WHANGAROA HARBOUR AND CATCHMENT STUDY

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MOANA™
NEW ZEALAND

by:

Katherine Short, Partner,
Terra Moana Ltd

Eva Siwicka, PhD, Paewai Rangahau - Research Fellow, Te Whare Takiura Mātai Pūtaiao Moana - Institute of Marine Science, University of Auckland

Professor Simon Thrush, FRSNZ, Institute of Marine Science, Te Whare Takiura Mātai Pūtaiao Moana & George Mason Centre for the Natural Environment, The University of Auckland

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Executive summary

Whangaroa Harbour (Figure 1) is important to many people and organisations and provides a range of cultural, social, environmental, and economic benefits. The harbour is one of the most important sites for Moana New Zealand's oyster farming operations, contributing approximately 29% of the company's oyster production currently.

The connection between the land and sea is critical for the health of the harbour and most local residents, and Moana New Zealand are concerned that the health of Whangaroa Harbour has deteriorated. Under current resource management approaches, those connections between land and sea are not well managed. Pollutants (sediments, nutrients and bacteria contaminants carried by the rivers and streams) are entering the harbour reducing its health. From a scientific perspective, little current information is available on the broader ecology of the harbour, its productivity, richness or even the range of habitats represented. A big management challenge that Whangaroa Harbour faces is the lack of consistent and long-term data and monitoring of the harbour's health, which would help assess the scale and types of degradation and identify potential remediation opportunities.

Moana New Zealand has undertaken this study to review the current health of the harbour and, based on available knowledge, to characterise the impact of activities in the Whangaroa catchment on the harbour. The report uses the Nature's Contributions to People framework which has developed the earlier ecosystem-services review methodology. Nature's contributions framework is also more aligned to Te Ao Māori, Māori world view of the natural order of the universe. This is the first time that this framework has been applied to the marine environment in New Zealand. This report also shows how the harbour and oyster aquaculture can contribute to the wellbeing of local communities and others who directly use the harbour. We offer this study and report to inform future conversations about how to improve the health of Whangaroa catchment and harbour.

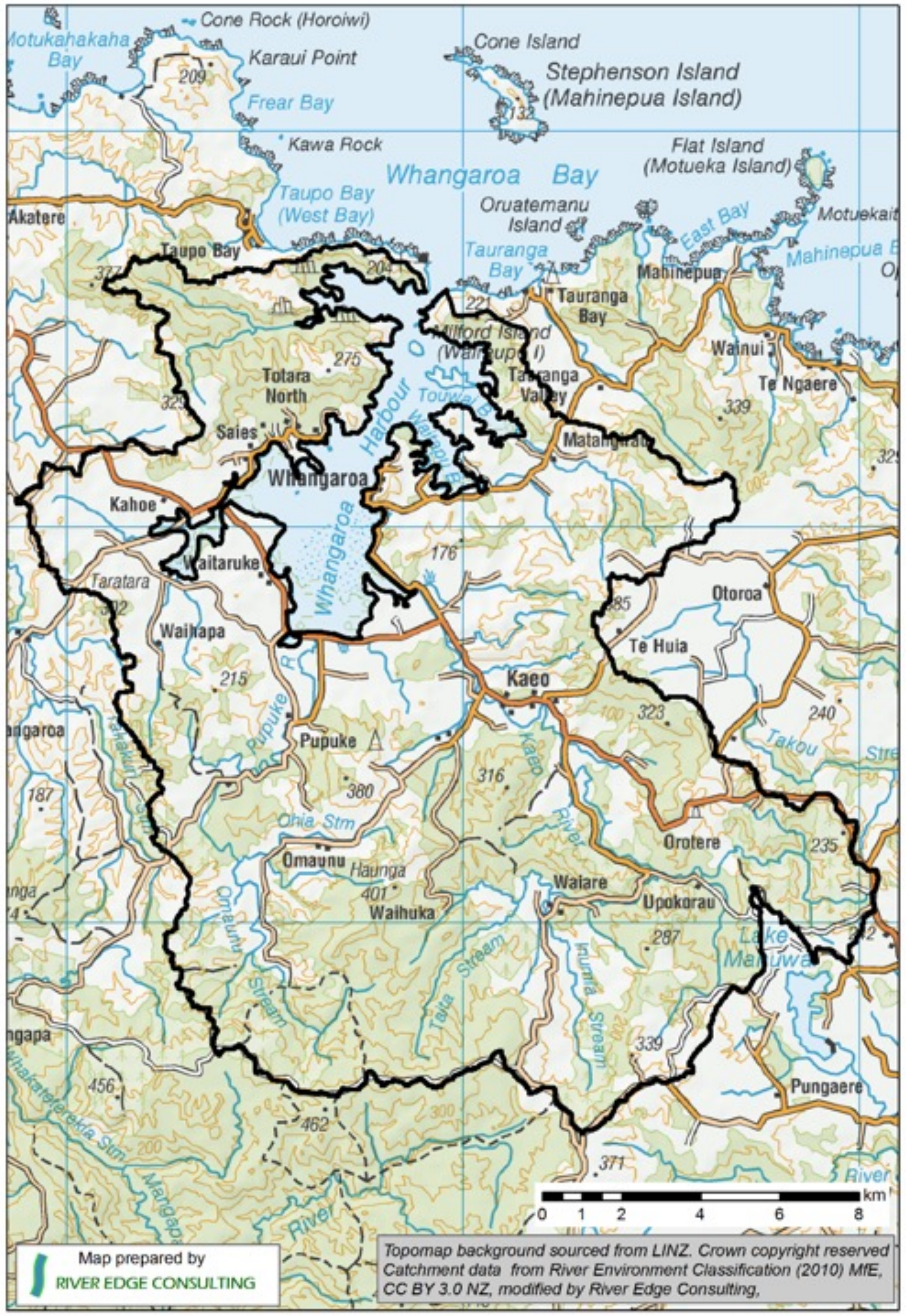


Figure 1. Whangaroa catchment and harbour.

Study objectives

1. Create an information baseline from available monitoring data to understand the current state of the catchment;
2. Understand what stressors impact harbour health;
3. Understand the impact of the stressors on the harbour's potential to contribute to our wellbeing;
4. Develop a response plan to inform actions that Moana New Zealand and others may take to improve harbour health.

Key findings

1. Whangaroa Harbour contributes to many aspects of people's wellbeing

The review of Whangaroa harbour highlights the wide range of benefits that people can enjoy, emphasising the need to safeguard harbour health and improve management.

2. Oysters are an integral part of Whangaroa Harbour

Oyster farms regulate harbour health and are also important for social and economic wellbeing. The contributions oysters make whether farmed or living around the harbour can be both positive and negative. Oyster farms depend on good harbour water quality.

3. Significant habitats modification

The Whangaroa catchment has been heavily modified by human activities. The most significant impacts arise from deforestation, mangrove reclamation, agriculture, road construction and faecal contamination. Those activities contributed to increased sedimentation and reduced water quality in the harbour. Seafloor habitats within the harbour also have been modified and currently there is no quantitative record of these changes. Creating baseline maps of Whangaroa catchment and harbour showing habitat change paired with consistent monitoring data will help provide strong evidence for change to the current management.

4. Inconsistent monitoring data

Data from monitoring is sporadic and there is a lack of consistent methodology. Environmental studies have been done, although with variable methods and at different harbour locations, limiting our ability to make detailed comparisons over time. Implementing an extensive monitoring program, including cultural monitoring and appropriate use of mātauranga Māori, that will bring together the industry, Iwi, hapū and whānau, and management agencies is important and necessary to enable a better future for the harbour. It will provide solid baseline information to improve our understanding about climate change and inform where management changes are critical and ensure that the right measures are being monitored in the harbour. This will be critical to track that catchment restoration activities are tangibly improving harbour health.

Recommendations

The study has collated the following recommendations for consideration by interested parties:

1. Establish a consistent environmental monitoring system

Uundertaking regular monitoring of water quality in the harbour and applying consistent methodology across study sites will allow a better understanding of changes to Whangaroa Harbour condition. Methods to monitor the health of the harbour also should be developed, including exploring local community cultural health, mātauranga and citizen science. Data from monitoring such as Moana New Zealand's water quality/salinity closure data, along with the rainfall/water quality/official Northland Regional Council records are an important start and inform environmental management. Moana New Zealand is willing to support local Iwi, hapū and whānau in their future conversations with council and management agencies about implementing a long-term monitoring program. Moana New Zealand will also continue monitoring of waters in the harbour surrounding oyster farms to improve understanding of the effects that changes in water quality have on oysters.

2. Supporting the management of stressors to the harbour

One of the key findings of this report is that the main stressors affecting harbour health are linked to habitat modification around the catchment that has caused changes to sedimentation rates, lowered water quality and reduced the capacity of harbour ecosystems to respond to change. Moana New Zealand is committed to engaging in catchment restoration efforts, such as riparian planting, and to reduce its own impacts on the harbour. The Tio Transformation project is a key initiative by Moana to switch to floating longlines to enhance water flow through the farm and to improve farm productivity and working conditions. It is also reducing shell debris input to the harbour and minimising seafloor disturbance.

