Ngā tohu o te taiao: Observing signs of the natural world to identify seastar over-abundance as a detriment to shellfish survival in Ōhiwa Harbour, Aotearoa/New Zealand

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Abstract

Māori understandings and experiences of the natural world encompass not only what is known but how it is known, and the intergenerational connectedness of that knowledge with the environments from which it is derived. Ngā tohu o te taiao (hereafter 'tohu'), or the cultural and environmental signs and indicators of the natural world, are widely used by kaitiaki or local practitioners to identify trends or changes in the state or health of marine taonga (culturally important) species and their associated environments (Paul-Burke, 2017). Māori worldviews position humans *within* nature and focus on ways in which cultural understandings and intergenerational connections between people and their bio-physical contexts assist in the retention and protection of biodiversity and ecologically sustainable ecosystems (Lyver et al., 2016). Tohu are a fundamental expression of kaitiakitanga or active guardianship and are based on the primal instinct of survival and recognising that in order to survive one must pay attention to the natural signs and signals thoughtfully, so as to manage our mahinga kai (food harvesting area) and ourselves into the future (Paul-Burke et al., 2020). This article considers the example of the over-abundant eleven-armed seastar (pātangaroa, *Coscinasterias muricata*; hereafter 'seastar') predating on culturally and ecologically important shellfish populations in a traditional mahinga kai of Ōhiwa Harbour in the Bay of Plenty region of Aotearoa/New Zealand. The over-abundance of seastars was considered a contemporary tohu of a degrading harbour. It was deemed imperative by iwi (tribe) members that a trial using quantitative methods to investigate predation pressure of seastars on the green-lipped mussel (kuku or kūtai, *Perna canaliculus*) population be conducted in the harbour. Between September 2018 and February 2019 field trials were undertaken that prioritised mātauranga Māori (Māori knowledge) alongside marine science to assist with a better understanding of the degrading harbour. It was hoped that the research would help and promote recovery, in particular but not limited to, the once abundant but now severely reduced mussel reefs in the soft-mud-bottomed harbour.

Keywords Tohu; Mātauranga Māori; Shellfish; Restoration; Seastars

Introduction

> The world is a vast family, and humans are children of the earth and sky, and cousins to all living things. Such unity means that nature is the ultimate teacher about life. (Royal, 2010, p. 9)

Māori, like many global Indigenous societies, developed formal or ritualised processes to better understand and regulate our relationships with the natural world. Resource management practices and techniques were developed from the necessity to create patterns of use that ensured the ongoing survival of humans and the sustainable management of local resources (Stephenson, 2001).

A Māori worldview sees that all living things are connected. This includes land, animals, plants, mountains, sea, sky, forest, where all are deemed as important as the other and with a spiritual essence that reflects a symbiotic relationship with the living and non-living worlds. This approach to human existence was nested in mauri (life-force) and the prevailing belief that all parts of the natural world are genealogically related. Flowing from this deep familial interrelation comes a duty of respect which demands that the world is cared for in a reciprocal cycle of tapu (sacredness), noa (unsacred), survival and kinship ties (Jefferies & Kennedy, 2009; Mead, 2003).

However, Māori knowledge systems have suffered forced cultural erosion over the past 200 years (Lyver & Davis, 2008; Reid et al., 2013; Smith, 2008; Stephenson, 2014). There has been a breakdown in transmission of mātauranga Māori (Māori knowledge) because of cultural assimilation with European culture (Durie, 2008; Reid et al., 2013; Walker, 1990). This was accelerated by the forced separation of Māori from natural resources through government land confiscation and harvest prohibitions (Lyver & Davis, 2008). The World Wildlife Fund (2014) warns that traditional knowledge of Indigenous cultures is being forgotten. This includes knowledge related to the uses of natural species such as medicinal plants and fishing methods, as well as the vast array of spiritual beliefs and practical understandings of the natural world.

A Māori worldview considers the wellbeing of natural resources to be directly related to the wellbeing of the people (Mead, 2003; Royal, 2006). The degradation of the environment, including the exploitation of fisheries, land management practices and pollutants affecting waterways and estuaries, threatens the preservation of Māori cultural practices (Department of Conservation et al., 2005). There is growing evidence that accelerated biodiversity decline has a direct effect on human wellbeing (McCarthy et al., 2013) and the need to retain cultural diversity as a component of ecological diversity is becoming increasingly apparent (Stephenson, 2008). This is “no more prevalent than within the cultural inter-generational knowledge exchange of traditional ecological understandings, practices and protection of biologically diverse ecosystems for present and future generations” (Brake & Peart, 2013, p. 141). Cultural diversity is related to biodiversity, and both are important for improving the life sustainability of the world’s ecological systems (Berkes & Folke, 1995).

