānanga | To meet and discuss, deliberate, consider |
| Whakaaro | Thoughts |
| Whakahaere | Manage |
| Whakapapa | Genealogy |
| Whakataukī | Proverb |
| Whakatōhea | Tribe of Eastern Bay of Plenty |
| Whakautu | Respond |
| Whānau | Family |
| Whanaungatanga | Relationships, kinship, sense of connection |
| Whenu | To twist, spin |
| Whenua | Land |

## Acronyms

| | |
|---|---|
| AMAA | Awhi Mai Awhi Atu |
| ANOVA | Analysis of variance |
| BOPRC | Bay of Plenty Regional Council |
| CMA | Coastal and marine area |
| CPUE | Catch Per Unit Effort |
| DOC | Department of Conservation |
| EBM | Ecosystem-based management |
| ECR | Early career researcher |
| FNZ | Fisheries New Zealand |
| HECS | Human Ethics Committee |
| HSD | Honestly significant difference |
| IQR | Interquartile range |
| MfE | Ministry for the Environment |
| MMAP | Mussel Management Action Plan |
| OHIF | Ōhiwa Harbour Implementation Forum |
| OHS | *Ōhiwa Harbour Strategy* |
| OHSCG | Ōhiwa Harbour Strategy Coordination Group |
| SMAP | Starfish management action plan |
| STAG | Scientific and Technical Advisory Group |
| TRoNA | Te Rūnanga o Ngāti Awa |
| UNDRIP | United Nations Declaration on the Rights of Indigenous Peoples |

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# Chapter 1:
# General Introduction

## 1.1 Introduction

There is a growing demand for multiple ways of thinking and approaches to better understand and address complex environmental issues, such as climate change (C. Alexander et al., 2011; Nyong et al., 2007), biodiversity loss (Bond et al., 2019) and biosecurity risks (Lambert et al., 2018). Drawing on multiple knowledge systems, including local, Indigenous and science-based, can improve our understanding of social-ecological interdependencies, identify desirable research pathways, strengthen trust in decision-making and lead to innovation for environmental research and management. However, there is often a strong disparity in recognising and implementing different understandings, and Eurocentric values and practices often dominate, while Indigenous knowledge and values are frequently dismissed (S. M. Alexander et al., 2019). This thesis addresses this disparity and intentionally engages in research that places Indigenous knowledge at the forefront of the research design as an appropriate method for contemporary marine science.

Parallels between Indigenous knowledge and ecology exist (Bélisle et al., 2018). Indigenous people and nature have an interdependent relationship that over time generates a body of dynamic intergenerational knowledge, ethics and practices, intimately bound to one place (Durie, 2004). This has allowed Indigenous communities to preserve biodiversity while maintaining their livelihoods (Ruiz-Mallén & Corbera, 2013). In science, the field of ecology is similar, incorporating knowledge (however acquired) of living things, including humans, and their relationship with their environment (Berkes, 1993). Both Indigenous knowledge and ecology can be applied to help inform later 20th-century emergent concepts and practices, such as ecosystems-based management, restoring resilient social-ecological systems and integrated planning and policy (Harmsworth & Awatere, 2013; Maxwell et al., 2018). This has driven greater research involving Indigenous knowledge, for example, the number of studies involving Indigenous knowledge (expressed as several different terms) has increased from five in 1990 to 1401 in 2018, with ecology making up 528 of the totals (Jessen et al., 2022). This is expected given how well ecology and Indigenous ideologies complement each other, however, it has been highlighted that the involvement of Indigenous knowledge is often superficial and that

there is a concern Indigenous knowledge will be extracted, further perpetuating discrimination of Indigenous peoples (Robinson et al., 2021).

In the field of marine research and management, Indigenous knowledge is used increasingly to resolve disputes over management, encourage sustainable fishing techniques, provide deeper intergenerational ecological understandings, generate novel approaches to restoration and provide historical information (Aswani & Lauer, 2006; Newman & Moller, 2005; Paul-Burke et al., 2018; Thornton & Scheer, 2012; von der Porten et al., 2019). Several countries—including Canada, the United States of America, Mexico, Colombia, Ecuador, Peru, Aotearoa New Zealand, Australia and Norway—have adopted the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP, 2007), which recognises Indigenous peoples' 'right to maintain, control, protect and develop their cultural heritage, traditional knowledge and traditional cultural expressions' (p. 22). Consequently, alongside national policies and conservation initiatives, the UNDRIP has spurred significant advancements in bridging Indigenous and science-based knowledge in marine research and management, particularly in the regions of North America followed by Oceania (Lam et al., 2019; Rist et al., 2019; Thornton & Scheer, 2012).

In Aotearoa New Zealand, there is a greater commitment to engaging in Indigenous knowledge, referred to as 'mātauranga Māori', in all fields of science. For example, the Wai262 (1991) Claim, highlighted the Crowns mismanagement and disregard for iwi and hapū to maintain practices and knowledge that supported the protection and use of taonga (treasured) flora and fauna. In response, the Waitangi Tribunal put forward a report with recommendations to support the continuation of mātauranga Māori as a poignant contributor to safeguard the environment for the future (Waitangi Tribunal 2011). Furthermore, a national public policy known as 'Vision Mātauranga' was introduced in 2005 to encourage greater Māori involvement and representation in the sciences, as well as to provide guidelines for science to engage with Māori communities (Ministry of Research, Science and Technology, 2007). Coastal iwi (Māori tribes), hapū (Māori subtribes) and whānau (Māori family) are actively seeking to participate and incorporate their mātauranga moana (ocean knowledge) in management practices, policies, and research of their marine rohe (area) and mahinga kai (food gathering places) (Lyver et al., 2008; Ogilvie et al., 2018; Paul-Burke et al., 2018). Having Māori at the forefront in the decision-making process for marine research pathways and management means Māori can exercise kaitiakitanga (active guardianship), install mātauranga Māori, maintain cultural practices and

knowledge inherent to these activities, ensure aspirations and outcomes are met, and develop new knowledge and skills (Stewart-Harawira, 2020).

However, the consensus is that decision-making for the marine environment in most countries is still based on scientific information and bureaucratic legislation that pose significant barriers to the inclusion of Indigenous world views and knowledge (S. M. Alexander et al., 2019; Lam et al., 2019). Many projects continue to fall short at integrating local knowledge systems and Indigenous epistemologies in a manner that achieves a respectful synthesis, nor have successfully been applied to substantiate appropriate scientific methods, research pathways or assist in management decisions and developing environmental policies (S. M. Alexander et al., 2019; Thornton & Scheer, 2012). In Aotearoa New Zealand, there remains limited scientific ecological literature that engages with mātauranga Māori in meaningful ways (McAllister et al., 2019). Furthermore, there has been acknowledgment that the implementation of the Vision Mātauranga policy has been problematic, to bring the policy up to date, *A guide to Vision Mātauranga: Lessons From Māori Voices in the New Zealand Science Sector* (Rauika Māngai, 2020) and *A Tiriti–Led Science-Policy Approach For Aotearoa New Zealand* (Kukutai et al., 2021), have addressed the shortfalls and provided recommendations.

Working across knowledge systems requires intellectual flexibility, because this type of research traverses different fields of expertise (i.e., in this case, te ao Māori, marine ecology and environmental policy), and there is a lack of practitioners—both Indigenous and non-Indigenous—who can work across these disciplines (Durie, 2004; Lemos & Morehouse, 2005; Ministry for the Environment [MfE], 2019). In part, this can be because of a lack of insight on key factors associated with processes and mechanisms that give effect to the successes and failures. Governmental reports now identify transdisciplinary researchers in mātauranga Māori and Western science as one of the top five issues for marine scientific endeavours in Aotearoa New Zealand (MfE, 2019).

As a Māori woman of Ngāti Awa, Te Patuwai and Tainui ancestry, my research will be transdisciplinary and integrate different fields of expertise including mātauranga Māori and marine ecology as relevant and complementary components for contemporary marine science within the context of Aotearoa New Zealand. The incorporation of mātauranga Māori is not just considerate of the place-based intergenerational ecological knowledge but also the methodologies (tikanga Māori and kaupapa Māori principles) and methods, Māori and iwi participation and Māori value sets, and it acknowledges mana whenua (Māori authority over

their tribal land/ocean) and Māori with the responsibility for their mātauranga Māori. Furthermore, the research acknowledges mātauranga Māori is intimately bound by place and therefore engaging with mātauranga Māori means engaging with Māori communities and issues relevant to them (Berkes, 2009; Mercier, 2018).

An ideal case study area for collaborative marine research is Ōhiwa Harbour, located in the Bay of Plenty of Aotearoa New Zealand. The harbours environment is managed by a long-standing partnership between local iwi/hapū and councils. This partnership means management decisions are inclusive of tangata whenua (local Māori) environmental and cultural concerns and practices (Bay of Plenty Regional Council [BOPRC], 2008). One of the greatest issues raised is the overabundance of the eleven-armed starfish (*Coscinasterias muricata*), pātangaroa, and cushion star (*Patiriella regularis*), which is hindering recovery of the traditional mussel, or kūtai beds due to increased predation pressures (Paul-Burke, 2015; Paul-Burke et al, 2022a). This thesis investigates the overabundant starfish and management strategies by co-developing and co-implementing with local iwi/hapū and councils a research endeavour inclusive of mātauranga Māori and marine ecology.

## 1.2 Mātauranga Māori and Marine Management

### 1.2.1 Mātauranga Māori

'Mātauranga Māori' is defined as a body of knowledge originating from Māori ancestors, including Māori world view, perspectives, and cultural practices' (Hikuroa, 2017; Mercier, 2018). Although mātauranga Māori is a continuum of knowledge with Polynesian origins, according to Doherty (2010), 'it is through the environment that examples of knowledge are witnessed, experienced, explained and conceptualised' (p.217), thus the organisation of Indigenous knowledge is founded on the interdependent relationship between Indigenous people and nature (Durie, 2004). This also highlights that mātauranga Māori is place-based, forming unique tribal understandings and practices—what we refer to as 'mātauranga-a-hapū', 'mātauranga-a-iwi' or 'mātauranga-a-whānau' (Cheung, 2008). As Mead (2003) explains: 'it [mātauranga Māori] is a tool for thinking, organizing information, considering the ethics of knowledge, the appropriateness of it all and informing us about our world and our place in it' (p. 306).

The concept of place-based knowledge differs significantly from the principles of Western science, which often seeks generalizable laws and truths, assuming objectivity and therefore

the ability to be applied across contexts (Berkes, 2018). While Western science emerged in Western Europe during the Scientific Revolution of the 16th and 17th centuries, it was subsequently globalized through colonization, imperial expansion, and missionary efforts (Raj, 2007). As a result of its widespread dominance and entanglement with colonial power structures, many institutions around the world have come to regard Western science as the sole bearer of 'truth' and the only legitimate method for producing knowledge, therefore completely disregarding Indigenous knowledge as evidence based and scientific (L. T. Smith, 1999).However, mātauranga Māori is not subject to fixed knowledge but rather a dynamic and evolving knowledge system. The values might have come from long ago, but as all knowledge, they evolve and change, including taking up new scientific methodologies (Mead, 2012)—it is not just Western society that has that privilege (L. T. Smith, 1999). Mātauranga Māori can be viewed as:

> a core of traditional knowledge plus the values and ethics that go with it and new knowledge, some of which we have added as a result of our discoveries and research, and some we have borrowed outright from western knowledge and from our experiences of living with exponents of other belief systems and other knowledge systems. We are now reshaping, rebuilding, reinterpreting and reincorporating elements of mātauranga Māori to make it fit the world that we live in today. (Mead, 2012, p. 14)

There are several core principles that underpin mātauranga Māori. Some of these principles include whakapapa (genealogy), which acknowledges relationships between all components and positions humans within nature, this influences how we as Māori act. This kinship relationship between people and nature situates Māori as part of the natural world. The interconnectedness between humans and nature (social-ecological relationships) is reflected in our formal introductions (pepeha), where both self and tribal identity are conveyed by reference to our whenua (land), awa (rivers), moana (ocean) and other important landscape features (Harmsworth & Awatere, 2013). This relationship between Māori and the environment expresses the notion of 'familial relationship' with other components of the natural world (M. Roberts et al., 1995). Another key principle is the sacredness of nature: all entities have their mauri (life force) and mana (prestige); this in turn evokes ethical concepts such as tapu (set apart; possessing the potential for power and sacredness; restricted) and noa (to be free from the extensions of tapu; unrestricted), reciprocity and responsibility (Harmsworth & Awatere, 2013; Mead, 2003).

Kaitiakitanga confers the responsibility or obligation to sustain and maintain the well-being of people and natural resources and thus uphold mauri and mana, both through practical and spiritual application based on tikanga (culturally correct customary practices) (Marsden & Henare, 1992). Kaitiaki (custodians) are direct or indirect facilitators of reciprocity through mediums of tohunga (experts) or animal guardians, therefore kaitiaki or kaitiakitanga became essential in everyday Māori life and practices. The word 'kaitiaki' comes from 'tiaki', which means 'to guard' or 'to protect', and 'kai', which denotes the doer of the action, and 'kaitiakitanga' is the act of guardianship (M. Roberts et al., 1995); therefore, kaitiakitanga is not a passive responsibility but an active one.

Environmental kaitiakitanga is important today, in the past it safeguarded and protected the complex networks within the taiao (natural world), and thus ensured balance was maintained. The act of kaitiakitanga allowed Māori to acquire knowledge of the biotic environment coupled with physical processes, which informed practices to allow Māori to successfully manage their taiao (Selby et al., 2010). Therefore, to be a kaitiaki required a wealth of mātauranga Māori, sourced from experimental understandings and traditional ecological knowledge passed between generations (Paul-Burke, 2015).

Mātauranga was conceptualised, developed and maintained through practice and connection. For coastal Māori, the activities surrounding harvesting, preparing and protecting customary marine species not only ensured their preservation but also the preservation of the intergenerational transmission of cultural and ecological knowledge (Paul-Burke, 2015). This wealth of mātauranga Māori is invaluable and can set precedence in how we collectively better manage our marine environment.

### 1.2.2 Integrating mātauranga Māori in marine management and research

A review by Jarvis and Young (2019) regarding marine research priorities for Aotearoa New Zealand highlighted 'disparate legislation and significant knowledge gaps [which] continue to limit the country's ability to effectively conserve and manage its resources' (p. 1) *Our Marine Environment 2019* report noted that 'working together across mātauranga Māori (Māori knowledge systems) and other science disciplines is improving our holistic, place-based knowledge that is crucial in understanding cumulative effects' (MfE, 2019, p.6). Including two of Aotearoa's rich knowledge systems, mātauranga Māori and Western science, to co-develop understandings of marine ecosystem recoverability and coordinate different practices ensures

contemporary marine management that is relevant and has multiple sources of evidence (Lyver et al., 2016; Paul-Burke et al., 2018). Furthermore, collaborative research inclusive of Indigenous knowledge is appealing as it provides greater baseline data and opportunity to co-create new knowledge, methodologies and/or action that would otherwise be overlooked when working in silo (Lyver et al., 2008).

These promises highlight the need for mātauranga Māori to sit alongside marine science to reshape marine management in Aotearoa New Zealand and globally. This would entail transdisciplinary research bringing together expertise in different disciplines including natural and social sciences, tangata whenua (Indigenous people of that area), practitioners, policymakers and community groups (Jarvis & Young, 2019; Lundquist et al., 2016; Paul-Burke et al., 2020). Contemporary Māori are still attempting to exercise tino rangatiratanga (sovereignty) in how they interact with the taiao and have traditional practices recognised, relating to moana management. At large, mātauranga Māori is still an unrecognised significant contributor to contemporary marine research and management (MfE, 2019).

One way to be more inclusive is through procedural inclusion at multiple governance levels (Lowry & Simon-Kumar, 2017). Government and non-government organisations in Aotearoa New Zealand responsible for managing and protecting the environment have established policies and practices for engaging with iwi, hapū, whānau and Māori communities. For example, the Department of Conservation has the 'Conservation General Policy' and 'Conservation and Environment Science Roadmap', while the MfE has the Manu Taiao Team. These account for their responsibilities to engage with tangata whenua and meet their obligations as Te Tiriti o Waitangi (The Treaty of Waitangi) partners. However, these policies are somewhat broad (lacking hapū-iwi-specific values and principles) and often fall short of what iwi and hapū articulate as appropriate engagement (Harmsworth & Awatere, 2013; Maxwell et al., 2020).

Collaborative management frameworks for marine environments can support and encourage the use of Māori knowledge, values and ethics and thus build collaboration across science, society and governance. Recently, there has been an increase in frameworks and assessment tools supporting shared decision-making regarding environmental management and research, which has resulted in stronger inclusion of Indigenous knowledge and perspectives alongside Western science (Stewart-Harawira, 2020). An example in the marine sector is the integrated Kaipara Harbour management model, which is place-based (Makey & Awatere, 2018), while

other models have been developed for nationwide application, such as the Waka-Taura framework, a conceptual model that integrates traditional Māori knowledge and contemporary scientific approaches to support environmental and cultural sustainability in coastal management (Maxwell et al., 2020). There are also international examples such as the Two-Eyed Seeing, or Etuaptmumk (in Mi'kmaw), framework in Canada, which seeks and acknowledges the strengths of Indigenous ways of knowing from one eye, and the strengths of Western ways of knowing from the other eye. This has been applied more broadly to Indigenous and science communities worldwide both in environmental and health-related contexts (Reid et al., 2021). A framework supporting the collaboration between marine science, mātauranga Māori and environmental policy in the context of Ōhiwa Harbour is relevant and important.

## 1.3 Ōhiwa Harbour

### 1.3.1 Background

Located in the Eastern Bay of Plenty, Ōhiwa Harbour is regarded as one of the most natural harbours in Aotearoa New Zealand with 'significant conservation, ecological, biological, wildlife, scenic, landscape, historic and cultural values' (BOPRC, 2013, p. 1). Ōhiwa Harbour lies within the ancestral homelands of Ngāti Awa, Te Ūpokorehe, Whakatōhea and Waimana Kaaku (Tūhoe) iwi (Johnston, 2003). The name 'Ōhiwa' comes from 'Te Ōhiwa o Awanuiārangi', meaning 'the standing place of Awanuiārangi'. Awanuiārangi is an ancestor of Ngāti Awa people (Te Rūnanga o Ngāti Awa [TRoNA], 2019). Te Ūpokorehe recognise the harbour as 'Te kete kai a Tairongo', 'the food basket of Tairongo' (the ancestor of Te Ūpokorehe), or Te umu tao noa a Tairongo, 'the place where Tairongo found an abundance of food ready to eat' (BOPRC, 2014). These whakataukī (traditional proverbs) not only highlighted Ōhiwa Harbour as an important mahinga kai (food gathering place) for resident Māori but also the responsibility as kaitiaki (Black, 2014).

Traditionally and legislatively, Ngāti Awa has mana moana (ocean authority) on the western side of Ōhiwa Harbour (*Ngati Awa Claims Settlement Act 2005*), which also falls under Whakatāne District Council and BOPRC jurisdiction (BOPRC, 2014) (Fig. 1.1). Te Ūpokorehe hapū (subtribe) have mana moana over the eastern side of Ōhiwa Harbour, which also falls under Opotiki District Council and BOPRC jurisdiction (BOPRC, 2014; K. C. Johnson, 2012). Supporting iwi, Tūhoe (Waimana Kaaku) and Te Whakatōhea are also recognised as having traditional and customary interests in Ōhiwa Harbour (Johnston, 2003). However, Ngāti Awa

in the west and Te Ūpokorehe in the east are recognised, in traditional and contemporary contexts, as the lead Māori management agencies in their respective sides of the harbour (Paul-Burke, 2015).

In 1866, the government proclaimed the Eastern Bay of Plenty under the provision of the New Zealand Settlements Act 1863. As a result, many iwi and hapū were dispossessed of their land, which included Ōhiwa Harbour (Johnston, 2003). This affected the ability of Māori to occupy, manage and exercise kaitiakitanga for Ōhiwa Harbour (Rother, 2016). The confiscation meant that Māori epistemological values and practices were lost, and Māori could no longer govern and manage their natural resources. Over time, Māori had to bear witness to the degradation of Ōhiwa Harbour, including its once-abundant shellfish.

In 2005, after over a hundred years of dissatisfaction with Governmental mismanagement of the harbour, a collaborative partnership between iwi/hapū of the Harbour, Te Ūpokorehe, Ngāti Awa, Te Whakatōhea and Waimana Kaaku (Tūhoe), thus initiating a working group. The working group and commitment to protect and care for Ōhiwa Harbour was recognised by the BOPRC, which initiated an integrated management strategy seeking the inclusion of Māori (Paul-Burke, 2015). The *Ōhiwa Harbour Strategy 2008* and the subsequent *Ōhiwa Harbour Strategy: Te Rautaki mō Ōhiwa: Refreshed October 2014* were then established. Today, decision-making for Ōhiwa Harbour includes a non-statutory co-management arrangement, where Ōhiwa Harbour is co-governed by a collective group of elected members from the BOPRC, Whakatāne and Ōpōtiki District Councils, Ngāti Awa, Te Ūpokorehe, Te Whakatōhea and Waimana Kaaku (Tūhoe), known as the 'Ōhiwa Harbour Implementation Forum' (OHIF). The OHIF committee oversees and monitors the implementation of the *Ōhiwa Harbour Strategy: Te Rautaki mō Ōhiwa: Refreshed October 2014* (BOPRC, 2014) (Fig. 1.2).

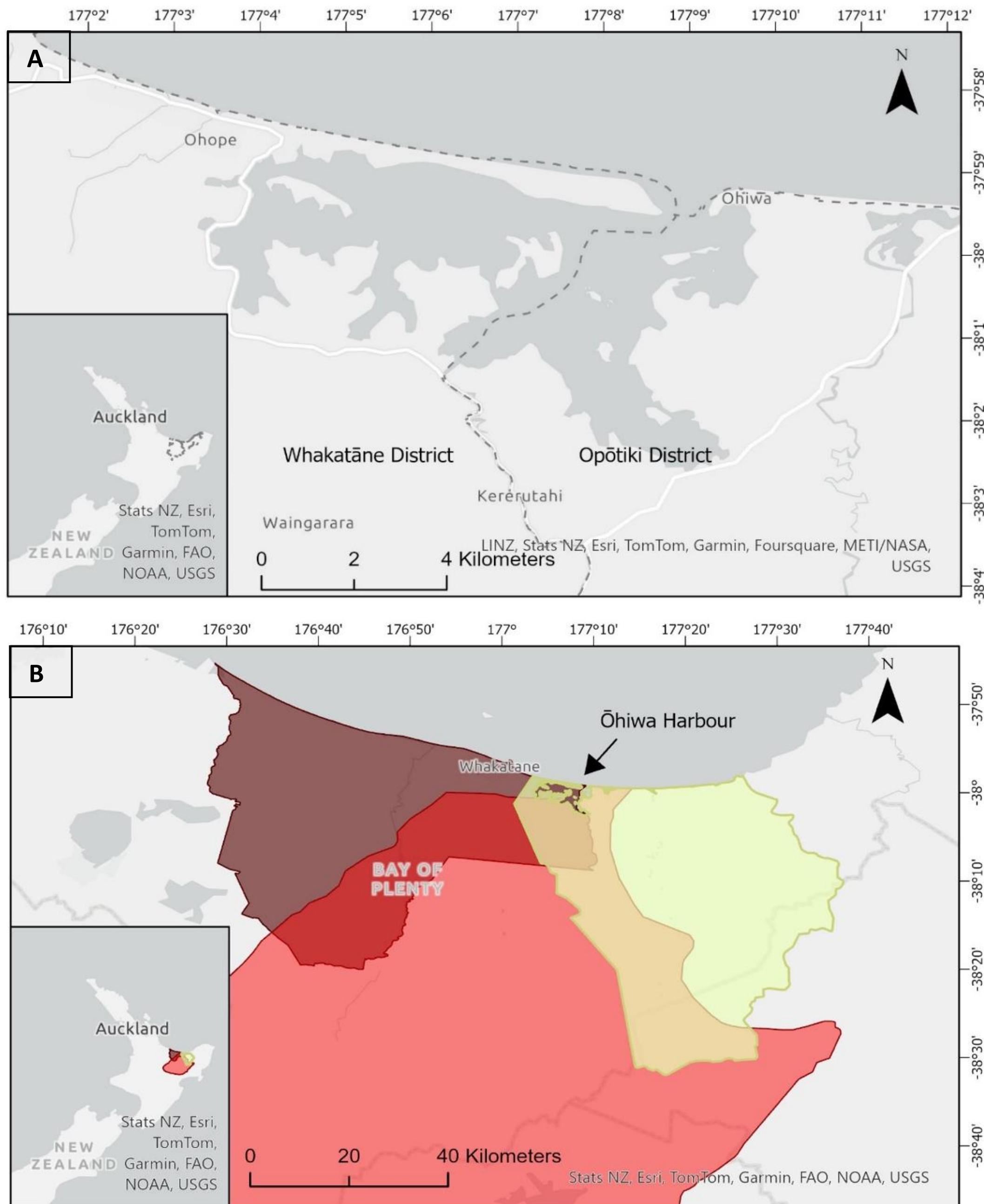


**Figure 1.1: Maps showing (A) Ōhiwa Harbour administrative boundaries (dashed line) of Whakatāne and Ōpōtiki District Councils (data sourced from Stats NZ [2018]), and (B) traditional territory of iwi—Ngāti Awa (brown), Tūhoe (red) and Whakatōhea (yellow) (of which Te Ūpokorehe is recognised as a hapū, or subtribe)—relative to Ōhiwa Harbour in the Eastern Bay of Plenty (data sourced from data.govt.nz [2017])**

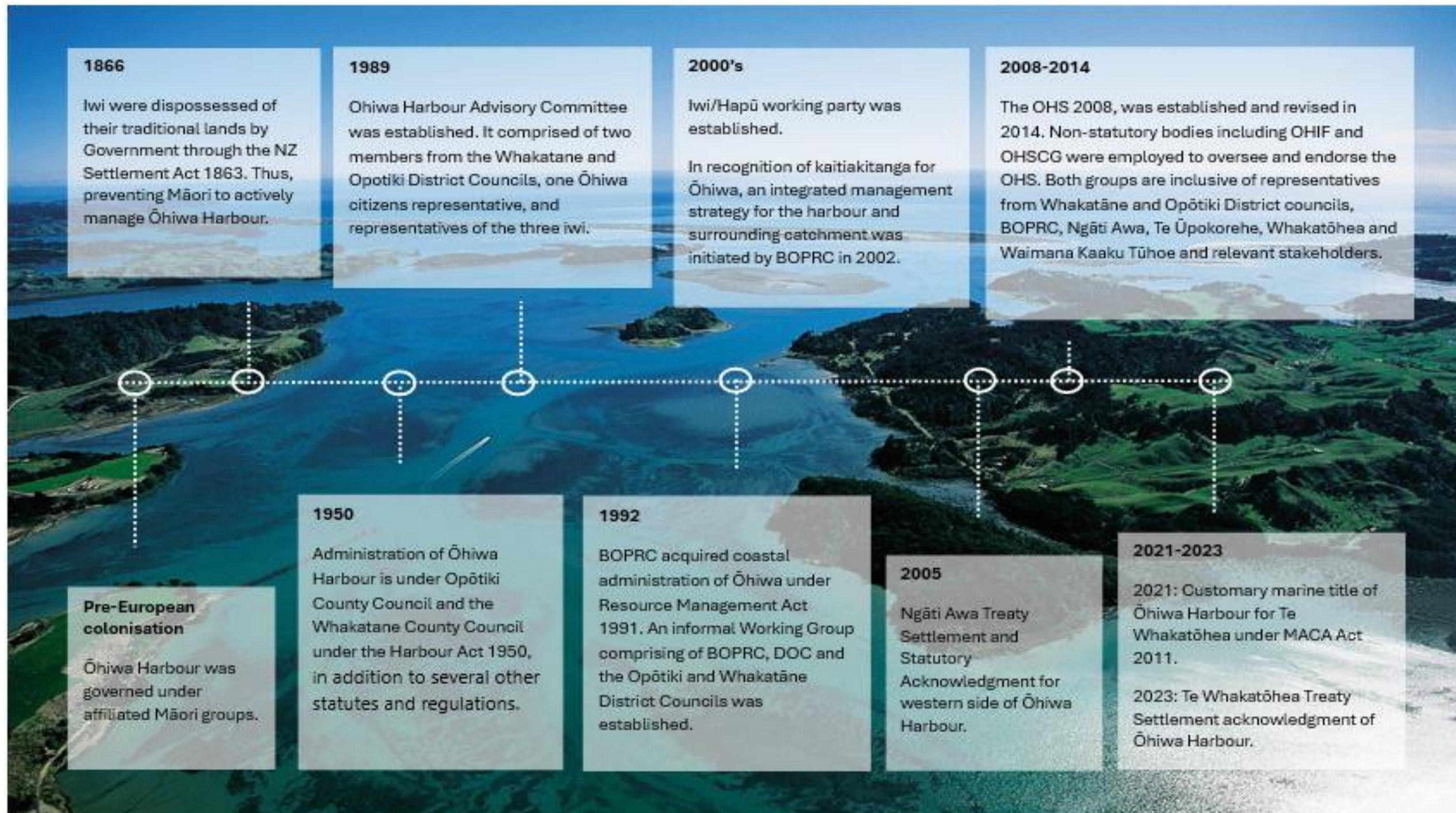


**Figure 1.2: Timeline of key events demonstrating the evolution of the management of Ōhiwa Harbour through time to the non-statutory co-management forum, the Ōhiwa Harbour Implementation Forum (OHIF), of today (Quinn, 2002)**

BOPDC = Bay of Plenty District Council, DOC = Department of Conservation, MACA Act 2011 = Marine and Coastal Area (Takutai Moana) Act 2011, OHS = *Ōhiwa Harbour Strategy*, OHSCG = Ōhiwa Harbour Strategy Coordination Group

### 1.3.2 *Ōhiwa Harbour Strategy 2008 / Ōhiwa Harbour Strategy: Te Rautaki mō Ōhiwa: Refreshed October 2014* and mussel management action plan

The *Ōhiwa Harbour Strategy* (OHS) was developed in 2007 and launched in 2008 to support and provide guidance for the management of Ōhiwa Harbour and its catchment. It identifies key issues, community values, visions and recommended actions to achieve those aspirations raised by iwi/hapū, community and agencies involved in various aspects of harbour management (BOPRC, 2008). Extensive consultation was undertaken with all participants and the strategy was drafted in 2007, launched in 2008 and later revised in 2014 (BOPRC, 2014). The strategy promotes action plans, processes and practices that can be employed by councils, iwi, hapū and members of the community, and is overseen by the OHIF and a working group known as the 'Ōhiwa Harbour Strategy Coordination Group' (OHSCG) (see Fig. 2.2 in Chapter 2 for a structural diagram of the management entities).

Five years after the OHS was released in 2008, the BOPRC (2013) released a document titled *State of the Ōhiwa Harbour and Catchment*. This report aimed to present a snapshot of the prevailing physical and ecological conditions of Ōhiwa Harbour, encompassing the status of mussel bed populations. Notably, the report highlighted a significant reduction in the size of mussel beds in 2009 compared with 2007, with concurrent observations of starfish actively consuming the mussel bed population (BOPRC, 2013). Emphasising the need for further investigation, the report underscored 'more work is required to gain a comprehensive understanding of the ecological cycle between mussels and starfish within the harbour, as well as the potential consequences of human interference, before engaging in efforts to modify this cycle' (BOPRC, 2013, p. 40). Furthermore, the latest OHS (BOPRC, 2014) highlighted community issues including 'Kaimoana in the Ōhiwa Harbour is threatened by overfishing, inappropriate gathering methods, starfish predation, and changes in the harbour environment' (p. 30). This document included harbour management actions listed under 'Investigate shellfish populations and advocate for sustainable shellfish management' (BOPRC, 2014, p. 31).

In response, Paul-Burke et al. (2018) carried out a transdisciplinary marine research project prioritising mātauranga Māori to formulate appropriate management approaches for the green-lipped mussels in Ōhiwa Harbour. Their findings founded the mussel management action plan (MMAP), which promoted co-development and co-design between local Māori, local government bodies and researchers. This partnership supported local Māori to establish

meaningful strategies and practical management, outline objectives for the MMAP and exercise kaitiakitanga.