3. Prepare a long-term catchment restoration plan

Restoring native vegetation improves water quality in the streams and rivers flowing to harbour and therefore the harbour itself. A catchment restoration plan is a critical and urgent action step. Even though the Whangaroa catchment has been forgotten in NZ national or regional strategies, there are opportunities to change this and start taking records of changes to the harbour's health based on quantitative experiments and mātauranga working together. As well as catchment restoration, restoration of in-harbour vegetation of seagrass will enhance water quality and biodiversity. Moana New Zealand recognises the strong potential for building relationships with local landowners, communities and management agencies and will look to how it can best support local community initiatives. Developing and actioning long term catchment restoration plans will generate win-win gains that address water quality issues, improve the health of the catchment, improve te hauora mō ngā tāngata whenua (the health of the people of the land) and address social issues, including growing local employment.

4. Co-governance and commitment to being a good tenant

Moana New Zealand recognises the complex social context for managing the harbour. Whangaroa Harbour has been neglected by public agencies including Northland Regional Council which has not identified it as a priority catchment. The changes to environmental management will require a collaborative approach to succeed. Moana New Zealand is modernising their Whangaroa oyster farming operations and is committed to empowering the community to develop related businesses to work with Moana New Zealand, and to supporting initiatives that restore the health of the catchment, harbour and community wellbeing.

5. Undertake more research to understand complex social-ecological relationships

This report is a result of scientific research undertaken by researchers from the Institute of Marine Science, Auckland University and review of a wide range of material by Terra Moana Ltd. Moana New Zealand wants to continue improving our knowledge about the role of oyster farms in regulating the natural processes in the Whangaroa Harbour. Moana New Zealand continues to improve its knowledge about the ecological responses of the marine environment to multiple stressors and the effects that changes in management can have on people's wellbeing.

6. Elaborate a long-term 'Nature's Contributions to People marine research' case study

Moana New Zealand welcomes exploring this for Whangaroa Harbour, especially in relation to harbour health being methodically monitored by local whānau and hapū, the wider community, and where appropriate agencies. This could include supporting the development and use of mātauranga Māori marine cultural health monitoring.

Ecosystem-based management in Whangaroa Harbour

The health of the catchment and harbour are interconnected (Figure 2). They are also tied to the wellbeing of the human communities of Whangaroa, including as a kete for kaimoana.

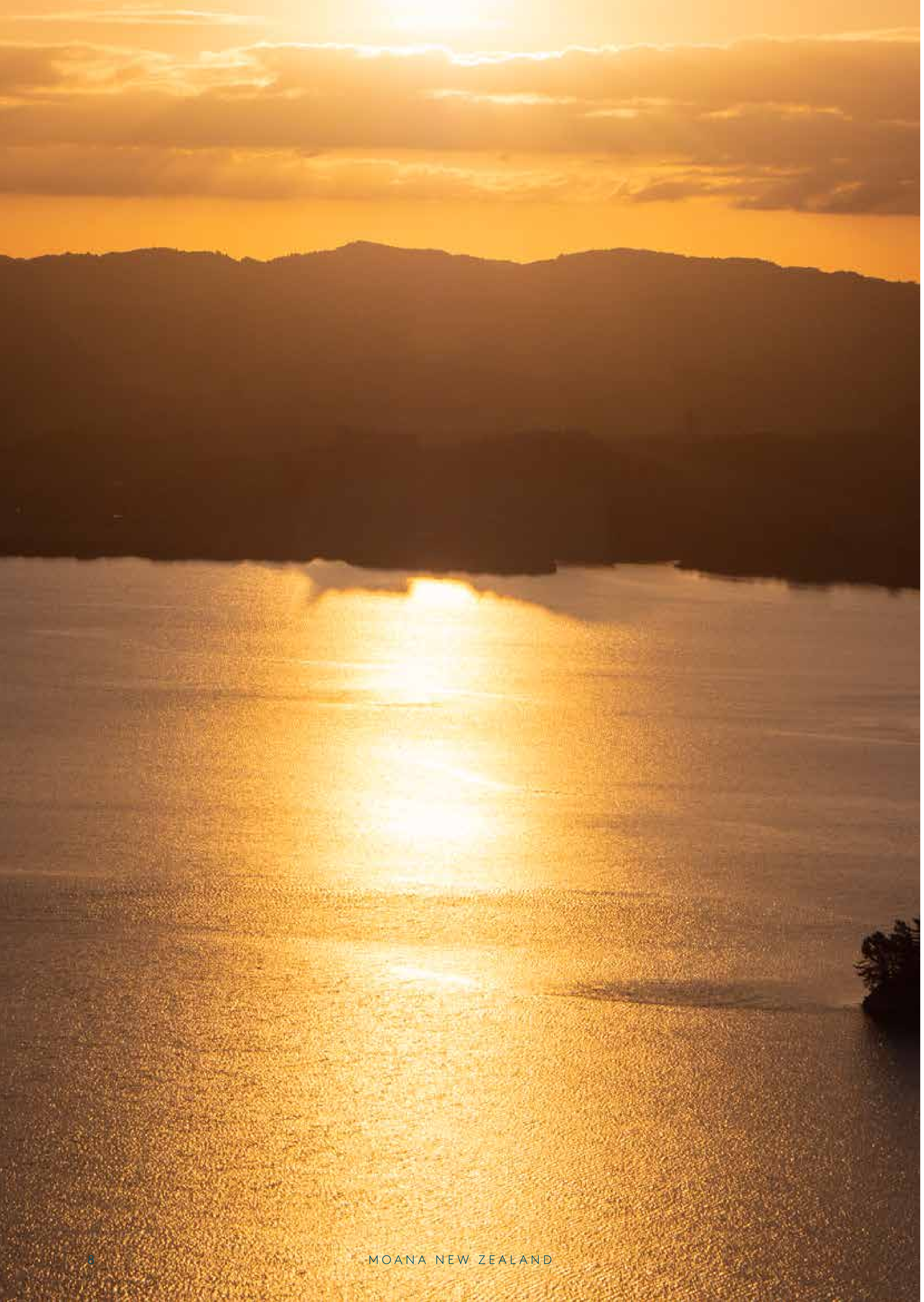
Ecosystem-based management (EBM) is an approach to environmental management that recognises the interconnectedness between land, sea and harbour habitats as well as people who use, rely on and enjoy the harbour. In the context of managing Whangaroa Harbour, having a **Ki Uta Ki Tai** (from mountains to sea) perspective is critical to ensuring that stressors from the catchment are well managed as inputs from the land via rivers and streams have a fundamental role in regulating harbour health.

Other ecosystem-scale effects include direct human activity, e.g., anchoring, fishing (commercial, recreational, customary), industrial activity (such as dredging) or larger system effects such as ocean acidification, climate fluctuations and marine heatwaves. Ecosystem-based management is a holistic management system. **Kaitiakitanga** is being explored for modern ecosystem-based management of marine ecosystems by iwi, hapū and whānau across the motu as well as in the Sustainable Seas National Science Challenge (of which Moana New Zealand is a part of several relevant projects).

This report provides baseline knowledge of catchment-scale effects, including the review of stressors from the catchment affecting the harbour and the review of harbour's contribution to people's wellbeing using the framework of **'nature's contributions to people'** (see Box 1).

As a Māori-owned seafood company, Moana New Zealand has kaitiakitanga as a core value and thus takes sustainability to heart. We recognise that human activity on the land affects marine ecosystems. Some of the land-based effects are on Māori owned land. In the bigger picture, the health of the oceans also affects the land through global-scale weather, climate and other biophysical processes. There is an opportunity to foster more joined-up strategies nationally where Moana New Zealand quota owning shareholders run land-based operations adjacent to important fishing areas.

Moana New Zealand recognises that it is a privilege to farm oysters and is committed to being a good tenant, a valued cultural and community partner, and responsible corporate citizen. The 2021 sustainability strategy documents Moana's current commitments which can be found at www.moana.co.nz/responsibility.