Ngā tohu o te taiao—Signs of the natural world

Mātauranga Māori experiences of the natural world encompass not only what is known but how it is known (Paul-Burke et al., 2018) and the intergenerational connectedness of that knowledge with the environments from which it is derived (Jackson et al., 2017; Mercier, 2019). Ngā tohu o te taiao (hereafter ‘tohu’), or the cultural and environmental signs and indicators of the natural world, can highlight if ecological systems are getting better or worse and recognise ecological tipping points.

If a natural resource is under strain or its environment is potentially unhealthy, the resource will present a mauri that lacks in vitality. An example includes a series of interviews conducted with kaumātua (elders) from Ngāti

Awa, an iwi (tribe) centred in the Bay of Plenty region of Aotearoa/New Zealand, in 1987 regarding their recollection of customary fishing experiences and observations. At the time, it was noted:

> In the mouth of the Whakatāne river white pipi (*Paphies australis*) were plentiful and provided the local supply of pipi to the people of Ngāti Awa. The pipi had a white shell with no mud marks disfiguring them and was considered a regular source of food that was never diminished, prior to the establishment and consequent discharge of effluent from the Board Mills further up the river.
>
> First signs of the pipi mauri declining were the discolouration of the shells and the rapidly diminishing numbers. The pipi were then considered too polluted for safe consumption and were deemed tapu or unhealthy to eat. (Paul-Burke et al., 2010, p.14)

Māori carefully scrutinised the natural world; they took special note of seasons, maramataka (lunar phases) and habitual cycles, including harvesting patterns (Paul-Burke et al., 2020). Maramataka can be understood as a Māori lunar calendar that identifies different phases of the moon (Roberts et al., 2003; Tawhai, 2014). Each moon phase signals environmental and ecological indicators, or tohu, in conjunction with the celestial movements of the sun, stars and moon (Clarke & Harris, 2017). Many Māori use these indicators to identify the most productive times for procuring and tending to food resources. It is understood that each hapū (sub-tribe) and iwi have their own localised understandings of the maramataka relative to their environmental contexts, experiences, observations and understandings of species interactions and patterns of use (Paul-Burke et al., 2020). The concepts work in synchronicity, informing and guiding humans to mana-a-kī (manaaki; to view or imbue something or someone with mana [prestige]) to ensure the wise use and respectful care of the natural world and its many resources.

The acts of observation and information gathering were integral to the range of established sustainable management practices that governed the harvesting and use of natural resources to ensure the sustainable longevity of the species and mahinga kai into the future. Intergenerational observations and ecological understandings of species' interactions and patterns of use have been accumulated and are grounded in the existence of Māori, which are intimately bound to residing in one place for many generations (Cheung, 2008). Attention was given to recognising, interpreting and responding to tohu and the cumulative effects, causes and events associated with the natural world (Paul-Burke et al., 2020). In time, this information became common knowledge and was conveyed from one generation to the next.

Using tohu

Tohu are still widely used today to forecast changes in the environment (King et al., 2006). Different activities conducted in different natural environments acquired different types of indicators. It was important to recognise that tohu changed in unison with the dynamic landscape and make-up of ecosystems. For example, observations relating to the presence of a species or the changes in the distribution of species were easily interpreted by hapū (Lyver et al., 2016).

In freshwater environs, Tipa and Tierney (2006, p. 10) note that tohu can be identified as:

> factors that kaumātua and resource managers believe are conducive to a healthy river and a strong and vibrant mauri. It is understood that a waterbody with a healthy mauri will sustain healthy ecosystems, support cultural uses (including mahinga kai) and be a source of pride and identity to the people.

The long-finned *tuna* (eel, *Anguilla dieffenbachii*) is recognised by many Māori as a kaitiaki tohu (guardian species indicator). It was understood that the health of the *tuna* was an indicator of the health of the ecosystem in which they live. For example, the long-finned *tuna* is susceptible to pollution. If the lips of *tuna* became completely covered with fungal growth, it was a tohu, or sign, that the waterways were suffering from poor water quality (Figure 1). The health of the tuna was likened to the health of the awa (river) (Paul-Burke, 2016; Potangaroa, 2010).

In terrestrial or forest environments, food procurement indicators included direct observations of the abundance of particular species (e.g., bird abundance, flock size) or signs left by the species (e.g., browse damage, tracks, faecal pellets). The identification and interpretation of tohu were typically informed by multiple trips or hunting expeditions. A number of indicators were also used to represent the abundance and potency of resources for uses other than food, such as fronds of the mauku (hen and chicken fern, *Asplenium bulbiferum*), which were used to make clothing and rongoā (medicine) (Lyver et al., 2016).