Through the MMAP, a mussel restoration initiative was actioned that has led to successful mussel recruitment and translocations (Paul-Burke et al., 2022). However, mussel recovery is limited by the excessive numbers of eleven-armed starfish (*Coscinasterias muricata*) and cushion star (*Patiriella regularis*). Starfish are a natural predator of mussels, but in vast numbers can present significant predation pressures (Paul-Burke & Burke, 2016; Wilcox & Jeffs, 2019). Local iwi and hapū now recognise the overabundant eleven-armed starfish and cushion stars in Ōhiwa Harbour as a contemporary tohu (environmental indicator) of a degrading or unbalanced system and believe intervention is necessary to alleviate predation pressures on the traditional shellfish beds and improve shellfish recovery efforts (Paul-Burke et al., 2022a).

### 1.3.3 Chronic starfish infestation

Chronic starfish infestation has plagued Ōhiwa Harbour since 2009 and continues to limit mussel recovery. In 2009, an iwi-led monitoring program found an estimated 1.2 million *C. muricata* and a substantial number of the smaller starfish species, *P. regularis*. Between 2007 and 2009, mussel populations declined from 112 million to 16 million (Paul-Burke & Burke, 2016). This trend, coupled with observations of starfish predating on mussels, led iwi and researchers to believe the overabundant *C. muricata* caused significant loss of the traditional mussel population and *P. regularis* was to some degree reported as a potential barrier for mussel recovery. Green-lipped mussels (*Perna canaliculus*) are a highly valued species, culturally and commercially, so the threat of starfish predation should be considered in mussel management. Despite this, there has been little investigation into mitigation strategies to reduce or control starfish outbreaks in Aotearoa New Zealand.

The *State of the Ōhiwa Harbour and Catchment* report stated that investigation of potential drivers of starfish outbreaks and the ecological cycle between starfish and mussels was necessary before engaging in efforts to modify this cycle. However, extensive literature review on possible causes of the *C. muricata* outbreak found that, despite decades of starfish outbreak monitoring, little knowledge exists regarding primary outbreak locations and direct causes of these outbreaks (I. Miller et al., 2015; Uthicke et al., 2009). There are several hypotheses behind starfish outbreaks including both natural processes and anthropogenic activities (Babcock et al.,

2016; Birkeland, 1982; Branham et al., 1971; Brodie et al., 2005; Dana et al., 1972; Fabricius et al., 2010; Inglis & Gust, 2003; I. Miller et al., 2015; Thrush & Dayton, 2002; Wooldridge & Brodie, 2015). In practice, assigning causes to outbreaks is complicated; they are probably a result of several factors that vary with time and space. To date, no single hypothesis has indisputable and worldwide support (Pratchett et al., 2014, Pratchett et al., 2021). Furthermore, undertaking an investigation would require historical population data coupled with environmental information that do not exist for Ōhiwa Harbour.

The decline of the traditional mussel bed and the lack of information regarding the drivers of the starfish outbreak in Ōhiwa Harbour has led local iwi and the OHIF to call for management actions to minimise predation impacts of *C. muricata* and potentially *P. regularis*. Starfish management needs to account for several factors. While understanding the drivers of the starfish outbreak in Ōhiwa is of significant value, control measures would be the most beneficial short-term solution to the outbreak, while existential issues can be investigated and addressed. This action would allow the community and agencies to take a proactive approach entailing a comprehensive plan to intervene early, a monitoring regime to provide necessary information for real-time management and a management structure enabling allocated agencies to respond and take effective and practical action (Babcock et al., 2020).The development of a starfish management action plan (SMAP) addressing these prerequisites will be employed to ensure that although the outbreak has been ongoing for some time, managers can now be equipped with knowledge and tools to address outbreaks should they continue to hinder recovery of the mussels.

## 1.4 Thesis Purpose

The thesis research is concerned with integrating different fields of expertise, including mātauranga Māori and marine ecology, as relevant and complementary components for contemporary marine science, within the context of Aotearoa New Zealand. In doing so, the study addresses the disparity that exists in marine research and places Indigenous values, ethics and practices at the forefront of the research design. I address this by co-developing a SMAP with appointed iwi/hapū and council members to address the overabundant *C. muricata* and *P. regularis* to support the recovery of the green-lipped mussels in Ōhiwa Harbour.

Therefore, the purpose of this thesis is twofold. First, it describes how the research engages with mātauranga Māori (Māori knowledge), marine science and environmental policy through

co-development and co-management. I employ a mātauranga Māori–led co-development framework that supports and guides the inclusion of mātauranga Māori and Western science practices to assist in decision-making and management action. Furthermore, the thesis explores how I contextualise and operationalise the framework to both place and people to provide lessons and explicitly describe the co-development process from the position of a Māori early career researcher (ECR) in Aotearoa New Zealand.

Secondly, the thesis identifies an appropriate starfish management approach from evidence-based information and contributes the findings to the development of a SMAP. It was anticipated that the SMAP would assist Māori decision-making for the effective management of starfish in Ōhiwa Harbour. To meet this aim, the research first sought to answer the following question: What are the options, practices and processes available to assist Māori in the contemporary management of *C. muricata* and *P. regularis* populations in the whole of Ōhiwa Harbour?

### 1.4.1 Chapter overview

Chapter 2 explores the co-development aspect of the research in its entirety with our iwi partners and how I sought to apply mātauranga Māori and marine field science principles to assist in decision-making for the management of the starfish outbreak in Ōhiwa Harbour. The chapter aims to explain the research methodologies and how they informed our approach to ensure the research was collaborative in all aspects. This is achieved through the co-developed mātauranga Māori and Western science framework that facilitates research pathways and supports the weaving of the two knowledge systems within the social-ecological backdrop of Ōhiwa Harbour.

Chapter 3 explores how I integrated mātauranga Māori and marine science through practice in developing a starfish trapping methodology. The aim of the field study was to produce a starfish trap that was efficient, accessible for iwi/hapū to replicate and minimised bycatch. We also sought to produce a natural resource trap to minimise plastic in the ocean. This was achieved by co-designing a starfish trap with a tohunga raranga (master weaver), applying her mātauranga weaving principles and traditional weaving materials. This involved trialling different trapping designs, bait types and soaking times (i.e., the length of time the trap was left in the water). Findings from this study were used to inform the starfish removal study described in Chapter 4.

The field methods used to collect empirical information for the starfish removal field study are described in Chapter 4. The most efficient removal method based on starfish catch per unit effort (CPUE) is identified. The field study involved trialling different removal techniques, which included trapping (informed by the trapping methodologies described in Chapter 3), removal by hand collection via SCUBA diving and a combination of the two. Findings from the field highlighted the combined effort as the most efficient method.

Chapter 5 describes the development and submission of a SMAP for Ōhiwa Harbour based on the findings of the field studies described in Chapters 3 and 4 in addition to the expert knowledge (mātauranga ā iwi). The chapter outlines how I co-developed and implemented a SMAP in all areas of Ōhiwa Harbour in collaboration with relevant Māori authorities and explains how this management plan was accepted and endorsed at the highest local/regional co-management level; namely, by the OHIF.

In Chapter 6, I synthesise the findings described in the previous chapters regarding the management of starfish through a collaborative process. Aspects of the thesis that may inform future research are also presented.

# Chapter 2:
# Kaupapa Māori–led Co-development: Methods and Methodologies

*Ehara taku toa i te toa takitahi, engari he toa takitini*

*'Success is not the work of an individual, but the work of many'*

## 2.1 Introduction

Collaborative research that is inclusive of Indigenous knowledge and communities are often responsible for adhering to Indigenous methodologies (Pidgeon & Riley, 2021; Williams & Shipley, 2023). This ensures that the Indigenous cultural practices and epistemologies are integrated, and in doing so, promotes respectful collaboration, mutual learning and increased trust in decision-making and empowers Indigenous voices (Paul-Burke et al., 2022; Reid et al., 2021). Indigenous research methodologies are frequently concerned with the positionality of the researcher, cultural protocols, values and relationships prior to the methods being employed (Pidgeon & Riley, 2021; L. T. Smith, 1999; Williams & Shipley, 2023). Indigenous world views typically emphasise principles such as respect, reciprocity, relevance and responsibility (Kirkness & Barnhardt, 1991). Several scholars articulate and present strategies to restore Indigenous ways of conducting research (Bartlett et al., 2007; Bishop, 1995; Chilisa, 2019; L. T. Smith, 1999). In Aotearoa New Zealand, collaborative research endeavours engaging in mātauranga Māori (Māori knowledge) have a strong connection to kaupapa Māori (Māori methodology). Kaupapa Māori provides an 'Indigenous methodological framework steeped in foundations of mātauranga, designed to guide and inform the approaches taken to research with and by, Māori' (Haitana et al., 2020, p. 1). Kaupapa Māori research methodologies incorporate Māori ways of knowing, being and doing when undertaking scientific research (Bishop, 1995; Henry & Pene, 2001; Rameka, 2021; L. T. Smith, 1999).

This research employs both mātauranga Māori (Māori knowledge) and science to assist in marine management decision-making for Ōhiwa Harbour. It sits under a wider project funded by the Sustainable Seas National Science Challenge called 'Awhi Mai Awhi Atu: Enacting a Kaitiakitanga-based Approach to EBM [ecosystem-based management]', which also addresses and combines mātauranga Māori, science and local kaitiakitanga to understand the culturally and ecologically important species in Ōhiwa Harbour better. Consequently, this PhD thesis is concerned with the collaborative endeavour, which involved the research objectives, study

design and implementation being co-developed and reviewed by mātauranga Māori and science advisors, with support from co-management partners. In this chapter, I introduce the philosophical approach for this thesis and show how it has been informed by kaupapa Māori principles and the conceptual co-developed framework. In doing so it assists in gathering, engaging and analysing information within a marine ecological and socio-ecological context. The inclusion of Indigenous methodologies allowed the research to identify appropriate research questions and methods inclusive of both science and mātauranga Māori knowledge and practices, these questions and methods are explicitly outlined in a timeline of engagements, data collection and dissemination. The methods employed and their respective findings to ascertain appropriate management strategies are further investigated in Chapters 3 and 4 and the critical operationalisation of the co-developed framework is realised in Chapter 5.

## 2.2 Kaupapa Māori Research Methodologies

Kaupapa Māori research methodologies are regarded as a process of inquiry that determines the methods used (L. T Smith, 1999). This is achieved by drawing on Māori principles, values, experiences and world views, ensuring that research carried out is culturally sensitive and aligns with Māori aspirations (Barnes, 2000; Edwards et al., 2005; Jones et al., 2006; Pihama, 2010). Indigenous methodologies are an integral part of the research process because 'It frames the questions being asked, determines the set of instruments and methods to be employed, and shapes the analyses' (L. T. Smith, 1999, p. 144). Kaupapa Māori methodologies are often the silent part of research and not explicitly described; this thesis acknowledges kaupapa Māori methodologies as a poignant part of the research (Jones et al., 2006). L.T. Smith (1999) explains:

> Indigenous methodologies tend to approach cultural protocols, values, and behaviours as an integral part of methodology. They are factors to be built into research explicitly, to be thought about reflectively, to be declared openly as part of the research design, to be discussed as part of the results of the study and to be disseminated back to the people in culturally appropriate ways and in a language that can be understood. (p. 15)

These traditional processes and philosophies allow researchers who engage with Māori communities to do so in a culturally appropriate manner. Therefore, employing a transdisciplinary approach which adheres to kaupapa Māori principles is a plausible and important first step for this research. There are many kaupapa Māori research principles, some more appropriate than others relative to the researcher and community needs. Within this

research, I adhered to Te Awekotuku (1991) kaupapa Māori guiding principles, which lists several key principles as protocols prescribed for researchers in cultural terms. This allowed me as the researcher to conduct myself within our Māori communities in a culturally appropriate manner. I adhered to the following principles throughout my research:

1. Aroha ki te tangata (a respect for people)
2. Kanohi kitea (a face seen)
3. Tītiro, whakarongo, kōrero (look, listen, then speak)
4. Manaaki ki te tangata (share and host people, be generous)
5. Kia tūpato (be cautious)
6. Kaua e takahia te mana o te tangata (do not trample over the mana of people)
7. Kia māhaki (be humble).

Furthermore, despite the term 'kaupapa Māori' research emerging relatively recently in the 20th century, its origins can be traced back to mātauranga Māori. Kaupapa Māori has arisen as a 'conscientised, transforming' response (G. Smith, 2003) to the struggles for Māori autonomy and identity that span generations (Mead, 2003; Pihama et al., 2002). Kaupapa Māori draws its strengths from Māori traditions, or tikanga. Tikanga Māori is a means of social control; it can be interpreted as Māori ethics, customs, habits, rules, approaches, rights and authority and is both an exercise and a concept (Mead, 2003; Pere, 1982). Central principles such as whanaungatanga (kinship), manaakitanga (hospitality), mana (power), tapu (sacredness), and utu (reciprocity) underpin tikanga, offering guidelines for conduct and organisation of activities (Mead, 2003). As Mead (2003) describes: 'Tikanga are tools of thought and understanding. They are packages of ideas which help to organise behaviour and provide some predictability in how certain activities are carried out' (p. 12).

For researchers, kaupapa Māori provides a foundation rooted in traditional Māori practices or tikanga Māori, informing modern research methodologies (Jones et al., 2006; Mead, 2003). Elders often uphold tikanga, to assist guidance for the research ensuring appropriate actions are taken (Pihama, 2010). Throughout this research endeavour, a consistent commitment to consult with Ngāti Awa iwi at all levels and all stages of the research was maintained, from the project's inception through its duration. Their concerns and aspirations were fundamental in shaping the conceptualisation of this thesis.

### 2.2.1 University of Waikato ethics

To ensure kaupapa Māori principles were upheld in this thesis study, I further adhered to the ethical policies of my academic institute. The process involved completing the University of Waikato ethical application and gaining approval from the University of Waikato Human Ethics Committee (HECS) (approval number: HREC(HECS)2021#14, 14th April 2021, see Appendix A). Within the application, I detailed the research design and methods, emphasizing ethical considerations, legal issues, as well as the guiding principles of kaupapa Māori. Furthermore, I addressed access to participants, obtaining informed consent, maintaining confidentiality, minimizing potential harm to participants and what information participants can expect to receive. I also discussed the use of information, cultural sensitivity, participant compensation, dispute resolution processes and disclosed any financial contributions beyond those from the university, noting that there were no conflicts of interest.

The principles stated in my application for human ethics included:

1. Ensure the iwi is recognised throughout the study and work closely with participants.
2. Ensure the needs of everyone are met not just what the researcher 'wants'.
3. Outline in detail how the research being carried out will better the iwi.
4. The values of Māori culture are a key focus.
5. Allow for the participants to have a significant say in the methods and overall research being conducted.

A detailed description of how I adhered to these thesis principles is presented below in section (2.3). It was crucial to demonstrate kaupapa Māori research principles in the ethics application. This allowed me as the researcher and the University of Waikato to commit to the collaborative approach of the work being carried out.

## 2.3 Co-developed Framework: Ka Mua, Ka Muri

*Ka mua ka muri—I look to the past to inform the future*

This whakataukī, or proverb, reflects the philosophical approach to this research. It refers to the importance of knowing, understanding and building on past knowledge for achieving Māori aspirations today and into the future (Rameka, 2016). The whakataukī provides a conceptual

framework, hereafter referred to as the ‘ka mua ka muri co-developed framework’. The whakataukī enables this research to navigate the interface of mātauranga Māori and science—where we look to Māori perspectives of the past (i.e., Māori philosophies) and contemporary tools and knowledge of today (i.e., science-based and mātauranga Māori practices). It also allows us to come together collectively to enact management, or kaitiakitanga (active guardianship), and research endeavours into the future. Te Awekotuku’s (1991) kaupapa Māori guiding principles are situated within this co-developed framework.

To assist my research design, I developed a visual representation of the ka mua ka muri co-developed framework (Fig 2.1). The vertical threads, or whenu (brown strands), represent important stages of the research, and the two horizontal strands twined together, known as the aho, represent mātauranga Māori (green strand) and marine science (blue strand). The traditional weaving technique known as whatu illustrates two world views coming together to strengthen and support the whenu, or different stages, of the research. The weave further illustrates the ‘Māori perspective of time, where past present and future are viewed as intertwined’ (Rameka, 2016, p. 1)—depicted by the arrows on the aho strands. The framework is further manifested in the literal sense through the production of the māhanga pātangaroa, or natural resource starfish traps (described in Chapter 3). The starfish traps are made from traditional Māori weaving materials and bound together using the ancient whatu weaving technique (Fig. 3.2). The traps were co-designed with a tohunga raranga kuia (master weaver elder), drawing from traditional practices, to assist in co-implementing starfish management tools to inform future starfish management actions.

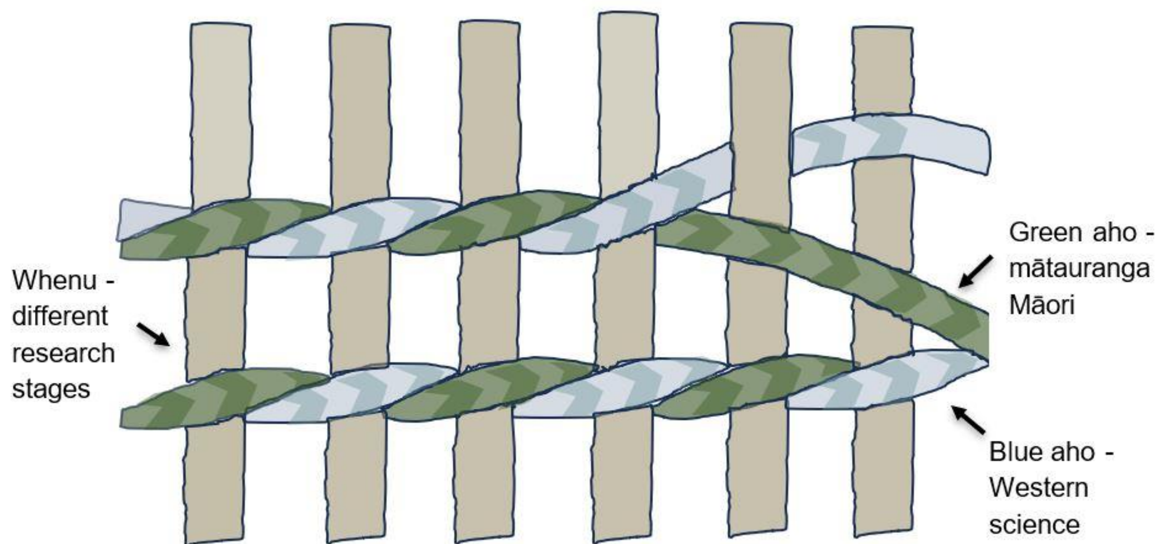


**Figure 2.1: Conceptual ka mua ka muri ('I look to the past to inform the future') co-developed framework demonstrating the weaving together of mātauranga Māori and marine science**

This framework provides a pathway that translates environmental priorities reflective of Indigenous voices and values. It is inclusive of both scientific and mātauranga Māori knowledge and methods and ensures the research outcomes can transcend into management decisions and policy for the future. The ka mua ka muri co-developed framework is grounded in mātauranga Māori perspectives and does not assume mātauranga Māori as 'knowledge that can be extracted' but rather as a practice through generating new knowledge in parallel with science (Mead, 2003). Furthermore, the framework assumes the research concepts originate from a mātauranga-ā-iwi (place-based intergenerational knowledge) or Māori perspective.

## 2.4 Advisors and Co-management Partners

For this research study, kaumātua (tribal elders) identified and guided the active inclusion of mātauranga Māori. Within a Māori construct, kaumātua are regarded as holders of knowledge, nurturers, guardians of tikanga and leaders and are responsible for selecting and teaching other members everything they need to know to understand (Mead, 2003; Pere, 1982). As a Ngāti Awa descendant, I was identified in 2018 and mentored by my Ngāti Awa tribal elders to carry out this research to support and help our harbour and our people further. The relational dynamics between kaumātua and myself as the researcher adhere to a tuakana–teina model ('tuakana' meaning 'older' or 'more experienced' and 'teina' meaning 'younger' or 'less experienced'); where the kaumātua provides culturally appropriate guidance to assist with the

research and, in return, I exchange information of value to the community. Research should be both informed and informative. Thus, the principle of reciprocity, where there is equitable exchange between elders, mātauranga Māori advisors and academic researchers, is a significant part of this research and builds capability among community and academic partners (Arsenault et al., 2018). Furthermore, the tuakana–teina model shifts the power dynamics from the individual to the collective. Kaumātua advocate the collaborative voice of their community members, and so, within this Māori cultural construct, the tuakana-teina model enables collective views to be accounted for in this research and for the research to be more accepted (Bishop, 1995). As Mead (2003) establishes, following the correct process, procedures, and consultations within a tikanga framework ensures 'that everyone who is connected to the research is enriched, empowered, enlightened and glad to have been a part of it' (p. 318).

Prior to the commencement of my PhD research, a mātauranga Māori advisory group collectively referred to as 'te rōpū kairangahau' was initiated by my chief supervisor (Fig. 2.2). The advisory group is made up of two representatives from Ngāti Awa iwi, both well-respected kaumātua who hold leadership roles among their respective iwi as well as hapū. Tūwhakairiora O'Brien is the chairman for TRoNA (Ngāti Awa iwi council) and Charlie Bluett is the customary fisheries manager for TRoNA. Both advisors also sit as Ngāti Awa iwi representatives for the OHIF. Their position within this research was to provide cultural guidance and advocate the collaborative voice of their whānau, hapū and iwi members. Furthermore, they provided mātauranga-ā-iwi, or placed-based ecological knowledge, that is of significant value to this research. Kaumātua participation was central to my kaupapa Māori research approach, as they offered guidance, spiritual oversight and protection and ensured cultural practices remained a priority (Glover, 2002; Walker et al., 2006).

The science and technical advisory group (STAG), comprising expert marine ecologists and a technical advisor, was also established by me to provide scientific and technical support, guidance and oversight. My chief supervisor also has whakapapa (ancestral connections) to Ōhiwa and actively promoted and conducted kaupapa Māori research methodologies within her research practices. She also provided support and guidance around appropriate customs and practices when carrying out the research. Furthermore, the technical field advisor has extensive experience in boating and scientific diving in Ōhiwa Harbour and has collaborated with local iwi for two decades. It was important that members were not only experts in their respective fields but open to alternative approaches to traditional science practices. This is because one of the greatest limitations for Indigenous doctoral students is having strong support from their

academic supervisors (McKinley et al., 2011; Williams & Shipley, 2023). As discussed in Chapter 1, the co-management entity, OHIF, and working group, OHSCG, provided support and feedback regarding the research outcomes. Both the OHIF and OHSCG have high Māori representation from the four affiliated iwi (Ngāti Awa, Te Ūpokorehe, Whakatōhea and Waimana Kaaku–Tūhoe), and the elected chairperson for the OHIF is of Māori descent. Furthermore, this study is part of a wider research project referred to as Awhi Mai Awhi Atu research – Enacting Kaitiakitanga EBM (Ecosystem Based Management), which comprises of other researchers who are working on other projects to support the mussel recovery and are referred to as the Awhi Mai Awhi Atu team.

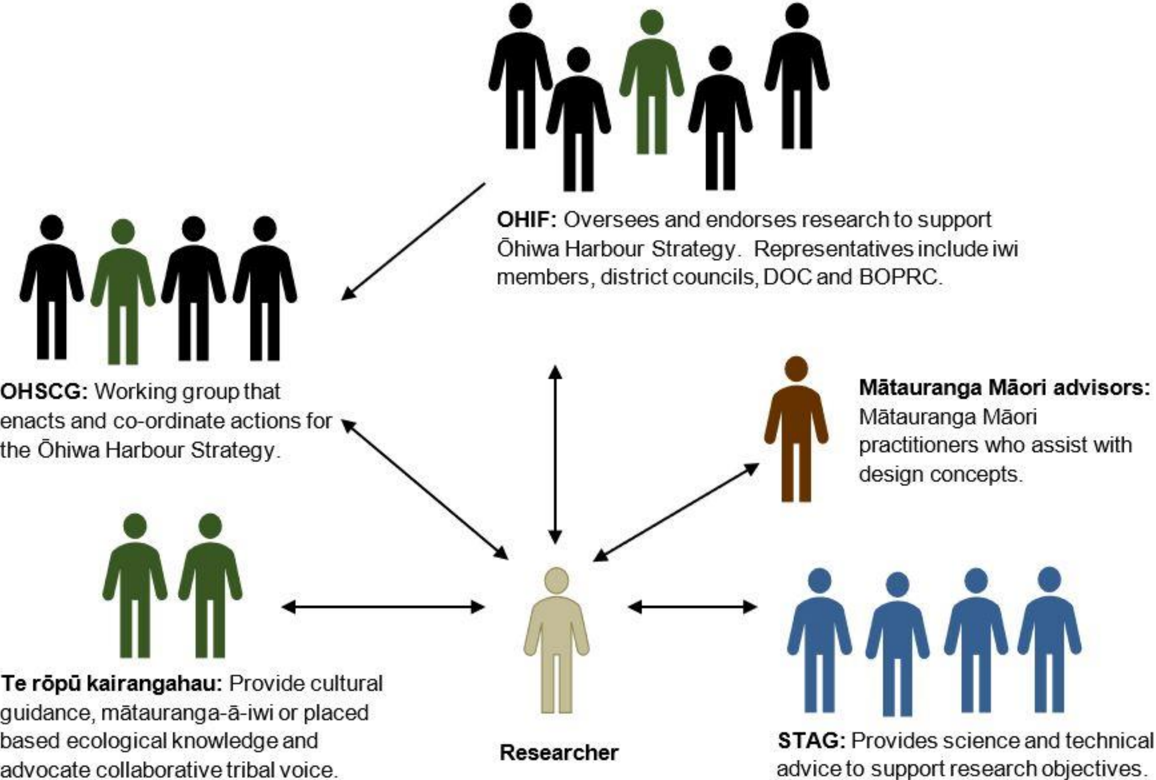


**Figure 2.2: Diagram of relationships between researcher (beige), te rōpū kairangahau (cultural advisors) (green), mātauranga Māori practitioners (brown), science advisors (blue), co-management partner (Ōhiwa Harbour Implementation Forum [OHIF]) and working group (Ōhiwa Harbour Strategy Coordination Group [OHSCG]) (black)**

BOPRC = Bay of Plenty Regional Council, DOC = Department of Conservation, STAG = science and technical advisory group.

## 2.5 Engagement Following Kaupapa Māori Principles

Engagement for the PhD thesis with iwi advisors and co-management partners adhered to kaupapa Māori research principles. Engagements took place on a regular basis between 2019 and 2023 and were either in the form of hui (meetings) or wānanga (knowledge sharing) (Fig. 2.3). Hui included in person, video meetings, phone calls and emails. In addition, the Awhi Mai Awhi Atu research team disseminated information through presentations at national and international conferences; local and regional komiti Māori hui (Māori committee meeting) and carried out several education outreach programs at local primary and secondary schools. In total, 220 engagements, in the form of co-developed hui or wānanga, were carried out by the wider Awhi Mai Awhi Atu research team. Of those, 27 were either led by me or directly related to my PhD research (see Table 2.1). At these meetings, updates were presented and co-development options for the research were discussed, approval and feedback were sought afterwards to support the next stage of the research.

**Figure 2.3: Image of myself (in brown jersey) with members of the science and technical advisory group and te rōpū kairangahau at a wānanga in September 2021 at Te Rūnanga o Ngāti Awa, discussing starfish management feasibility study**

**Table 2.1: Total number of engagements, presentations, wānanga and other informal engagements from wider project Awhi Mai Awhi Atu (AMAA) and my PhD research between 2019 and 2023**

| | Hui/ Meetings | Wānanga/ Workshops | Presentations/ Conferences | Education outreach | Total engagements |
|---|---|---|---|---|---|
| AMAA project members | 180 | 13 | 46 | 7 | 246 |
| PhD researcher | 23 | 4 | 13 | 2 | 42 |
| Total | 203 | 17 | 59 | 9 | 282 |

Most engagements were kanohi kitea (Te Awekotuku [1991] kaupapa Māori guiding Principle 2: 'a face seen'). This allowed for greater transparency and understanding and a sense of showing up, kanohi kitea also provided opportunity for greater critique (Te Awekotuku, 1991; L. T. Smith, 1999). Our engagements were arranged by my chief supervisor, who has a long-standing relationship with our iwi partners, this step follows tikanga Māori, where you turn to your elders for guidance (Mead, 2003). I always ensured engagements considered our iwi partners' schedules and hui were kept short, so they were not taxing. In my initial engagements, I would 'tītiro, whakarongo, kōrero' (Te Awekotuku [1991] kaupapa Māori guiding Principle 3: 'look, listen then speak'). This allowed kaumātua voices to be heard and respected and therefore shaped the research around their whakaaro (thoughts) first and foremost. I ensured refreshments were provided, as this follows another principle: manaakitanga (Te Awekotuku [1991] kaupapa Māori guiding Principle 4: 'share and host people, be generous'). I used maps to assist participants with identifying areas such as our study site and the mātauranga Māori affiliated to a particular place in the harbour (Fig. 2.3). Hui often took place at the Te Rūnanga o Ngāti Awa building or at their selected marae (tribal meeting place). This gave a sense of familiarity that shifted further the power dynamics from the researcher to the participants (Paul-Burke et al., 2020). I also made sure to use appropriate language so everyone could understand—this helps to 'demystify, to decolonize' science (Principle 6: kaua e takahia te mana o te tangata—do not trample over the mana of people) (Kennedy & Cram, 2010; L. T. Smith, 1999).

The OHIF meetings were scheduled every six months. Through these meetings, updates research progress updates were provided and approval and feedback sought for endorsement of

the next research stage. A written short report was also submitted to the OHIF and OHSCG to assist in disseminating findings (see Appendix C). Prior to any OHIF meetings, we shared new information with our iwi partners so that there were no surprises, and that any concerns around information sharing was filtered through them. Ultimately, this methodology helped to guide which data I would collect and how I would collect it.

## 2.6 Timeline of Engagements and Field Research Following Ka Mua Ka Muri Co-developed Framework

Putting our co-developed framework into practice, we collectively co-designed and implemented an experimental starfish removal study. Figure 2.4 depicts a timeline showing the key co-development stages with Ngāti Awa kaumātua, co-management partners and scientific advisors (see Appendix D for a full list of engagements). Each time stamp includes a brief description of the actions taken as well as important feedback that assisted in the study design and execution. Some of the stages are discussed in greater detail in Chapters 3 and 4.

The timeline depicts the whakapapa (in this context, meaning 'origin') of this research, beginning with a Ngāti Awa–led subtidal mussel monitoring program in Ōhiwa Harbour in response to mussel decline. The monitoring found infestation of the eleven-armed starfish to be limiting mussel recovery because of over-predation (Paul-Burke & Burke, 2016). Given mussels are a highly valued species, an investigation into drivers of starfish outbreaks and management was of high importance for Ngāti Awa and other affiliated iwi, the OHIF and OHSCG (see Appendix B for supporting documents). Furthermore, prior to starting the thesis, I was identified by tribal elders of Ngāti Awa in 2018 as a suitable candidate to further mātauranga-led research in Ōhiwa Harbour. I attended several hui as a spectator in 2019 and 2020, including several OHIF biannual meetings and hui-ā-iwi (tribal gatherings). This meant I became a familiar face, which assisted and strengthened whanaungatanga or relationships between myself and my tribal elders.