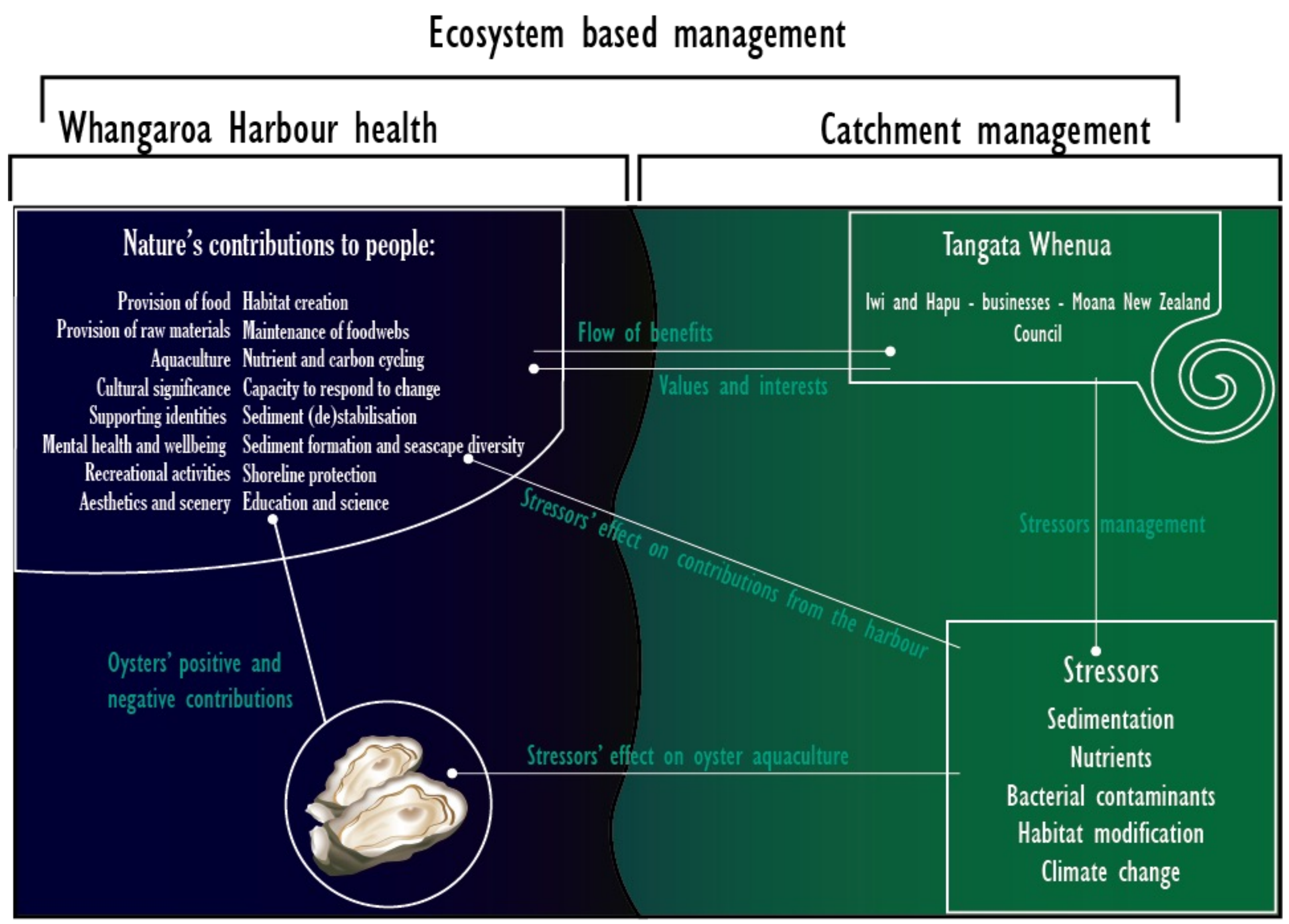


Figure 2. Different elements of ecosystem-based management visualising the relationships between stressors, harbour's health and tāngata whenua.
Credit: Eva Siwicka

Stressors affecting Whangaroa Harbour

In this report, stressors are the physical and chemical features that have a negative effect on harbour health. Stressors can directly result from human activity (e.g., septic-tank leachate, plastic waste) or represent natural processes changed by people (e.g., high rates of soil and nutrient runoff from land).

Estuaries are transitional habitats connecting land and sea (Kennish 2002). Whangaroa's inner harbour is very muddy and the waters are murky due to a history of soil inputs as the catchment was converted from the native forest. Rivers and streams play a critical role in linking the effects of land management on harbour health (Mead and Moores 2005, PCE 2020). In the context of Whangaroa Harbour, sediment, nutrient and contaminant runoff, and habitat modification are identified as the main threats.

1. Sedimentation

Changes in land cover, erosion from poor land practices, earthworks, and hoof erosion by animals are major contributors to soil runoff. For example, forest clearing and removal of native vegetation contribute to the loosening of soil material, increasing the potential for sediment runoff to many of our harbours (Thrush et al. 2013). Data from monitoring land use in Whangaroa's catchment has shown that 43% of the original native vegetation has been lost, 19% in recent years. Deforestation has a long history in Whangaroa Harbour dating back to kauri logging, and the use of rivers and dams to transport the logs began the sedimentation in the 1800s (see Supplementary material).

Soil runoff leads to high sedimentation in harbours and is a serious problem. Extreme rain events can lead to slips and slides that deliver big sediment loads that change the harbour's seafloor and ecology. Suspended sediments in the water reduce light levels reaching the seafloor and which reduces plant growth. Sedimentation also impacts the ability of filter-feeding animals to feed. The harbour has had significant loss of scallops which in the Tasman area at the top of the South Island is known to be due to sedimentation (Newcombe et al 2015). However, some-filter feeding shellfish, like oysters, can reduce turbidity by removing suspended material from the water column and depositing it on the seafloor (Forrest et al. 2009). But the ability of filter feeders to clean the water can be disrupted if the sediment levels in the water are too high.

Sedimentation is a high priority to address for both local people and Moana New Zealand oyster farm operations.

2. Nutrients

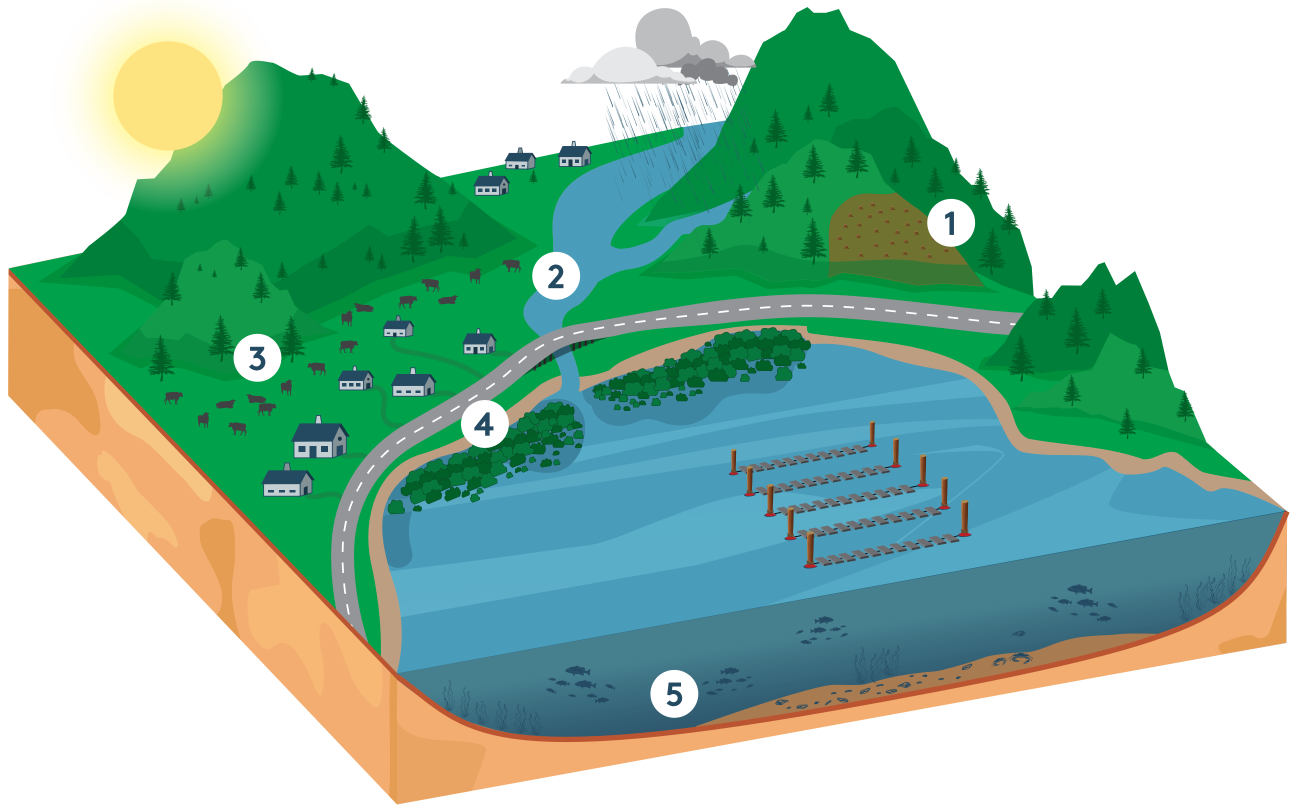
Nutrients arrive in the harbour from point sources such as sewage discharge and diffuse sources such as agricultural runoff. Too much nutrient input leads to increased primary productivity, resulting in algal blooms (sometimes toxic) and lowered oxygen concentrations on the seafloor. This disrupts many important ecosystem functions linked to nutrient and carbon cycling (Kennish 2002, Thrush et al. 2004, Howarth 2008).

In 2013, Northland Regional Council undertook a monitoring study in Whangaroa Harbour. Measured were the size of sediment particles (grain size), nutrients, phosphorus and organic carbon levels across the estuary (Figure 3). The proportion of mud was the highest in the inner harbour in five out of eight sites. More sandy sites were located close to the harbour entrance and Kaeo River Mouth. All measured sites showed low concentrations of nutrients and low to moderate concentrations of phosphorus. Moderate concentrations of organic carbon were also reported.

3. Bacterial contaminants

High levels of faecal contaminants come from the surrounding catchment, again influenced by weather conditions. Bacterial contaminants may be sourced from humans, farm animals and wildlife. The Kaeo River is a significant aggregator of these contaminants and therefore an important source of contamination. Bacterial contaminants enter the harbour not as a constant discharge but intensify after heavy rainfall or point source contamination of the rivers and streams.

Moana New Zealand's operations rely on the good quality of water in the harbour. Oysters are filter feeders, therefore, all bacterial contaminants suspended in the water column are absorbed during their feeding process and are retained in oyster gills (Hay and Roberts 2012). Moana New Zealand undertakes regular water quality monitoring. If water quality measurements indicate that the contamination level is above regulatory guidelines, harvest is stopped, and a periodic site closure is implemented.