In marine environments, whai (stingray, *Dasyatis thetidis*) and whai-repo (eagle ray, *Myliobatis tenuicaudatus*) (Figure 1) are considered kaitiaki tohu of a system that is recovering or recovered. If a system is out of balance then the whai and whai-repo will leave the area. Their reappearance is considered a tohu that an ecological system is improving. Whai and whai-repo are also considered a symbol of protection and seabed health (Paul-Burke, 2019; Tawhai, 2014). Many coastal hapū and iwi have stories of whai and whai-repo helping to protect the areas where shellfish are harvested. It is understood that if people do not follow the right tikanga (traditional practice of only harvesting what you need) and try to take too many shellfish, the whai and/or whai-repo will present themselves in different ways such as, swimming very close to divers, swooping the water as they pass, or positioning themselves next to the reef rock to remind people to leave enough shellfish for another day.

Figure 1. Top L: Eagle ray kaitiaki at Motunau (Plate Is.) (Image: Paul-Burke, 2014); Top R: Eel with fungal lip infection (Image: Alton Perrie, 2010); Bottom L: Harvesting kina at Whakaari (White Is.) (Image: Burke, 2014); Bottom R: Pōhutukawa tree in bloom (Simpson, 2015).

Many practices used by Māori serve to manage species diversity, retain quality habitat and manage intensity of use, thereby enhancing the diversity of biological resources available (Berkes et al., 1995; Reid et al., 2013). An example includes the harvesting of kina (*Evechinus chloroticus*, sea urchin) in conjunction with the flowering of the pōhutukawa (*Metrosideros excelsa*) (Figure 1). For generations, coastal Māori have used the whakataukī (proverb) of the flowering Pōhutukawa in summer as a tohu that signals the ripening of the kina and its readiness for harvesting (Department of Conservation et al., 2005). The intergenerational transmission of knowledge and associated practices have assisted self-regulating harvesting and management regimes for the mahinga kai (food harvesting area) (Paul-Burke et al., 2020).

The ability of a society to comprehend and respond to changes in the environment relies on a robust system of understanding ecosystem structure and processes, and the inter-relationships between the physical, biological, cultural and ecological components of a place and its species. A Māori worldview is shaped by a relational and conscious connection of humans with and within the natural world. This worldview is central to the ways in which humans experience and make sense of the world and our place within it. A biological-cultural (bio-cultural) perspective positions humans within nature and focuses on ways in which cultural understandings and intergenerational connections between people and their ecological context assist in the retention and protection of biodiversity and ecologically sustainable ecosystems. This includes the role of ira tangata (humans) in recognising, interpreting and responding to the signs of the natural world to ensure the survival of present and future generations. It is the direct connection of humans with taonga (culturally important) species that assists that relationship.

Taonga species

The Waitangi Tribunal (2014) explains that taonga include particular iconic sites such as mountains, rivers, resources or species. Whether a species or a place is a taonga is a matter that can be tested by establishing the nature of the relationship that Māori have with a species or place.

A taonga species can be identified as one that has been gathered by Māori for generations or one that holds significant cultural, spiritual, ecological and historical value for the people of a region. The intergenerational transmission of cultural and ecological knowledge regarding activities associated with harvesting, preparing and protecting species and spaces as important sustainable resources is extremely important to Māori (Paul-Burke, 2015). For example, these understandings are supported by Te Ūpokorehe Iwi Management Plan (Johnson, 2012) and Ngāti Awa customary fisherperson. O'Brien (2010). Both discuss the significance of taonga species and traditional places in association with customary fishing practices of Māori:

> For generations the hapū have managed, maintained and preserved the (Ōhiwa) Harbour and all its precious taonga, for it is the lifeline and identity of the local native people.... [F]or generations it has been passed on and understood that it is of the utmost importance we preserve this significant taonga. (Johnson, 2012, p. 6)

> Fisheries are a traditional source of economic and cultural wealth for iwi and hapū. Being able to provide fish or shellfish to feed whānau (family) or manuhiri (visitors) has always been part of the cultural heritage of tangata whenua. (O'Brien, 2010, p. 1)

For many Māori it has become increasingly essential to retain knowledge of traditional harvesting practices and customs because taonga species are much more than just food. They are an important component of tribal prestige, responsibility and honour (Te Rūnanga ō Ngāti Awa, 2019). Taonga species are considered central to a sense of belonging and cultural identity (Paul-Burke, 2017). There are three main types of taonga: spiritual, psychological, and biological (Royal, 2003). The three categories are inter-related and are pertinent to understanding Māori principles of and for the natural world:

- Wairuatanga is concerned with mana (prestige, personal power), tapu (sacredness) noa (common or not sacred). The importance of mana within Māori society is paramount. It embraces virtues such as honour, and prestige but also represents authority and control. (Kearney et al., 2013)

- Psychological taonga relates to the quest for security, a sense of belonging, of place, whakapapa (genealogy), identify, self-esteem, and dignity. Whakapapa denotes a worldview of a vast and complex family, where everything—humans and non-humans—is related. The traditional principle of whanaungatanga (relationships) denotes pertinent understandings of the natural world that are important and meaningful to Māori. (Royal, 2010)

- Biological taonga pertain to a conscious ethic of and for the environment, survival, resilience, connectivity, and mauri, which can be translated to encompass the life-force-sustaining capacity of environment and society. (Reid et al., 2013)

An example of a taonga species is the includes the green-lipped mussel (kuku or kūtai, *Perna canaliculus*; hereafter 'mussel') beds in Ōhiwa Harbour in the Eastern Bay of Plenty. Mussels are considered taonga as the knowledge and customs pertaining to traditional harvesting practices are still present and relevant today. Examples include when to harvest, how to harvest, preparation for storage, environmental signs and conditions; and information pertaining to life cycle, distribution, predator-prey relationships, habitat variability, and traditional management practices (Paul-Burke, 2015). Mussels are further considered an indicator species or tohu as their continued abundance and presence in a soft bottom estuary or harbour is recognised as a sign of a balanced marine system.

Ōhiwa Harbour

Ōhiwa Harbour (Figure 2) is regarded as one of the most natural harbours in Aotearoa/New Zealand with high conservation and outstanding wildlife values

Figure 2. Ōhiwa Harbour (Image: Peter James Quinn, 1995).

(Bay of Plenty Regional Council [BOPRC], 2014). With its geographical location, geological history and range of important ecological habitats and cultural sites of significance, Ōhiwa Harbour is recognised as having outstanding natural features and landscape values. It is considered locally, regionally and nationally as an area of significant ecological and cultural importance (BOPRC, 2013).

Positioned within the ancestral homelands of Ngāti Awa, Te Ūpokorehe, Te Whakatōhea and Tūhoe (Waimana Kaakū), Ōhiwa is steeped in the significant history of Māori who have lived and harvested from the harbour and its environs for centuries. For Māori, the harbour is an important mahinga kai for shellfish and seafood (Morrison, 2007). It is widely understood that Māori knowledge of the abundant food resources of Ōhiwa has endured for many consecutive generations (BOPRC, 2008).

Unfortunately, over the years increased harvesting pressures, eleven-armed seastar (pātangaroa, *Coscinasterias muricata*; hereafter 'seastar') predation, sedimentation, and other changing environmental conditions have taken its toll on the harbour's shellfish (BOPRC, 2014; MacKenzie, 2013). In particular, the mussels have struggled to maintain their existence in the once abundant food basket of Ōhiwa.

Mussels are an important intergenerational source of mātauranga Māori and food resources for Māori. Mussels occur in dense beds, creating large reefs on soft-bottom environments. The beds increase diversity by providing habitat for a number of species, including fish, and food availability for predators such as the seastar. As filter feeders, mussels help improve water clarity and quality by removing detritus from the water column. They reduce sediment resuspension by reproducing bio deposits and improving light availability (McLeod et al., 2011). Mussel reefs also help control nitrogen from land-derived sources by promoting denitrification (MacKenzie, 2013). They are an important socio-cultural-ecological species and are considered a significant marine taonga for Māori.

However, in recent decades there has been increasing concern about the state of the mussels in the harbour. For hapū/iwi, the practice of kaitiakitanga (active guardianship) and the need to actively combine and implement mātauranga Māori with marine science to better understand a degrading harbour and assist recovery of shellfish/mussels have become a priority (Paul-Burke et al., 2018). This priority has resulted in strong support from surrounding hapū/iwi, communities and government agencies for promoting shellfish as the number-one management action in the refreshed Ōhiwa Harbour Strategy 2014 (BOPRC, 2014).

Research undertaken in Ōhiwa Harbour by Paul-Burke (2007, 2008, 2009) used mātauranga Māori to determine the traditional baseline of mussel population distribution, abundance and sizing in order to assist marine science sub-tidal dive surveys in the western side of Ōhiwa Harbour. A mussel reef nearly 2km in length was observed with an estimated 112 million mussels present; 90% of the population were identified as new recruits. Between 2007 and 2013 the mussel population in the western side declined from 112 million to 2 million (Paul-Burke & Burke, 2014). In 2016, the western side was re-monitored and for the first time the traditional beds on the eastern side were mapped and surveyed by replicating the same mātauranga Māori and marine science sub-tidal dive survey methods conducted in 2007.