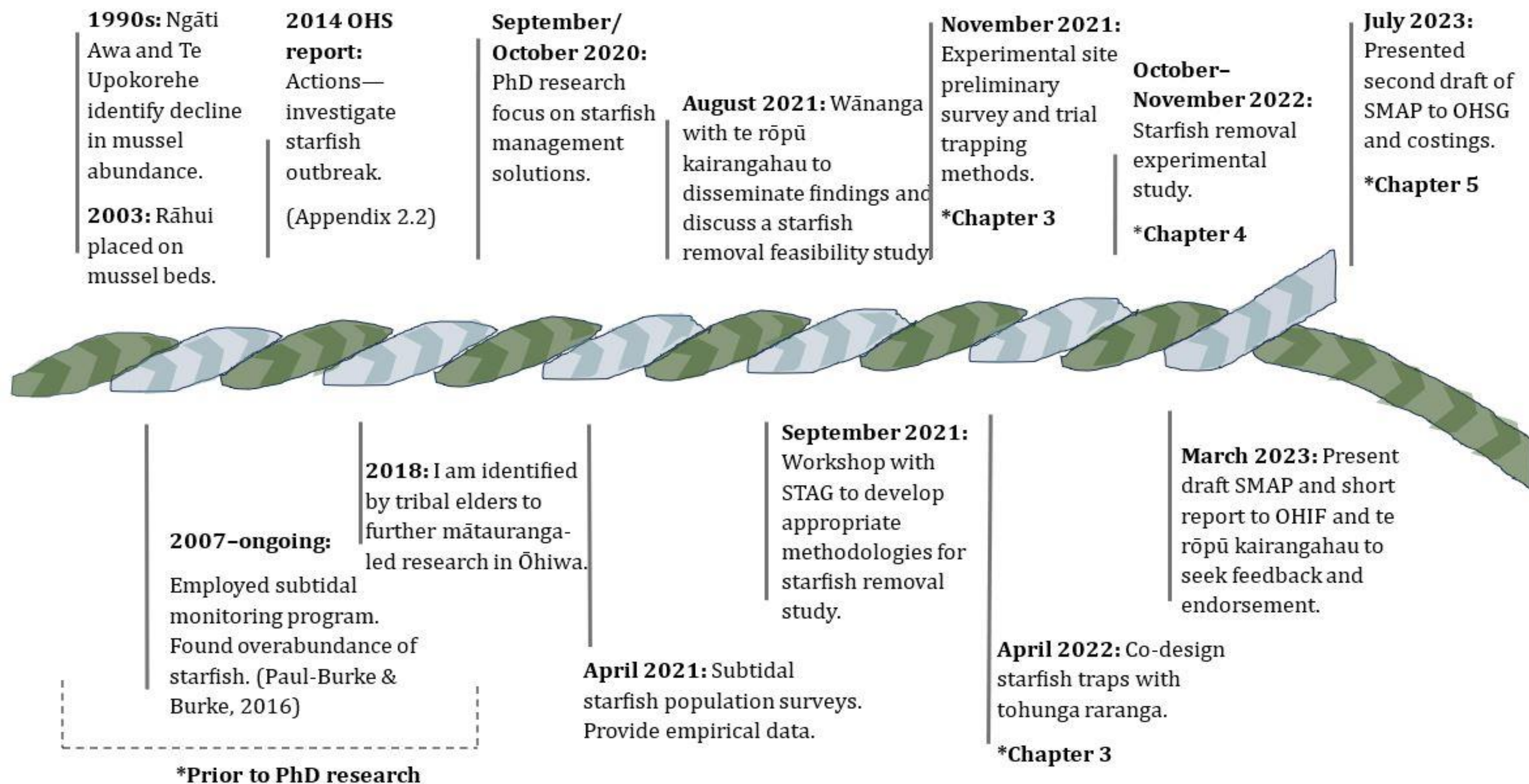


**Figure 2.4: Figure adapted from ka mua ka muri co-developed framework (Fig. 2.1) demonstrating research informed by mātauranga Māori through engagement and co-design of research with te rōpū kairangahau and marine science to assist in developing the starfish management action plan (SMAP)**

OHIF = Ōhiwa Harbour Implementation Forum, STAG = science and technical advisory group, OHS = *Ōhiwa Harbour Strategy*.

To support this kaupapa (issue), understanding the current state of the starfish infestation (abundance and distribution) was deemed of high priority by our te rōpū kairangahau to attain empirical evidence and assist in deciding research priorities for this research. Therefore, a starfish population survey was carried out (the methods are described in Appendix E). We then presented the findings, and, based on the feedback received from te rōpū kairangahau, a starfish removal feasibility study was recommended to support and inform the SMAP.

Subsequent wānanga, hui and presentations were carried out to formulate a starfish removal study based on experiential study design principles and feedback from the rōpū kairangahau, OHIF and STAG. Based on feedback, I conducted a preliminary trapping study to identify the most appropriate trapping methodology and co-designed and co-developed a natural resource starfish trap (described in Chapter 3). This approach informed the starfish removal study (described in Chapter 4). Findings from the starfish removal study and a draft SMAP based on information gathered from the field work were presented to the rōpū kairangahau and OHIF (described in Chapter 5). Amendments based on feedback were made to the draft SMAP and a final draft was presented at the OHSCG biannual meeting.

## 2.7 Conclusion

This chapter describes the theoretical frameworks that supported and guided this thesis research. It also explores a research study that appropriately sites itself in kaupapa Māori research methodologies, whereby research priorities and methods used to collect information and information sharing ensured the study was truly co-developed and inclusive of both mātauranga Māori and marine science. Although engagement processes do take significantly more time, these should be built within research methodologies (L. T. Smith, 1999) to ensure participants' (representatives from their respective communities) viewpoints and knowledge are represented and disseminated in a dialogue that is can be interpreted and acted on (Paul-Burke et al., 2018).

The timeline and outcome from the engagements show the interrelationship between the research I conducted (described in Chapters 3 and 4) and the co-development process I undertook, which involved returning to our kaumātua/iwi advisors with the study results to discuss the next research stage. Chapters 3 and 4 describe in detail the undertaken field-based research employing both mātauranga-ā-iwi and marine science field methods to assist and

inform the SMAP. The co-development of the SMAP ensured iwi voices were heard and, more important, unanimously supported by all members of the research project, including the OHIF, the OHSCG and te rōpū kairangahau.

# Chapter 3: Māhanga Pātangaroa: Co-developing an Optimal Starfish Trapping Methodology

## 3.1 Introduction

Worldwide, there have been several recorded removal (research) programs to address starfish outbreaks, including trapping (Andrews et al., 1996), starfish mops (a modified dredge dragged across the sea floor) (Calderwood et al., 2016; Lee, 1951; Park et al., 1997; G. F. M. Smith, 1940), hand collection by divers (Andrews et al., 1996; Yamaguchi, 1986), and biological and chemical control (Boström-Einarsson & Rivera-Posada, 2016; Buck et al., 2016; Grand et al., 2014; D. B. Johnson et al., 1990; Rivera-Posada et al., 2014). Each approach presents distinct advantages and disadvantages as outlined in Table 3.1. The practicalities and ethical considerations associated with each method were evaluated against the Ōhiwa Harbour socio-cultural-ecological backdrop. Drawing on the scientific literature and discussions with iwi partners, trapping proved to be a suitable alternative to other methods because it does not require expensive tools or materials; selective scientific specialists nor cumbersome safety protocols, all of which could present barriers for future efforts by tribal participants. This consideration is particularly important in the context of a community-driven starfish management program such as that of Ōhiwa Harbour.

The use of traps also presented opportunities to co-design a trapping methodology further aligned with kaitiakitanga principles (conservation, protection and maintenance of resources from a Māori–centric perspective) and encouraged participatory involvement. The kaitiakitanga principles included little to no bycatch, replicable, accessible and produced minimal environmental harm. In addition, the production of traps allowed the exploration of natural resources traditionally used by Māori to fashion into aquatic traps. This was raised from earlier discussions with kaumātua (tribal elders) and the rōpū kairangahau (mātauranga Māori, or Māori knowledge, advisors) on minimising plastic in the ocean (see Fig. 2.4 in Chapter 2 for summary of engagements regarding study design and removal methods). It was also believed that natural materials would attract and/or retain a greater number of starfish; this theory builds on past observations in which starfish exclusion cages were trialled to assist in mussel seeding on the Ōhiwa Harbour Sea floor (Paul-Burke et al., 2022a). The study found greater starfish retention on cages made from natural resources than on those made from artificial materials (e.g., plastic and metal wire), long after mussels had disappeared.

**Table 3.1: Summary of the advantages and disadvantages of different starfish removal methods based on literature review**

| Removal type | Advantages | Disadvantages | Supporting literature |
|---|---|---|---|
| Diver hand collection | • More rapid response, as does not require specialist equipment<br>• Initial set-up cost is low<br>• Targets desired species, no bycatch | • Requires qualified scuba divers<br>• Limited by depth and water conditions<br>• Collected starfish need to be disposed of<br>• May be biased towards larger starfish<br>• Operational costs are high, especially if management area is large | Yamaguchi (1986)<br>Andrews et al. (1996) |
| Chemical/Biological control | • Effective for high starfish density compared with diver hand collection<br>• Does not require additional handling of starfish (e.g., disposal) | • May result in cannibalism, as conspecifics are attracted into removal area<br>• Potential to harm other marine organisms<br>• Dead starfish are not removed from the system<br>• Divers must carry large quantities of chemical solution<br>• Little social and political acceptance<br>• Limited by depth and water conditions | Boström-Einarsson and Rivera-Posada (2016)<br>Buck et al. 2016<br>Rivera-Posada et al. (2014)<br>D. B. Johnson et al. (1990)<br>Grand et al. (2014) |
| Starfish mop | • High removal rate<br>• Not subject to water visibility | • Requires specialised equipment (e.g., dredge and boiler)<br>• Efficiency is density dependent<br>• Potential to harm other marine organisms<br>• Collected starfish need to be disposed of<br>• Calm seas required to operate boiler (a vat containing hot water)<br>• Removing starfish from mops is time-consuming<br>• Operational costs are high | Calderwood et al. (2016)<br>Lee (1951)<br>Barkhouse (2007)<br>Galtsoff and Loosanoff (1939)<br>McEnnulty et al. (2001) |
| Trapping | • Not subject to water visibility or depth<br>• Low operational cost<br>• Does not require expertise or specialised equipment<br>• Traps can be tailored to site and available materials | • May require longer removal period<br>• Only suitable for localised and chronic infestation<br>• May attract starfish outside of targeted area<br>• Risk of bycatch<br>• Initial set-up cost is high | Andrews et al. (1996) |

With regards to deployment performance, the efficacy of starfish trapping is dependent on several factors, including environmental conditions (e.g., hydrodynamics, topography), bait type, soaking time (the length of time a trap is left in the water until bait is replaced), the trap's physical characteristics (e.g., trap design, size, mesh size, enclosed/open) and biological considerations (i.e., species' behaviour, mobility, migration and body shape and size) (Araya-Schmidt et al., 2019; Boutson et al., 2009; Cullen & Stevens, 2017; Naimullah et al., 2022). Initial planning is important to ensure traps are successful in attracting, retaining and maintaining the highest possible catch rates. Therefore, the overall aim of the study described in this chapter was to determine a fit-for-purpose trapping method applicable to environment, species (in this case pātangaroa, or eleven-armed starfish [*Coscinasterias muricata*], and cushion star [*Patiriella regularis*]), and community and cultural ethics and values (outlined by Ngāti Awa iwi members).

This chapter discusses the field pre-trial investigative efforts to identify appropriate materials and techniques for trapping, prior to the commencement of the actual starfish management removal field work (discussed in Chapter 4). This chapter is divided into three parts. Part 1 (section 3.1.1) provides a literature review of starfish ecology, trap design and deployment techniques, and traditional customary materials and techniques for aquatic management; Part 2 (section 3.2.1) explores the most effective trapping technique based on deployment optimisation—that is, soaking time, bait type and trap construction; and Part 3 (section 3.2.2) focuses on the exploration of natural materials for starfish traps as an alternative to synthetic materials termed 'māhanga pātangaroa'. The process of co-developing a starfish trap was aimed to produce a natural-based solution and encourage greater participation and access to starfish management tools for hapū and iwi, thus further supporting kaitiakitanga responsibilities. This co-development approach follows kaupapa Māori principles and the ka mua ka muri co-development framework outlined in Chapter 2.

### 3.1.1 Part 1: Literature review

#### *3.1.1.1 Coscinasterias muricata and Patiriella regularis ecology*

Both *C. muricata* and *P. regularis* are native to Ōhiwa Harbour (Fig. 3.1). *C. muricata* and *P. regularis* are members of the class Asteroidea, of the phylum Echinodermata, and are widely distributed in both Aotearoa New Zealand and Southern Australia. Their distribution includes open coastal to estuarine environments and sheltered intertidal to high-energy subtidal zones in

both rocky and soft-sediment habitats (Barker, 1978; Waters & Roy, 2004). *P. regularis* have shown size partitioning, where small individuals have been found in the high intertidal zone and become progressively larger further towards the sublittoral fringe (Creese, 1988; Glockner-Fagetti & Phillips, 2020).

*C. muricata* and *P. regularis* can reproduce asexually through fission, a typical trait of many starfish species, although this is believed to occur when there is a lack of food or from predation (Sköld et al., 2002). They also reproduce sexually, when they broadcast spawn millions of gametes into the water column. Fertilisation rates are likely to increase when *C. muricata* are within proximity to each other (< 2 m), as has been demonstrated by Inglis and Gust (2003). Where their simulation models predicted a 1500-times-greater zygote production in mussel farmed sites with high starfish aggregation than in non–mussel farmed sites. Both species produce planktotrophic larvae, meaning they are dependent on exogenous nutrients such as phytoplankton. Larvae spend several weeks in the water column before settling on suitable substrate (Barker, 1978; Byrne et al., 1999). Broadcast spawning starts at the beginning of the austral summer and has been reported to occur twice in one season for *C. muricata* (Georgiades et al., 2006).

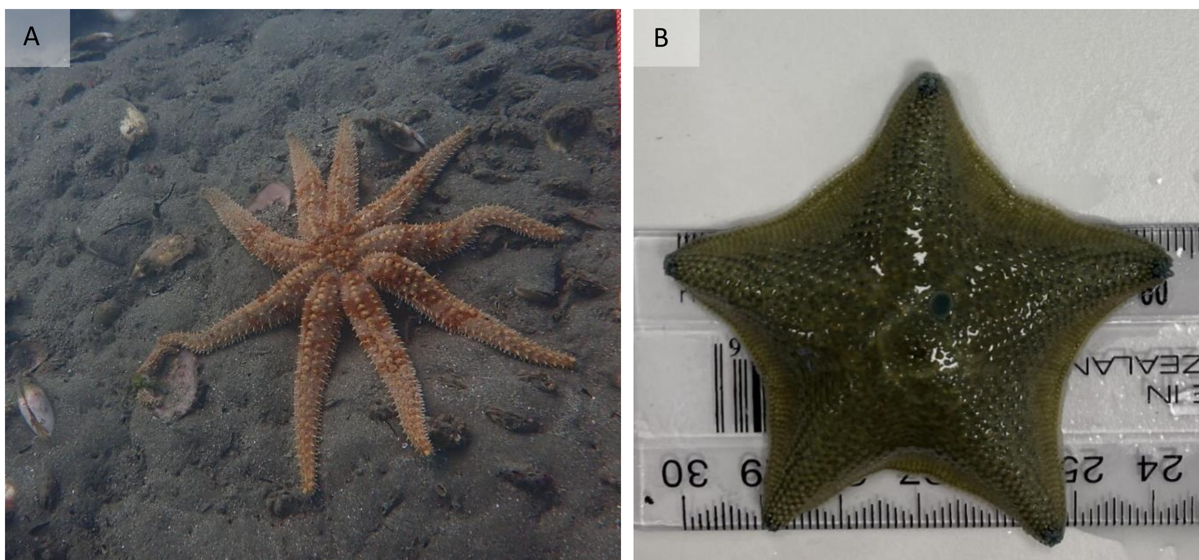


**Figure 3.1: Image of (A) pātangaroa, or eleven-armed starfish (*Coscinasterias muricata*), and (B) cushion star (*Patiriella regularis*)**

During their settlement stage, *C. muricata* are considered omnivores and are a relatively generalist feeder, although little is understood about what they feed on as juveniles and at what age/size threshold they transition to being strictly carnivores. Many adult starfish species have

demonstrated feeding and growth plasticity, allowing them to subsist in somewhat hostile environments until food conditions become favourable (Achituv & Sher, 1991; Deaker et al., 2020). *P. regularis* are considered generalist feeders throughout their benthic life, their diet mainly consisting of crustose coralline algae, microbiota, micro phytobenthos, carrion and small invertebrates (Crump, 1971). *P. regularis* have also been recorded feeding on live mussels (20-30 mm), but it took 15 h for several individuals to consume one mussel (Witman & Grange, 1998). Both starfish species detect food via their chemoreceptors, and their ability to detect prey and carrion depends on whether it is a preferred prey species, if it is fresh or decayed, the strength and direction of current (upstream carrion is detected more easily) and the tidal flow (Drolet & Himmelman, 2004; Rochette et al., 1994).

Like many Asteroidea species, *C. muricata* and *P. regulari* are subject to large population fluctuations, often referred to as 'boom and bust' cycles (i.e., large population density variation) (Uthicke et al., 2009). Life traits such as planktotrophic larvae and growth plasticity, exhibited by both species, can help explain why they experience large population fluxes (Crump & Barker, 1985; Uthicke et al., 2009). An outbreak of *C. muricata* can have detrimental effects on shallow water coastal communities, causing significant changes in ecosystem structure and nutrient cycling (Paine, 1969). However, few studies have estimated densities of *C. muricata* and *P. regularis* in Aotearoa New Zealand. Past surveys have recorded densities from 4 to 12 individuals per square metre (ind. $m^{-2}$) of *P. regularis* on the Otago Peninsula (Palmer, 2010) to as many as 90 ind. $m^{-2}$ on the south coast near Princess Bay and Breaker Bay (Byfield, 2013). A recruitment study by Glockner-Fagetti and Phillips (2020) on the south coast of Aotearoa New Zealand found fewer than 1 ind. $m^{-2}$ of *C. muricata* and *P. regularis* and a recent *C. muricata* population survey in Ōhiwa Harbour found up to 5 ind. $m^{-2}$ in a subtidal pipi (*Paphies australis*) bed in 2019 (Paul-Burke, Ngarimu-Cameron, Paul, et al., 2022).

#### *3.1.1.2 Starfish trap design and deployment*

Trapping starfish typically requires the alteration of existing traps or production of new traps through sourcing independent materials (Andrews et al., 1996). This means starfish traps can vary considerably in cost, and initial set-up can be expensive in comparison to other removal techniques. However, trapping can provide a long-term solution, as operational costs tend to be inexpensive compared with other removal methods such as hand collection via SCUBA diving and starfish mops. This is of particular importance if the area of interest is experiencing chronic, localised starfish infestation, as is the case with Ōhiwa Harbour (Andrews et al., 1996; Paul-

Burke & Burke, 2016; Paul-Burke et al., 2022a). Starfish traps are typically devoid of any covering, providing an opening where starfish are freely able to move on and off the trap.

Bait is used to attract and retain starfish on the trap, as starfish are guided by olfaction through their chemoreceptors to locate food sources (Garm, 2017). Different bait types can generate different levels of attraction and retention (Drolet & Himmelman, 2004), this is useful for *C. muricata*, who have displayed food preferences, particularly for mussels (Day et al., 1995). Another consideration is bait freshness. Bait can become stale after a certain time, with some baits deteriorating more quickly than others, which could deter some starfish species (Garm, 2017; Major & Jeffs, 2017). Previous starfish trapping exercises have reported differences in starfish catch rates relative to soaking time, where traps became saturated between 24 and 48 h; however, these results were dependent on bait type (Andrews et al., 1996). Therefore, understanding the most appropriate bait type and its optimal soaking time is important to minimise cost and effort.

Local hydrodynamics, such as prevailing current, can alter the distance and direction in which bait odour travels; thus, trap position and possibly configuration relative to starfish location are important (Andrews et al., 1996). Furthermore, tidal currents can affect trap structural integrity. Ōhiwa Harbour experiences strong tidal forces (> 1 m $s^{-1}$; [S. Park, 1991; Richmond et al., 1984]), so it is important to ensure the traps deployed can maintain position and form for an extended period. These considerations coupled with kaitiakitanga principles were explored further in the design, production and deployment of the starfish traps to assist with catching starfish and maintaining the highest catch rate.

*3.1.1.3 Traditional Māori materials and practices to inform contemporary environmental management*

Indigenous knowledge and ecological understanding can provide access to innovative tools and technologies to assist in improving marine biodiversity and management (Díaz et al., 2019; Kusabs et al., 2018; Paul-Burke et al., 2022). With the growing interest in bridging mātauranga Māori and Western science, there are helpful examples of research that has applied traditional Māori materials, principles and tikanga within their research design and methodologies.

Kusabs et al. (2018) applied the traditional method of tau kōura (a trap used by Māori to collect freshwater kōura) to assess population abundance and structure in several lakes in the Central North Island of Aotearoa New Zealand. They found this method provided a better

representation of kōura populations than Western trapping methods because it had a higher CPUE and was not size and sex selective. The method also had a significantly lower colonisation time (24 h as opposed to six weeks), allowing for prompt presence/absence kōura studies. Other benefits included low cost and accessibility, which allowed iwi to monitor their kōura fisheries to assist in sustainable management decision-making.

Paul-Burke et al. (2022) re-imagined commercial mussel spat lines, which are typically made from plastic, by making them from traditional Māori natural fibres such as tī kouka (*Cordyline australis*), harakeke (*Phormium tenax*), pīngao (*Ficinia spiralis*) and pirita (*Ripogonum scandens*). These materials were selected as they were traditionally used by Māori for their ability to withstand the harsh marine environment for extended periods. Different materials were woven and hung suspended in the water column. These natural mussels spat lines, referred to as taura kuku, were extremely successful at recruiting and growing mussels. The purpose of this exercise was to demonstrate a pragmatic approach to applying mātauranga Māori to design and implement a biodegradable resource as a tool to assist in mussel recovery.

In another study, Ogilvie et al. (2018) implemented mātauranga Māori principles such as kaitiakitanga as the impetus to improve environmental performance of the scampi fisheries. These principles informed alternative trawl fishing methods, such as using pots inspired by tāruke (crayfish pots) and hīnaki (eel traps), as these targeted only desired species and minimised bycatch. They also collaborated with local commercial fisherman on these traditional concepts, thus co-producing a new technology for the scampi fisheries.

All case studies are examples of the application of mātauranga Māori and/or local knowledge to assist and inform pragmatic environmental management practices. This follows kaupapa Māori methodologies, where the research is inclusive, transformative and beneficial (L. T. Smith, 1999). The advantage of these approaches is greater uptake by iwi/hapū and the wider community, support of environmental stewardship and more fit-for-purpose, thus ultimately better safeguarding of nature (Díaz et al., 2019). Furthermore, it has opened greater opportunity to expand knowledge, the ability to apply novel techniques that draw on ancient knowledge, practices and materials, and ensures that mātauranga Māori is re-invigorated and maintained through generations.

## 3.2 Methods

### 3.2.1 Part 2: Optimal trap deployment: soaking time, bait type and trap construction

The trapping study was carried out in November 2021 and occurred over six days to refine an optimal deployment technique. This was achieved by comparing the performance of two trap designs through assessing structural integrity (signs of warping), type and amount of bycatch and any evidence of drag from original deployment position throughout the study period. CPUE was also assessed for two bait types and their respective soaking times.

*3.2.1.1 Trap design and construction*

The two trap designs included a semi-enclosed box trap (hereafter, 'box trap') and an open metal trap design (hereafter, 'metal trap') (Fig. 3.2). The box trap is commonly used for marine biosecurity monitoring and management (Inglis et al., 2006). It is a lightweight, commercially available collapsible trap (63 cm × 42 cm × 20 cm) with a 13 mm mesh netting (Fig. 3.2C) (Morrisey et al., 2007). Animals enter the box trap through slits in the inward sloping panels at each end. Bait is contained within a screw-top bait holder and secured to the upper frame; a shark clip is attached on the top central part of the trap for float lines.

This trap is a relatively affordable option; however, concerns regarding its durability and risk of bycatch were raised. To ensure the box trap would maintain position, 7 kg of lead weight was attached to each trap. The metal trap was inspired by the Whayman–Holdsworth starfish trap (Andrews et al., 1996) and an open crab trap made from a discarded bicycle-wheel frame that an Ōhiwa local had fashioned and deployed in the harbour. The design concepts for the metal trap ensured little to no bycatch, a low profile to withstand strong tidal forces, accessibility and being large enough to hold a substantial number of starfish. Although the metal trap could not stop starfish from leaving, given starfish have a naturally aggregative behaviour, it is thought that they would stay in the trap for a long period (> 24 h) (Andrews et al., 1996; Gaymer et al., 2001b; Inglis & Gust, 2003). The metal trap was made from a 6 kg 20 mm steel frame welded into 1 m by 1 m square with 20 mm mesh sewn onto this. A bait holder was secured in the centre of the trap. A 80 cm polypropylene rope was spliced onto each corner of the trap and each rope end was spliced onto a metal ring, forming a harness. A surface float was attached to each trap to ensure easy retrieval. The surface float consisted of a 10 m polypropylene rope with a low-drag ribbed cray float attached on the surface end and a shark

clip spliced to the other end and used to attach to the trap's harness O ring. Two metal traps were made to compare performance with the box traps.

*3.2.1.2 Deployment*

Fourteen traps were deployed (12 box traps and two metal traps); seven were baited with frozen bonito fish (400 g) and seven with mixed live and crushed green-lipped mussel (400 g) sourced from the harbour. These bait types were selected as they are both commonly available commercial species. Traps were randomly deployed in the western channel of Ōhiwa Harbour within a known eleven-armed starfish population (Fig. 3.3). Spacing between traps was greater than 80 m to ensure no interaction, as some starfish species have been recorded to travel up to 20 m in 24 h (Andrews et al., 1996). All traps were left in the water for 24 h before being pulled and *C. muricata* and *P. regularis* numbers were recorded before being removed from the traps. Other species were recorded as bycatch, excluding small crab species. Traps were then re-baited and relocated to another site within the study area. Additional observations included whether each trap type remained in its original deployment position (did it drag?) and any signs of warping. This was repeated for 48 h and 72 h soak times.

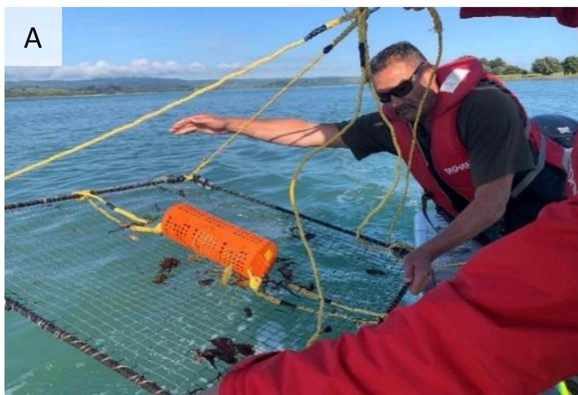

**Figure 3.2: (A) Open metal trap being deployed by local kaitiaki (Ngāti Awa). (B) Bycatch from semi-enclosed box trap. (C) Semi-enclosed box trap with eleven-armed starfish**

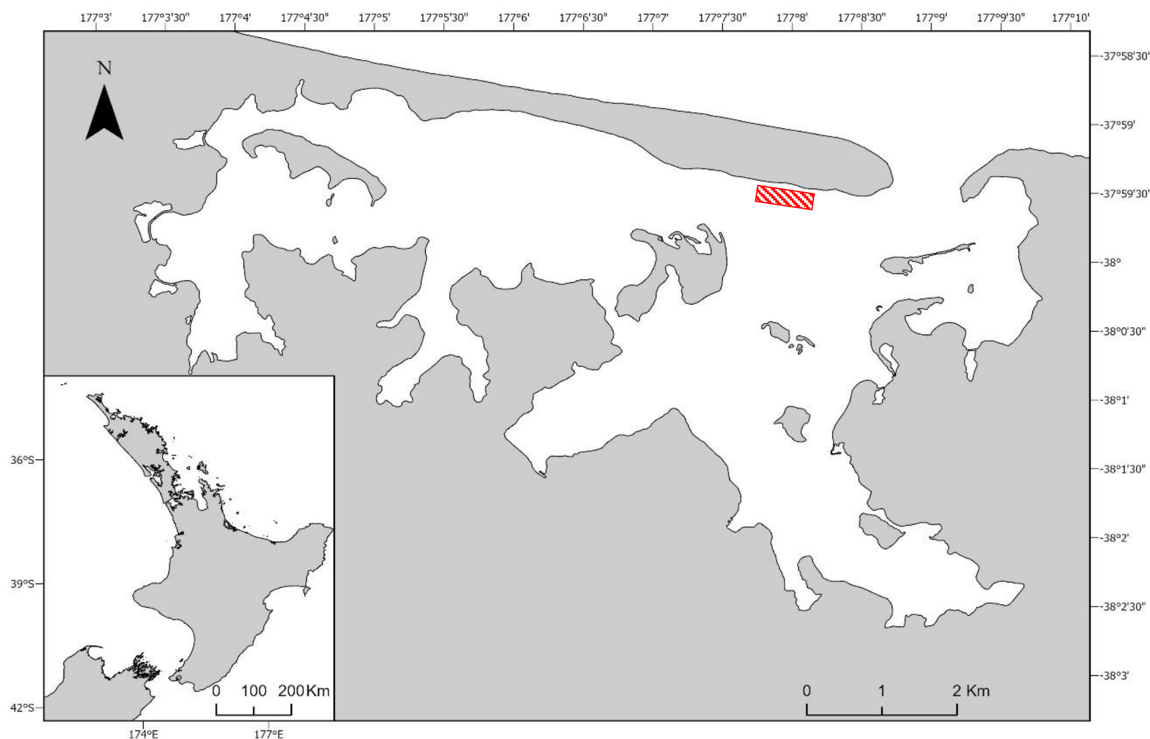


**Figure 3.3: Map of Ōhiwa Harbour, Aotearoa New Zealand, showing location of trapping deployment site (red-shaded rectangle)**

### 3.2.2 Part 3: Co-developing a natural resource starfish trap

The development of a natural resource starfish trap, or māhanga pātangaroa (hereafter 'natural trap'), was achieved by co-designing with tohunga raranga (master weaver) Rokahurihia Ngarimu-Cameron in April 2022, applying her mātauranga Māori weaving principles and traditional Māori weaving materials. The application of raranga (weaving) and use of traditional Māori materials to make starfish traps aligned with kaitiakitanga principles because this process was inclusive, sustainable, encouraged experimental observation and understanding, and adhered to tikanga (McAllister et al., 2023). Inspired by the deployment performance of the metal trap (Fig. 3.1A), the natural trap was designed to have similar physical characteristics, including open concept, low profile and same-size area (1 m × 1 m). Through wānanga with tohunga raranga (weaving expert) Rokahurihia Ngarimu-Cameron, we selected native

materials, including pirita (*Ripogonum scandens*, supple jack) and harakeke (*Phormium tenax*, flax), to make the natural traps (Fig. 3.3).

The materials pirita and harakeke are native to Aotearoa New Zealand and are widely distributed throughout the country. Pirita is a woody evergreen vine that inhabits all types of forests (Macmillan, 1972), while harakeke is an evergreen perennial plant that thrives in lowland flood zones but can also be found in coastal and montane areas (Wehi & Clarkson, 2007). Pirita provides a strong, pliable wood stem so was highly favoured by Māori for construction, particularly for hunting (McCallum & Carr, 2012). This is evident in Māori tradition, where the vines were believed to have grown from the tail of the eel god Tunaroa, and eel traps, or hīnaki, from pirita were constructed to catch Tunaroa's children (Vennell, 2019). Pirita was also commonly employed in the construction of other aquatic traps, including the tāruke (crab trap) and fishnets (Te Rangi Hiroa, 1926). Harakeke produces stiff, fan-like leaves that grow 1–3 m long and are 5–12 cm wide (McCallum & Carr, 2012). Harakeke leaves can be stripped down to produce a fibrous material known as 'muka', and this would be used to make anything for day-to-day life, including clothing, fishing lines, nets, mats, baskets, rope, sails and house panels (Vennell, 2019). The significance of harakeke is highlighted in Māori pūrākau (ancient legends), the most infamous being when Mauī (a well-respected demigod among Māori) used ropes made from harakeke to slow the sundown, and when he hauled up the North Island of Aotearoa New Zealand, Te Ika a Maui (the fish of Maui). These metaphors highlighted the strength and durability of harakeke. Its suitability and ease of preparation made it the most commonly used weaving material in Aotearoa New Zealand. It was also readily used by early European settlers to make rope and became a popular exported material in the early 1800s (McRae-Tarei, 2013; Riley, 2004).