4. Habitat modification

Whangaroa Harbour itself has also experienced changes in habitat cover. Mangrove extent and location has shifted, also affected by the roading. The road going to Whangaroa and SH10 between the Kaeo river bridge and Waitaruke has been built on the seafloor and have created an opportunity for farmers to reclaim ~500ha of wetlands and mangroves. The harbour lost approx. 54% of mangrove cover between 1909 and 1981. Other habitats in decline include seagrass and saltmarshes. Small saltmarsh areas (the main breeding areas for endemic birds) declined from 240 hectares in 1909 to only 45 hectares in 1981 (81% loss) (see Supplementary material).

Oyster operations have also contributed to modifying the seabed through shell debris deposition. The main original infrastructure was established by Sanford Ltd and Moana New Zealand has owned the farm since 1996. A significant area of the approved aquaculture lease has not been used by Moana New Zealand to date. Oyster farms typically modify the seabed directly under the farm. The natural reproduction of farmed oysters contributes to spat fall on the intertidal rocky shores of the harbour. They are sharp and make access to the water edge difficult in some areas of the harbour which is a cause of concern for the mana whenua. Oyster reefs can be built up with sediment and shells have changed the nature of some beaches too, which is also a community concern. Moana New Zealand is modernising the farm changing the long-term wooden frame infrastructure to the semi-automated farming technology which significantly reduces seabed-based oyster farming infrastructure.

5. Climate change

Predicted near-future changes in climate and globally increasing temperatures produce different weather patterns and changing environmental conditions (IPCC, 2019). Habitats within the harbour are likely to be influenced by rising water temperature (including wider effects such as algal blooms and increased biosecurity risk from diseases), acidification, sea-level rise and cumulative risks (MfE, 2019). The resilience of different habitats within Whangaroa Harbour is not well understood and there is a need for more research in this area. For example, while Pacific oysters are temperature tolerant, the risk of the whole ecosystem potentially shifting (increased temperature, more frequent floods and ocean acidification) and its effect on oysters growth and resilience is unclear.

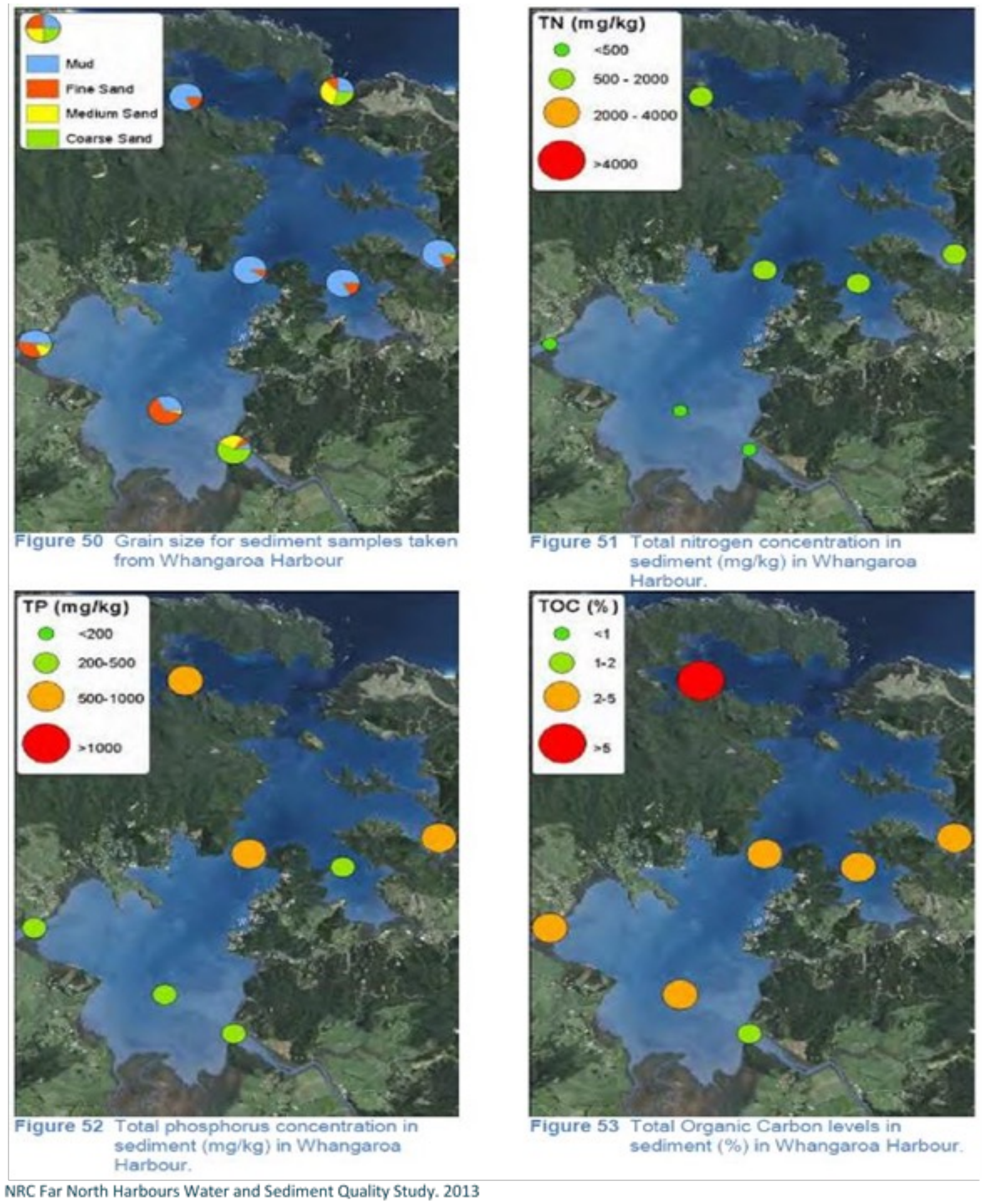


Figure 3. Grain size (top left), total nitrogen (top right), total phosphorus (bottom left) and total organic carbon (bottom right) levels in different sites across Whangaroa Harbour.

Diagram was derived from Northland Regional Council Far North Harbours Water and Sediment Quality Study, 2013.

Conclusions - Stressors affecting Whangaroa Harbour

To overcome the challenges involved in understanding and addressing the complexity of these stressors and large-scale landscape effects, and to achieve shared environmental interests and integrated ecosystem-based management, decision-making involving multiple stakeholders is needed (Basher et al. 2003, Fenemor et al. 2011). Specifically, improving the management of on-land activities and building long-lasting relationships with Iwi, hapū and whānau, local communities, land managers and business operators will result in improved health of Whangaroa Harbour.

The lack of ecological data from the harbour, the impacts of in-harbour activities (e.g., fishing), roading and other structures around the harbour and impacts from the coastal ocean currently limit our ability to fully understand the state of the harbour. Advancing our understanding of the harbour will allow us to identify all the opportunities to improve the quality of the harbour for a wide range of the people who use the harbour and value its biodiversity (see next section on nature's contributions to people from Whangaroa Harbour).

Accounting for the connections between land and sea plays a critical role in improving current management. Moana's oyster farming operations open and close depending on rainfall and freshwater input which is a proxy for potential E.coli contamination. These are thus significant drivers of Whangaroa Harbour health and oyster operations. Good quality freshwater delivers essential nutrients allowing habitats within the harbour to thrive.

Thus, management effort to reduce these stressors is in the interest of all harbour users to enable farming operations, to protect harbour health and to sustain the flow of benefits. Reduction in bacterial and sediment transfer from land to sea is achievable by better catchment management.

Moana New Zealand is committed to supporting actions towards integrated catchment management to ensure good water quality in the harbour such as increasing water quality monitoring, tracking sources of pollutants, identifying new riparian restoration zones that will mitigate the impacts of heavy rainfall, conducting more site-specific research and improving relationships between the oyster farming operations, and landowners, the community, and other users to achieve better catchment-scale outcomes.

Review of nature's contributions to people from Whangaroa Harbour

To fully value the relationships between Whangaroa Harbour and people, we use the framework of nature's contributions to people (Diaz et al. 2018).

Nature's contributions to people describe the many different ways that people obtain benefits from nature with a particular focus on cultural context and the different values of different people (Pascual et al. 2017). Characterising the relationships between people and Whangaroa Harbour using 'nature's contributions to people' helps capture a broader range of potential uses and values (Kadykalo et al. 2019). These can then be discussed in co-developed solutions to improve the harbour ecology and its capacity to support diverse interests within the local community. In this report, nature's contributions are classified as material, non-material and regulating (Table 1). We describe their relationship to enhancing the quality of life and living in harmony with nature (Box 1) (Christie et al. 2019). This approach better supports and recognises alignment with Te Ao Māori (Harmsworth and Awatere 2013) than the more utilitarian ecosystem-services.

Nature's contribution to people - the contributions, either positive or negative, that people obtain from nature. It is emphasises the plurality of values and quality of life. Nature's contribution to people are categorised into material, non-material or regulating while most of them can straddle across these categories (Diaz et al. 2018).

Quality of life - an expression of fulfilment of human life, here in relation to the human-nature relationship and nature's contributions. The quality of life can be enhanced through instrumental values and relational values:

- **Relational values** - contribute to desirable relationships, in particular those between people and nature;
- **Instrumental values** - use and non-use values that can be linked to economic values.