Results showed that two of three traditional beds in the eastern side were no longer present and that 99% of the original 2007 mussel bed had disappeared, with only an estimated 485,000 mussels in the harbour (Paul-Burke & Burke, 2018). In 2019, less than 80,000 mussels remained in the harbour. In 2009, 672 tonnes or 1.2 million seastars were observed with mussels in the western side (Paul-Burke, 2014). In 2019, 100,000 seastars were observed in a 2-hectare traditional pipi bed in the harbour (Figure 3).

Figure 3. Top L: Over-abundance of eleven-armed seastars in pipi bed; Bottom L: Green-lipped mussels; Bottom R: Cushion star in Ōhiwa Harbour (Images: Paul-Burke & Burke, 2020).

Seastars are voracious predators of mussels and other shellfish (Paine, 1966, 1976; Paul-Burke & Burke, 2015; Wilcox, 2017) and are thought to be the main cause of decline in mussels, pipi and cockles in the harbour (Paul-Burke et al., 2016; Wilcox & Jeffs, 2019).

Recognising, interpreting and responding to contemporary tohu

The over-abundance of seastars was considered a contemporary tohu of a degrading harbour. It was deemed imperative by iwi members that a trial using quantitative methods to investigate the predation pressure of seastars on the mussel population be undertaken in the harbour. Using mātauranga

Māori alongside marine science, the trial aimed to provide better understanding of the degrading harbour and promote recovery, in particular but not limited to, the once abundant but now severely reduced mussel reefs in the soft-bottomed harbour. In order to better understand the degradation in the harbour and inform its restoration, answers to the following questions were sought:

1. Can we relocate mussels from mooring chains and floats onto the harbour floor?
2. Will the mussels reattach, feed and recruit (reproduce)?
3. Can cages provide respite from seastar predation on the mussels?
4. Can we use mātauranga Māori to identify and establish restoration stations?

Methods

In September 2018, four restoration stations were established in the harbour (Figure 4). The sites were identified using intergenerational knowledge of traditional mussel distribution held by kaumātua. Stations 1 and 2 were identified by kaumātua from Te Rūnanga ō Ngāti Awa, stations 3 and 4 were identified by kaumātua from Te Ūpokorehe. In October 2018, at each of the 4 sites, 3 cages and 1 control were deployed. A 1m² quadrat or flat square open to the environment was placed on the harbour floor and used as the control site. The cages deployed at each site included 1 natural cage made out of piritā (*Ripogonum scandens* or supple jack), hereafter 'natural cage'; 1 steel re-barb frame cages with 25mm wire mesh, hereafter 'metal cage'; and 1 re-barb steel frame cage with 17mm plastic mesh, hereafter 'plastic cage' (Figure 4).

Figure 4. Top L: Restoration station locations in Ōhiwa Harbour as identified by kaumātua; Top R: Float markers of restoration stations and sites for mussel and seastar predation exclusion cages trial; Bottom L: Plastic and steel re-barb frame cage with plastic 17mm mesh cage on left and a metal cage with 25mm steel wire mesh cage on right; Bottom R: Natural cage made out of Māori traditional materials with chain to help sink (Images: Paul-Burke, 2018).

The cages were placed on the harbour floor and secured with steel pins and/or chain. All of the cages were then attached by line to a 250kg anchor train wheel securing each of the red master floats located at the surface. This was a safety precaution due to strong and dynamic currents in the harbour.

At the trial sites all cages were 1m × 0.5m in height, excepting for station 2 which had 1m × 1m cages with no tops. Station 1 had a cage with a top but no bottom to allow mussels to attach to the substrate. Station 3 cages were fully enclosed and station 4 cages had no bottom. The natural cages were approximately 1m × 1m.

Figure 5. L–R: Kaumātua from Te Ūpokorehe counting and measuring mussels prior to them being relocated into the cages and/or control; Ngāti Awa taiohi (youth) identifying and measuring seastars; Ngāti Awa PhD marine science student monitoring mussel restoration stations in the harbour (Images: Paul-Burke, 2019).

In September 2018, mooring lines from anchored boats within the harbour were checked for live mussels attached. Mooring lines which had exceeded their use-by date and had live mussels already growing on them were then relocated and hung from surface floats at the restoration stations. Sixty mussels were retrieved from the mooring lines and placed into the cages and the control. A total of 240 mussels measuring in size class 2 (20–39mm) across the widest part of the posterior end of the mussel were relocated to each of the restoration stations and were monitored monthly. Seastar and cushion star presence was also monitored. Seastars and cushion stars that had entered the cages were identified, counted and removed from the cage. Seastars and cushion stars that were on the outside of the cages were also identified, counted and removed.