#### *3.2.2.1 Making and deployment of māhanga pātangaroa*

Traditionally and in modern Māori society, the acts of harvesting, gathering and working with plants have strict tikanga, or protocols, specific to each plant species. This ensured the health and sustainability of the plant for generations to come (McCallum & Carr, 2012; Mead, 2003; Patterson, 1994). Therefore, prior to making the traps, our tohunga raranga demonstrated tikanga during the harvest, preparation and weaving of materials that included:

1. not harvesting when plants are in flower (so as not to disturb reproduction and pollinating species)

2. producing little waste—this meant calculating exactly how many metres of pirita we required and only selecting the straightest branches so as not to discard any unsuitable branches during production
3. giving karakia and thanks before taking any resources from the ngahere (forest)
4. selecting only the tīpuna (grandparent leaves) and leaving the rito (child or youngest leaf) and awhi rito (parents) sitting either side of the rito leaf, ensuring the sustainability of the harakeke plant is preserved for future generations. (McRae-Tarei, 2013)
5. cutting the leaves with a sharp blade on a downwards angle as close to the base as possible to ensure water flowed to the ground and did not rot the new growth
6. removing some of the old and dead leaves to help the harakeke grow and keep insect pests and diseases at bay
7. not collecting harakeke in the rain or when the plant is wet
8. not consuming food during raranga, as this practice is tapu (sacred state).

Ensuring I followed the correct protocols, pirita and harakeke were collected from several local ngahere. The pirita was cut into 1 m lengths and the harakeke was cut into strips 2 cm wide and wrapped in a wet towel for 48 h prior to use. The harakeke was then stripped to make muka, applying the teachings from our tohunga raranga. The 1 m lengths of pirita were bound together using the whatu technique (traditional Māori twining technique; see Fig. 3.4D) by twisting the muka with each pirita. Three pirita backbones were also attached for additional support, and this was repeated until the trap formed a $1 \times 1$ m dimension. The traps were weighted with lead and the bait boxes were weaved into kono (baskets) from leftover harakeke strips. The harness part of the trap was made by plating muka at each corner and connecting to a metal O ring (Fig. 3.4D). A nylon float line was then attached to the O ring on one end and a plastic float on the other end for retrieval.

**Figure 3.4: (A) Tohunga raranga Rokahurihia Ngarimu-Cameron (Te Whānau-ā-Apanui and Whakatōhea) (left) and myself (Ngāti Awa) harvesting pirita. (B) Three generations of wāhine Māori (myself (left), Rokahurihia (centre) and my chief supervisor Kura Paul-Burke (right)) whom all whakapapa or have genealogical connections to Ōhiwa Harbour discussing harakeke weaving techniques. (C) Demonstrating one of the weaving techniques. (D) The final māhanga pātangaroa, natural starfish trap, applying mātauranga Māori weaving principles and materials. (E) Deploying the māhanga pātangaroa prototype in Ōhiwa Harbour**

Three māhanga pātangaroa, or natural starfish traps, were made. To assess the performance of the māhanga pātangaroa against that of the metal traps, they were deployed during the fish-down (clearing of starfish) study in October–November 2022, as described in Chapter 4. The study included nine removal plots that were assigned one of three treatments: three plots were cleared of starfish by trapping, three plots cleared of starfish by divers prior to trapping and three plots cleared of starfish by divers rather than trapping. Five traps were assigned to each removal plot involving trapping. The allocation of the natural traps to removal plots was randomised, substituting one of the metal traps; thus, 27 metal traps and three natural traps were used during the fish-down. Starfish numbers were recorded every time traps were pulled and reset (48 h) to assess any difference in catch rates between the two trap types (ind. $d^{-1}$).

### 3.2.3 Data analysis

Analysis for the study was carried out to understand the most appropriate trapping methodology for the starfish removal experiment. Performance of the metal trap and the box trap was compared with regards to structural integrity, signs of dragging and bycatch, but because of low repetition of the metal trap for the initial deployment trial, no statistical analysis was carried out. Assumptions of normality and equivalence of variance in the data were assessed with the Shapiro–Wilk test and Levene's test, respectively. Catch rates of *C. muricata* were standardised to number of individuals caught per trap per day (ind. $d^{-1}$) to perform analyses. A two-way analysis of variance (ANOVA) was used to assess if daily *C. muricata* catch rates were different between soaking time, bait types and any significant interaction between the two variables. A Newman–Keuls post-hoc analysis was carried out to understand what soaking times and bait types were significantly different. To compare catch performance between the natural and metal traps, mean catch rates of *C. muricata* and *P. regularis* across replicates for a two-day soak over eight sampling events were compared with a paired two-sample *t*-test. A significance level of 0.05 was used for all analyses. All tests were performed in STATISTICA version 14.0.0 software by StatSoft.

## 3.3 Results

### 3.3.1 Trapping deployment study

Several of the semi-enclosed box traps showed evidence of having been dragged from their original deployment location, as well as warping, resulting in some traps opening. In contrast, the open metal traps maintained both position and structure, proving it can withstand against

the tidal forces exhibited in Ōhiwa Harbour. Both traps caught hermit crabs (*Pagurus novizealandiae*) and other crab species (but were excluded as bycatch as they could move freely on and off the traps); however, the box trap caught several other macrofauna species, including octopus (*Pinnoctopus cordiformis*), conger eel (*Leptocephalus verreauxi*) and sea horses (*Hippocampus spp*.) (Table 3.2). Bycatch increased with time for the box traps, where mean CPUE was lowest in the first 24 h and highest for the 48 h and 72 h soak times (Table 3.2). This differs from the CPUE pattern seen with *C. muricata* catch rates (Fig. 3.5).

**Table 3.2: Mean catch per unit effort (CPUE) of bycatch (ind. d$^{-1}$) ± 1 *SD* from metal and box traps relative to soak time (excluding crab species)**

| | **Trap type** | |
|---|---|---|
| **Soak time (h)** | **Metal (*n* = 2)** | **Box (*n* = 12)** |
| 24 | 0 ± 0 | 0.08 ± 0.08 |
| 48 | 0 ± 0 | 0.17 ± 0.25 |
| 72 | 0 ± 0 | 0.19 ± 0.26 |

No differences in *C. muricata* catch rates were found between fish- and mussel-baited traps (Fig. 3.4 and Table 3.3) and no interaction was found between soaking time and bait type—bait capture rates followed the same pattern through time, declining after 72 h of soak time (Fig. 3.5). Catch rates of *C. muricata* were similar for 24 h and 48 h soaks but began to decline by a third from 72 h (Fig. 3.5).

**Table 3.3: Results of a two-way analysis of variance for combined effects of bait type (bonito fish and mussels) and soak time (24 h, 48 h and 72 h) for the catch per unit effort (CPUE) of *Coscinasterias muricata* (ind. d$^{-1}$)**

| **Variation source** | **SS** | ***Df*** | **MS** | ***F*** | ***P* value** |
|---|---|---|---|---|---|
| Bait | 1.94 | 1 | 1.86 | 0.38 | 0.55 |
| Soak time | 33.76 | 2 | 17.37 | 3.29 | **0.04** |
| Bait*Soak time | 3.38 | 2 | 1.91 | 0.38 | 0.68 |
| Error | 179.06 | 36 | 4.98 | | |
| Total | 244.97 | 41 | | | |

MS = mean of squares, SS = sum of squares, ind. d$^{-1}$ = individuals per day

* Bold indicates significant difference

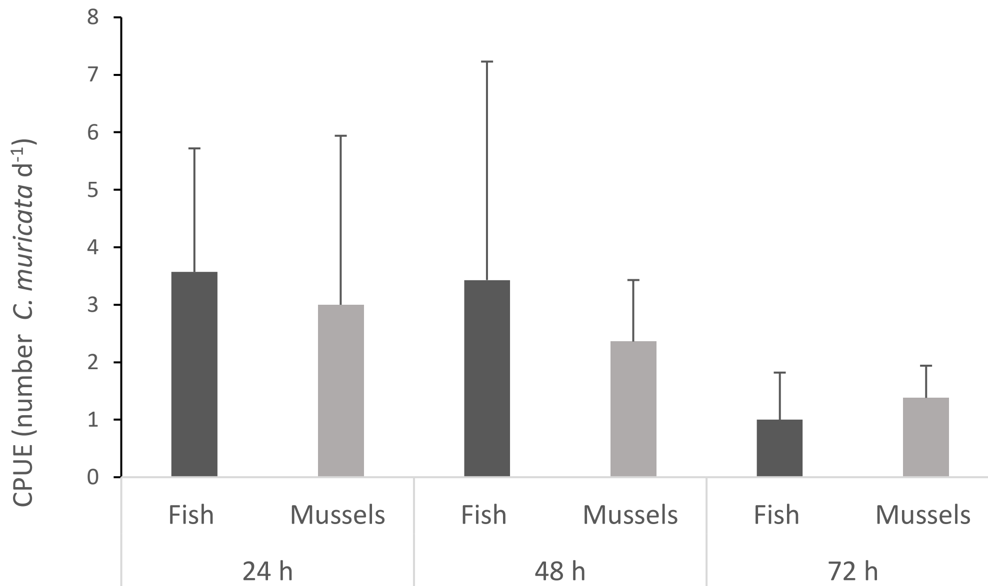


**Figure 3.5: Mean catch per unit effort (CPUE) of *Coscinasterias muricata* (+ 1 *SD*; *n* = 7 traps) as a function of bait type and soaking time**

### 3.3.2 Māhanga pātangaroa performance

Over the 18-day fish-down period, most of the traps maintained position and structural integrity. On day four of the fish-down, one of the three natural traps was lost, and on Day 10, one of the metal traps nettings became loose. Both these traps were replaced immediately with spare metal traps to maintain the same catch effort. On Day 14, one of the plastic bait boxes became detached and the kono showed signs of deteriorating. All bait boxes were replaced with spares. The mean CPUE of *C. muricata* did not vary significantly between trap types (paired *t*-test $t(8) = 1.69$, $p = 0.13$) but was significantly different for *P. regularis* ($t(8) = 3.94$, $p = 0.004$), where the metal trap CPUE was twice as high as that of the natural traps (Fig. 3.6).

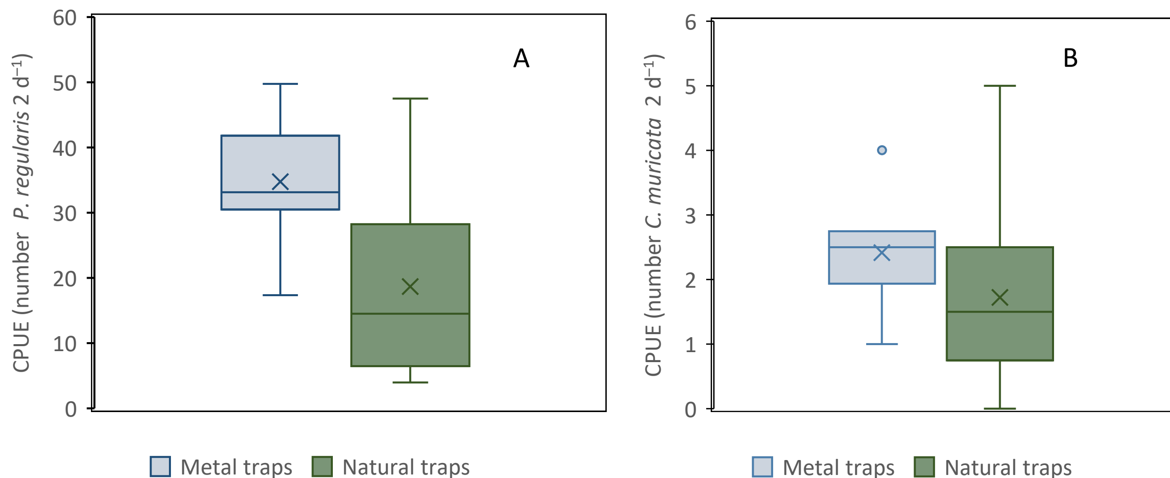


**Figure 3.6: Box plots displaying the catch per unit effort (CPUE) of (A) *Coscinasterias muricata* and (B) *Patiriella regularis* with median, interquartile range (IQR) and mean of different trap types (metal versus natural) from two removal plots during fish-down. The box represents the IQR, with the median marked by the horizontal line within the box. Whiskers extend to the minimum and maximum values. The mean is denoted by a × symbol.**

## 3.4 Discussion

The development of a starfish trap to reduce starfish numbers in Ōhiwa Harbour not only provided an accessible management tool but provided an opportunity to co-design a removal methodology more closely aligned with community and cultural ethics. This study applied both scientific study design field methods to understand optimal trapping technique, such as soaking time and bait type as well as mātauranga Māori principles and practices such as natural resources and weaving techniques, while ensuring that the trap design had minimal bycatch.

### 3.4.1 Optimal deployment technique

The study demonstrated that the efficacy of starfish traps is dependent on environmental conditions, physical characteristics and soaking time. The semi-enclosed box traps began to warp within 48 h of the deployment study, and several were found to have moved from their original deployment position due to tidal forces, despite having excessive weight (7 kg). Ōhiwa Harbour experiences significant tidal currents, with speeds exceeding 1 m $s^{-1}$ (S. Park, 1991; Richmond et al., 1984), particularly in the western channel where the starfish removal was carried out. It is important that traps maintain position and structural integrity to maintain same

the catch effort during starfish removal. Although box traps are inexpensive and commercially available (Inglis et al., 2006), their application was not appropriate in the context of Ōhiwa Harbour.

Furthermore, the box trap caught a greater number and variety of non-targeted macrofauna including octopus (*Pinnoctopus cordiformis*), conger eel (*Leptocephalus verreauxi*), sea horses (*Hippocampus spp*.) and small fin fish, whereas the metal trap only caught small crab species that could easily be removed. Minimising bycatch was of high importance for iwi, as was highlighted in our initial engagements regarding trap design. Furthermore, bycatch CPUE increased with soaking time—bycatch more than doubled from a 24 h soak to 48 h soak, indicating box traps would be inappropriate if traps were to be left in the water for this length of time or longer. The open metal trap allowed animals to move freely on and off, and, given starfish have a naturally aggregative behaviour, as previously discussed, it is thought that they would stay in the trap for long enough that catch rates would be maintained for more than 24 h (Andrews et al., 1996; Gaymer et al., 2001a; Inglis & Gust, 2003). The results demonstrated that daily catch rates were maintained for at least 48 h, proving this concept.

The results for *C. muricata* daily catch rates relative to soaking time were the same for 24 h and 48 h but dropped off after 72 h for both bonito fish and mussel bait, so to maintain maximum catch rates while reducing cost and effort, traps should be pulled and re-baited immediately before or after a 48 h soak. There was no evidence to suggest bait preference by *C. muricata*, however the time to collect and prepare the mussels was greater than that required to prepare the bonito fish bait, so fish bait was preferred for the starfish removal study (Chapter 4). Fish bait was also selected as it stayed intact after 72 h. To date, to the best of my knowledge, there has only been one study (Andrews et al., 1996) assessing best trapping methodology for starfish (Asterias amurensis). Their findings were similar—their traps became saturated between 24 and 48 h, and the starfish species of interest exhibited a slight preference for fish bait but this was dependent on soak time.

### 3.4.2 Māhanga pātangaroa

The co-development of the māhanga pātangaroa provided a natural resource tool to support the management of the starfish outbreak in Ōhiwa Harbour. Furthermore, the co-development of the trap encouraged participatory involvement in the design concepts and allowed me to draw on Māori traditions with regards to materials and weaving techniques. This is an important part

of the research study, as Indigenous communities are continuously considering ways to reassert Indigenous management practices in marine spaces (Paul-Burke et al., 2022). Past studies have demonstrated that conservation programs inclusive of Indigenous knowledge and people have greater uptake by local communities (Cinner & Aswani, 2007; Díaz et al., 2019). The natural traps also have the potential for use as a learning tool for community and school outreach programs.

The māhanga pātangaroa were successful in catching both *C. muricata* and *P. regularis* starfish species but had lower average CPUE than the metal trap for *P. regularis*. This may be attributed to the deployment of far fewer māhanga pātangaroa than metal traps, resulting in fewer opportunities to be dropped in isolated areas with higher starfish density. Furthermore, there were design faults with the natural traps that could have negatively affected catch rates. This included jagged edges causing the harness to snag while being pulled and tying the weights to the bottom of the trap instead of the top, causing the traps to sit higher off the sea floor and become more susceptible to drag. These issues can be easily rectified, and despite these design flaws, two of the three natural starfish traps lasted the full 18-day fish-down period.

The making of māhanga pātangaroa gave the opportunity to practice traditional customs and learn mātauranga inherent to weaving. This included identifying and locating natural resources, appropriate harvesting practices, preparing materials and learning and applying different weaving techniques. Furthermore, both harakeke and pirita are readily available resources and can be sourced from local forests in most areas of Aotearoa New Zealand (Wehi & Clarkson, 2007). However, considerations such as the amount of material necessary should be addressed and approval from local iwi or hapū sought prior to taking a significant amount of material. The production of natural traps does include additional steps such as locating, harvesting and preparing material prior to making the traps, which can take a considerable amount of time.

## 3.5 Conclusion

The chronic infestation of the eleven-armed starfish and cushion star that has plagued Ōhiwa Harbour and thus limited recovery of the traditional mussel beds has led iwi and hapū to call for management actions as described in Chapters 1 and 2. Furthermore, local Māori want to reassert kaitiakitanga, which ensures conservation, protection and maintenance of resources through implementing a Māori-centric approach, whereby actions, behaviour and conduct align with Māori principles and values (Kawharu, 2000; Paul-Burke & Rameka, 2015; M. Roberts et

al., 1995). The co-development of starfish management approaches and design with Ngāti Awa iwi members and tohunga raranga described in this chapter addresses these concerns. This involved my selecting starfish removal strategies and their respective methods. Drawing from starfish management programs across the globe and how they align with kaitiakitanga principles and practices, the most appropriate starfish removal techniques were determined as a prelude to comparing effort and efficiency relative to removal method described in Chapter 4. Ultimately, this process allowed us to provide greater access to a starfish management tool for hapū and iwi, thus supporting kaitiakitanga responsibilities further.

# Chapter 4:
# Starfish Removal Feasibility Study

## 4.1 Introduction

Predatory starfish can experience large population outbreaks that have the capacity to cause significant loss of wild shellfish stocks, hinder shellfish restoration and reduce aquaculture production of bivalve species (Benjamin, 2023; Gallagher et al., 2008; Guillou, 1996; Paul-Burke, et al., 2022). The chronic infestation of the eleven-armed starfish, or pātangaroa (*Coscinasterias muricata*), and cushion star (*Patiriella regularis*) has negatively affected wild green-lipped mussels, or kūtai (*Perna canaliculus*), and thus limited restoration efforts in Ōhiwa Harbour and other parts of Aotearoa New Zealand (Paul-Burke & Burke, 2016; Wilcox & Jeffs, 2019). Small-scale field experiments have demonstrated that reducing starfish numbers by mechanical removal can facilitate mussel recovery (Bertolini et al., 2019; Paine et al., 1985). Furthermore, a hybrid species distribution and Bayesian network model by Bulmer et al. (2024) predicted that if *C. muricata* densities were reduced below 0.1 ind. $m^{-2}$, high densities of mussels could be supported in areas meeting suitable environmental conditions in Ōhiwa Harbour. However, despite these propositions, there has been little to no investigation into the best strategies to reduce or control starfish outbreaks to support shellfish recovery in Aotearoa New Zealand.

As discussed in Chapter 3, numerous starfish management programs across the globe have implemented different removal techniques. The efficacy of each removal technique has not been well reported, with only a few studies quantifying starfish removal effectiveness (% of population removed) and efficiency (removal rate) (Table 4.1). The starfish removal programs also vary in spatial extent, starfish species, socio-ecological context and desired outcomes; therefore, the effectiveness of one removal method does not apply to all scenarios. Furthermore, few studies which compared two or more removal techniques simultaneously. With the lack of data on the practical application of the techniques, it is difficult to evaluate the most feasible method with regards to efficiency and cost.

**Table 4.1: Published starfish removal studies providing information on method efficiency (removal rate) and effectiveness (% of population removed)**

| Region | Species | Removal method | Effort | Initial density | Total removal area (ha) | Initial removal rate/ % removed | Source |
|---|---|---|---|---|---|---|---|
| Samal Islands, Philippines | *Acanthaster planci* | Hand collection via SCUBA diving | 42 h dive time. 225 ind. removed | 0.0021 - 0.0056 ind. $m^{-2}$ | 1.2 ha | 12 ind. $h^{-1}$ 100 % | Bos et al. (2013) |
| Grub Reef, Townsville | *A. planci* | Chemical injected via SCUBA diving | 251 h dive time. 3,175 ind. removed | 12.3 ind. $m^{-2}$ | Unk. (64 ha boundary) | 12.6 ind. $h^{-1}$ 40 % * | Johnson et al. (1990) |
| Belfast Lough, Northern Ireland | *Asterias rubens* | Mop from a commercial dredger | 81 tows over 9 d. 400–900 m tow length. 24,000 ind. removed* | 0.5 ind. $m^{-2} \pm 0.2$ | 30 ha | > 2,600 ind. $d^{-1}$ * 27% | Calderwood et al. (2016) |
| Derwent Estuary, Australia | *Asterias amurensis* | Trapping low density | 49 traps, reset 14 times over 51 d | 0.46 ind. $m^{-2} \pm 0.04$ | 1 ha | 688.6 ind. $d^{-1}$ * 160% | Andrews et al. (1996) |
| | | Trapping high density | 49 traps, reset 14 times over 51 d | 8.49 $m^{-2} \pm 1.97$ | 1 ha | 1,330 ind. $d^{-1}$ * 53% | |
| Ryukyu Islands, Southern Japan | *A. planci* | Hand collection via SCUBA diving and freediving | 13 years continuous hand removals across several hundred small island coastlines | Unk. | Unk. | 100 $d^{-1}$ Unk. % | Yamaguchi (1986) |
| Lelepa Reef, Vanuatu | *A. planci* | Hand collection via freediving | 763 h dive time (est.) | 0.05 ind. $m^{-2} \pm 0.04$ | 28 ha | 30.8 ind. $h^{-1}$ 87 % * | Dumas et al. (2016) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Lizard Island, Australia | *A. planci* | Chemical injection via SCUBA diving | 10-month period, visited weekly x 10 then biweekly – 2 divers | 0.03 ind. $m^{-2}$ | ± 0.01 | 2 ha | 12 ind. $h^{-1}$ Unk. % | Fisk and Power (1999) |

*Calculated from data provided in the paper. Ind. = individuals, Unk. = unknown.

The starfish outbreak in Ōhiwa Harbour presents an opportunity to investigate best starfish management practices that support the restoration of wild mussels on soft bottom habitats, address iwi and community concerns, and better equip future starfish management programs in Aotearoa New Zealand. Investment into research exploring the practicality of starfish removals would be of significant value. Given that the research was a community-driven project, it was important that the removal techniques reflect the resources and expertise available.

Following from Chapter 3, this chapter focuses on understanding the practicalities of trapping and hand collection via SCUBA diving, and a combination of these two removal methods. I examine and compare the different methods of starfish removal from an area in Ōhiwa Harbour that has a known starfish population and was a traditional mussel bed location. The removal trials compared efficiency and effectiveness for each of the removal techniques, and learnings from this study helped inform the SMAP described in Chapter 5.

## 4.2 Methods

### 4.2.1 Study location

The removals were conducted in the western subtidal channel of Ōhiwa Harbour, which is situated in the Eastern Bay of Plenty, Aotearoa New Zealand (Fig. 4.1). The harbour is 26.4 km² of estuarine lagoon enclosed by Ōhope and Ōhiwa barrier spits (BOPRC, 2013). The harbour is tidally dominated and is relatively shallow, with 83% of its area exposed at low tide (S. Park, 2005), and the deepest part of the harbour is 14 m at the entrance. The substrate is dominated by soft sediment, which is largely made up of sand, shell hash and gravel in the lower reaches, and silt and clay in the upper reaches, with very little hard substrate (S. Park, 2005; Richmond et al., 1984). There are 16 major freshwater inflows to Ōhiwa Harbour, with Nukuhou River being the largest freshwater source (BOPRC, 2013).

In 2007, there were several subtidal mussel reefs (*Perna canaliculus*) in Ōhiwa Harbour, with the largest estimated at 112 million on the western (Paul-Burke & Burke, 2016) (Fig. 4.1). Surveys found 1.2 million *C. muricata* or 6.19 *C. muricata* $m^{-2}$ within the largest mussel bed and observed the starfish predating on the mussels, by 2016 the western mussel bed had declined by as much as 99% (Paul-Burke & Burke, 2016). Only one traditional mussel bed remains in the harbour entrance (Paul-Burke, Ngarimu-Cameron, Burke, et al., 2022).

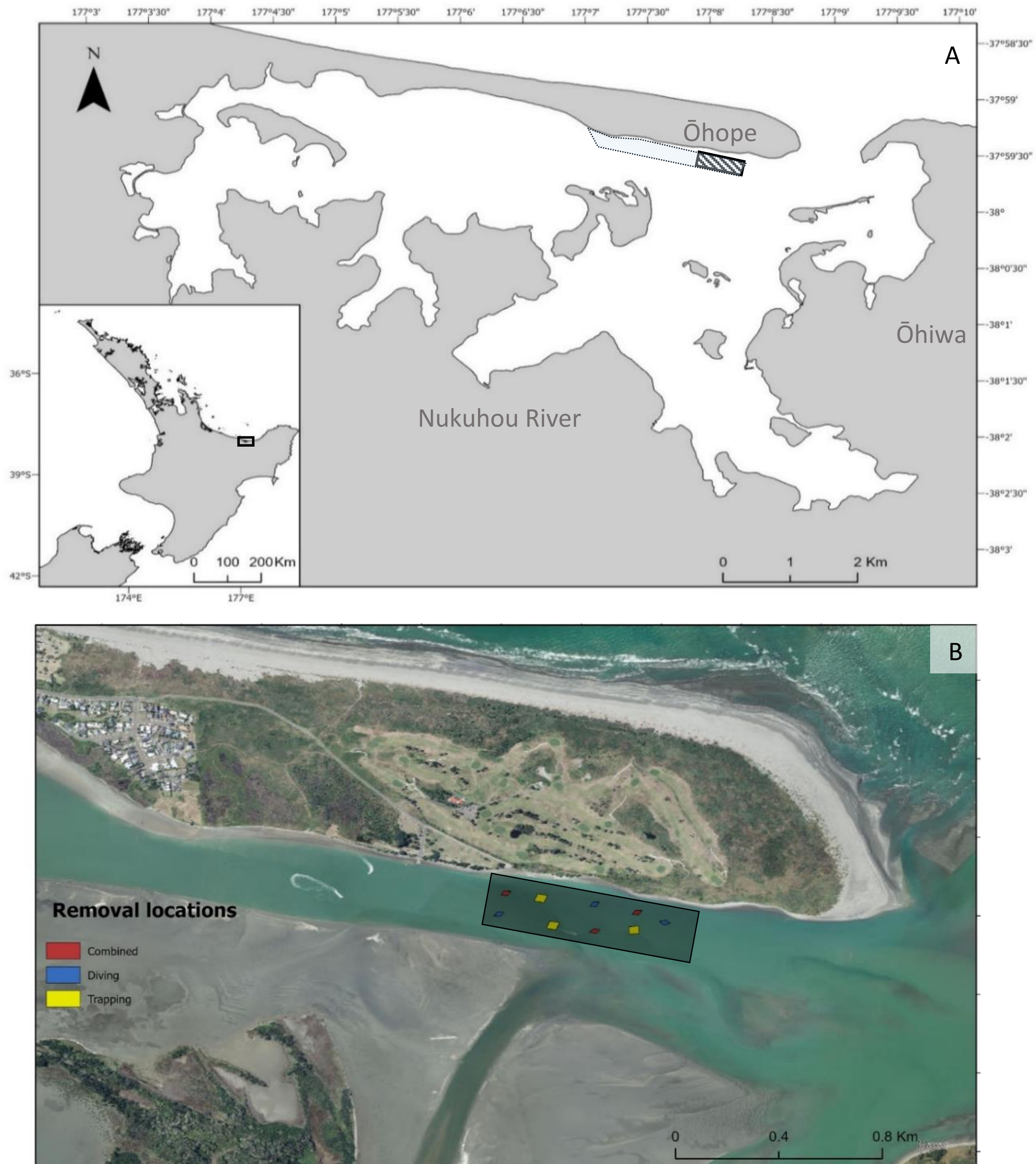


**Figure 4.1: (A) Map of experimental site location (black-shaded square) and extent of traditional mussel bed (blue shaded rectangle) recorded from subtidal surveys carried out in 2007 in western channel (Paul-Burke & Burke, 2016), Ōhiwa Harbour, northeastern Aotearoa New Zealand. (B) Location of removal treatment sites for hand collection via diving (blue shapes), trapping (yellow shapes) and trapping assisted by dive removals (red shapes)**

### 4.2.2 Site selection criteria and description

To draw comparisons between the efficiency of different removal methods, the experimental area had to meet several selection criteria inclusive of experimental fieldwork design principles and cultural protocols outlined by te rōpū kairangahau and logistical constraints. The criteria required the selected site to:

a. be within the western channel of Ōhiwa Harbour comprising part of Ngāti Awa traditional rohe moana (a coastal and marine area (CMA) over which an iwi or hapū exercises cultural practices) for cultural consent reasons
b. be in an area identified by Ngāti Awa kaumātua as a potential restoration site based on traditional mussel bed locations (Paul-Burke & Burke, 2016)
c. be a large enough area to allow for twelve 1,200 $m^2$ removal and control plots with a 100 m buffer between each plot. The buffer ensures little disturbance between neighbouring removal plots. The 1,200 $m^2$ removal plots also ensured I could gain valuable information for subsequent larger-scale removals, as small-scale removals would fill in knowledge gaps, validate methods and improve starfish management efficiency (Englund & Cooper, 2003). The small-scale removal plots also meant that divers could feasibly remove starfish within the limited dive time due to tidal currents and weather events. Furthermore, too large an area is resource-intensive and would require more traps to be deployed. The size selected also insured we could 'fish down' each plot (i.e., remove a substantial proportion starfish)
d. have *C. muricata* present in densities $> 0.1\ m^{-2}$ and evenly distributed. Densities $< 0.1\ m^{-2}$ was deemed too low for removals, as removal impact might be difficult to detect (Inglis & Gust, 2003). This was also a conservative value relative to the negative impacts on newly establishing mussel populations (Wilcox & Jeffs, 2019; Witman et al., 2003)
e. show substrate homogeneity, with preference for sand and similar bathymetry
f. have a maximum depth of $< 8$ m due to bottom-time limitation for SCUBA diving
g. have an unobstructed bottom so no underwater features could interfere with diver removal circle search
h. pose little obstruction to boat traffic from surface floats
i. be readily accessible for the size of the vessel operating.

Initial reconnaissance located a suitable area using mātauranga ā iwi (localised ecological knowledge). This was achieved by conducting a series of hui (meetings) and wānanga (long meeting period over which a reciprocal exchange knowledge and information occurs) with te rōpū kairangahau and STAG members in August and September 2021 (see Appendix D for iwi engagements and feedback), which was shortly followed by a preliminary starfish population survey. The site identified is 8 ha in size and makes up a proportion of the traditional mussel bed boundary in the western channel of Ōhiwa Harbour (Fig. 4.1). The boundary marks for our study site were gathered from a previous mussel survey conducted in 2007 (Paul-Burke & Burke, 2016) and were entered into Esri ArcGIS Pro version 2.9.1 software.