Intrinsic values - inherent value of nature independent from people's judgement.

(Christie et al.2019)

Box 1. Key definitions relating to the 'nature's contributions to people' framework. Adapted from Siwicka and Thrush (2020)

Table 1. Nature's contributions to people from Whangaroa Harbour. Contributions can straddle between different groups with a dark blue indicating the primary role and light blue indicating a secondary role.

Nature's contributions to people	Groups			Values types	
	Material	Non-material	Regulating	Instrumental	Relational
Provision of food					
Provision of raw materials (non-food)					
Aquaculture					
Cultural significance and supporting identities					
Mental health and wellbeing					
Recreational activities					
Aesthetics and scenery					
Habitat creation					
Maintenance of food webs					
Nutrient and carbon cycling					
Capacity of the harbour to respond to change					
Sediment (de)stabilisation					
Sediment formation and seascape diversity					
Shoreline protection					
Education and science					

Provision of food and raw materials

Whangaroa Harbour is a source of food harvested for cultural, recreational, and commercial reasons. Examples of food products from the harbour include snapper, oysters, scallops, pipi, and cockles. Commercial extraction of food resources can be easily expressed in monetary terms. Cultural values are far deeper and more cherished. Recreational seafood harvesting is difficult to fully capture in monetary terms. It is often associated with other qualities such as spending time out in nature or having a hobby (non-material).

Moana New Zealand is a commercial aquaculture operation providing a food product. Aquaculture is a part of food provision services that is very significant to Whangaroa Harbour and its users. Whangaroa Harbour hosts one of the largest oyster farms in the Southern Hemisphere. Oyster aquaculture began in 1979 in the harbour, but Moana New Zealand was involved as of 1996. Aquaculture is a material contribution to people's quality of life by generating direct income from aquaculture sales. Aquaculture also significantly contributes to job creation. Moana New Zealand's oyster operations employ over 25 people locally at Whangaroa and 30 more people at their Wiri oyster processing plant in Auckland. Although not quantified for Whangaroa Harbour, along with the material benefits, oyster aquaculture is also likely to play an important role in water filtration and regulation of ecological processes such as nitrogen and carbon cycling (van der Schatte et al. 2020).

Whangaroa Harbour also involves a non-direct human consumption (non-food products) (Barbier et al. 2011). The examples include plants that can be used as fertiliser, fish food and grazing for livestock; sand as a construction and building material; or shells and plant material for traditional, decorative and ornamental purposes (Thrush et al. 2013, Aotearoa Fisheries 2014).

Cultural and recreational significance

Whangaroa Harbour is a place of special cultural and spiritual significance to tāngata whenua – people of the land. The strong bonds between Iwi, hapū and whānau with Whangaroa Harbour are anchored in Kaitiakitanga – guardianship and protection. The life force relationship between tāngata whenua and Whangaroa has a high intergenerational significance. Iwi, hapū, whānau and non-Māori local communities of Whangaroa are connected and actively involved in restoring, enhancing, and protecting the mauri and unique biodiversity of Whangaroa. Some are seeking to restore the area of Whangaroa to its former state when 250 years ago 9000 people lived there within an abundant ngahere (native bush) and diverse environment. The life of an average tree in the ngahere is 500 years. This equals 20 x 25 year generations of caring kaitiaki, and is the long term goal of the Whangaroa Ngahere and Taiao (environment) Restoration project run by Kaitiaki Whangaroa. People are connected with nature through whakapapa and transcendental experiences such as spirituality, appreciation of the beauty of nature, finding peace and enjoying open space all contribute to increasing wellbeing and reducing stress. Te Ao Māori has an entirely integrated view of te taiao and human health and wellbeing, whether physical, spiritual, intellectual, or emotional.

Whangaroa Harbour is also a popular destination for recreational activities both in the water or on the shore such as recreational seafood harvesting, swimming, snorkelling, bird watching, boating, kayaking, walking, camping and generally being in nature. While primarily these activities lead to fulfilling non-material life qualities, they can also result in material goods (e.g., recreational fishermen enjoy being out on a boat while catching fish is a secondary benefit). Tourism driven recreation additionally materially benefits the region, including job creation and income generation. Recreational restoration is active in the catchment with a strong predator-free community in Whangaroa providing recreation, training, education, time in nature and the ecological service of pest management.

Finally, the aesthetics of the estuarine landscape can have a positive effect on property prices and land value (Thrush et al. 2013). The spectacular scenery of Whangaroa Harbour attracts movie producers and visitors who enjoy its inherent beauty.

Habitat creation and maintenance of food webs

Whangaroa Harbour is home to many plant and animal species, including large marine species (e.g., dolphins, turtles), fish (e.g., snapper, kingfish, stingrays), invertebrates (e.g., scallops, crustaceans), shorebirds (e.g., New Zealand dotterel, banded rail) and seabirds (e.g., gannets, seagulls). How long these animals stay in the harbour varies with some being permanent residents while others visit occasionally (potentially exploiting breeding or nursery grounds). Historically, Whangaroa Harbour also supported diverse vegetation, including mangroves, seagrass, and saltmarshes. Estuaries are very productive ecosystems that support a high abundance of seafloor-living species that are a food source for higher trophic levels, such as birds and fish (Livingston 2002, Rullens et al. 2019). High productivity rates are underpinned by complex biogeochemical processes, including primary production by plants and nutrient cycling linking basic ecosystem functions to the larger and more visible species in the harbour.

Ecology of the harbour

Every day, important processes occur in Whangaroa Harbour that are not visible to the human eye. The habitats within the harbour perform many complex processes such as primary productivity, nutrient cycling, carbon sequestration, waste removal and decontamination that together describe the work that the harbour does for us (nature's contributions to people). These processes play a vital role in mitigating harmful effects of human activities and terrestrial input of pollutants such as nitrogen and contaminant runoff. These processes also represent the critical capacities of the harbour to respond and adapt to future change. Continuous performance of those ecological processes underpins balanced and stable ecosystem function and good ecosystem health assuring that all biodiversity can thrive. Whangaroa Harbour has an inherent capacity to absorb some level of negative effects and maintain its identity and critical functions. However, the capacity of Whangaroa Harbour to stay resilient to change is currently being challenged by the high levels of sedimentation and contaminant runoff.

Seascape

As well as the hidden processes described above, there are other aspects of the harbour ecology that we can directly observe. For example, some of the harbour sediment is generated by the breaking down of calcium carbonate shells of animals such as bivalves and snails (Thrush et al. 2013). Some bivalves that occur in high densities, such as cockles or oysters, form beds or reefs that substantially diversify the seascape and contribute to increased sediment stability (Ysebaert et al. 2018). Physically diverse seafloor structures create shelter and provide refuge from predators for juvenile fish or small invertebrates. The breakdown of shells through natural physical forces is a long process. Fragmented shells can remain in the ecosystem for centuries playing a vital role in generating sandy beaches. Sediment formation and seascape diversity has a mainly regulating role and can also contribute to non-material aspects of people's wellbeing by providing leisure opportunities such as walking on sandy beaches.

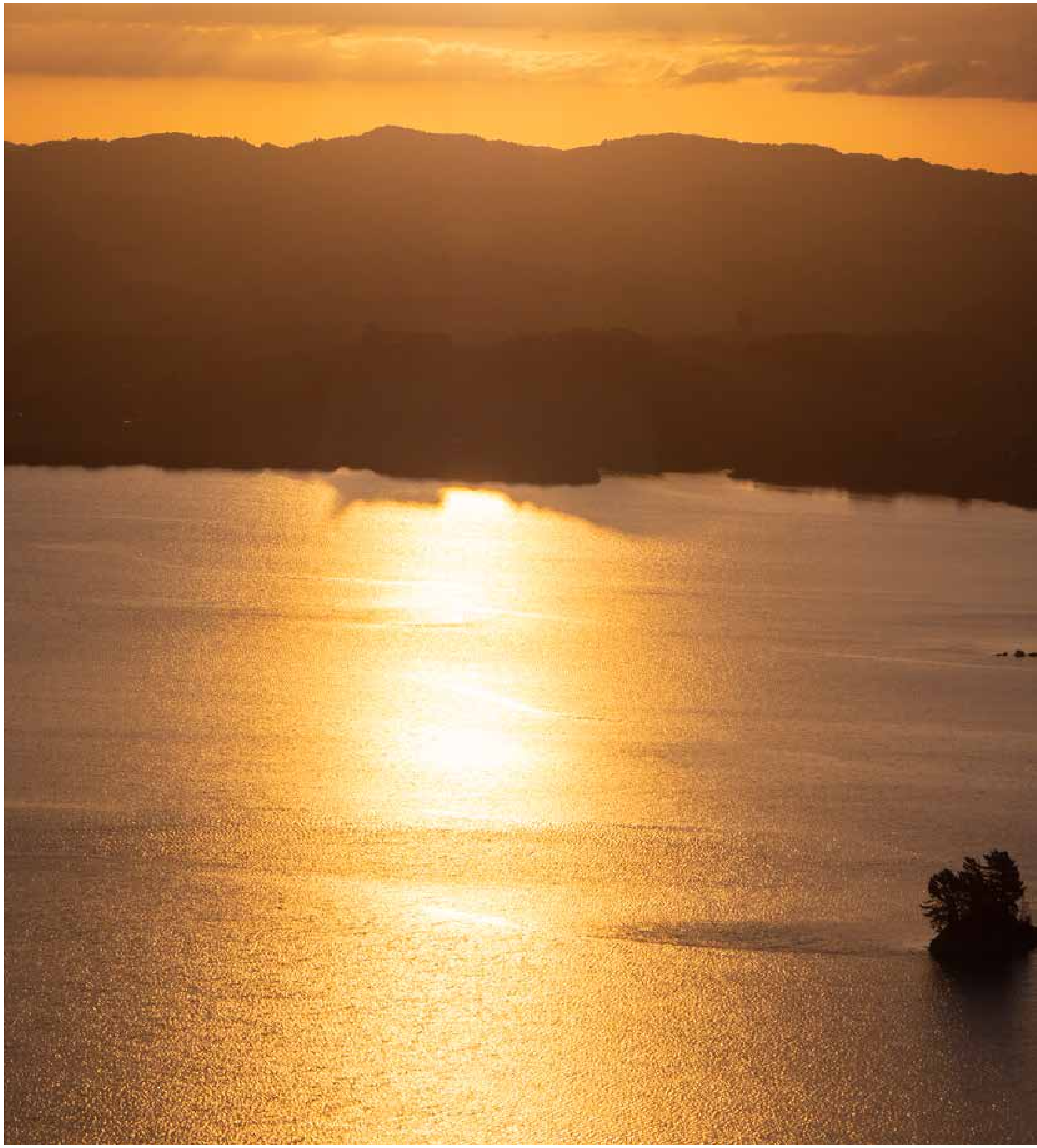
Seafloor sediment also moves around naturally influenced by animal movement or digging. Sediment movement is essential to facilitate ecological processes by moving food to deeper sediment layers where processes critical to maintaining good ecosystem health are performed (Lohrer et al. 2004, Siwicka and Thrush 2020). Whangaroa Harbour also has sediment stabilising vegetation such as mangroves and seagrass that trap sediment with their rooting systems (Mead and Moores 2005); organisms producing shells that create reefs (Rullens et al. 2019); and crabs and worms that build types of structure (tubes and burrows) that influence sediment erosion (Reise et al. 2009, Thrush et al. 2013). Both sediment stabilisation and sediment movement are important regulating contributions. Importantly a healthy harbour should have a range of habitats supporting different processes.