Results

Mussels that were relocated to the harbour floor reattached and were feeding within 24 hours of being relocated. No live mussels remained in the control after 14 days of being relocated to the substrate. It was presumed that they had been eaten due to the presence of fresh empty shells remaining in the control quadrat. At station 1, no live mussels were present after mid-December 2018 (Table 1). At station 2, no live mussels were present after mid-November 2018. At station 3, no live mussels were present after mid-January

2019. At station 4, no live mussels were present after mid-February 2019. As with the control, it was presumed that the mussels had been eaten due to the fresh empty shells left in the cages. The mussels at station 4 survived the longest. Station 4 had the least amount of seastars present throughout the trial.

Table 1. Length of time relocated mussels survived in predator-exclusion cages

	October 2018	November 2018	December 2018	January 2019	February 2019
Control					
Station 1					
Station 2					
Station 3					
Station 4					

All seastars located inside and attached on the outside of the cages were recorded. Across all trial sites, it was found that an average of 5 seastars and 4 cushion stars were observed in or on the metal cages (Figure 6). Plastic cages recorded an average of 9 seastars and 5 cushion stars present either inside or on the outside of the cages. The natural cages recorded an average of 13 seastars and 18 cushion stars either inside the cage or attached to the outside of the cage. Although the live mussels in the control station were no longer present after 14 days, an average of 0.25 seastars and zero cushion stars was recorded in the empty control quadrat.

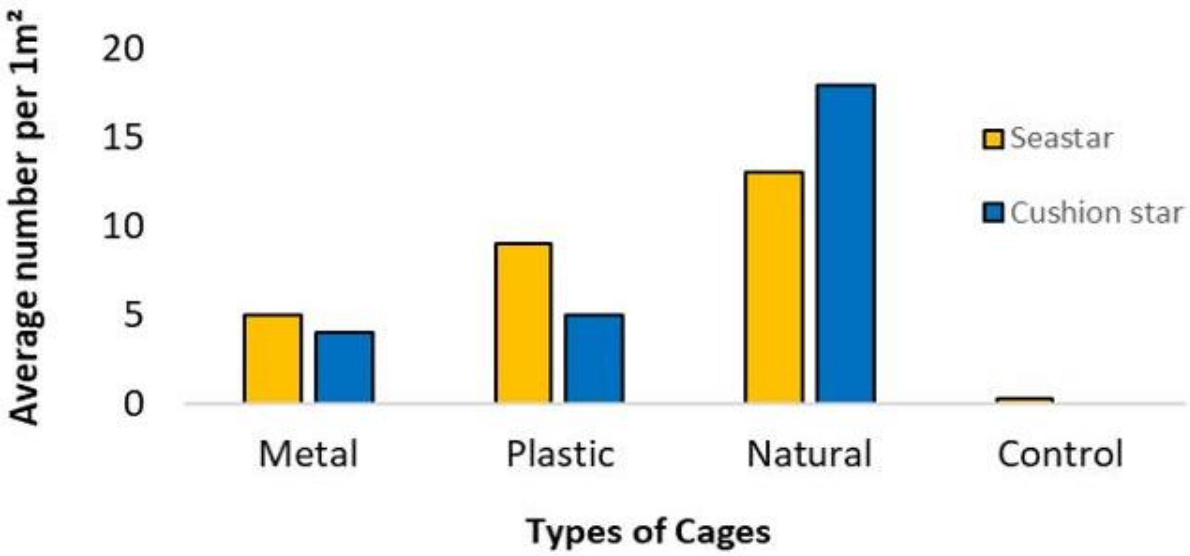

Figure 6. Average number of seastars and cushion stars in or on predator exclusion cages in Ōhiwa Harbour

The natural cage recorded the highest number of seastars (40) and cushion stars (30) inside the cages, with a further 43 cushion stars on the outside of the cages across all restoration stations (Figure 7). The metal cage had the least amount of seastars (13) inside the cages across all sites. The plastic cages had 17 seastars inside and a further 18 on the outside. Overall, the majority of seastars were identified inside the cages with the mussels.