The initial starfish population survey was carried out in October 2021 to estimate mean density of *C. muricata* within the study site by carrying out eight 5-minute timed swim counts in the study site. Average *C. muricata* were estimated at $0.16 \pm 0.07$ ind. $m^{-2}$ or 12,805 ind. within the experimental area (8 ha), and results from a Chi-square goodness-of fit test indicated *C. muricata* densities were evenly distributed ($\chi^2$ (7, N = 8) = 0.26, $p = 0.999$). Background densities were therefore deemed sufficient to conduct our removal study. However, because the fish-down experiment was delayed by several months because of poor water visibility and weather, *C. muricata* populations were re-quantified by counting the number of *C. muricata* removed in our diver removal plots at the beginning of the fish-down in October 2022 (described in Section 4.2.3). The experimental area ranged in depth from 3.4 m to 7.6 m at mean high tide. The bottom is relatively homogenous and is predominantly made up of shell hash and sand, and peak flow velocity within the study area can be greater than 1 m $s^{-1}$ (Richmond et al., 1984). Both local ecological knowledge and scientific field methods provided evidence that the site selected possessed the necessary characteristics to carry out the removal experiment.

#### 4.2.3 Starfish removal experiment

To identify the method most efficient at removing starfish (according to catch rates per day), three replicates of each removal treatment were carried out. The removal treatments were trapping, hand collection via SCUBA diving (hereafter referred to as 'dive removals') and hand collection via SCUBA diving followed by trapping (hereafter referred to as 'combined'). I also wanted to understand how long it would take to clear an area of starfish by trapping or if this was even possible given their aggregative behaviour (Andrews et al., 1996; Inglis & Gust, 2003). Furthermore, I wanted to understand if diver assistance affected trapping catch rates and if starfish recolonise cleared areas within a short period (one to two weeks). To ensure fair

comparisons, the same effort was applied for each removal method; this involved three crew and 3 h on the water.

The starfish removal study was carried out in the experimental site identified earlier in consultation with te rōpū kairangahau and from the preliminary dive survey (Fig. 4.1). The experimental site was divided into three evenly sized blocks to account for any spatial variation in environmental variables. Within each block, one dive removal plot, one trapping plot, one combined plot and one control plot were assigned a random coordinate using 'Create Random Point' function in ArcGIS Pro (Fig. 4.1B). A buffer feature was created around each plot using the 'Buffer' tool, the buffer distance was set to > 100 m between the edges of each plot to ensure little disturbance between neighbouring removal plots. The boundaries for each 1,200 m$^2$ plot were entered into a mounted Garmin chart-plotter on the vessel to ensure the traps stayed within the trapping sites each time they were reset.

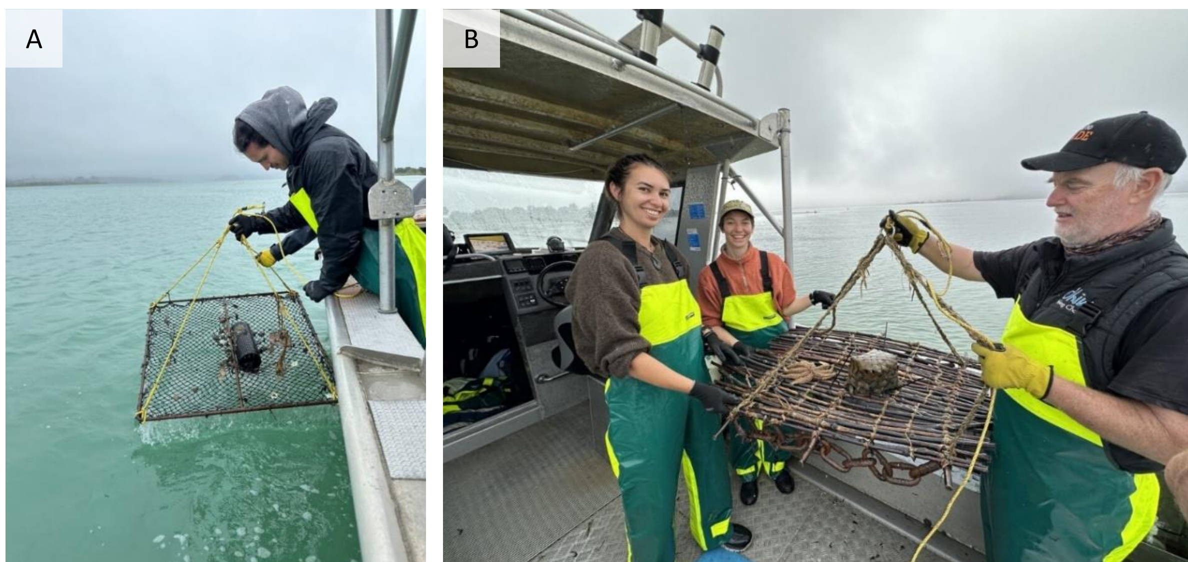


**Figure 4.2: Open starfish traps used in Ōhiwa Harbour, Aotearoa New Zealand during fish-down: (A) metal trap and (B) natural resource trap made from pirita and harakeke**

*4.2.3.1 Fish-down*

The starfish removal commenced in October 2022 when conditions were suitable. Dive removals began at the start of the fish-down followed by trapping (refer to Fig. 4.3 for the timeline of removals). Divers cleared the diver-cleared sites first, followed by combined sites in subsequent days. The dive removals consisted of two SCUBA divers, a vessel and one skipper. Because of strong tidal currents, SCUBA diving could only operate 45 min either side of the high tide; low tide proved too turbid. An average of 36 min was required for two divers

to clear one plot of *C. muricata* and as many *P. regularis* as possible; therefore, two plots were cleared per day, meaning three days were needed to clear six 1,200 $m^2$ plots. To ensure divers could clear a 1,200 $m^2$ plot without drifting outside the designated area, the circle search method was employed. Divers would hold onto a 10 m rope attached to a weighted drop line and would conduct a full circle search at 2 m increments along the rope, starting at the centre (drop line anchor). Thus, at the end of the circle search, divers had cleared an area of just over 300 $m^2$. To ensure divers cleared a 1,200 $m^2$ area, the circle search was repeated an additional three times—a total of four circle searches per removal plot. Each drop line was evenly spaced 20 m apart to form a rhombus shape. The 20 m distance ensured little to no crossover between circle search areas; however, this did mean divers did not cover all the search area. The total number and the size class of *C. muricata* and total number of *P. regularis* were recorded from each plot cleared by divers. Starfish were sized by measuring maximum arm length ($R_{max}$); that is, from the central part of the aboral surface to the tip of the longest arm to the nearest millimetre.

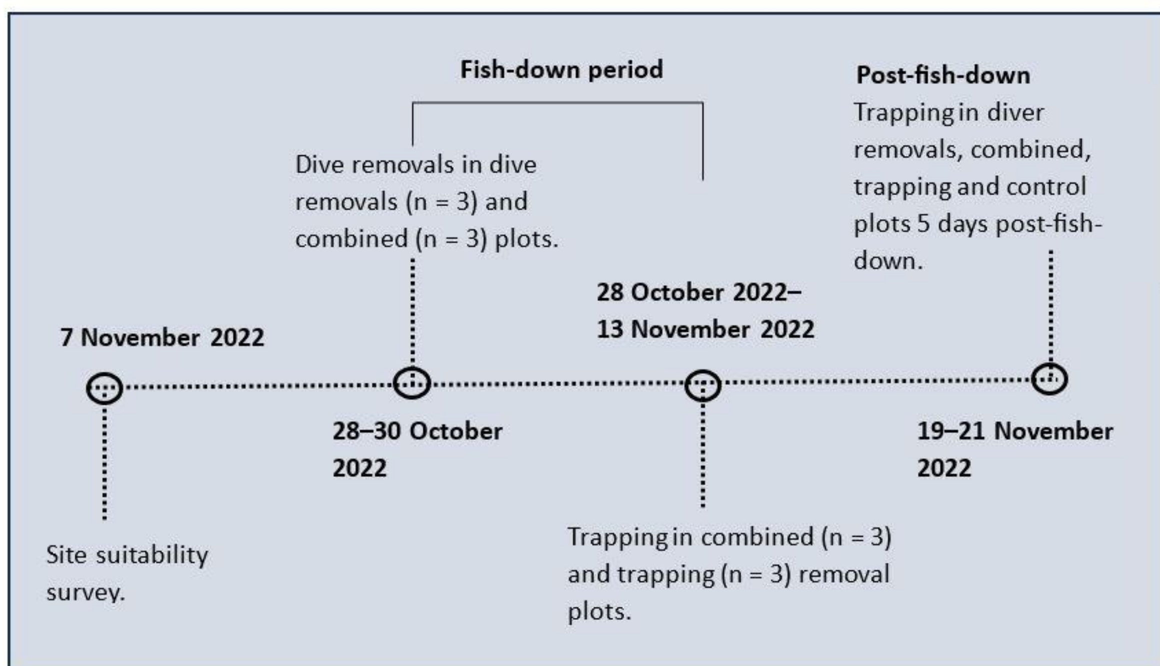


**Figure 4.3: Timeline of events including initial site suitability survey, fish-down period (starfish removal by dive removals, trapping and a combination of these two methods) and post-fish-down**

Five starfish traps were assigned to each trapping and combined removal plot, giving a total of 30 traps. Three natural resource traps were deployed in the fish-down study—one natural trap was assigned to a trapping or combined site and substituted one of the open traps. Results from

the natural traps are discussed in Chapter 3. Traps were pulled, emptied, re-baited and reset nine times over an 18-day period at intervals of 48 h. Pulling of traps took an average of 20 min per removal site or 4 min for one trap. For each removal plot, the total number and size of *C. muricata* and total number of *P. regularis* were recorded for every day we pulled. Any traps lost or needing repair were replaced immediately to maintain the same catch effort and the average number of starfish caught was taken from the remaining number of traps. Catch rate decline was not detectable after intensive trapping in a relatively small area, but, because of cost and resource constraints, we ended the trapping after 18 days.

*4.2.3.2 Post-fish-down*

The initial plan was to carry out a starfish count via dive surveys shortly after the fish-down; however, the weather prevented us from diving because of poor visibility. Therefore, traps were reset in each of the removal plots, as well as in the control plots, 5–7 days after the fish-down period. Traps were left for 48 h and then pulled and the total number and size of *C. muricata* and total number of *P. regularis* recorded. This allowed us to understand whether catch rates were different between removal treatments, whether catch rates would be different at an unfished site (control sites) and if catch rates post-fish-down were significantly different to the average catch rates from the last three pulls during the fish-down.

### 4.2.4 Data analysis

To understand which removal method (diver removals, trapping or combined) was most efficient (removal rate) at clearing *C. muricata* and P. regularis, mean daily catch rates (ind. $d^{-1}$) were compared relative to treatment. For the dive removals treatment, the daily catch rate was the number starfish removed per day by two divers (effort) across three days / replicates. For trapping, the daily catch rate was the number starfish removed each day by trapping (trapping effort = 30 traps) across three replicate plots over 18 days. The combined treatment daily catch rates were calculated by adding trapping and diver removals daily catch rates together. Assumptions of normality and equivalence of variance in the data were assessed with a Shapiro–Wilk test and Levene's test. To assess if there was any significant difference in mean daily catch rates for both starfish species, a one-way ANOVA and a Kruskal–Wallis ANOVA was used for *P. regularis* and *C. muricata*, respectively. A post-hoc analysis was carried out to identify which removal methods were significantly different.

To assess if CPUE (ind. 1 $d^{-1}$) of *C. muricata* and *P. regularis* changed significantly over time as a result of trapping and if diver assistance (combined treatment) affected CPUE, a repeated measures two-way ANOVA was employed. CPUE was calculated by averaging the total number of collected starfish across three replicates for each treatment per day. To meet the assumption of sphericity, the degrees of freedom were adjusted using the Huynh–Feldt correction. A post-hoc Tukey's honestly significant difference (HSD) test was conducted to identify which removal methods were significantly different.

To determine if there were any differences in starfish numbers between treatments, including control plots, after the fish-down, the mean number of starfish caught from trapping over a 2-day soak per treatment was compared using a one-way ANOVA. In addition, a paired *t*-test was used to assess if catch rates from trapping post-fish-down were significantly different to the average catch rates from the last three trapping dates during fish-down.

A Friedman test was used to see if there was a significant difference in mean size between treatments and post-hoc Dunn's test was used to identify which were significant. To investigate temporal variation in *C. muricata* arm length, a repeated measures two-way ANOVA was conducted to see the effect of soak day and treatment; to meet assumptions of normality, data were log transformed. All tests were performed in STATISTICA.

## 4.3 Results

### 4.3.1 Treatment removal efficiency and effectiveness

During the fish-down in October and November 2022, *C. muricata* densities had dropped from the 0.16 ± 0.07 obtained from the initial population survey in October 2021 to an estimated 0.06 ± 0.02 ind. $m^{-2}$ (Table 4), or 4,802 individuals, within the experimental site in October 2022. Numbers were also recorded for *P. regularis*; however, density estimates were excluded because divers probably missed a proportion of these starfish during the dive surveys and removals because of their small size and cryptic nature. In total, 450, 282 and 543 *C. muricata* were cleared in the diver removals, trapping and combined treatments, respectively, and 975, 4,203 and 5,335 *P. regularis* were cleared in the diver removals, trapping and combined treatments, respectively.

**Table 4.2: Mean daily catch rate (ind. d$^{-1}$) of *Coscinasterias muricata* and *Patiriella regularis* in starfish removal study in Ōhiwa Harbour relative to removal method (trapping effort equates to 30 traps and diver removals effort equates to two divers)**

| Species | Treatment | *Mean No.* starfish removed d$^{-1}$ ± *SD* |
|---|---|---|
| *C. muricata* | Trapping ($n = 3$) | 31.33 ± 6.11 |
| | Diver removals ($n = 6$) | 150 ± 45.99 |
| | Combined ($n = 3$) | 198.67 ± 42.62 |
| *P. regularis* | Trapping ($n = 3$) | 467 ± 133.75 |
| | Dive removals ($n = 6$) | 325 ± 108.75 |
| | Combined ($n = 3$) | 920 ± 284.83 |

Treatments were found to have significantly different daily catch rates for both starfish species (*P. regularis:* $F$ (2,9) = 18.160, $p < 0.001$ and *C. muricata*: $H$ (2) = 7.22, $p = 0.027$). The combined treatment had a significantly higher daily catch rate for *P. regularis* than trapping ($p = 0.008$) and diver removals ($p < 0.001$); however, no significant difference in daily catch rate was found between diving and trapping (Table 4.2). A post-hoc Dunn's test indicated the combined treatment had significantly higher *C. muricata* daily catch rates than trapping ($Z = 2.6$, $p = 0.028$) but no significant difference was found between other treatments.

There was a significant difference in overall performance between treatments for both starfish species: *P. regularis*: $H$ (2) = 8.63, $p < 0.013$ and *C. muricata*: $F$ (2,9) =17.36, $p < 0.001$. The combined treatment was significantly more effective at removing *C. muricata* than trapping ($p = 0.006$) and diver removals ($p < 0.001$). This is reflected in the percentage of the population removed, which was 241% within the combined treatment plots. For *P. regularis*, diving proved less effective than combined treatment ($Z = 2.68$, $p = 0.022$). No significant difference was found between any other treatments.

### 4.3.2 Trapping

Catch rates from trapping for *C. muricata* and *P. regularis* fluctuated over the fish-down period, as illustrated in Fig. 4.4. Differences in catch rates over time were detected for both starfish species; however, there was no significant difference found between the methods; where sites assisted by dive removals did not impact on trapping catch rates (Table 4.3). Additionally, there was no significant interaction effect between time and treatment for both starfish species (Table 4.3). A Tukey HSD post-hoc test revealed significant differences in *C. muricata* catch

rates between soak day 2 (28 November 2022) and day 12 (7 November 2022). Similar differences were observed for *P. regularis*, where catch rates between soak days 2 and 12, as well as days 12 and 14 (9 November 2022), were significant.

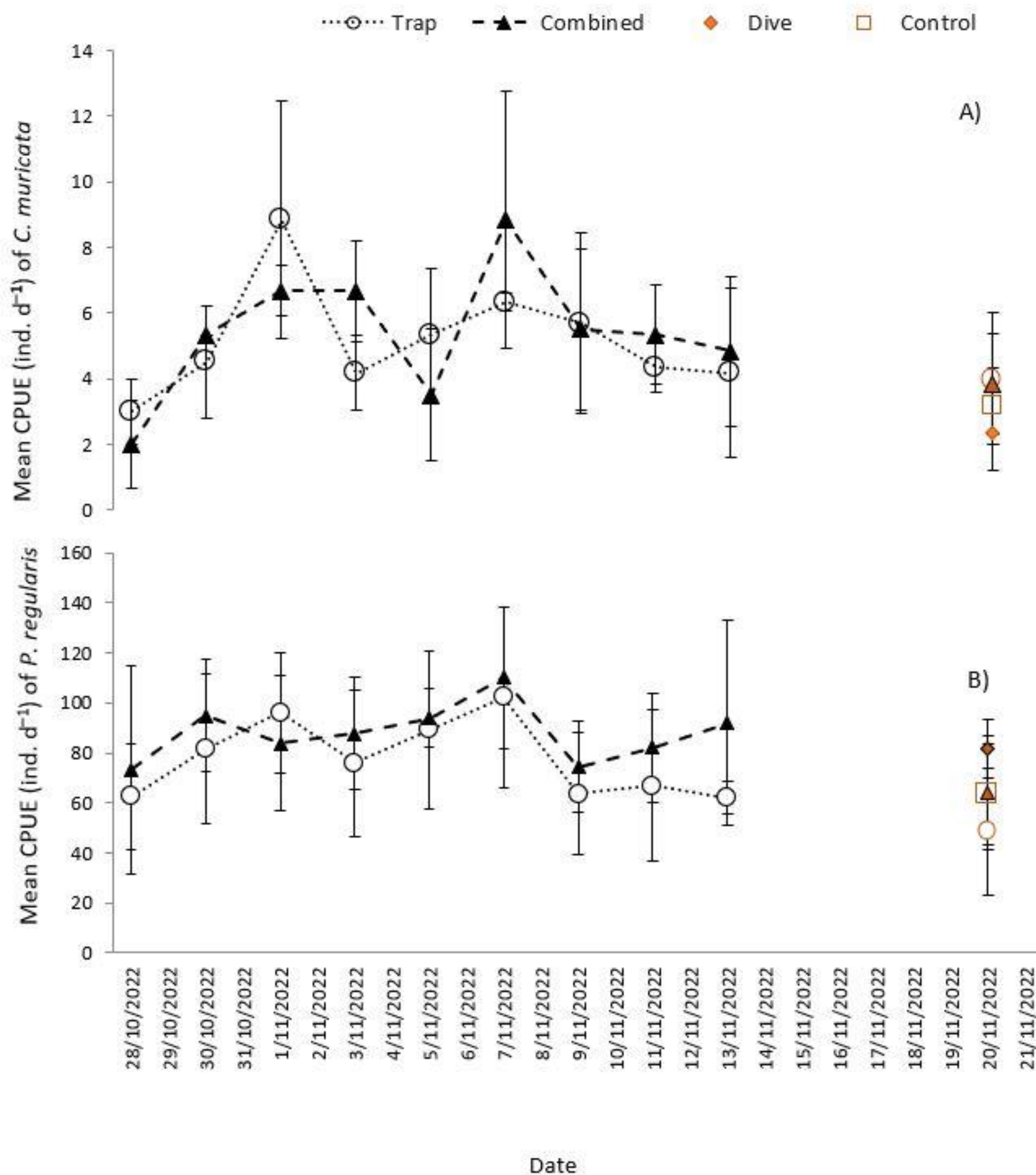


**Figure 4.4: Mean catch per unit effort (CPUE) (ind. d$^{-1}$) of (A) *Coscinasterias muricata* and (B) *P. regularis* caught from traps in trapping (*n* = 3) and combined (*n* = 3) removal plots over fish-down period (18 days) and post-fish-down (depicted by orange symbols) including the dive removals (*n* = 3) and control plots (*n* = 3), Ōhiwa Harbour, New Zealand. Error bars show the standard deviation**

Ind. = individuals

**Table 4.3: Results of a repeated measures two-way analysis of variance for combined effects of time and removal method (trapping and combined) for daily catch rates of (A) *Coscinasterias muricata* and (B) *Patiriella regularis***

**A**

| **Variation source** | ***SS*** | ***Df*** | ***MS*** | ***F*** | ***P* value** |
|---|---|---|---|---|---|
| Method | 2.67 | 1 | 2.67 | 0.07 | 0.809 |
| Time | 511 | 8 | 63.86 | 4.74 | **0.001** |
| Time*method | 147.67 | 8 | 18.46 | 1.37 | 0.248 |
| Method (plot) | 17.6 | 1 | 17.61 | 0.81 | 0.373 |
| Error | 431.78 | 32 | 13.49 | | |

**B**

| **Variation source** | ***SS*** | ***Df*** | ***MS*** | ***F*** | ***P* value** |
|---|---|---|---|---|---|
| Method | 5,460 | 1 | 5,460 | 0.35 | 0.584 |
| Time | 29,413 | 8 | 3,677 | 2.56 | **0.028** |
| Time*method | 5,649 | 8 | 706 | 0.49 | 0.853 |
| Method (plot) | 597 | 1 | 596.8 | 0.23 | 0.635 |
| Error | 45,983 | 32 | 1,437 | | |

*MS* = mean squares, *SS* = sum of squares

*Bold = Significant difference

Mean catch rates for both starfish species were not significantly different between the last three trapping dates of the fish-down period (9 November to 13 November 23) and post-fish-down (20 November 23) (trapping sites: *C. muricata*: $t(2)=0.52$, $p = 0.655$; *P. regularis*: $t(2)=1.41$, $p = 0.294$, and combined sites: *C. muricata*: $t(2)=1.02$, $p = 0.416$; *P. regularis*: $t(2)=0.24$, $p = 0.465$). Catch rates between removal methods (trapping, diver removals, combined and control sites) post-fish-down were also found not significantly different (*C. muricata*: $F(3,8) = 0.78$, $p = 0.534$; *P. regularis*: $F(3,8) = 1.28$, $p = 0.344$).

A Friedman test found the removal method had a significant effect on the mean starfish size, $\chi^2(2, n = 280) = 10.33$, $p = 0.006$), and a Dunn's pairwise comparison found *C. muricata* caught over the duration of the fish-down in combined sites were significantly smaller ($M = 38.5$, $SD = 26.85$) than in diver-cleared ($M = 60.29$, $SD = 40.1$, $p < 0.001$) and trapping sites ($M = 47$, $SD = 34.13$, $p = 0.004$). $R_{max}$ was not significantly different between trapping and dive

removal treatments ($p = 0.081$) (Fig. 4.5). Size classes were not accounted for for *P. regularis*, although they were noted as being of similar size classes throughout the removal campaign (30–50 mm arm span).

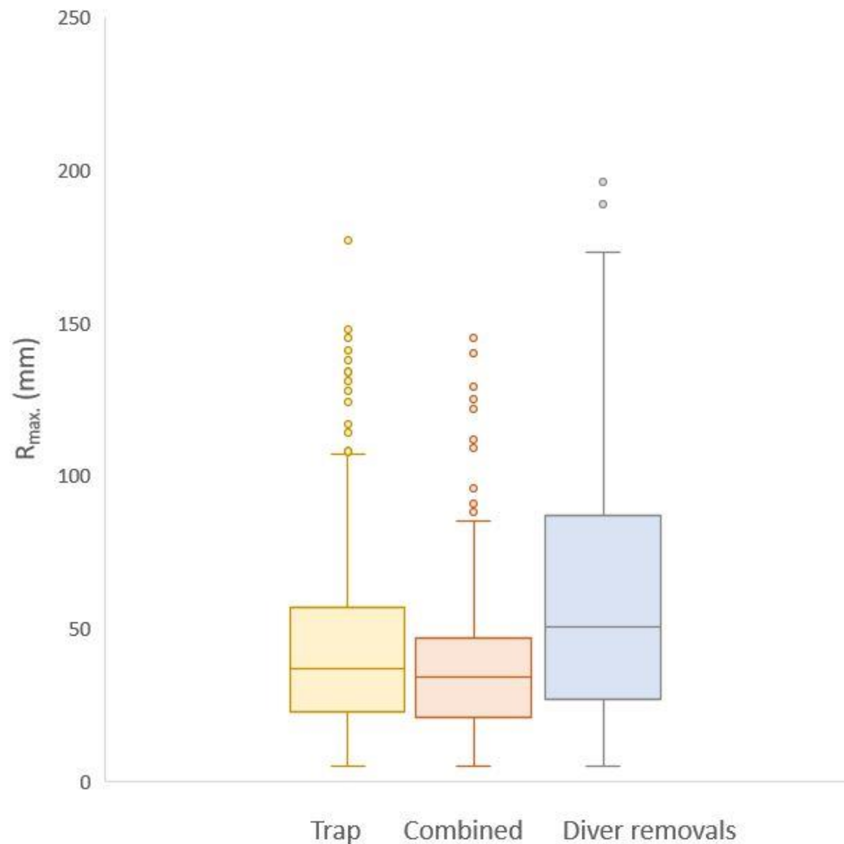


**Figure 4.5: A boxplot for *Coscinasterias muricata* length ($R_{max}$) (median, interquartile range and outliers) caught over the duration of the fish-down relative to treatment (trapping: *n* = 280, combined [from trapping]: *n* = 294, diver removals: *n* = 450), Ōhiwa Harbour, Aotearoa New Zealand**

$R_{max}$= Maximum arm length

Soak time had no effect on temporal variation in *C. muricata* mean arm length, however sites that were cleared by divers prior to trapping had an impact on the size of starfish caught: *C. muricata* $R_{max}$ was significantly smaller in the combined sites than trapping sites throughout the duration of the fish-down period (Table 4.4 and Fig. 4.6).

**Table 4.4: Results of a repeated measures two-way analysis of variance for combined effects of time and removal method (trapping and combined) on *Coscinasterias muricata* arm length (data log transformed)**

| Variation source | *SS* | *Df* | *MS* | *F* | *P* value |
|---|---|---|---|---|---|
| Method | 0.78 | 1 | 0.78 | 6.49 | **0.017** |
| Time | 0.99 | 8 | 0.12 | 1.8 | 0.078 |
| Time*method | 0.91 | 8 | 0.11 | 1.64 | 0.115 |
| Method (plot) | 1.18 | 1 | 1.18 | 12.56 | 0.001 |
| Error | 15.53 | 224 | 0.69 | | |

*MS* = mean squares, *SS* = sum of squares

*Bold = Significant difference

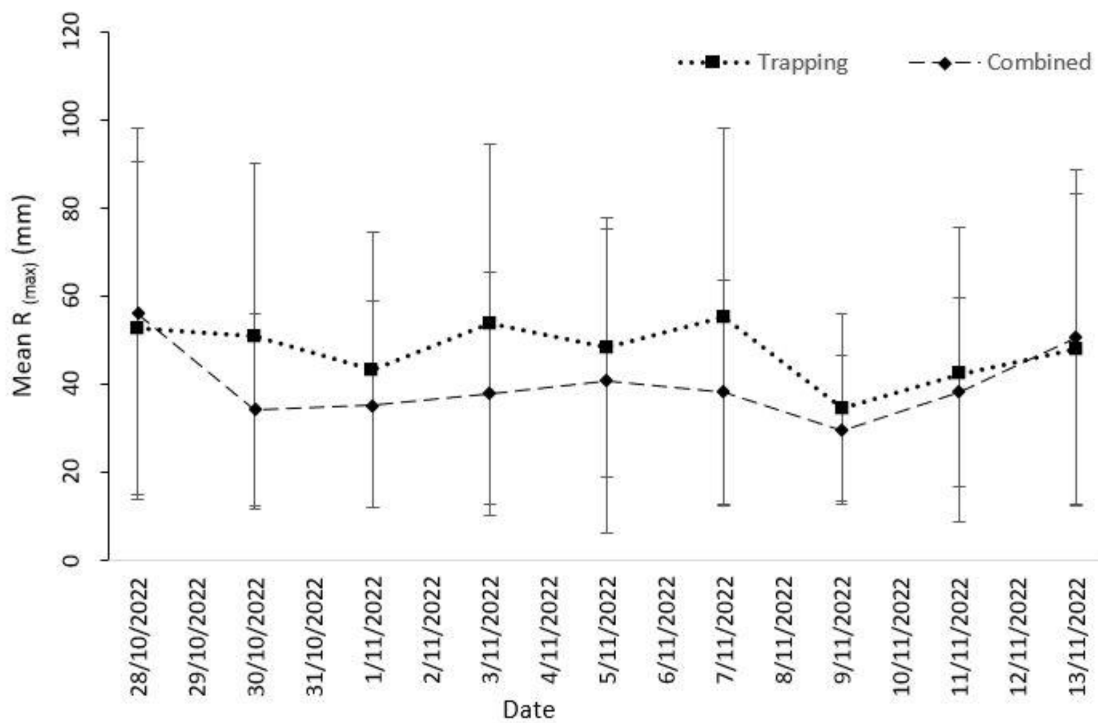


**Figure 4.6: Mean size ($R_{max}$) of *Coscinasterias muricata* caught from traps in trapping and combined sites over fish-down period (18 days), Ōhiwa Harbour, New Zealand. Error bars show standard deviation**

$R_{max}$= Maximum arm length

### 4.3.3 Visual observations

During the fish-down, some traps became inundated with newly recruited juvenile green-lipped mussels (*Perna canaliculus*) (Fig. 4.7). The size of the juvenile mussels varied between 3 and 5 mm in shell length. *P. regularis* were also observed predating (using their everted pyloric caeca) on the juvenile mussels on the traps and in holding tanks (Fig. 4.7D), with some consuming up to 10 juvenile mussels smaller than 5 mm or one juvenile mussel of between 10 and 15 mm.

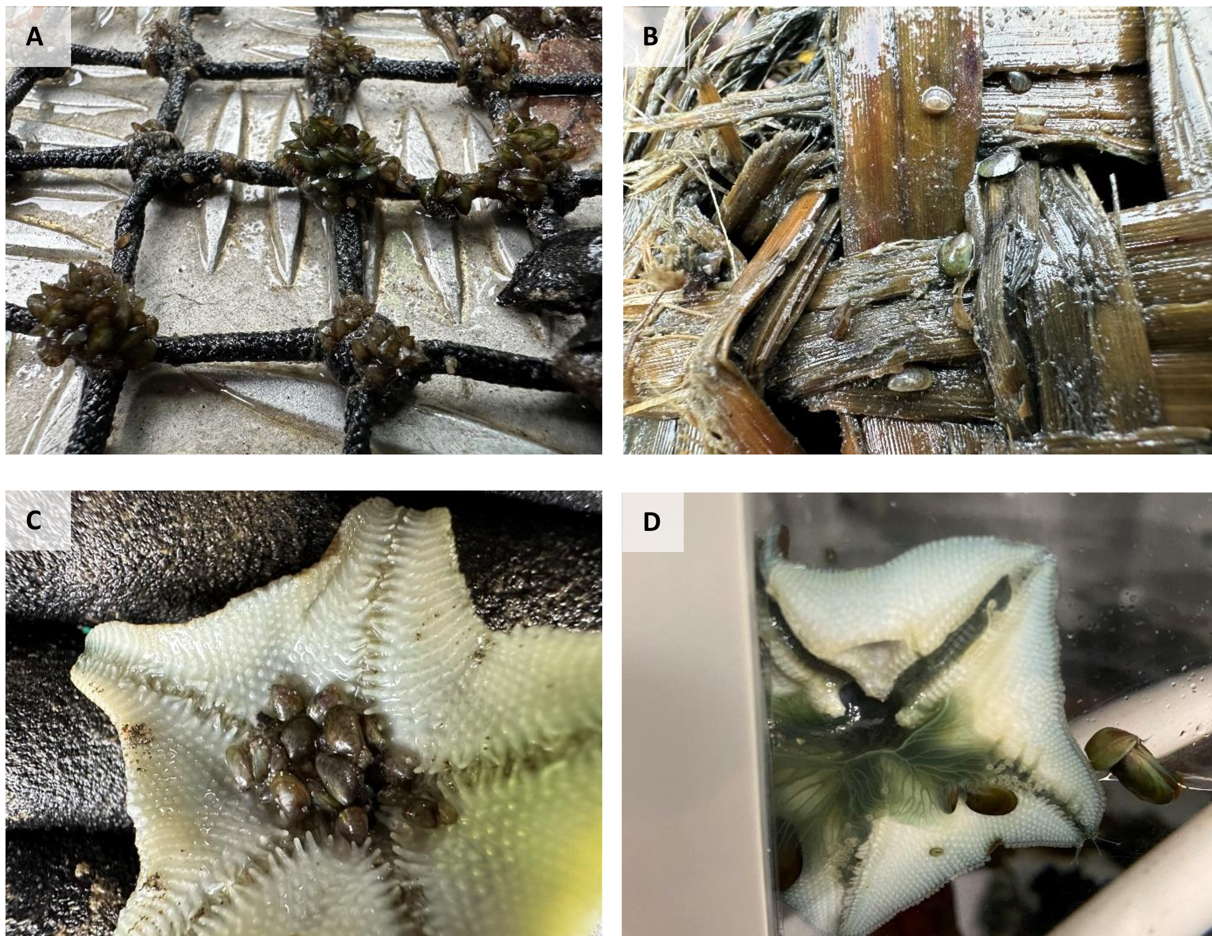


**Figure 4.7: (A and B) Juvenile mussels settling on both the metal and natural traps. (C) Oral surface of *Patiriella regularis* pulled off trap with several juvenile mussels (< 5 mm in length) near its mouth. (D) *P. regularis* actively feeding on several juvenile mussels (5–10 mm in length) in a holding tank with everted stomach (both species were collected from Ōhiwa Harbour)**

## 4.4 Discussion

Over the entirety of the study, 450 *C. muricata* and 975 *P. regularis* were cleared by hand collection via SCUBA diving over three days and 576 *C. muricata* and 8,949 *P. regularis* were cleared by trapping over 18 days. The combined treatment had a significantly greater daily catch rate of *C. muricata* via trapping but not to diver removals, nor were there differences between diver removal and trapping. The combined treatment was also found to have significantly greater daily catch rates for *P. regularis* than trapping and diver removals. The rate of the dive removals from our study (150 and 325 ind. $d^{-1}$) is greater than previous estimates of 12–30 ind. $h^{-1}$ (Bos et al., 2013; Dumas et al., 2016; Fisk & Power, 1999; D. B. Johnson et al., 1990) (although I reported per day, we dived for 1.5 h). However, these studies specifically addressed *Acanthaster planci*, a cryptic tropical reef starfish, whereas we cleared starfish from an open flat sandy bottom, thus we probably spent less time searching. This indicates the diving removal rate could depend on both species behaviour and seafloor rugosity, which should be a consideration when selecting it as a potential method.