Shoreline vegetation

Shoreline vegetation, including mangroves and saltmarsh acts like a sponge and controls water release that can help prevent flooding. Shoreline vegetation also regulates the impact of tidal surges and storm events protecting shoreline properties. The Whangaroa Harbour shoreline has been heavily modified by roading, construction and logging. Substantial areas of mangrove, saltmarsh and seagrass habitats have been lost (Whangaroa Harbour Study, 1985.).

Education and science

Whangaroa Harbour plays an important role in stimulating scientific research. This report is part of that process. Moana New Zealand also regularly monitors water quality that could be used in scientific research to enhance our understanding of ecosystem functioning and nature-people relationships. We all learn by doing and the potential for growing our understanding of how the harbour works and how it is changing is immense. Ideally this would involve Moana New Zealand and other commercial users of the harbour, Northland Regional Council and other relevant agencies, scientific research organisations, citizen science initiatives and enabling mātauranga Māori throughout. At the national scale, Moana New Zealand is involved in the Sustainable Seas National Science Challenge participating in the projects: 'Risk and Uncertainty', 'EBM and Kaitiakitanga' and 'Hauraki Gulf Indicators'. In 2021 Moana New Zealand published its second Patai Rangahau portfolio and continues to foster relationships with the research community. These create opportunities to develop learning, tools, and further research in Whangaroa Harbour.



Review of nature's contributions to people from oysters in Whangaroa Harbour

Good harbour health is fundamental for healthy functioning oysters that can then contribute to people's wellbeing in many more ways than as just a tradable commodity (Grabowski et al. 2012, van der Schatte et al. 2020). In this section, we outline and characterise oysters' contributions to people in the context of Moana New Zealand's operations in Whangaroa Harbour. This review is based on a combination of overseas and local scientific research on the interactions of bivalves (mainly oysters and mussels) with the environment and the benefits we derive from natural reefs and aquaculture.

Cultural significance and supporting identities

In Te Ao Māori (Māori world view of the natural order of the universe) the stewardship of ecosystems and balance are core principles. As the only commercial entity fully owned by all Iwi Māori, Moana New Zealand was established in 2004 as Aotearoa Fisheries Ltd through the Māori Fisheries Act and it remains an important part of the inter-generational settlement with the Crown. The nature of the settlement means that Māori will always be involved in fisheries and aquaculture. This makes these oyster farms unique. The profits from oyster operations, other than the balance retained to fund long term sustainable growth initiatives (such as modernising farming techniques), are returned to Iwi.

Moana New Zealand Aquaculture

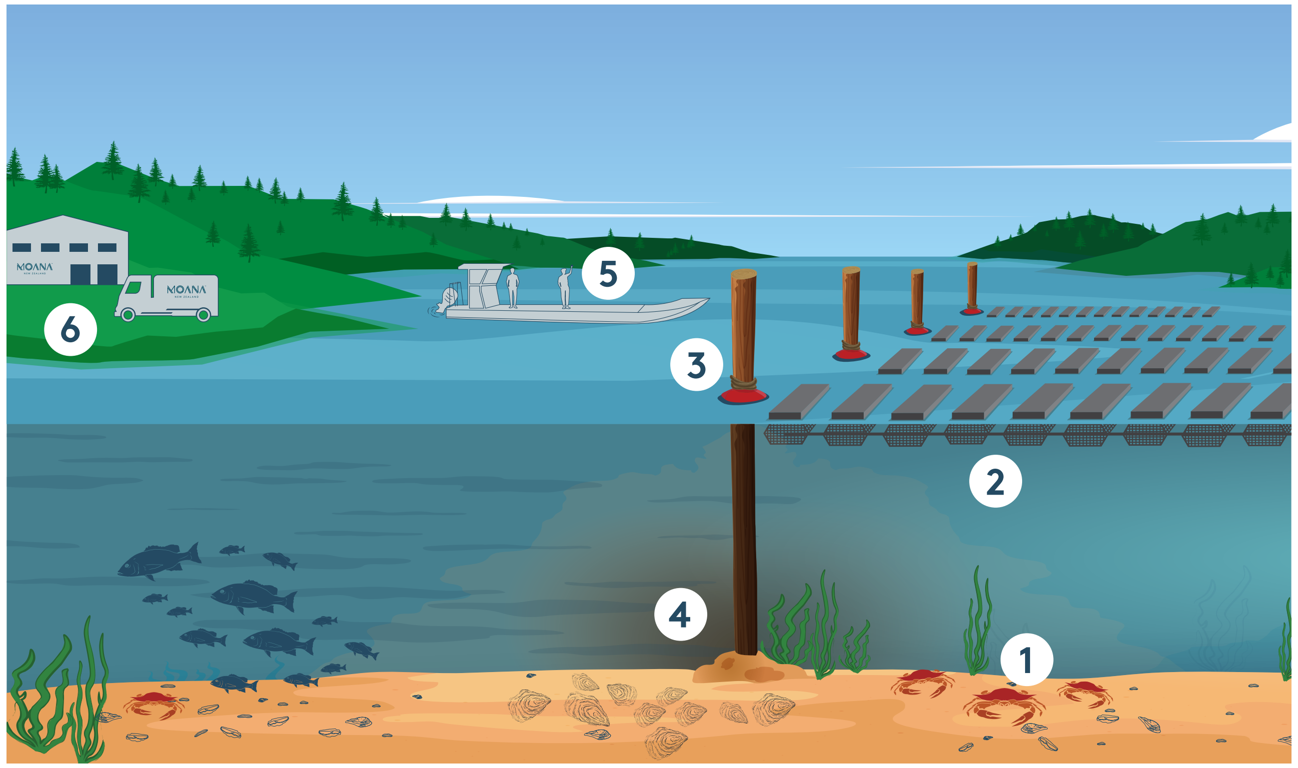
Pacific Oysters (Crassostrea gigas) are native to Japan and were first observed in New Zealand in 1971. Pacific oysters have been farmed in Whangaroa Harbour since 1979 for export and domestic markets. Altogether, 113.4 ha of the harbour are consented for oyster farming (this includes all farms, not just those operated by Moana New Zealand). Currently, a total of 90 ha has been developed. This covers 3.6% of the harbour and 14.5% of the intertidal mudflat area. Whangaroa Harbour is one of the most important sites for Moana New Zealand's oyster farming operations, contributing approximately 29% of the company's oyster production currently. The ability to supply consistent top-quality oysters all year by growing hatchery-bred sterile oysters provides more stable business and more consistent employment. Another product from oyster aquaculture is shell material. Historically, oyster shells were deposited to the seabed contributing to habitat modification. Since Moana New Zealand began farming oysters, oyster shells from their operations have been used for grit in chicken farms in Wiri, Auckland, and for farm roading around the Coromandel oyster processing facility however the chicken farm grit option has recently ceased, and Moana New Zealand is seeking other uses for shell waste.

1. Habitat creation and seascape diversification

Shell deposition in moderate amounts benefits estuarian systems as it promotes higher levels of biodiversity, plays a role in creating refugia (e.g., for juvenile crabs) and supports feeding grounds (e.g., juvenile fish) (Snover and Commito 1998, Grabowski et al. 2005). Besides hard shells, artificial structures such as racks, cages, nets, and ropes also create habitat for species to reside. Studies have shown that Pacific oyster reefs can contribute to greater species diversity (Herbert et al. 2012).