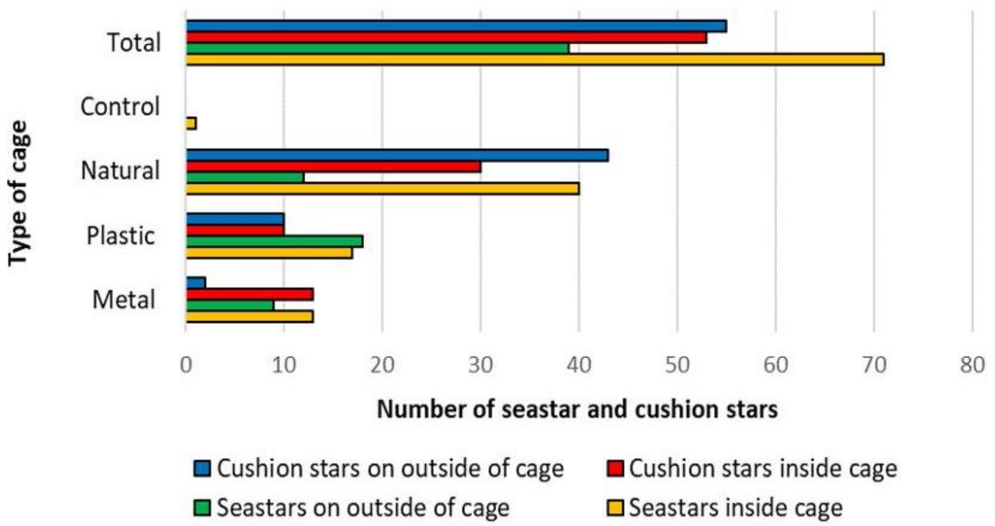

Figure 7. Total number of seastars and cushion stars in or on predator-exclusion cages

The natural cages had wider gaps than both the metal- and plastic-mesh netting of the steel-framed cages. This may account for the larger number of seastars present in the natural cages. However, how large seastars were able to enter through 25mm and 17mm mesh-sized holes is unknown. Sediment build-up in the inside of all of the cages was observed. The cages in station 2 in particular accumulated sediment build-up of over 0.5mm covering the fresh dead shell debris.

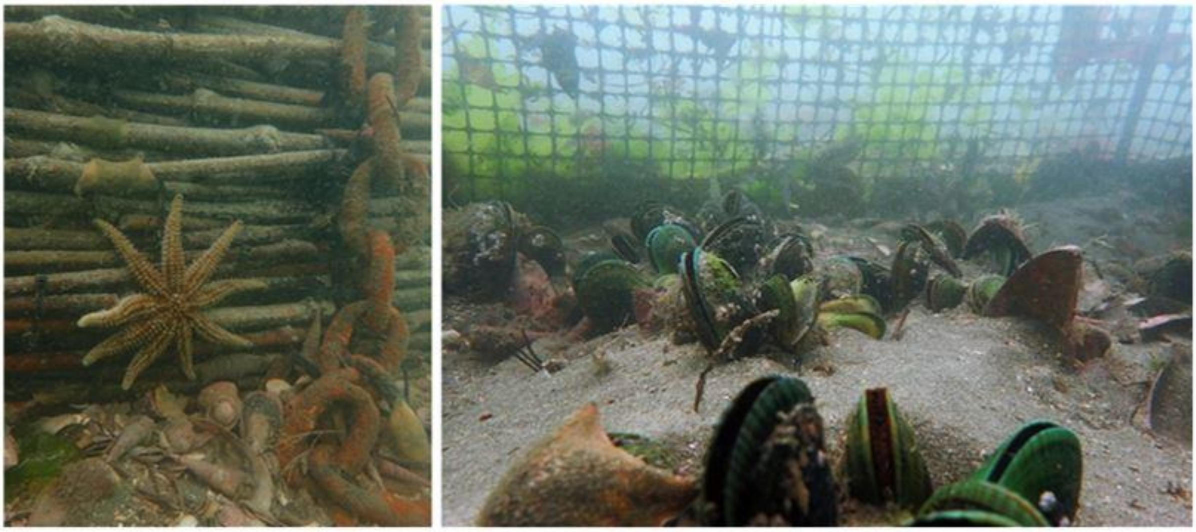

Figure 8. L: Seastar and cushion star on the outside of a natural cage; R: Relocated mussels inside a plastic predator-exclusion cage, attached and feeding on the harbour substrate (Images: Burke 2019).

Discussion and conclusion

All steel frame cages were measured with a 1m² surface area on the harbour floor. The natural cage had a slightly larger surface area due to its shape. An average of 14 seastars and cushion stars combined per 1m² was recorded in or on the metal cages. An average of 15 seastars and cushion stars per 1m² was recorded in/on the plastic cages (Figure 8). Natural cages recorded the highest average, with 31 seastars and cushion stars in/on the cages across all restoration stations. The higher average for the natural cages could be attributed to the cages having wider gaps, which allowed easier access for the seastars and cushion stars to enter.