Over the total fish-down experiment, the effectiveness of the combined treatment was greater than that of diver removals and trapping. The combined treatment cleared 240% of the initial *C. muricata* population, whereas diver removals cleared 100% and trapping cleared 125%. This indicates a combination of hand collection via diving and trapping simultaneously will have the greatest impact on reducing *C. muricata* numbers. The diver removals were found less effective at removing *P. regularis* than the combined removal technique, but there was no difference found among any other treatments. Therefore, similarly to *C. muricata*, the combined treatment would be the best approach to clear *P. regularis*. The poorer outcome of the diver removals for *P. regularis* could be due to many of them remaining undetected by divers because of their small size (< 80 mm arm spread).

The arm length data for *C. muricata* indicate that dive removals appeared biased towards larger individuals, while plots cleared by divers prior to trapping caught smaller *C. muricata* than locations that were only trapped. This could suggest diving may only be an appropriate removal method if the population predominantly comprises sub-adult and/or adult starfish or if managers are focused on reducing the numbers of larger individuals in an established adult mussel bed, as small starfish may not exhibit the same predation pressure as their larger conspecifics (Wilcox & Jeffs, 2019). However, trapping can target smaller and more cryptic starfish such as *P. regularis* and may be a suitable method if managers want to remove all sizes.

Although no analysis on daily catch rate relative to density was carried out, previous studies have demonstrated a positive relationship between removal rate and density for hand removal via diving until a given maximum threshold (Bos et al., 2013; Dumas et al., 2016; K. I. Miller & Shears, 2023). This suggests locations with greater starfish density are offset by an increased removal rate from diving. However, removal rate has not been shown a function of starfish density for trapping (Andrews et al., 1996), despite trapping being a common assessment method for understanding population size and structure for other species (Efford, 2004). With regards to predatory starfish, trapping rate is probably dependent on their feeding behaviour. Studies have demonstrated temperate starfish feeding rate declines with decrease temperature (Agüera et al., 2012; Barbeau & Scheibling, 1994; Watts & Lawrence, 1990). Furthermore, it has been hypothesised that sites with high starfish density (> 0.4 ind. $m^{-2}$) probably have sufficient food, as high food abundance causes a swarming effect (Inglis & Gust, 2003), therefore, starfish are less attracted to bait plumes from the traps. Our locations had low to moderate starfish density (0.06 ind. $m^{-2}$), possibly indicating less food availability, and therefore the traps probably drew starfish in from adjacent areas. This is supported by our results showing trapping had cleared more *C. muricata* from the trapping and combined plots than the initial population estimate.

Overall, the fish-down reduced the number of *C. muricata* by 21.3% of its original population estimate, despite removal plots only making up 13.5% of the total study area (8 ha). This could be explained by the trapping and combined results, which reduced *C. muricata* numbers by 125% and 240%, respectively. Neighbouring starfish potentially migrated into the trap field, thus traps cleared a larger area than the designated 1,200 $m^2$ plots. Furthermore, we saw no significant decline in catch rates for both species over time in the combined and trapping plots. This was found to be the case for Andrews et al. (1996), who observed 1,160% of the initial population was removed after 51 days of trapping in low to moderate density sites; however, only 53% of the population was removed from high density sites. Trapping effort directed at the moderate density sites could fail to control the seastar population, and this should be a consideration before employing this removal technique.

The efficacy of each method is also place specific. *C. muricata* are commonly found in estuarine environments that experience tidal currents and this can be a determining factor in the amount of effort (hours) expended in clearing per day (Glockner-Fagetti & Phillips, 2020). The location the starfish removals were conducted in is exposed to tidal currents that can reach speeds > 1 m $s^{-1}$ (Richmond et al., 1984), which limited diving to operate for only 1.5 h $d^{-1}$ at slack

high tide. Further limiting factors for diving included depth and visibility. In contrast, trapping is not subject to current (to a certain extent), visibility or depth, so daily effort can increase. For this study, we ensured the effort (number of people and hours per day) was consistent to draw comparisons. In other locations not susceptible to strong currents, diving hours could extend for longer thus significantly increasing the area cleared per day.

For sites cleared by divers prior to trapping, the diving had no impact on daily catch rates from trapping for both starfish species. This means the combined approach is more efficient at clearing starfish, as traps can maintain the same catch even if starfish have been cleared by divers beforehand. This would also explain why the total starfish removed relative to each treatment was greatest in the combined treatment. As mentioned, starfish probably migrate into removal plots, as seen in another starfish trapping study by Andrews et al. (1996). However, diver removals did significantly alter the size structure, as divers removed a higher portion of larger individuals and therefore in the combined sites, the traps caught*C.* significantly lower *C. muricata* mean size than the trapping and diver removals sites. The size structure of starfish did not change over time from trapping, proving traps are not size selective.

Initially, population census dive surveys were planned post-fish-down to record new background densities and size structure of *C. muricata*. However, the visibility was below acceptable diving conditions, so traps were reset to understand if catch rates were significantly different. Five days post-fish-down, we reset the traps in all the removal plots and control plots to understand if total starfish caught (a function of starfish numbers) were significantly different between the different removal treatments and if there were any differences in trapping catch rate between the last three trapping days of the fish-down and post-fish-down. The results were not significant, indicating that treatments were unsuccessful in removing an adequate number of both starfish species to see any decline. This demonstrates that a large amount of effort is necessary to reduce starfish numbers significantly, although the results may be different if we conducted the experiment in locations of high starfish density.

During the fish-down, we witnessed juvenile mussels settling on the traps, indicating a recent recruitment event. We also witnessed *P. regularis* predating on the juvenile mussels on the traps, sometimes on several at a time. The literature suggests the *P. regularis* diet mainly consists of crustose coralline algae, microbiota, microphytobenthos, carrion and small invertebrates (Crump, 1971). To the best of my knowledge, only one other study has recorded *P. regularis* predating on mussels, but that reported several *P. regularis* predating on one

mussel (Mytilus edulis, shell length 35–50 mm) (Witman & Grange, 1998). Our observations indicate the starfish were selectively feeding on juvenile mussels. This observation, coupled with the vast numbers of *P. regularis* caught via trapping, could suggest that *P. regularis* is a potential barrier to juvenile mussel recruitment until mussels reach a maximum size threshold. Therefore, both starfish species should be considered for management, as they target mussels at different life stages, and further research into mussel predation by *P. regularis* should be explored.

In response to the recent mussel recruitment on the sea floor, a team of divers mapped the new mussel bed in 2023. The bed is 3.5 ha in size and has an estimated 16 million mussels (shell width < 40 mm) (Appendix F: *Whakatāne Beacon*, 15 December 2023). The recent mussel bed established within the traditional western mussel bed (Paul-Burke & Burke, 2016), where the mussel restoration stations (several mussel spat lines suspended in water) were located and my starfish removal experiments were conducted. The outstanding results highlight the appropriateness of the site selected for my research trials, and equally as important, substantiates the kōrero (knowledge conversations) and mātauranga Māori by kaumātua. Continuous monitoring is necessary to understand the impact of starfish and initiate removals if necessary.

## 4.5 Conclusion

With the increasing interest in mussel restoration and the growing concern about the implications of starfish predation on mussel recovery, this study offers insights into the feasibility of different starfish removal methods. Understanding removal rates and the factors that impact rates can aid managers in determining the feasibility of the removal method, and the effort necessary to clear an area of predatory starfish. Here, we found the combined effort of diver clearing and trapping produced the highest daily catch rates for *C. muricata* and *P. regularis*, indicating this could be the most efficient method for both species. However, given this would be the most expensive option, the study provides insight into the best alternative removal method specific to each starfish species. In this regard, we found diver removals could also effectively remove *C. muricata* without the aid of trapping, whereas trapping proved the best alternative for *P. regularis*, as it had higher daily catch rates than dive removals alone.

The discovery of the new mussel bed of 16 million mussels underscores the importance of continuous monitoring, active mussel restoration and mitigating or reducing stressors that

inhibit mussel recovery, such as starfish predation. This research contributes valuable information to the ongoing efforts in understanding and mitigating the impact of starfish outbreaks on mussel populations, emphasising the need for adaptive management strategies grounded in both scientific findings and mātauranga Māori.

# Chapter 5:
# Ka Mua Ka Muri: Moving Towards a Starfish Management Action Plan

## 5.1 Introduction

As mentioned in Chapter 1, the *Ōhiwa Harbour Strategy: Te Rautaki mō Ōhiwa: Refreshed October 2014* (Appendix B) explicitly outlines the need for further investigation into the starfish outbreak in Ōhiwa Harbour. Currently, there are no management regimes for starfish in Ōhiwa Harbour or nationally in Aotearoa New Zealand. The SMAP was developed to assist decision-makers to address the outbreak of the starfish *Coscinasterias muricata* and *Patiriella regularis* in Ōhiwa Harbour. Therefore, the overall intent of the research was to: 1) co-develop and implement a management action plan for starfish in all areas of Ōhiwa Harbour, in collaboration with relevant Māori authorities, and 2) have the management plan accepted and enforced at the highest local/regional governance level—namely, by the OHIF. The SMAP's acceptance by our co-management partners and possible implications to its implementation are critically discussed in this chapter.

## 5.2 Decision-making for Marine Management

The management of CMAs is a social, political and ecological endeavour (Leenhardt et al., 2015; Leslie & McLeod, 2007). These environments are multi-use spaces that experience stressors from both land and sea, leading to cumulative effects that are complex and difficult to manage. In addition, decision-makers lack comprehensive data, leading to uncertainty (Hewitt et al., 2022; Rullens et al., 2022; Thrush et al., 2016). This is further compounded by a gap between science and policy, whereby science outputs do not necessarily align with policy agendas (Bradshaw & Borchers, 2000; Bremer & Glavovic, 2013). In Aotearoa New Zealand, CMAs fall under several agencies with different legislative priorities and obligations that are not always conducive to Māori practices and principles such as kaitiakitanga (environmental guardianship) and rangatiratanga (self-autonomy) (Peart, 2007). Inclusive concepts such as ecosystem-based management (EBM) can assist in coordinating research and management between Māori, government agencies, researchers and stakeholders that encapsulate societal and Māori values and different knowledge systems including scientific, mātauranga Māori and local knowledge. This will significantly improve environmental outcomes. Examples of integrated management include Rutherford et al.'s (2005) integrated ocean management plan;

Burger et al.'s (2007) Amchitka Science Plan; Peart's (2019) Seachange—Tai Timu Tai Pari; and Makey and Awatere's (2018) integrated Kaipara Harbour management model.

Taking the example of shellfish restoration, there have been global efforts to re-establish wild shellfish beds, including oysters and mussels, in soft-sediment coastal environments (Alder & Hillman, 2024; Benjamin 2023; Bersoza Hernández et al., 2018; Brumbaugh et al., 2006). Most efforts focus on the 'recruitment-limited' strategy, whereby adult shellfish are translocated to restoration sites to increase larvae supply lacking because of insufficient nearby broodstock (Brumbaugh & Coen, 2009). However, the decline is attributed to several stressors, including sedimentation, predation, overharvesting and habitat degradation (McLeod et al., 2012; Thrush & Dayton, 2002). In Aotearoa New Zealand, great efforts have been made to restore green-lipped mussel (*Perna canaliculus*), which typically involve dumping thousands of tonnes of commercial mussels that do not reach export standards onto the sea floor (Fisheries New Zealand [FNZ], 2023; Revive our Gulf, 2023). Unfortunately, after almost a decade, this method has resulted in large die-offs with little to no recruitment action in the human derived beds (Revive our Gulf, 2024). From an environmental standpoint, this approach does not address the multiple stressors shellfish and mussel habitats continue to face, such as predation (Alder et al., 2022; Benjamin et al., 2022; Wilcox & Jeffs, 2019), access to suitable substrate (Benjamin et al., 2022; Wilcox & Jeffs, 2019) and poor water quality (McLeod et al., 2012). From a cultural standpoint this approach negates the importance of place-based mātauranga Māori to identify intergenerational traditional mussel bed locations as sites for optimal shellfish restoration (Paul-Burke et al, 2022). From a social and economic standpoint, restoration programs often lack adequate funding, appropriate success measures, insufficient engagement and investment by stakeholders and community, and face regulatory hurdles (Baggett et al., 2015; Fitzsimons et al., 2020; S. M. Roberts et al., 2023). Consequently, restored shellfish beds often fail to become an established and self-sustaining population (FNZ, 2023; Mann & Powell, 2007; McLeod, 2009). A comprehensive and collaborative adaptive management action plan that takes a whole system approach, is inclusive of different methods and addresses multiple stressors would be the best approach.

The Sustainable Seas project Awhi Mai Awhi Atu: Enacting a Kaitiakitanga-based Approach to EBM (hereafter, Awhi Mai Awhi Atu) (part of the Aotearoa New Zealand Government National Science Challenge project) has co-developed a harbour-wide shellfish management action plan with local iwi, council and stakeholders that addresses multiple limitations to the wild mussel bed recovery. The project includes the development and execution of taura kuku

(natural-fibre mussel spat lines) that have successfully recruited mussels to increase broodstock population (Paul-Burkeet al., 2022); annual mussel and starfish population surveys to monitor their current distribution and abundance (and identify signs of recruitment on the sea floor) (Paul-Burke et al., 2022); a hybrid spatial species distribution model and Bayesian network (SDM-BN) to identify suitable mussel restoration sites based on local expert knowledge and environmental parameters (Bulmer et al., 2024); and the starfish removal feasibility study, which informs the SMAP discussed in this thesis. While these studies are small in scale, they allowed the research team to test methods for improving mussel populations, as well as provided evidence of the value of restoration initiatives—a 'proof of concept' (Fitzsimons et al., 2020). The SMAP encompasses both marine experimental field studies and mātauranga ā iwi to assist managers and streamline decision-making.

## 5.3 Starfish Management Action Plan Grounded in Ka Mua Ka Muri Codeveloped Framework

The draft SMAP (Fig. 5.1) was co-developed in consultation with te rōpū kairangahau and endorsed by the co-management decision-making forum—the OHIF—and the working group, OHSCG, for implementation in Ōhiwa Harbour. The SMAP was grounded in mātauranga ā iwi through the inclusion of localised place-based knowledge with regards to the experimental field designs (see Chapter 4) and through the co-design of the māhanga pātangaroa, or natural resource starfish traps (Chapter 3). This is consistent with my ka mua ka muri co-developed framework that seeks to draw on mātauranga Māori and Western science to enact kaitiakitanga. The SMAP also follows Te Awekotuku (1991) kaupapa Māori principles (Chapter 2) through encouraging collaboration, respect and reciprocity.

Following the ka mua ka muri co-developed framework, iwi members were involved in formulating the research objectives and overseeing its development and implementation at every stage and level. Throughout the course of this project, presentations regarding the current state of starfish populations in Ōhiwa Harbour and the removal trials were made to te rōpū kairangahau, the OHIF and the OHSCG. This involved discussion at each stage of the project, when I and researchers from the Awhi Mai Awhi Atu team met with iwi members to discuss proposed issues and appropriate research that could assist and streamline decision-making in the management of *C. muricata* and *P. regularis* for Ōhiwa Harbour. I always returned to iwi members and co-management partners with new findings, discussions and recommendations for each stage before progressing to the next stage (Paul-Burke, 2015; Paul-Burke et al, 2018).

This process helped strengthen relationships and continued over many hui and workshops. Ultimately, the ka mua ka muri co-developed framework, shaped by Te Awekotuku (1991) kaupapa Māori research principles, provided a culturally sensitive foundation for the SMAP that was inclusive of marine science and mātauranga Māori practices.

## 5.4 Starfish Management Action Plan

The SMAP (Fig. 5.1) was presented with various options to ensure it can be adaptive and applicable relative to resources, expertise, funding and the status of starfish in Ōhiwa Harbour. Prior to the SMAP, the MMAP developed by Paul-Burke et al. (2018) addressed the recovery of mussels in Ōhiwa Harbour and was a prelude to the SMAP. The SMAP follows a similar format to the MMAP, to promote consistency and confidence for the decision-makers regarding the SMAP. The timeframe of the SMAP is consistent with other research carried out in Ōhiwa Harbour. Phase 1 (mātaki or observe) of the SMAP seeks to establish a monitoring regime for the starfish and mussel population in Ōhiwa Harbour and investigate further the predation impact of *P. regularis*. This would be achieved by first selecting the area(s) of interest for mussel recovery and conducting starfish and mussel population surveys to identify if starfish removal is necessary. The areas selected would be based on mātauranga ā iwi (place-based intergenerational knowledge) (Paul-Burke & Burke, 2016), supported by the hybrid spatial SDM-BN (Bulmer et al., 2024). To achieve this, Phase 1 of the SMAP offers three options: (1) do nothing, (2) establish an annual monitoring program (Action A1), or (3) investigate predation impacts of *P. regularis* on juvenile mussels in addition to the monitoring program (Action B1), which would entail an experimental study.

If the results of the monitoring indicate the starfish population is at low density ($< 0.1$ ind. $m^{-2}$), and therefore poses no threat to mussels, no intervention would be necessary. In this case, continuous monitoring would be advised, and decision-makers could proceed to Phase 4 (whakahaere, or manage). However, if starfish density is moderate to high ($> 0.1$ ind. $m^{-2}$), decision-makers could decide to proceed with Phase 2 (whakautu, or respond) .

Phase 1 provided flexibility and considered unexpected situations like resource constraints. The Phase 2 options of the SMAP seek to act on findings from Phase 1 to respond appropriately and conduct best-practice management options. If Phase 1 findings found starfish populations a potential threat to mussel recovery, options A2a to A2c were available: (A2a) do nothing and continue with monitoring only, (A2b) conduct starfish removals using the combined effort of

diver removals and trapping, or (A2c) conduct diver removals only. Findings from the starfish removal study (Chapter 4) indicated the combined removal method is the most efficient and will target both starfish species effectively. Information from the starfish removal study can also assist decision-makers in allocating resources, time and funds to clear an area based on the number of divers and traps employed. Chapter 3 identified the optimal trapping technique and trap design to maximise catch rates while minimising effort.

If option A2b or A2c is selected, findings will allow decision-makers to decide if further intervention is necessary. If the results from surveys after the removal effort find starfish density has reduced to the minimum threshold ($< 0.01$ ind. $m^{-2}$), no further intervention is necessary, and decision-makers could proceed to Phase 3 (hangarua, or repurpose). If starfish density has not dropped below minimum threshold, further removal is recommended, and decision-makers should consider revisiting Phase 2. In Phase, several options for decision-makers were investigated by the research team with regards to repurposing the starfish after they have been removed. This step was important to include, as to moumou (waste) starfish would seem at odds with Māori perspectives. Three options were presented to deal with the removal of the starfish: (C3a) take removed starfish to a composting plant, (C3b) use starfish waste for a bioactive product (a feasibility study investigating the bioactive potential of starfish has already been undertaken; Wilkinson, 2021), or (C3c) find an alternative option.

Phase 4 (whakahaere, or manage) of the SMAP acts on findings from Phase 1 or 2, in that decision-makers can now relocate or monitor mussel populations in restoration areas. This would entail translocating mussels from taura kuku (mussel spat lines) to the sea floor. The following options were available: (A4a) translocate mussels to restoration site, (A4b) monitor mussel population and starfish population in addition to option one or do something else (A4c).

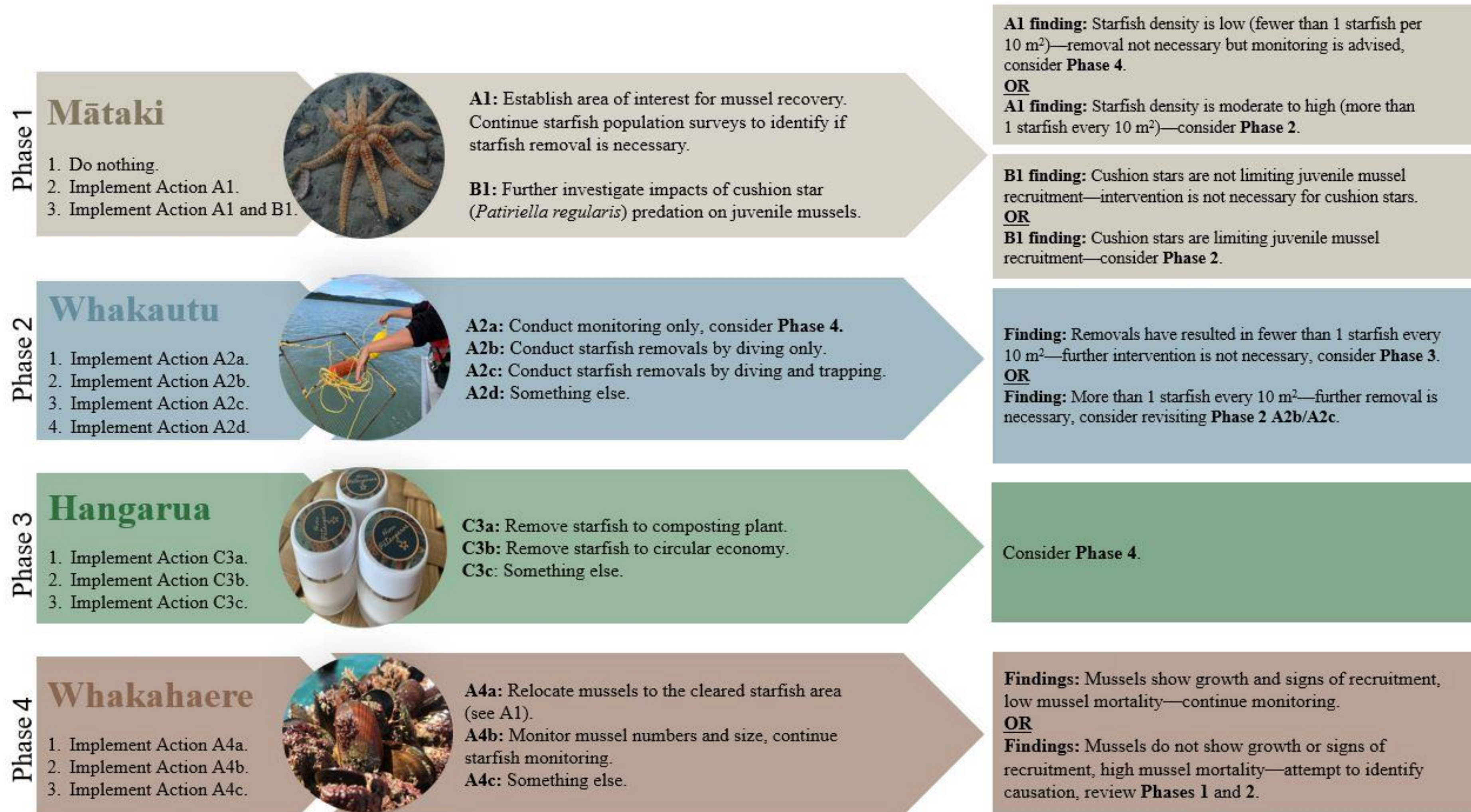


**Figure 5.1: Starfish management action plan (SMAP)—underpinned by ka mua ka muri co-developed framework—for the management of *Coscinasterias muricata* and *Patiriella regularis* outbreak in Ōhiwa Harbour**

## 5.5 Acceptance of Starfish Management Action Plan

The latest draft of the SMAP combined with the harbour-wide management plan was presented to members of the OHIF on 22 February 2023 and OHSCG on 11 July 2023 (see Appendix C for meeting minutes) and was unanimously accepted. Based on the options from the SMAP and wider harbour management plan, participants decided on a three-year management option focused on the western side of Ōhiwa Harbour. The option was inclusive of annual starfish removals using the combined effort of diver removals and trapping; conducting biannual population surveys; and maintaining taura kuku, or mussel restoration lines.

The acceptance recommendations were recorded in the OHSCG meeting minutes (Appendix C), which state:

- The following discussion resulted in the present members unanimously preferring Option 1 which combined population surveys, mussel spat lines relocation and starfish management (SMAP).
- Someone looking into funding avenues would need to enquire about the who, what, how much you can get, and when the applications were opening/closing.

Actions:

1. The OHSCG members make a recommendation to OHIF for approval to pursue option 1.
2. In the interim, OHSCG recommends that OHIF resources option 2 from the OHIF budget.
3. BOPRC to do a fundraising appraisal.

The unanimous acceptance of the SMAP can be attributed to several mechanisms. Consistent attendance at hui (meetings) by myself and the wider Awhi Mai Awhi Atu team demonstrated a commitment to the collaborative process. This regular presence not only facilitated ongoing communication and strengthened relationships and reinforced the credibility and reliability of the research team. A co-developed process further allowed us to present incremental findings, ensuring participants contributed and supported the reasoning behind the different options presented in the SMAP. Ultimately, this transparency in the research journey enhanced everyone's understanding and confidence in the proposed management strategies. We also conducted hui with our iwi partners prior to the management forum. This tikanga based strategy provided an opportunity for iwi advisors to focus on their specific interests and concerns,

fostering a more detailed and targeted discussion relevant to tribal aspirations and priorities for our collective harbour.

The SMAP also operates at a local scale, both in geographical area and governance, which in turn 'enables proactive rather than reactive responses to changes in a local ecosystem' (Bennett-Jones et al., 2022, p.413). This means resources and research can be more directed towards place-based issues. Local governance structures are often more agile than national level governance and can adapt more quickly to changing circumstances or feedback, enabling more dynamic and responsive management (Berkes et al., 2000). Furthermore, engaging local iwi and relevant stakeholders in the planning and implementation process generates a sense of ownership and responsibility, enhancing community support and participation. This bottom-up approach not only improves the effectiveness and sustainability of interventions but also empowers communities, building local capacity and resilience.

The SMAP addressed Action 2.1 under Area 2 of the *Ōhiwa Harbour Strategy: Te Rautaki mō Ōhiwa: Refreshed October 2014* (BOPRC, 2014). This action seeks to 'advocate and research for sustainable shellfish management' and 'identifies kaimoana in the harbour as threatened by overfishing, inappropriate gathering methods (e.g. grapples), starfish predation, and barriers to fish spawning' (BOPRC, 2014, p. 30). The research objectives and outcome of this thesis study aligned with OHIF and OHSCG commitments outlined in the *Ōhiwa Harbour Strategy: Te Rautaki mō Ōhiwa: Refreshed October 2014*. The SMAP is founded on empirical evidence (both mātauranga Māori and Western science). The evidence-based approach instilled confidence in the proposed management strategies and potential positive outcomes. The practicality and adaptability of the SMAP further played a pivotal role in its acceptance. The SMAP was designed to be easy to follow and action; providing several options that can be tailored to the available resources, funding and other specific community circumstances. This flexibility allowed participants to see the SMAP as a dynamic and adaptable tool co-developed specifically to suit the unique needs and environments of Ōhiwa Harbour.

## 5.6 Limitations to the Implementation and Effectiveness of the Starfish Management Action Plan

The implementation and effectiveness of the SMAP can be limited by several political and ecological factors. The turnover of representatives charged with the responsibility to advise and action the SMAP can cause disruption. This is particularly true for representatives in the

council, as regional and district representatives must be (re)elected every three years. Changes in leadership can disrupt continuity in decision-making, for example elected councillors whose politics determine the balance between economic, social, and environmental priorities can hinder long-term strategies. Turnover also disrupts relationships with researchers and others; a great deal of time is required to re-establish new relationships and trust in the mātauranga Māori and science that underpins the management decisions (Hewitt et al., 2022). Within the lifetime of the Awhi Mai Awhi Atu project, and subsequently during this PhD thesis research, the OHIF has seen a change in iwi and council representatives including the forum chair. Changes in representatives is possible in the implementation phase of the SMAP and could lead to challenges to implementation in the future.

Access to funding to support the implementation of the SMAP is in process. Current funding allocated to the Ōhiwa Harbour catchment cannot cover operational costs for the combined effort of starfish removals (diver removals and trapping), maintenance of mussel lines and annual monitoring. Suggestions from the OHSCG were to implement a cheaper option which seeks to maintain the taura kuku lines while the forum attempts to source funding to carry out the additional tasks. In the past, much of the work undertaken in Ōhiwa Harbour with regards to monitoring the current state of marine taonga species was voluntary, particularly by local Māori. However, to assign responsibility and obligation for the health of Ōhiwa and species to any one sector of the community is ethically unjust (Paul-Burke, 2015). To date, the OHIF has established a working party to explore different funding options.

From an ecological standpoint, the SMAP operates at a harbour-wide spatial scale, but bio-physical interactions expand beyond estuary borders and are inclusive of surrounding tributaries, landscapes and open ocean. While the SMAP and the sea floor mussel restoration regime assist in the recovery of mussels through in-water intervention (e.g., mussel spat lines, mussel translocation and starfish removals), they do not address activities from the connecting landscapes and seascapes that could be contributing to the decline of the traditional mussel beds and affecting starfish outbreaks. For example, it has been hypothesised that human-induced land run-off may be a contributing factor to the increased numbers of starfish. The 'terrestrial run-off theory' posits an increased amount of terrestrial nutrients in the water allows for denser phytoplankton populations, making for better starfish larval survival and thus yielding more adult starfish (Birkeland, 1982; Brodie et al., 2005; Fabricius et al., 2010; Wooldridge & Brodie, 2015). From 1975 to 1995, land usage in the Ōhiwa Harbour catchment saw a 1,032% increase in forestry activity and 168% increase in urban development (S. Park, 2005). The varying land

activities are likely to be contributing to increase sedimentation and nutrient supply to Ōhiwa Harbour. Monitoring by the BOPRC has indicated that Ōhiwa Harbour is experiencing rapid infilling by open coastal supply, as well as land-derived sediments; consequently, the morphology and ecology of the harbour is changing rapidly (BOPRC, 2013).