2. Waste removal and water filtration

Oysters are efficient at filtering water, with the pumping rate significantly higher (26 to 34 l h–1) than other bivalves (ranging from 0.12 to 2.07 l h–1) (van der Schatte et al. 2020). Removal of suspended organic material reduces turbidity enhancing water quality and clarity as well as resulting in higher light transmission to seafloor plants and animals. This can promote the growth of some habitats, for example, seagrass (Shumway et al. 2003, Newell and Koch 2004) and the critically important microscopic organisms that live on the seafloor and fuel most of the harbour's functions (Hope et al. 2020). Water filtration by shellfish transfers material from the water column to the seabed (biodeposits). These 'biodeposits' enhance the settlement of organic-rich material to the seabed. In some circumstances, biodeposits can provide conditions preferred by some sediment-dwelling animals (Shumway et al. 2003, Forrest et al. 2007), or act as a fertiliser for benthic vegetation (Newell et al. 2002, Grabowski et al. 2012). However, in other cases, too much biodeposit can lead to localised problems which will have negative effects on the farmed oysters and surrounding habitats. Well-flushed farms and estuaries have a lesser potential for experiencing problems associated with biodeposit build-up.



Oysters also have been observed to promote a process that removes bioavailable nitrogen and returns it in a gaseous form to the atmosphere (denitrification), thus helping to mitigate the consequences of anthropogenic nitrogen excess in estuaries (Newell et al. 2002, Piehler and Smyth 2011, Kellogg et al. 2013). Oysters also retain nitrogen in their tissues and, when harvested, the nitrogen is permanently removed from the system resulting in about 100 kg of nitrogen removed per year based on a weekly harvest of 10,000 oysters (Shumway et al. 2003). Based on this measurement, we can estimate that Moana New Zealand oyster farm removes ~900 kg of nitrogen per annum.

3. Carbon sequestration

From a scientific perspective, storing carbon in marine sediments is potentially an important contribution to our national carbon budget. The role of bivalves in direct and indirect contributions to carbon storage is unresolved. On the one hand, oysters sequester carbon in the form of calcium carbonate shells (Tang et al. 2011). On average, a shell contains 11.7% of carbon and is a long-term carbon sink, but of course, the animal in the shell is still respiring carbon dioxide. Studies have shown that natural oyster reefs are more effective than other forms of blue carbon sequestration (van der Schatte et al. 2020). One study has shown that oyster farms are capable of sequestering between 3.81 and 17.94 tons of carbon per hectare per year (Hickey 2009). But this research needs to be balanced against the energetic cost of carbonate production and animal growth – metabolic activities that return CO2 to the water and atmosphere (Thinkstep Ltd, 2021).

4. Sediment stabilisation/Shoreline protection

In heavily sedimented systems, the sediment stability feature can turn into a negative contribution. Shell litter accumulation in Whangaroa Harbour is considered to be high. Large quantities of shell deposition occurred before Moana New Zealand took over the farm and although shell litter continued whilst Moana New Zealand was stick farming, this has been significantly reduced in the switch to the semi-automated farming technology. Coupled with a large anthropogenic sediment loading from the catchment, the excess of shell hash is at least anecdotally believed to contribute to sediment trapping in the inner parts of the estuary. While this hinders sediment removal by physical tidal forces to deeper parts of the harbour, it could mean that because the sediment is stored on the mudflats, it does not impact deeper living sensitive species. Dealing with a historical accumulation of shell debris is challenging, and more monitoring and research in assessing the current baseline, the ecological impact of shell accumulation and the potential removal of sediment through the shift to floating long-lines is needed.

Education and science

Oysters' functioning and contributions to people require context-specific research to better understand how their ecological role changes in relation to the multiple stressors across the harbour. The results from Whangaroa Harbour specific research will generate baseline data and allow for the identification of best management practices to improving harbour health. Moana New Zealand is willing to engage in scientific research to understand the ecological effects of their operations and develop a broader understanding of harbour health.

Conclusions - nature's contributions to people from oysters in Whangaroa Harbour

To gain more insight into the ecological and social relationships between Moana New Zealand's oyster farm, Whangaroa Harbour and its catchment, more local research is needed, including supporting kaupapa Māori research. Studies elsewhere have shown that oyster functionality can be both positive and negative depending on the local context. Similarly, changes in physio-chemical sediment properties under oyster farms attracts selected species, usually leading to the proliferation of small-bodied deposit feeders (capitellid polychaetes and other marine worms) and the displacement of other macrofaunal species (Forrest et al. 2009). Therefore, site-specific studies are necessary to develop a good understanding of ecosystem dynamics. Such context-specific knowledge involves data on the level of stressors (e.g., nutrient, sediment and bacterial contamination from the catchment), the geomorphological and hydrodynamic properties of the estuary, the types of farmed species, farming method, stocking density; and the types of habitats and communities present (Haggitt et al. 2008).

Management challenges and moving forward

Moana New Zealand recognises the complex social context in Whangaroa and that to change things for the better and improve the health of the harbour and its catchment that the management of pollutants, sediment, and contaminants from land to the harbour (ki uta ki tai) must improve.

There is significant potential to increase and improve communication and to develop collaborative action to improve harbour health involving business, Iwi, hapū and whānau, Moana New Zealand, Northland Regional Council and other agencies to generate win-win solutions. The purpose of this report is to provide an information baseline and highlight where the gaps are to inform future actions.

To produce this report we assembled a significant database of literature about Whangaroa Harbour that is now available to access at Moana New Zealand. Based on this review, we identified that increasing monitoring across the harbour so that it is long-term, regular and applies consistent methodology, as well as developing baseline maps of the seafloor are critical to understanding environmental change in the harbour. The review of nature contributions to people presented in this report demonstrates the significance of Whangaroa catchment and harbour to local people, business, and the wider community. Therefore, it is a duty of all catchment users to collaborate and take more, higher impact steps to mitigate harmful terrestrial inputs into the harbour. In return, a healthier harbour will better support tāngata whenua, and Moana New Zealand's oyster farming operations now, and will continue to do so for future generations.

There is significant potential to increase and improve communication and to develop collaborative action to improve harbour health involving business, Iwi, hapū and whānau, Moana New Zealand, Northland Regional Council and other agencies to generate win-win solutions. The purpose of this report is to provide an information baseline and highlight where the gaps are to inform future actions.

References

Aotearoa Fisheries. Pāua as taonga. Understanding Pāua's Place in Aotearoa. ; 2014.

Barbier E. B., S. D. Hacker, C. Kennedy, E. W. Koch, A. C. Stier, and B. R. Silliman. 2011. The value of estuarine and coastal ecosystem services. *Ecological Monographs* **81**:169-193.

Basher LR, Barringer JRF, Bowden WB, Davie T, Deans NA, Doyle M, Fenemor AD, Gaze P, Gibbs M, Gillespie P, Harmsworth G, Mackenzie L, Markham S, Moore S, Phillips CJ, Rutledge M, Smith R, Thomas JT, Verstappen E, Wynne-Jones S, Young R. The Motueka and Riwaka Catchments: a technical report summarizing the present state of knowledge of the catchments, management issues and research needs for integrated catchment management. Lincoln, New Zealand: Landcare Research; 2003. 120 p.

Christie M., B. Martín-López, A. Church, E. Siwicka, P. Szymonczyk, and J. Mena Sauterel. 2019. Understanding the diversity of values of "Nature's contributions to people": insights from the IPBES Assessment of Europe and Central Asia. *Sustainability science* **14:**1267-1282.

Diaz S., U. Pascual, M. Stenseke, B. Martin-Lopez, R. T. Watson, Z. Molnar, R. Hill, K. M. A. Chan, I. A. Baste, K. A. Brauman, S. Polasky, A. Church, M. Lonsdale, A. Larigauderie, P. W. Leadley, A. P. van Oudenhoven E., F. van der Plaat, M. Schroter, S. Lavorel, Y. Aumeeruddy-Thomas, E. Bukvareva, K. Davies, S. Demissew, G. Erpul, P. Failler, C. A. Guerra, C. L. Hewitt, H. Keune, S. Lindley, and Y. Shirayama. 2018. Assessing nature's contributions to people. Science *(American Association for the Advancement of Science)*; Science **359:**270-272.

Fenemor A., C. Phillips, W. Allen, R. Young, G. Harmsworth, B. Bowden, L. Basher, P. Gillespie, M. Kilvington, R. Davies-Colley, J. Dymond, A. Cole, G. Lauder, T. Davie, R. Smith, S. Markham, N. Deans, B. Stuart, M. Atkinson, and A. Collins. 2011. Integrated catchment management—interweaving social process and science knowledge. *New Zealand Journal of Marine and Freshwater Research* **45:**313-331.

Forrest B. M., N. B. Keeley, G. A. Hopkins, S. C. Webb, and D. M. Clement. 2009. Bivalve aquaculture in estuaries: Review and synthesis of oyster cultivation effects. *Aquaculture* **298:**1-15.

Forrest BM, Elmetri I, Clark K. Review of the ecological effects of intertidal oyster aquaculture . Cawthron Report No. 1275; 2007.