The predator-exclusion cages were not successful in keeping the seastars from predating on newly relocated and feeding mussels and, as such, would not be considered a viable long-term management option for the harbour. It was observed that even after mussels were no longer present in the cages, seastars and cushion stars were still present in and on the natural cages. However, both the metal and plastic cages and the control no longer appeared to attract seastars once the mussels were gone.

The attraction of seastars and cushion stars to the natural resource cages may be attributed to mauri. For many Māori the vitality of all species is encapsulated with life-sustaining energy. In environmental terms, mauri can be expressed as an overarching characteristic, being the life-force of objects and the environment (Coffin, 2015).

The natural cages were made from freshly harvested untreated wood which emitted a living, earthy scent as opposed to the plastic and steel cages which had a non-living, metallic scent. Seastars are chemoreceptors—that is, they are able to detect the faintest smell or scent of their prey and determine the direction from which it is coming through the water column. The materials used for the natural cages had been freshly harvested and may have emanated a scent or mauri which seastars were attracted to. This is consistent with the work of Kusabs and Quinn (2009), who found that tau koura (freshwater crayfish) were more attracted to bait stations made from traditional natural materials than manufactured traps. This information could be useful in the future, if options to bait seastars were considered as a potential management directive.

Seastar and cushion star predation in the Ōhiwa Harbour is significant. Seastars are important keystone predators in many marine ecosystems (Menge & Sanford, 2003). They have been identified as a species whose feeding activities often control the distribution of associated species within an ecosystem (Lamare et al., 2009). Seastars play a major role in structuring subtidal benthic communities like mussels and other shellfish. The role of seastars in benthic communities depends not just on the abiotic environment and characteristics of the predators themselves, but also on prey characteristics (Menge & Sanford, 2003). Seastar predation is a stressor that has potential to impose a significant limitation on the success of mussel recovery efforts (Wilcox, 2007; Wilcox & Jeffs, 2019).

The research project described in this article highlighted local iwi observations of over-abundant seastars as a contemporary tohu of a declining mussel population in Ōhiwa Harbour. The researchers sought to actively respond to the signs of the harbour with a mātauranga Māori and marine science field trial to assist the restoration of the rapidly declining mussels. In Ōhiwa Harbour, the intergenerational transmission of wild mussel stock assessment over consecutive generations has provided local iwi with an in-depth historical knowledge of ecological changes over time and space (McCarthy et al., 2013). These practices are supported by Sagarin and Pauchard (2012, p. 76), who note:

> [O]ften these nature observations have been made as a routine part of daily life. Traditional and local knowledge holders have spent abundant time in direct connection with nature. Through this connection they are able to observe far more and with far greater context than a scientist might in a limited field season.

Using tohu to co-develop understandings of ecosystem stability, recoverability and resilience across many consecutive generations, including coordinated managerial approaches, is increasingly recognised as an important tool for contemporary marine management and restoration (Forster, 2012; Lyver et al., 2016; Paul-Burke et al., 2018). Tohu are grounded in the base instinct of survival. The ability to recognise, interpret and respond to changing tohu in Ōhiwa Harbour was an important and meaningful strategy for empowering Māori voices and action in the wise use, care and practical management of marine taonga species and spaces, for present and future generations.

The combination of mātauranga Māori and marine science in the research reported here is a tangible example of transdisciplinary research that blurs any clean distinction between the social, cultural and natural sciences. The science undertaken in Ōhiwa Harbour was inseparable from the intimate knowledge of place held by the local iwi, mātauranga derived from long-term inhabitation and rooted in the associated sociocultural-ecological context. Such knowledge is also dependent on the relationships of whakapapa, whereby human interaction with the natural world is one of close familial connection and responsibility, not categorical separation (Barber 2022 *pers comms*). It remains, however, rigorously scientific supported by the connections of people and place over and above pretension to empty universality.

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Acknowledgements

The authors acknowledge the important contributions of participating kaumātua and pūkenga from Ngāti Awa, Te Ūpokorehe; and the Ōhiwa Harbour Implementation Forum made up of elected members from Ngāti Awa, Te Ūpokorehe, Te Whakatōhea, Tūhoe (Waimana Kaakū), Bay of Plenty Regional Council, Ōpotiki District Council and Whakatāne District Council. The authors further acknowledge the immense support from the Sustainable Seas National Science Challenge. This research was co-funded by MUSA Environmental and the Bay of Plenty Regional Council.

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Kerry Cameron (Ngāti Kahungungu, Ngāti Porou) worked with kaumātua to construct the natural cages.

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Te Upokorehe Resource Management Team shellfish restoration in the Eastern side of Ōhiwa Harbour with kaumātua of Te Upokorehe.