Ocean-based activities could also be a contributing factor to the starfish outbreak. Natural causes such as meteorological and oceanographic events, coupled with starfish life-history traits can lead to an increase in larval survival (Babcock et al., 2016; I. Miller et al., 2015). Anthropogenic activities along the coastline such as overfishing can remove natural starfish predators, causing the starfish population to increase, as predation is predominantly thought to be a natural control measure of juvenile starfish (Endean, 1977). Furthermore, existing starfish populations may be brought together under food limitation from overfishing their food sources or habitat destruction. Starfish could also be brought together because of active behavioural phenomena, where chemo-attraction between animals may serve to bring starfish together. Both instances can generate a swarming effect and result in potentially high fertilisation rates from clumped distributions of starfish (Dana et al., 1972; Inglis & Gust, 2003; Thrush & Dayton, 2002).

Ongoing anthropogenic changes to the coastal marine environment may have caused a fundamental shift in the population dynamics of *C. muricata* and *P. regularis* in Ōhiwa Harbour or have undermined the capacity for mussels and other shellfish to withstand these periodic disturbances (e.g., increased predation pressures from starfish outbreaks); to date, this field of ecology is still poorly understood (Babcock et al., 2016; Pratchett et al., 2017; Pratchett et al., 2021). Suppressing *C. muricata* and *P. regularis* during or preferably before an outbreak is therefore appropriate. While understanding the drivers of the starfish outbreak in Ōhiwa Harbour is of significant value, control measures would be the most beneficial short-term solution to the outbreak while existential issues can be investigated and addressed. Suggestions for future research to help close the knowledge gaps and further support the work undertaken in Ōhiwa Harbour are described in Chapter 6.

## 5.7 Conclusion

This chapter investigates management options and implications of the starfish outbreak in Ōhiwa Harbour. Quantitative experimental field studies, scientific literature, mātauranga Māori and kaupapa Māori research methodologies have ultimately supported the development of the

SMAP and are consistent with the wider AMAA project initiatives that seek to refresh harbour management tactics that are sensitive to ecological, cultural and societal priorities. The unanimous acceptance of the SMAP serves as a testament to the effectiveness of this approach, which is holistic, inclusive and collaborative. By fostering an adaptive management approach allowing for the flexibility of strategies based on ongoing assessment and real-world feedback, it ensures successful community-scale management and local restoration efforts, thereby contributing to the broader objectives of coastal marine management in Aotearoa New Zealand. Thus, this chapter describes how the thesis research has transcended into environmental management actions reflecting both mātauranga Māori and marine ecology-based information.

# Chapter 6:
# General Discussion

## 6.1 Summary

The focus of my thesis was to situate mātauranga Māori alongside marine science, recognising its relevance in contemporary marine management. This was achieved by co-developing management strategies with a relevant Māori authority to address the outbreak of starfish *C. muricata* and *P. regularis* in Ōhiwa Harbour in Aotearoa New Zealand. The benefit of bridging two of Aotearoa New Zealand's rich knowledge systems was that I was better equipped to address a complex marine socio-ecological issue. This thesis explores how the research traversed different fields of expertise, including te ao Māori (Māori world views), marine ecology and environmental policy.

Chapter 2 provided a comprehensive overview of the foundational principles and methodologies underpinning of the research, focusing on the integration of Indigenous knowledge and scientific approaches in marine management decision-making. It set the theoretical frameworks that supported and guided the thesis research. It highlighted and celebrated research that situated itself firmly in kaupapa Māori research methodologies. Enacting research priorities and methods to collect information and information sharing ensured that the research was truly co-developed with tribal elders and inclusive of both mātauranga Māori and marine science. This conscious approach ensured iwi viewpoints and knowledge were represented and disseminated in a dialogue that is appropriate and can be interpreted and acted on (Paul-Burke et al., 2018). The timeline and outcomes from the engagements outlined in Chapter 2 identified the interrelationship with the field research effort outlined in Chapters 3 and 4. Further, the co-development process underpinned by kaupapa Māori research methodologies identified the importance of returning to iwi advisors at every stage of the research, as integral to the success not only of the field work and the unanimous acceptance of the SMAP by the co-management OHIF forum in Chapter 5, but also to myself as a Māori early career researcher (ECR) in the Western dominated field of marine science in Aotearoa New Zealand.

In Chapter 3, I enacted a collaborative approach with mātauranga Māori, science and technical advisors to co-design an optimal starfish trapping methodology. Through consultation, I trialled

different designs, materials, bait, and soaking times. Consequently, we developed a new trapping methodology effective at removing starfish while minimising bycatch and being sensitive to local ecology and cultural values. Just as pertinent was the process of working collaboratively. The co-development of a starfish trap produced a nature-based solution, encouraged greater participation and provided greater access to a starfish management tool for hapū and iwi, thus further supporting kaitiakitanga responsibilities. The findings described in Chapter 3 helped inform the methods for the starfish removal study discussed in Chapter 4.

Despite evidence demonstrating that reducing starfish numbers can aid in shellfish recovery, there is a noticeable gap in research on effective control strategies for starfish outbreaks in Aotearoa New Zealand (Paul-Burke & Burke, 2016; Wilcox & Jeffs, 2019). The lack of comprehensive data on the efficacy of removal techniques initiated an investigation into practical solutions aligned with community-driven management goals that is described in Chapter 4. Results indicate the combined treatment, involving diver clearing and trapping simultaneously, yielded the highest daily catch rates for both starfish species and was the most effective. Moreover, the discovery of a new mussel bed with a population of an estimated 16 million mussels within our experimental site highlights the significance of ongoing research and management initiatives.

In Chapter 5, the need for adaptive management strategies that address multiple stressors affecting marine ecosystems is underscored by showcasing the development and implementation of a SMAP aimed at addressing the outbreak of *C. muricata* and *P. regularis* in Ōhiwa Harbour. This is the first starfish management regime developed both locally and nationally. The SMAP is grounded in the conceptual ka mua ka muri co-developed framework discussed in Chapter 2 and the empirical data collected in Chapters 3 and 4 and research findings of the wider Awhi Mai Awhi Atu research team. The unanimous acceptance of the SMAP by local governance structures and relevant Māori authorities reflects the success of this collaborative process.

## 6.2 Reflection: A Māori Early Career Researcher Perspective

One of the greatest challenges for an Indigenous ECR navigating the interface of Indigenous and science-based research is juggling the 'two asymmetrical worlds, two asymmetrical cultures, and two asymmetrical languages' (Macedo, 2016, p. 148). There is additional cultural responsibility while aiming to produce a piece of research that meets the conventional standards

of academic excellence (McKinley et al., 2011). It is important to acknowledge this and recognise the background and experiences of ECRs, as this can often influence the co-development approach and success. While science positions itself as an objective observer of the world, other ways of acquiring knowledge do not, and some argue that all knowledge is socially constructed (Longino, 1990).

A noticeable difference for Indigenous ECRs when working with Indigenous communities is their positioning within the research paradigm. Often the researcher is viewed as the 'expert', but from te ao Māori (Māori world views), the traditional position of the researcher as 'tuakana' (expert or elder) shifts to the position of 'teina' (learner or younger person) (Bishop, 1995). Within the Māori construct, it is often kaumātua (elders) who are seen as the experts—not in the sense that they make all the decisions, but that they provide guidance on culturally appropriate procedures and act as a voice for their collective whānau members (Bishop, 1995). This means that the power shifts to the collective, where knowledge is created, gathered and processed for the benefit of everyone (Bishop, 1995). This does not exclude the valuable input ECRs can contribute with their respective communities but creates a relationship that is reciprocal and mutual.

The other challenge is how Indigenous ECRs are viewed by their respective colleagues and within their own communities. The reality for many who are forging a pathway that is inclusive of their culture within academia or research institutes is probably disconnected from the realities and expectations researchers encounter among their own Indigenous communities. L.T. Smith (1999) acknowledges Indigenous researchers are: 'seen as partially insiders and are employed for this purpose, but also partially as outsiders (by their own whānau and Māori communities) because of their western education' (p.5).

How I identify as Māori, whether that be tangata whenua (local) or rāwaho (not related to the hapū or iwi or whānau), fundamentally changes how I interact with people and place through research. As a wāhine Māori of Ngāti Awa descent, I have affiliation to Ōhiwa Harbour through whakapapa. Consequently, my positionality within the research situates me as both an 'insider' and 'outsider'.

Language and knowledge dissemination was something I had to navigate during this research. Māori researchers are required to interpret and translate different languages to communicate with both their scientific community and Māori community to ensure a cohesive dialogue

between the two that can then be enacted through management practices and policy. It was imperative that learnings from science be understood and negotiated so to provide opportunity for reflection and feedback and ensures the research continues to align with Māori values and aspirations bringing benefit to Māori communities (Hudson & Russell, 2009; Pohl & Hadorn, 2007).

Criticism and measures of success from academia and from Indigenous community are often isolated from one another, which can lead to greater expectations and higher workloads. In the case of my PhD thesis, how do I ensure I produce both real world/solving/transformative action and scientific excellence (McKinley et al., 2011; Pohl & Hadorn, 2007). There is also a concern that conducting research that is Māori centric precludes the research or the researcher from being 'systematic' and 'scientific' (L. T. Smith, 1999). The way in which society values science and can lead to scepticism regarding the application and use of other sources of information, such as Indigenous knowledge (Berkes & Davidson-Hunt, 2008). Here, I argue that embracing both world views will provide greater prospect for the future. In the words of Cheung (2008): 'My own work has been enriched by these parallels and paradoxes' (p. 5).

## 6.3 Conclusions

### 6.3.1 Co-developed ka mua ka muri framework

This research examined mātauranga Māori and science to inform and understand the best approach to address the impacts of a starfish infestation. I did so by drawing on mātauranga ā iwi from Ngāti Awa kaumātua of Ōhiwa Harbour and practitioners. I also followed kaupapa Māori research methods to engage with our mātauranga Māori advisors, who assisted in the research focus, design, implementation and interpretation. Specifically, mātauranga Māori identified the research question 'How do we best manage the starfish infestation?', assisted in novel approaches to manage starfish through co-developing a novel trapping methodology and helped inform the experimental study design. Applying mātauranga Māori and kaupapa Māori research methods represents a distinctive approach in marine science, with only a few scientists actively adopting and advocating for this methodology. Through this application, I was able to ensure the research was respectful, ethical, grounded, accessible and empowered Māori communities (Paul-Burke, 2015; G. H. Smith et al., 2012).

Furthermore, the inclusion of marine science techniques such as field surveys and experimentation within this research meant decision-makers were better equipped to make

informed choices grounded in evidence (while also supported by iwi) rather than reliant on intuition or anecdotal observations. Bridging science and mātauranga Māori requires flexibility, a respect for other ways of knowing and doing, and proactively promoting knowledge co-production (Durie, 2004; Lemos & Morehouse, 2005). I was able to achieve this through my co-developed ka mua ka muri framework. This framework provided a philosophical foundation that aided me in bridging different disciplines, value sets, ethics and customs, as described in Chapter 2.

The co-developed framework I created and employed throughout the thesis study, helped instil and guide a thoughtful, kaupapa Māori approach to bridging marine science and mātauranga Māori. While the framework was used in the context of Ōhiwa Harbour, it can easily be applied in other settings to provide equitable opportunities for Indigenous and science-based knowledge; practices; and values; to support environmental management actions and holistic initiatives such as EBM. This is exemplified in the co-developed transmission of information through different methodological approaches (both science and mātauranga Māori), including the acceptance and operation of the SMAP. Importantly, for a co-developed framework to have effect, initial foundational steps are necessary. These include identifying and building authentic and trusting relationships with knowledge holders and practitioners, the establishment of a co-management/co-governance body that can implement recommendations moving forward, and the alignment of legal and regulatory frameworks to support and enforce the outcomes.

### 6.3.2 Field study findings

From 2021 to 2022, field research on the western side of Ōhiwa Harbour was carried out to ascertain the best method to remove starfish. This research was to provide evidence-based information for the management of starfish outbreak and thus support the recovery efforts of the traditional mussel beds. This was achieved first by developing a trapping methodology that explored different trap designs including a semi-enclosed box trap and a open trap. I found the open trap outperformed the box trap. We also compared CPUE of starfish with different soaking times and found CPUE was maintained from 24 to 48 h before declining. Thus, we decided on a 48 h soak time to minimise effort. Lastly, we compared crushed mussel bait and bonito fish bait. Although no significant difference was found, we decided on the fish bait, as sourcing mussels took more time. However, the fish bait can become costly, so repurposing fish waste could be the best option.

To reduce plastic in the ocean, I co-designed a natural resource trap with a tohunga raranga (master weaver), incorporating her mātauranga weaving principles into the design. We constructed a trap similar to the open trap but made from pirita and harakeke, traditional weaving materials used for fishing. The natural traps were successful in capturing starfish; however, some faults led to lower catch rates than from the traps made from synthetic materials. These faults can easily be rectified.

I then compared different removal techniques—trapping, hand collection via diving and a combination of the two. During field experiments, the combined treatment was found the most effective, removing 241% of the *C. muricata* population, followed by trapping, which removed 125% of the population within their respective treatment plots. For *P. regularis*, the combined treatment also proved superior in daily catch rates compared with individual methods. Combined effort was also the most efficient, with the highest daily catch rates for both species. However, diver removals obtained the second highest daily catch rates for the larger species, *C. muricata*, whereas trapping obtained the second highest daily catch rate for the smaller species, *P. regularis*.

Interestingly, the size of *C. muricata* caught varied depending on the removal method. Those caught in combined sites were significantly smaller than those caught in areas where only divers or traps were used, possibly as a result of diver removals being biased towards larger individuals, so allowing smaller starfish to remain. The CPUE was maintained after 18 days of intensive trapping for both starfish species. This means traps are relatively efficient over an extended period. However, past literature (Andrews et al., 1996) has argued trapping rates are dependent on the background density of starfish, whereby sites with a low starfish density produce higher catch rates than sites with high starfish density. This is probably because high-density sites have other available food sources. Thus, trapping effort should be employed in locations where there is a moderate to low density starfish to remove a significant proportion of the population effectively.

An additional observation from the field experiments was *P. regularis* predating on juvenile green-lipped mussels. This observation, coupled with the vast numbers of *P. regularis* caught via trapping, could suggest *P. regularis* are a potential barrier for juvenile mussel recruitment until mussels reach a maximum size threshold. This observation stirred interest in investigating the impacts of *P. regularis* predation on mussel recruitment.

### 6.3.3 Starfish management action plan

Using mātauranga Māori and marine science to develop understanding of ecosystem state, and recoverability, including traditional managerial practices, are increasingly being recognised as relevant to the sustainable management of marine environments, and in doing so, fosters shared management strategies and responses (Berkes & Davidson-Hunt, 2008; Ogilvie et al., 2018; Paul-Burke, et al., 2022)

This thesis sought to investigate different options to assist in the management of starfish in Ōhiwa Harbour through the development of a SMAP. This plan sought to:

1. co-develop and implement a management action plan for starfish in all areas of Ōhiwa Harbour in collaboration with relevant Māori authorities
2. have the management plan accepted and enforced at the highest local/regional governance level; namely, by the OHIF, as a cohesive, whole-harbour approach.

Both aims were successfully accomplished. I outline the phased approach of the SMAP in Chapter 5. The plan integrated options for starfish removal, mussel restoration and repurposing of removed starfish, which were supported by the research carried out from this thesis, as well as from the wider Awhi Mai Awhi Atu research team. This ensured a comprehensive and culturally sensitive management strategy. The SMAP was also flexible and adaptable accounting for changes to the state of starfish (e.g. low density or moderate to high density status) and access to resources. The acceptance of the SMAP by the Ōhiwa Harbour Forum and Ōhiwa Harbour Strategy Coordination Group underscores the success of the collaborative approach, sustained by transparency, regular communication and the incremental presentation of findings.

However, challenges remain, including turnover of representatives, funding limitations and ecological complexities beyond estuary borders. Addressing these challenges requires ongoing engagement, adaptive strategies and holistic approaches that consider both terrestrial and ocean-based activities contributing to the starfish outbreak and broader ecosystem health in Ōhiwa Harbour.

## 6.4 Recommendations

Based on the findings of the marine field research, it is recommended that:

- The combined effort should be prioritised as the first option in the management of the starfish outbreak in Ōhiwa Harbour.
- Post-removal population census surveys should be undertaken, as these are necessary to understand starfish recolonisation rates and the effectiveness of removals.
- The construction of natural-based traps and repurposing of fish waste for bait to support more sustainable trapping practices be investigated further.

### 6.4.1 Future research

The research conducted in Ōhiwa Harbour identified a gap in our knowledge concerning ecological understandings of the starfish outbreak and implications of the removals. Further evidence is required, and several recommendations for future research remain. These include:

- Predation impacts of *P. regularis* on juvenile mussels on the seafloor of the harbour.
- Investigation into life stage (size) in which starfish species pose a threat to mussels.
- A harbour-wide monitoring program of starfish to understand the current status and build a historical record, as well as help identify targeted managed sites.
- The identification of alternative sites for mussel restoration that may be less susceptible to starfish predation.
- Investment in research investigating the drivers of starfish outbreaks.

## 6.5 Closing Comments

When undertaking this thesis, I sought to reclaim mātauranga Māori in the field of marine science to better inform marine management decision-making, specifically to address the needs of Ōhiwa Harbour. This research has achieved that goal through a mixed-methods approach that is inclusive of place-based traditional ecological knowledge, or mātauranga ā iwi, kaupapa Māori research methodologies, tikanga, marine field surveys and experimental study design. This thesis is relatively unique in contributing to our growing understanding and application of Indigenous knowledge in the marine sector and how it can better equip decision-makers when faced with a novel challenge.

This research has demonstrated valuable insights in co-developing a SMAP with local iwi, stakeholders, community and policy makers to address the starfish outbreak in Ōhiwa Harbour. It highlights the dynamic interplay between culture, science and environmental stewardship in Aotearoa New Zealand's marine ecosystems. The SMAP that addresses a starfish outbreak grounded in mātauranga Māori and science is the first of its kind and can provide a model for ways in which other practitioners, iwi/ hapū, researchers and managers can integrate different sources of knowledge and practices to ensure a positive outcome.

With regards to the management of starfish infestation in the context of shellfish recovery, this research highlighted several possible avenues for future studies. These include further investigation into the ecological impacts of starfish predation on mussel recruitment (particularly *P. regularis*); identification of sites for mussel restoration that may be less susceptible to starfish predation if removal efforts are beyond resourcing; investigation of potential drivers of starfish outbreak so that managers can make decisions more directed at minimising outbreaks in the future; and, lastly, the conduct of post-removal population census surveys to better understand recolonisation rates of starfish and the long-term efficacy of removal efforts. In doing so, additional research will provide valuable insights and inform evidence-based management strategies for addressing starfish outbreaks and promoting the recovery of shellfish populations in coastal ecosystems.

*Ka mua ka muri—walking backwards into the future.*

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# Appendix A

## Ethics approval letter

The University of Waikato
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0800 WAIKATO (924 528)

HECS Human Ethics Committee
Brett Langley
Telephone +64 77 838 4060
Hecs-ethics@waikato.ac.nz

THE UNIVERSITY OF
WAIKATO
*Te Whare Wānanga o Waikato*

14 April 2021

Megan Pareue Ranapia
Conrad Pilditch
Kura Paul-Burke
Richard Bulmer

**Re: HECS Ethics Approval of Application HREC(HECS)2021#14 "A co-developed mātauranga Māori and science approach to inform marine research and management: A case study of the pātangaroa (*Coscinasterias muricata*) overabundance in Ōhiwa Harbour, Aotearoa New Zealand."**

Kia ora Megan:

Thank you for submitting your amended application HREC(HECS)2021#14 for ethical approval.

We are pleased to provide formal approval for your project, including the following activities:

- Recruit participants via the rōpū kairangahau (mātauranga Maori advisory group made up of elected iwi representatives from Ngāti Awa and Te Upokorehe), and Kura Paul-Burke (affiliated to Ngāti Awa).
- Carryout kanohi kitea (Face-to-face) interview with open-ended questions.
- Use maps and/or a day out on the harbour to assist participants with identifying areas of significance and the mātauranga Māori affiliated to a particular place in the harbour.
- Allow participant's involvement in revising, amending and approval of draft interview notes.

Please contact the committee by email (hecs-ethics@waikato.ac.nz) if you wish to make changes to your project as it unfolds, quoting your application number with your future correspondence. Any minor changes or additions to the approved research activities can be handled outside the monthly application cycle.

We wish you all the best with your research.

Ngā manaakitanga,

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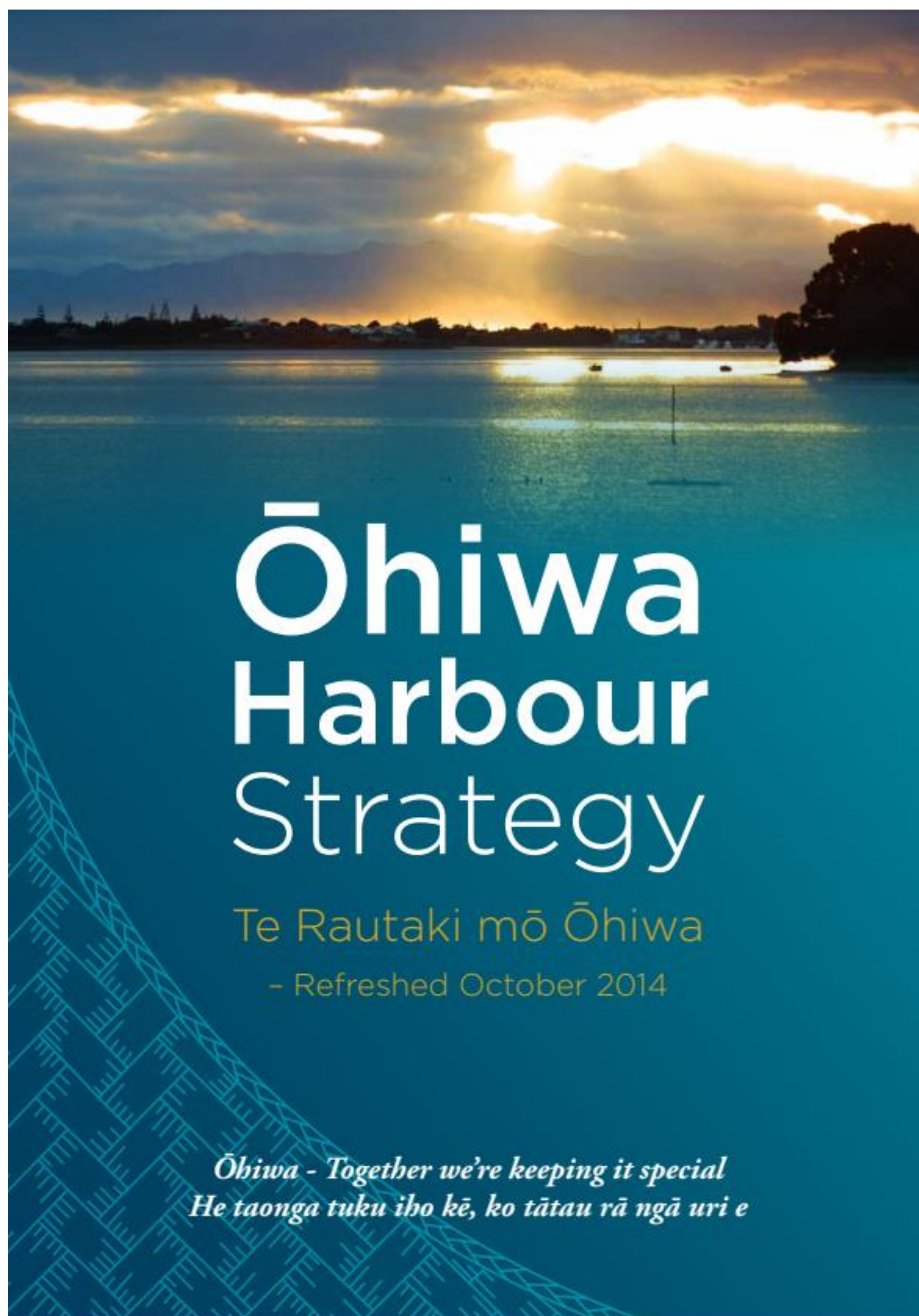
**Brett Langley, PhD**
**Chairperson**
**HECS Human Ethics Committee**
**University of Waikato**

# Appendix B

**Supporting documents for a starfish management OHS Strategy 2014 (refresh) and newsletter.**



Wāhi Mahinga 2
- Hāpai i te mauri o Ōhiwa

# Action Area 2 – Harbour management

The health and ongoing availability of kaimoana in the harbour is of utmost importance to the community, particularly tangata whenua. If the rest of the harbour is healthy and managed appropriately, kaimoana will thrive.

However, this resource needs to be protected to ensure its ongoing availability.

## 3.3 Community issues – harbour management

1. Kaimoana in the Ōhiwa Harbour is threatened by overfishing, inappropriate gathering methods, starfish predation, and changes in the harbour environment, particularly sedimentation. This has led to the disappearance of some species and is threatening those species that remain.

2. Much more needs to be done to raise awareness of the issues, protect the resource and to police the rules and regulations around fishing and shellfish gathering.

3. Ongoing research is necessary to understand the threats to the resource and this should take more of a bicultural focus.

# Appendix C

## OHIF and OHSCG short reports and meeting minutes from 2021-2023.

**Report to** Ōhiwa Harbour Implementation Forum

**Date** 09 September 2021

**Report from** Kura Paul-Burke, Megan Ranapia, University of Waikato

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**Update on the Ōhiwa Harbour, Awhi Mai Awhi Atu, Sustainable Seas, National Science Challenge project, September 2021**

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### 1.0 Summary

This report provides an update overview of the Sustainable Seas funded Awhi Mai Awhi Atu project and research activities that have been carried out in Ōhiwa harbour on Kūtai, *Perna canaliculus*, Green-lipped mussels and Pātangaroa, *Coscinasterias muricata,* Eleven-armed seastar, between September 2020 and May 2021.

### 2.0 Report

**Mussel and Seastar surveys**: in September 2020, three newly formed mussel beds were identified in close proximity to the mussel restoration stations in the harbour. The newly formed beds were code named K1, K2 and K3. The last remaining traditional bed was identified as still present and code named K4.

Figure 1. Map of 2020 newly formed mussed bed sties K1, K2, K3 (yellow) and last remaining traditional mussel bed site K4 (blue).

Between April - May 2021, a series of mussel and seastar distribution, abundance and size frequency dive surveys were undertaken at the four identified mussel bed sites in Ōhiwa harbour.

It was found that all 4 mussel sites were still present. Abundance (mussel numbers) had increased in three of the four sites, with a significant decrease recorded in K3. It is understood that site K3 is located in the same vicinity as the two-hectare pipi bed that recorded an estimated 100,000 seastars in 2019 (50,000 per hectare). Seastars were identified in two of the four sites surveyed including K1 on the Western side and K3 on the Eastern side.

In November 2020 there were an estimated 470,000 mussels across the four identified mussel bed sites in the harbour. Within five months, by April 2021 the total number had increased to an estimated 745,000 mussels self-recruiting (re-producing) on the harbour floor.

## 3.0 Recommendation

**That the Ōhiwa Harbour Implementation Forum under its delegated authority:**

1. Receives the report, update on the Ōhiwa Harbour Awhi Mai Awhi Atu, Sustainable Seas, National Science Challenge project, September 2021.

Report prepared by:

**Assoc Professor Kura Paul-Burke and Megan Ranapia (PhD Candidate)**
University of Waikato

27 August 2021

| | |
|---|---|
| **Report to** | Ōhiwa Harbour Implementation Forum |
| **Date** | 10 April 2022 |
| **Report from** | Assoc. Professor Kura Paul-Burke, University of Waikato; Dr Matt Miller, Cawthron Institute; Megan Ranapia (PhD student), University of Waikato. |

**Update on the Ōhiwa Harbour, Awhi Mai Awhi Atu, Sustainable Seas, National Science Challenge project, April 2022**

## 1.0 Summary

This report provides an update overview of the Sustainable Seas funded Awhi Mai Awhi Atu project and research activities that have been carried out in Ōhiwa harbour on Kūtai, *Perna canaliculus*, Green-lipped mussels and Pātangaroa, *Coscinasterias muricata,* Eleven-armed seastar, between September 2021 and April 2022.

## 2.0 Report

Seasonal sampling of two species of seastars, Pātangaora (*Coscinasterias muricata*, Eleven-armed seastar) and Reef star (*Sticaster australis*) across four seasonal timeframes consistent with the maramataka (Māori lunar calendar) have been completed.

Figure 1. Images of (R) Pātangaroa (*Coscinasterias muricata*, Eleven-armed seastar) and (L) the Reef Star (*Sticaster australis*).

It was found that seastars, as with most creatures, are mostly water (~70%). Once dried, the seastars produce good levels of collagen at an average of 10%, along with marine protein (33%) and a high amount of ash (50%) made mostly from calcium carbonate. Calcium carbonate helps to make the tough endoskeleton (hard, spiny exterior) components known as ossicles. Analysis of the seastar samples for a series of minor components such as potential bioactives (omega 3, marine toxins, heavy metals etc.,) has commenced. The seastar collagen prototype skin care product and process are now under development with the results and final product anticipated for March 2023.

Figure 2. Collecting reef star samples on reef rocks outside of Ōhiwa harbour.

**Seastar management trials**: in November 2021, seastar management trials were undertaken in the harbour led by Megan Ranapia (PhD student). Trial trapping was carried over 3 different time periods, 1) 24 hours soak, 2) 48 hours soak, and 3) 72 hours soak timeframes (soak = time left in the water). It was found that the 48 hours soak time generated the highest number of seastars caught.

Using two different trap designs (open trap and semi-enclosed trap) and two different baits (mussels versus bonito fish bait). We found that the open traps with bonito fish bait attracted more seastars with an average of 3.5 seastars per day as opposed to the semi-enclosed traps baited with mussels attracting an average of 2.7 seastars per day.

Based on the findings of the November 2021 trial, in May 2022 we will conduct a feasibility trial for removing seastars in the harbour. The strategies will include: 1) diver removal, 2) trapping and 3) combined diver removal and trapping. An experiment area located in the western channel approximately 8 hectares in size with an estimated 12,805 seastars currently present (or 1.6 seastars per 10 metres square) will be trialled. It is estimated that 1 open trap, using bonito bait, soaking for 48 hours will clear an estimated area of 20metres square per day or 40 metres square in the 48hour time frame. It is anticipated that the results from the removal trials will be presented back to the OHIF in October 2022.

## 3.0 Recommendation

**That the Ōhiwa Harbour Implementation Forum under its delegated authority:**

1. Receives the report, update on the Ōhiwa Harbour Awhi Mai Awhi Atu, Sustainable Seas, National Science Challenge project, April 2022

Report prepared by:
**Assoc Professor Kura Paul-Burke**
University of Waikato

| | |
|---|---|
| **Report to** | Ōhiwa Harbour Implementation Forum |
| **Date** | 22 February 2023 |
| **Report from** | Prof. Kura Paul-Burke, University of Waikato; Megan Ranapia (PhD student), University of Waikato; Joe Burke, MUSA Environmental; Dr Matt Miller, Cawthron Institute; Dr Mathew Cumming, Plant & Food Research. |

**Update report on Awhi Mai Awhi Atu, Sustainable Seas, National Science Challenge project, February 2023**

## 1.0 Summary

This report provides an update overview of the Sustainable Seas funded Awhi Mai Awhi Atu project and research activities that have been carried out in Ōhiwa harbour on Pātangaroa, *Coscinasterias muricata,* Eleven-armed seastar between May 2022 – January 2023.

## 2.0 Report

**Seastar management trials**: Between October – November 2022 a feasibility trial for removing the eleven-armed seastars in the harbour led by Megan Ranapia PhD student and Joe Burke MUSA Environmental was conducted. During the trial large numbers of the cushion star (*Patiriella regularis*) were also identified predating on newly recruited baby (juvenile) mussels that had settled on the traps and the harbour floor. As a result, the trial was widened to include data collection information on the cushion star along with the eleven-armed seastar. The trial used three removal methods: 1) diver removal; 2) trapping; and 3) combined diver removal and trapping. The trial was conducted within a trial experiment area located in the western channel approximately 8 hectares in size. In 2022 there were an estimated 4,800 seastars present in the trial area (or 1 per 20 metres square).

The seastar removal trial was originally planned for June 2022 however excessive bad weather conditions including one of the highest annual rainfalls on record for the Bay of Plenty in 2022 required the trial continuously be put on hold for 20 consecutive weeks until a fair-weather window of 10 or more days finally appeared in late October early November. Within the actual trial only 3 consecutive days had some form of visibility to enable the diver removal trials to commence.

It was found that the diver method was the most effective at removing larger sized eleven-armed seastars with almost 500 seastars located and removed over a 3-day diving regime, in poor visibility, with a maximum 1.5 hours dive time (slack tide) per day (total 4.5 hours with 2 divers). The trapping method proved more effective at catching smaller animals with 30 traps collecting a further 550 eleven-armed seastars and 18,900 cushion stars over the 18-day trapping regime. The trial identified that trapping can be conducted year-round, however the diving regime can only be implemented with fair weather conditions and requires a level of visibility to locate seastars in an increasingly murky harbour.

**Pātangaroa product development project**: A seastar collagen prototype skin care product has been developed by Dr's Matt Miller and Mathew Cumming using two species of seastars Pātangaora (*Coscinasterias muricata*, Eleven-armed seastar) and Reef star (*Sticaster australis*). The project sought to identify potential products and economic values of harvesting seastars to assist population management. It was found that seastars are a potential bioactive resource, particularly as a source of marine collagen which is in high demand as a commercial cosmetic ingredient.

**Mussel restoration stations**: The Awhi Mai Awhi Atu project and associated funding from the Sustainable Seas National Science Challenge will conclude in June 2023. Currently there are 4 mussel restoration stations in the harbour. The stations have been extremely successful at recruiting mussels and assisting the generation of three new mussel beds on the harbour floor. In 2019 there was 1 mussel bed remaining in the harbour with an estimated 78,000 mussels. By 2021 there were four mussel beds with an estimated 750,000 mussels on the harbour floor. The mussel restoration stations require regular maintenance especially with the occurrence of more frequent large storm events

**Seastar management plan:** A draft seastar management plan (SMP) has been developed providing recommendations for seastar management in Ōhiwa harbour. This is consistent with Action Area 2 in the Ōhiwa Harbour Strategy: Te Rautaki mō Ōhiwa – Refreshed 2014, which identifies starfish predation as a significant issue for sustainable shellfish management in the harbour.

## 3.0 Recommendation

**That the Ōhiwa Harbour Implementation Forum under its delegated authority:**

1. Receives the report, Update report on Awhi Mai Awhi Atu, Sustainable Seas, National Science Challenge project, February 2023.

2. Supports a Seastar Management Plan to assist Action Area 2 of the Ōhiwa Harbour Strategy – Refreshed 2014.

Report prepared by:
**Professor Kura Paul-Burke**
University of Waikato

# Minutes of the Ōhiwa Harbour Strategy Coordination Group (OHSCG) meeting held Tuesday, 11 July 2023 at 9.00am, Te Rūnanga o Ngāti Awa, Whakatāne

Chairperson: Pim de Monchy (BOPRC)

Attendees: Tim Senior – Bay of Plenty Regional Council Toi Moana (BOPRC), Cr Malcolm Campbell (BOPRC), Charlie Bluett – Te Rūnanga o Ngāti Awa, Cr Dean Petersen – Ōpōtiki District Council (ODC), Andrew Iles – Whakatāne District Council (WDC), Cr Tu O'Brien – WDC, Garry Page – ODC, Dr Kura Paul-Burke – MUSA, Joe Burke – MUSA, Megan Ranapia – PhD Student/MUSA, Rebecca Hunter – Department of Conservation (DOC), Ayla Jack – DOC, Esther Coenen – BOPRC.

Karen Mokomoko (Whakatōhea) arrived at 9.30am.

Minutes: Tanja Rother (Shared Landscapes - Intercultural Research & Engagement Services)

The hui commenced at 9.10am.

## 1. Whakatau – Welcome

A karakia was provided by Tu O'Brien.
Charlie Bluett welcomed members to the hui.

## 2. Ngā Hōnea – Apologies

Cr Toi Iti (BOPRC), Gerard McCormack (ODC), Maude Edwards (Te Upokorehe)
Andrew Iles (WDC) from 10.30am, Ian Malony (WDC)

## 3. Mussel & Starfish Research – Update from Kura Paul-Burke

Kura began by providing an overview of the research and action undertaken since. Mussel population surveys and mapping of beds in 2007 showed one continuous mussel bed existed along Ohope Spit, containing approximately 112 million mussels. However subsequent surveys demonstrated that the mussel beds were shrinking and the mussel population was rapidly declining:

> 2007 112million
> 2008 56 million
> 2009 16 million
> 2013 2 million
> 2016 500,000
> 2019 8,000

The initial work, supported by Te Rūnanga of Ngāti Awa, focussed on the western side of the harbour. The eastern mussel beds were first mapped in 2013. Only one of three original musselbeds that had been confirmed by Te Upokorehe kaumātua was still present. It is located at the Ōhiwa Spit in the harbour mouth.

In 2009 and 2013, as well as in 2019 to 2022 through the Awhi Mai Awhi Atu Project (National Science Challenge Sustainable Seas), Kura and Joe and their team also surveyed and mapped the pipi beds and sea stars in the harbour. More specifically, they investigated the relationship between the pipi population and the presence of sea stars. Kura pointed out that in early June 2019 a 2ha pipi bed on the eastern side of the harbour contained 100,000 seastars, or 50,000 per hectare. By contrast, Kura added, 15,000 per hectare is considered a healthy population of seastars per hectare.

Alongside the eleven-armed sea star, the cushion star was also observed near mussel beds, although in less numbers. Surveys conducted in harbour have shown decreases of mussel populations correlating with increased presence of the eleven-armed starfish.
Starfish predation is assessed to be one of the leading causes of mussel declines within the Ōhiwa Harbour.

In 2014 Kura developed the first Mussel Management Action Plan (MMAP).

Awhi Mai Awhi Atu 2017 – June 2022

Just over $ 5 million of funding by NSC Sustainable Seas & BOPRC. The main research questions of this project were:

- Can we recruit our own mussels from Ōhiwa, in Ōhiwa, for Ōhiwa?
- Can we create biodegradable lines to assist spat settlement & reduce plastic pollution in the harbour?
- Can we build mid-water mussel restoration stations which also promote biodiversity retention in the harbour?
- Can mussels from the restoration stations be relocated to the last traditional mussel bed on the seafloor?

Rather than obtaining expensive mussel spat from Ninety Mile Beach the researchers trialled growing mussels from those still remaining in the harbour using mussel ropes to catch spat. The first mussel restoration trials went underway in 2017 using predator exclusion cages. However, it was soon realised that the sea stars were able to get through the tiny holes in the cages predating on the baby mussels.

Hence, in cooperation with local weaver Ruka Cameron natural resource cages were made as well as taura kuku - natural mussel spat settlement lines prepared from cabbage tree/ti kouka. Four restoration stations were installed in the harbour based on matauranga / original mussel beds. The restoration stations proved were very successful. Successful recruitment of mussels was confirmed in 2019 – 2021, 2022, and 2023, incl. to last traditional bed in the harbour.

The taura kuku measured to not touch the bottom - out of reach of the seastars. This proved successful for the retention of biodiversity in the harbour - approximately **57x** more individuals were found on the lines than found on the seafloor environments of the harbour.

This method is now being implemented around the country. Ōhiwa is leading the country in mussel restoration and in showing how traditional Māori knowledge and resources can help solving contemporary environmental problems. The project has always involved youth who started as volunteers. When funding became available they were awarded study awards.

As a result, the mussel distribution in the Ōhiwa Harbour expanded during 2019 – 2021 from a total population of 78,000 mussels in 2019 to 745,000 mussels in 2021.

**Tikapa Moana – Hauraki Gulf mussel restoration projects**

Kura then pointed out that similar work was done in the Hauraki Gulf but that the work in Ōhiwa Harbour had shown best results. Mussel restoration in the Hauraki Gulf encompasses four projects**:**

Ngāti Whātua Ōrākei [Revive our Gulf; TNC, Auckland Uni]
- Ōkahu Bay Waitematā Harbour
- November 2021
- 60 tonnes mussels deployed
- marginal results: 1,200 cubic metres shell hash

Ngāti Manuhiri
- Mahurangi Harbour
- June 2022
- 150 tonnes mussels deployed
- Creating natural mussel spat lines, 2022

Pou Rāhui (MBIE Endeavour Fund, Kura)
- 100% Māori-led by Ngāti Pāoa, Ngāti Rehua/Ngāti Wai, Ngāti Tamaterā, Ngāti Hei, Ngai Tai ki Tamaki
- Replicating work of Ōhiwa

Ahuriri Iwi Trust & Napier Port (MPI Customary Fisheries Fund)

2022: Western side of Ōhiwa Harbour

From 2022 Kura and her team's work continued solely on the western side of the harbour due to Upokorehe having other priorities on the eastern side.

A shellfish survey on the western side produced the following results: Tuangi (cockles) - 44 ha; Pātangaroa (starfish) – 8 ha; Titiko (mud snail) - 3,500; Pipi - 19 ha; Hururoa (horse mussels (20); Tipa (scollops) (300).

Starfish removal trials

Megan Ranapia provided details of the starfish removal trials begun in November 2021. The first traps the team put down came back with a lot of bycatches. Consequently, a steel trap designed by Joe Burke was adopted that would not trap other creatures but have starfish cling on to it. This open trap worked well. Different baits and soak times were trialled. Two days appeared to be an optimal time

for the traps to remain in the water. After only 48 hrs in the water the traps had juvenile mussels on them.
In addition to the traps, a total of 1800 starfish were removed in study area by dives. One diver can clear 1200 sqm area within one high tide. Catch rates amounted to 150 eleven armed / 320 cushion starfish per diver per day. Starfish are predating on newly recruited mussel babies.

Comparing both methods, diver removal is weather dependent and therefore in a season such as the one just passed very limited. However, dive removals are more effective for removing larger starfish. Trapping is less effective but not weather dependent.

Joe and Kura add that starfish are a global problem and their augmented numbers are associated with increased nitrate run-off from the land. Australia is doing a lot of research in this area.
Cushion starfish appear to further inhibit mussel recruitment and retention predating on smaller mussels but this is not fully understood yet. Megan is investigating this in her doctoral thesis which is due next year.

A short discussion followed with regard to the prospects of mussel restoration in the harbour given the presence of starfish. Kura said she was confident that lower starfish numbers will assist in mussel recruitment. The mussel bed at the harbour mouth shows this because there is no starfish there. However, there may be other predators that could kill the mussels.

Karen noted that the evidence appeared to indicate that ongoing management and removal was most likely required. Kura confirmed this view. Starfish are part of the natural ecosystem. Kura also emphasised that any removal efforts needed to be linked to a purpose such as the potential hand cream products that had already been trialled or the use of starfish in worm farms to produce fertiliser.

Funded by Sustainable Seas a Draft Starfish Management Action Plan (SMAP) was developed in 2023 by Megan Ranapia, Kura Paul-Burke, Joe Burke, Charlie Bluett and Tu O'Brien. The draft is not ready for public dissemination yet.

**Options for consideration**

**Kura completed her presentation describing the three main aspects of potential future action:**

**Population Surveys (annual or biannual)**
- **Current mussel & starfish distribution, abundance, sizing**

**Mussel spat lines and Relocation**
- **Maintenance, deployment, relocating to seafloor**

**Starfish Management**
- **Diving**
- **Trapping**
- **Combined diving and trapping**

Five options for the continuation of the work over a three-year period were presented. Each option provided for different emphasis on the three main aspects resulting in different funding requirements (see graph below).

4. Break for morning tea.

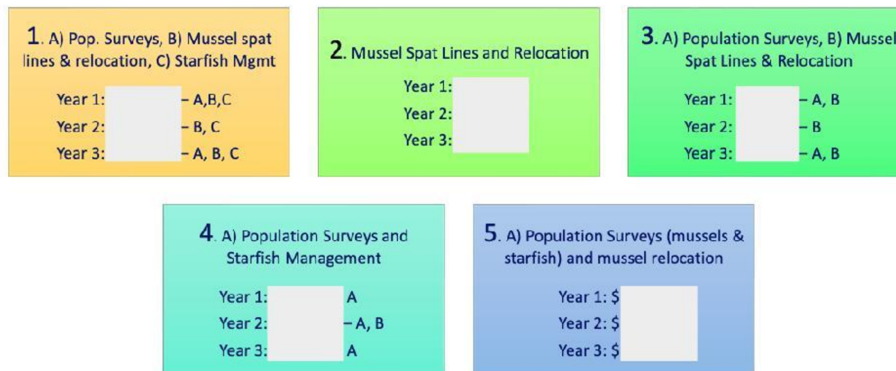
Andrew Iles left the meeting at 10.30am.

The meeting resumed at 10.40.

**5. Update from Kura and discussion continued**

Pim thanked Kura and her team for their work. He specifically highlighted the approach the team had taken over the years always including local rangatahi (young people). He also thanked Ngāti Awa as the original funder of the research project. While funding had ended in June 2023 the restoration project was still needed.

Discussion of options to continue the mussel restoration work




Cr Malcolm urged the members to determine for this to continue and to be done as a collective.

Pim felt that OHSCG was supportive of the continued efforts to restore the mussels and the mauri of the harbour. He asked what a 5-year outlook would look like if the predators were suppressed.
Joe responded that this is unknown but that it was likely that bigger mussel populations would be able to handle starfish better, however, this could only be confirmed once this point in time had been reached.

Karen enquired if a higher mussel population would attract more starfish to the harbour? According to Kura this was likely and relocating mussels to optimal area would therefore be very important, particularly to the western side habitat with hard sand available, as well as to the harbour mouth. Recent modelling of mussel beds confirmed mātauranga from generations ago. Joe added that the retention of the bed in the harbour mouth must be priority. Starfish do not like swift water and therefore this is an optimal location, the sand shifts there and there is not a lot of light as it is 14m deep.

were benefits in having the same people continuing this work as it would provide consistency in quality and approach. He hoped that turning to option 2 would not mean losing sight of option 1. Pim asked if the Ōhiwa mussel restoration work could also be framed within the work being done towards climate change adaption? Kura confirmed this view. Disappearing mussels meant the harbour was getting more turbid which would result in loosing other species. The project was trying to restore the ecological balance.

Councillors Tu O'Brien and Dean Peterson from Whakatāne and Ōpōtiki District Councils respectively also expressed the need for this project to be continued. Both saw the Long-Term District Plan review processes as a good opportunity to seek funding. They asked to be provided with a general brief detailing the significance of the project and an understanding of any other funding potentially available.

Garry Page from Ōpōtiki District Councils further suggested framing the programme for 4 years rather than 3. This would mean the project was up and running already when making funding applications.

**Actions:**
**1. The OHSCG members make a recommendation to OHIF for approval to pursue option 1.**
**2. In the interim, OHSCG recommends that OHIF resources option 2 from the OHIF budget.**
**3. BOPRC to do a fundraising appraisal.**
**4. Kura to prepare a brief rationale for Option 1.**

Finally, Pim enquired with Kura if MUSA would be available for the maintenance work this year. Kura advised that this could probably be done until Christmas. However, Kura queried if access to the eastern side would be reinstated. Upokorehe had denied access to the project team in recent times. Access was consistent to the western side.

## 6. Ōhiwa work programme report for 2022/3 year

Tim reported on the progress that had been made in this year's work programme. Taken the 'Ōhiwa Work Programme Update to June 2023' as read Tim highlighted a number of actions:

Actions 1.1 and 1.2
There are now 12 dairy farms in the catchment that have a Farm Environment Plan for mitigation work in place. Working with dairy farmers will over time influence harbour nutrients levels, sedimentation and water quality overall.

Action 1.4
Also in farming space, a new group of mostly dairy farmers in the Nukuhou catchment started a funding application for the training and education of farmers. However, this initiative has been held up by Upokorehe and the programme therefor may not happen This is unfortunate for the whole harbour.

Dean Petersen (ODC) advised that the group was planning to consult with Whakatōhea.

Ayla Jack (DOC) enquired what Upokorehe's objections were.

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| **Report to** | Ōhiwa Harbour Implementation Forum |
| **Date** | 25 September 2023 |
| **Report from** | Professor Kura Paul-Burke, University of Waikato; Joe Burke, MUSA Environmental; Megan Ranapia (PhD student), University of Waikato. |
| **Report title** | Final mussel restoration report for Awhi Mai Awhi Atu, Sustainable Seas, National Science Challenge project, September 2023 |

## 1.0 Summary

This report provides the final update and considerations from the Sustainable Seas National Science Challenge funded Awhi Mai Awhi Atu mussel restoration project carried out in Ōhiwa harbour, July 2019 – June 2023.

## 2.0 Report

**Mussel restoration stations**: The Awhi Mai Awhi Atu project and associated funding from the Sustainable Seas National Science Challenge concluded in June 2023. Currently there are 4 mussel restoration stations in the harbour. The stations have been successful at recruiting mussels and assisting the generation of three new mussel beds on the harbour floor. In 2019 population surveys identified that there was 1 mussel bed remaining in the harbour with an estimated 78,000 mussels. Further population surveys in 2021 identified 3 new mussel beds in close proximity to the restoration stations with an estimated 750,000 mussels on the seafloor. In July 2023, a further 3.5-hectare mussel bed with an estimated 16-million mussels was identified under restoration stations 1 and 2 in the Western side of the harbour. The majority of the mussels are juveniles (baby and teenage sized) and will require protection from human harvesting, to be able to grow to adults, reproduce and help stabilise the new bed.

**Seastar management trials**: In 2022, a feasibility study for removing eleven-armed seastars was carried out in an 8-hectare area on the western side of harbour using three removal methods: 1) diver removal; 2) trapping; and 3) combined diver removal and trapping. It was found that the diver removal method was more effective at catching larger sized eleven-armed seastars with almost 500 seastars removed by 2 divers over a maximum 6-hour diving regime. The trapping method was more effective at catching smaller animals with 30 traps collecting a further 550 eleven-armed seastars and 18,900 cushion stars (*Patiriella regularis*) over an 18-day trapping regime. The trial identified that method 3) combined diver and trapping regime was the more effective method. Removed seastars were 1) taken to local worm farm as feed; and 2) made into a hand cream using seastar collagen (3 seastars make 60 pottles of cream).

**Considerations:**
The mussel stations and combined seastar management trials have been very successful for mussel restoration in Ōhiwa harbour. The mātauranga Māori-led mussel project leads the country in mussel restoration.

If ongoing mussel restoration action was to continue in the harbour, the following considerations are required:

1. Maintenance and equipment for restoration stations to assist mussel recruitment.
2. Protection for the new 16-million strong mussel bed to allow the bed to stabilise.
3. Bi-annual mussel population surveys to identify mussel and seastar abundance on the seafloor.
4. Annual seastar management removal to assist mussel retention on the seafloor.
5. Funding.

## 3.0 Recommendation

**That the Ōhiwa Harbour Implementation Forum under its delegated authority:**

1. Receives the report, Final mussel restoration report for Awhi Mai Awhi Atu, Sustainable Seas, National Science Challenge project, September 2023.

2. Supports the considerations identified in this report consistent with the Action Area priorities of the Ōhiwa Harbour Strategy, Refreshed 2014.

Report prepared by:
**Professor Kura Paul-Burke**
University of Waikato

# Appendix D

**Table D1: Full list of engagements, presentations, wānanga and other informal engagements from wider project Awhi Mai Awhi Atu (AMAA) and my PhD research between 2019 and 2023.**

| Date | Description/ Purpose | With | By | Location | Conduct/ engagement type | Outcomes related to my research |
|---|---|---|---|---|---|---|
| 10/11/2019 | To meet Te Ūpokorehe iwi members at their hui-a-iwi, under the guidance of Kura Paul-Burke. | Te Ūpokorehe iwi members | Kura Paul-Burke, Joe Bruke, Megan Ranapia | Te Maromahue Marae, Kutarere | Face-to-face presentation/ hui | First time meeting Te Ūpokorehe iwi members, become a familiar face. |
| 22/06/2020 | To introduce myself and my research background, under the guidance of Kura Paul-Burke. | OHIF, Te rōpū kairangahau | Kura Paul-Burke, Joe Burke, Megan Ranapia | BOPRC Whakatāne | Face-to-face hui | Meet members of OHIF, become a familiar face. |
| August-September 2020 | Ōhiwa Harbour updates - lead by Kura Paul-Burke (chief supervisor) | Te rōpū kairangahau, Te Ūpokorehe iwi members | Kura Paul-Burke, Joe Burke, Megan Ranapia, Richard Bulmer, Gemini Stewart | Email, phone calls, Kutarere Marae | Email, phone calls, face-to-face hui | Discussion around research priorities regarding mussel restoration and starfish. Shifted focus of PhD research from mussels to starfish. |
| 27/10/2020 | Starfish discussion with te rōpū kairangahau - iwi advisory group | Te rōpū kairangahau | Kura Paul-Burke, Joe Burke. | Whakatāne & Kutarere | Face-to-face hui, phone calls | Confirming PhD research focus on starfish. |
| October-February 2020 | Discussed what science could be applied to assist in understanding starfish | STAG | Megan Ranapia | Online | Zoom, face-to face hui | ID first step: to assess current state of starfish abundance and ID signs of recruitment. |

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| | infestation and/or management. Literature review and proposal write up. | | | | | |
| 11/03/2021 | Ōhiwa Harbour Implementation Forum (OHIF) presentation by Kura Paul-Burke. Seek endorsement and feedback for PhD research to focus on starfish. | OHIF, DOC | Kura Paul-Burke, Megan Ranapia, Kiri Reihana | Kutarere Marae | Face-to-face hui | OHIF supported PhD research to focus on starfish outbreak to assist with management decisions. |
| 14/04/2021 | Awhi Mai Awhi Atu mid-way review led by Kura Paul-Burke. She provided research updates and sought approval for next stages of research, including subtidal monitoring of mussels and starfish. | Te rōpū kairangahau, Te Ūpokorehe iwi reps. Linda Faulkner & Beth Tupara-Katene (SSNSC theme leaders) | Kura Paul-Burke, Richard Bulmer, Joe Burke, Megan Ranapia, Kiri Reihana | Ōhiwa Harbour | Face-to-face hui, hikoi | Full approval for subtidal surveys. |
| April-May 2021 | Carried out mussel and starfish subtidal field surveys. | | Megan Ranapia, Joe Burke, Kura Paul-Burke, Cameron Lowe | Ōhiwa Harbour | N/A | Recorded mussel and starfish abundance and size classes within known mussel bed locations. |
| 23/07/2021 | Disseminate findings from population surveys and seek feedback on research that would be of value for a starfish management plan. | Tim Senior (Ōhiwa Harbour Manager), Josie Crawshaw, Gina Mohi (scientists from BOPRC) | Megan Ranapia, Kura Paul-Burke | Zoom | Zoom | Interested in starfish removals and ways in which bylaws could allow whānau to legally remove starfish themselves. Potential long-term plan. |
| 4/08/2021 | Focus of the wananga was to co-develop starfish management techniques and seek approval for in-water | Te rōpū kairangahau | Megan Ranapia, Kura Paul-Burke, Joe Burke (STAG members) | Te Rūnanga o Ngāti Awa, Whakatāne | Wānanga | Full support in a starfish removal feasibility study. Discussed potential methods and an interest in starfish |

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| | trials to be undertaken in November 2021. Disseminated findings from population subtidal surveys. | | | | | trapping designs, including natural materials. |
| 2/09/2021 | Workshop to assist in the study design of the starfish removal field work. | STAG | Megan Ranapia | Zoom | Zoom | Discussed methods for trapping study and experimental starfish removal study. |
| 7-9/10/2021 | Trialled different starfish trapping methods. | | Joe Burke, Kura Paul-Burke, Te Āmai Paul-Burke, Natalie Prinz Megan Ranapia | Ōhiwa Harbour | Field work | Identified most appropriate trapping methodology |
| 25-26/10/2021 | Carried out field surveys in potential experimental site to work out background starfish density and ensure site suitability for starfish removal study. | | Megan Ranapia | Ōhiwa Harbour | Field work | Located suitable experimental site and recorded background density of the eleven-armed starfish. |
| 15/04/2022 | Co-develop natural resource starfish traps with tohunga raranga, Rokahurihia Ngarimu-Cameron | Rokahurihia Ngarimu-Cameron (weaving expert), Kerry Cameron | Megan Ranapia, Gemini Stewart, Joe Burke, Kura Paul-Burke | Hāwai | Wānanga | Developed a natural-resource trap applying traditional materials and weaving techniques that I can replicate. |
| 22/04/2022 | Update field work including starfish trapping trials and seek feedback and endorsement for next stage of field work | Te rōpū kairangahau | Kura Paul-Burke, Joe Burke, Megan Ranapia | Te Rūnanga o Ngāti Awa, Whakatāne | Face-to-face hui | Full support of for next stage of field work. |

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| 26/04/2022 | Presented findings from starfish trapping trials and seek endorsement for the next stage of field work. | OHIF, BOP Regional Council scientists, Ōhiwa harbour catchment manager + interested iwi members | Kura Paul-Burke, Joe Burke, Megan Ranapia | Te Rūnanga o Ngāti Awa, Whakatāne | Face-to-face hui | Full support of for next stage of field work. |
| 10/05/2022 | Starfish fieldwork meeting discussed final study design methods. | STAG | Megan Ranapia | Online | Zoom hui | Finalised methods |
| 25-26/05/2022 | Natural resource starfish trap making wānanga | Kia Maia Ellis, Kiri Reihana, Natalie Prinz | Megan Ranapia | Maketū | Face-to-face workshop | Produced three natural resource starfish traps with tauira. |
| October-November 2022 | Carried out field work for starfish removal study. | | Megan Ranapia, Joe Burke, Greg Rackham | Ōhiwa Harbour | Field | Collected empirical data to help inform SMAP. |
| 09/03/2023 | Discussed starfish field trials and draft management plan, seek feedback and endorsement. | Te rōpū kairangahau | Megan Ranapia, Joe Burke, Kura Paul-Burke | Online | Zoom hui | Full approval of SMAP, feedback included costings associated to different management options |
| 14/03/2023 | OHIF bi-annual meeting. Presented starfish field trials and draft management plan, seek feedback and endorsement | OHIF | Megan Ranapia, Joe Burke, Kura Paul-Burke, Matt Miller, Matthew Cummings | Online | Zoom hui | Full approval of SMAP, feedback included costings associated to different management options |

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| 11/07/2023 | Presented SMAP and costings associated to different management strategies to OHSCG bi-annual meeting. | OHSCG | Megan Ranapia, Joe Burke, Kura Paul-Burke | Te Rūnanga o Ngāti Awa, Whakatāne | face-to-face hui | OHSCG decided on a four-year management option that was inclusive of maintaining mussel restoration lines, annual starfish removals using combined method, and conduct biannual population surveys. |

OHIF= Ōhiwa Harbour Implementation Forum, OHSCG= Ōhiwa Harbour Strategy Coordination Group, BOPRC=Bay of Plenty Regional Council, DOC= Department of Conservation, STAG= science and technical advisory group

# Appendix E

## Starfish and mussel 2021 population survey methods

*Coscinasterias muricata* and *Perna canaliculus* population surveys were carried out simultaneously at four sites in Ōhiwa Harbour in April 2021 (Fig. E1). The survey sites were identified based on mātauranga-ā-iwi from initial discussions with the rōpū kairangahau and then later surveyed to mark boundaries of existing and newly established mussel beds (Paul-Burke et al., 2022a). *C. muricata* surveys were carried out within the mussel bed boundaries because starfish species are highly associated with their prey species (Penny & Griffiths, 1984; Gaymer et al., 2001; Aguera et al., 2012). Within each survey site, 10-15 sampling locations were plotted using 'random point selection' in *ArcGIS Pro 2.9.1* and GPS co-ordinates were entered into an onboard Garmin chart plotter for underwater surveys.

At each sampling location, SCUBA divers recorded starfish abundance by placing a 1m$^2$ quadrat haphazardly on the seafloor four times and logged starfish numbers and sizes. Following starfish counts, mussel numbers and sizes were recorded in a 0.25m$^2$ quadrat that sat within the 1 m$^2$ quadrat. Mussels were sized by measuring the widest part of the mussel shell from the dorsal to the ventral surface and categorized in the following size classes; SC 1 <10mm; SC 2 10-20 mm; SC 3 21-30 mm; SC 4 31-40 mm; and SC 5 >40 mm.

The 'starting points' for each swim count was randomly selected using the 'random point selection' in ArcGIS Pro 2.9.1. The diver began the five-minute swim count at each 'starting point' and swam parallel to shore. The dive always began upstream of the prevailing tidal current to ensure the diver could cover as much ground as possible. The diver counted *C. muricata* one meter either side, giving a total bandwidth of two meters and the end point was marked with a float line to estimate total distance travelled by divers. Starfish density for each transect was quantified by multiplying the starfish count with the bandwidth and total distance travelled.

**Figure E1: Map of new mussel beds boundaries (pink) and remaining traditional mussel bed boundary (green) surveyed in 2021, Ōhiwa Harbour, Aotearoa New Zealand.**

Each survey site area was calculated by entering boundary co-ordinates into *ArcGIS Pro 2.9.1* to form a polygon, the area of each polygon was then calculated using the 'Calculate Geometry' tool (site K1 3 ha; site K2 1.55 ha; site K3 0.55 ha; and site K4 1.51 ha). Starfish and mussel abundance for each survey site was then estimated from the data collected from the underwater surveys and the area ($m^2$) of each survey site. This was achieved by multiplying average starfish density (individuals $m^{-2}$) with total area of survey site. The number of mussels were converted to a density of 1 $m^{-2}$ and then multiplied by total area of survey site as well.

# Appendix F

## News item on new mussel bed in Ōhiwa Harbour

# Rāhui to help rejuvenate mussels in Ōhiwa

NGĀTI Awa kaitiaki have placed a rāhui on the taking of green lipped mussels from an area of Ōhiwa Harbour near the Port Ōhope boat ramp in a bid to help regenerate a newly restored mussel bed.

Mac Kingi and Charlie Bluett performed a karakia at Te Tuarae o Kanawa near the Port Ōhope Boat Ramp on Monday to enact the rāhui.

Signs have been installed to inform people about the ban on taking mussels from the area.

Mr Bluett, who is also Te Rūnanga o Ngāti Awa customary fisheries officer, said the rāhui was in place to help the juvenile mussels to reach maturity.

"You can see the lines out by the buoys just off from the very end of Harbour Road.

"The mussels have been rejuvenated from an old traditional bed.

"There is one at that point, one closer to the mouth of harbour and another slightly further around on the other side."

Mr Bluett said the rāhui was part of a much bigger picture – an award-winning research project led by

■ Continued: Page 3

# Rāhui to help rejuvenate mussels in harbour

■ Continued from Page 1

Ngāti Awa uri, Professor Kura Paul-Burke from the University of Waikato.

The project was launched in 2019 by the Sustainable Seas National Science Challenge, with a focus to bring together mātauranga Māori and marine science to investigate pragmatic shellfish restoration action as it applies to the unique social, cultural and ecological context of Ōhiwa Harbour.

It was co-developed with hapū and iwi of Ōhiwa Harbour, including Ngāti Awa, and supported by Bay of Plenty Regional Council and the seven partners of the co-management group, Ōhiwa Harbour Implementation Forum.

Prof Paul-Burke said: "If we can provide a little time for the new mussel population to grow to adults, we may be fortunate enough for our collective grandchildren to have a naturally regenerating food basket for their children into the future.

"It is our hope that the temporary closure will help us achieve that."

Rūnanga chief executive Reuben Araroa said implementation of the cultural rāhui represented Ngāti Awa's unwavering commitment as kaitiaki to safeguarding the ecological balance of the marine environment whilst preserving the intergenerational benefits of a healthy marine harbour for the whole community.

"We thank all members of our community for respecting the prohibition and look forward to sharing the success of the rāhui in the near future."