Grabowski J. H., A. R. Hughes, D. L. Kimbro, and M. A. Dolan. 2005. How habitat setting influences restored oyster reef communities. *Ecology* **86:**1926-1935.

Grabowski J. H., R. D. Brumbaugh, R. F. Conrad, A. G. Keeler, J. J. Opaluch, C. H. Peterson, M. F. Piehler, S. P. Powers, and A. R. Smyth. 2012. Economic valuation of ecosystem services provided by oyster reefs. *BioScience* **62:**900-909.

Haggitt T, Mead S, Bellingham M. Review of environmental information on the Kaipara Harbour marine environment. Auckland Regional Council Technical Publication Number 354; 2008. 190 p.

Harmsworth G. R., S. Awatere. 2013. Indigenous Māori knowledge and perspectives of ecosystems. *Manaaki Whenua Press, Lincoln, New Zealand* :274-286.

Hay B, Roberts K. Faecal contamination of oyster growing areas in the Kerikeri Inlet: data analysis and recommendations for a faecal source tracking programme. AquaBio Consultants Ltd; 2012. 64 p.

Herbert RJ, Roberts C, Humphreys J, Fletcher S. The Pacific Oyster (Crassostrea gigas) in the UK: economic, legal and environmental issues associated with its cultivation, wild establishment and exploitation. ; 2012. 132 p.

Hickey J. P. 2009. Carbon sequestration potential of shellfish. .

Hope J. A., D. M. Paterson, S. F. Thrush, and K. Van Alstyne. 2020. The role of microphytobenthos in soft- sediment ecological networks and their contribution to the delivery of multiple ecosystem services. *Journal of Ecology* **108:**815-830.

Howarth R. 2008. Coastal nitrogen pollution: a review of sources and trends globally and regionally. *Harmful Algae* **8:**14-20.

Handley SJ, Swales A, Horrocks M, Gibbs M, Carter M, Ovenden R and Stead J. 2020. Continental Shelf Research 202, 104147

IPCC. (2019) Special Report on the Ocean and Cryosphere in a Changing Climate

Kadykalo A. N., M. D. López-Rodriguez, J. Ainscough, N. Droste, H. Ryu, G. Ávila-Flores, S. L. Clec'h, M. C. Muñoz, L. Nilsson, S. Rana, P. Sarkar, K. J. Sevecke, and Z. V. Harmáčková. 2019. Disentangling 'ecosystem services' and 'nature's contributions to people'. *Ecosystems and People* **15:**269-287.

Kellogg M. L., J. C. Cornwell, M. S. Owens, and K. T. Paynter. 2013. Denitrification and nutrient assimilation on a restored oyster reef. *Marine Ecology Progress Series* **480:**1-19.

Kennish M. J. 2002. Environmental threats and environmental future of estuaries. *Environmental Conservation* **29:**78-107.

Livingston R. J. 2002. Trophic organization in coastal systems. Baton Rouge: CRC Press, Baton Rouge.

Lohrer A. M., S. F. Thrush, and M. M. Gibbs. 2004. Bioturbators enhance ecosystem function through complex biogeochemical interactions. *Nature* **431:**1092-1095.

Mead S, Moores A. Estuary sedimentation: a review of estuarine sedimentation in the Waikato region. Environment Waikato Technical Report Series 2005/13; 2005. 50 p.

Ministry for the Environment & Stats NZ (2019). New Zealand's Environmental Reporting Series: Our marine environment 2019. Available from www.mfe.govt.nz and www.stats.govt.nz. Published in October 2019 by Ministry for the Environment and Stats NZ Publication number: ME 1468

Newell R. I. E., E. W. Koch. 2004. Modelling seagrass density and distribution in response to changes in turbidity stemming from bivalve filtration and seagrass sediment stabilization. *Estuaries* **27:**793-806.

Newell R. I. E., J. C. Cornwell, and M. S. Owens. 2002. Influence of simulated bivalve biodeposition and microphytobenthos on sediment nitrogen dynamics: a laboratory study. *Limnology and Oceanography* **47:**1367-1379.

Pascual U., P. Balvanera, S. Díaz, G. Pataki, E. Roth, M. Stenseke, R. T. Watson, E. Başak Dessane, M. Islar, E. Kelemen, V. Maris, M. Quaas, S. M. Subramanian, H. Wittmer, A. Adlan, S. Ahn, Y. Al-Hafedh, E. Amankwah, S. T. Asah, P. Berry, A. Bilgin, S. J. Breslow, C. Bullock, D. Cáceres, H. Daly-Hassen, E. Figueroa, C. D. Golden, E. Gómez-Baggethun, D. González-Jiménez, J. Houdet, H. Keune, R. Kumar, K. Ma, P. H. May, A. Mead, P. O'Farrell, R. Pandit, W. Pengue, R. Pichis-Madruga, F. Popa, S. Preston, D. Pacheco-Balanza, H. Saarikoski, B. B. Strassburg, M. van den Belt, M. Verma, F. Wickson, and N. Yagi. 2017. Valuing nature's contributions to people: the IPBES approach. *Current Opinion in Environmental Sustainability* **26-27:**7-16.

PCE. Managing our estuaries. Parliamentary Commissioner for the Environment; 2020. 220 p.

Piehler M. F., A. R. Smyth. 2011. Habitat-specific distinctions in estuarine denitrification affect both ecosystem function and services. *Ecosphere* **2:**art12.

Reise K., T. J. Bouma, S. Olenin, and T. Ysebaert. 2009. Coastal habitat engineers and the biodiversity in marine sediments. *Helgoland Marine Research* **63:**1-2.

Rullens V., A. M. Lohrer, M. Townsend, and C. A. Pilditch. 2019. Ecological mechanisms underpinning ecosystem service bundles in marine environments – a case study for shellfish. *Frontiers in Marine Science* **6.**

Shumway S. E., C. Davis, R. Downey, R. Karney, J. Kraeuter, J. Parsons, R. Rheault, and G. Wikfors. 2003. Shellfish aquaculture — in praise of sustainable economies and environments. *World Aquaculture* **34:**8-10.

Siwicka E., S. F. Thrush. 2020. Advancing approaches for understanding the nature-people link. *Ecological Complexity* **44:**100877.

Snover M. L., J. A. Commito. 1998. The fractal geometry of Mytilus edulis L. spatial distribution in a soft-bottom system. *Journal of Experimental Marine Biology and Ecology* **223:**53-64.

Tang Q., J. Zhang, and J. Fang. 2011. Shellfish and seaweed mariculture increase atmospheric CO2 absorption by coastal ecosystems. *Marine Ecology Progress Series* **424:**97-104.

Thinkstep Ldt. 2021. Life Cycle Assessment of New Zealand Mussels and Oysters. Prepared for: Aquaculture New Zealand & Ministry for Primary Industries

Thrush S. F., M. Townsend, J. E. Hewitt, K. K. Davies, A. M. Lohrer, S. F. Lundquist, and K. Cartner. 2013. The many uses and values of estuarine ecosystems. *Ecosystem Services in New Zealand – Conditions and Trends. Manaaki Whenua Press.*

Thrush S. F., J. E. Hewitt, V. J. Cummings, J. I. Ellis, C. Hatton, A. M. Lohrer, and A. Norkko. 2004. Muddy waters: elevating sediment input to coastal and estuarine habitats. *Frontiers in Ecology and the Environment* **2:**299-306.

van der Schatte O., L. Jones, L. L. Vay, M. Christie, J. Wilson, and S. K. Malham. 2020. A global review of the ecosystem services provided by bivalve aquaculture. *Reviews in Aquaculture* **12:**3-25.

Ysebaert T., B. Walles, J. Haner, and B. Hancock. 2018. Habitat modification and coastal protection by ecosystem-engineering reef-building bivalves. *Goods and Services of Marine Bivalves* :253-273.

Supplementary material

A1. Catchment characteristics and history

Catchment Geography, Land and Harbour

Whangaroa Harbour is a sheltered inlet located between Mangonui and the Bay of Islands on the east coast of Northland, New Zealand. The Whangaroa Catchment (26,000 hectares) and harbour (2530 hectares) are in the Whangaroa Ecological District which covers approximately 33,200 hectares and includes the small settlements of Kaeo, Matauri Bay and Whangaroa. It is predominantly rural with farming and fruit growing, oyster farming, commercial fishing, forestry and tourism as important industries. Since 1979 it has been used for the growth and supply of Pacific Oysters (Crassostrea gigas) for export and local markets. 113.4 Ha are consented for oyster farming in Whangaroa (includes all farms, not just Moana) with 90 Ha developed. This equals 3.6% of the harbour and 14.5% of the mudflat area. The harbour was formed about 6,000 years ago when rising sea levels drowned a river valley. It is a deep and sheltered estuarine embayment some 8km long and covers 19km^2 of which ~25% are mudflats. Although by definition an estuary, i.e. a semi-enclosed coastal body of water which has a reef connection with the open sea and is measurably diluted with freshwater from river inputs, it is an unusual estuary in having such a long entrance-way. It can be considered in two parts: the outer deep-water harbour, 9m deep at low tide with a marine dominated regime; and an estuarine inner harbour consisting of both marine and fluvial inputs of water and sediments.

It has an intricate coastline with four main arms. Rocky reefs extending sub-tidally to a depth of 15m are found at the entrance to the Harbour (Kerr 2005). Although the entrance to the harbour is narrow, the head of the harbour is large and reaches deep inland and is in part encircled by low-lying river plains and valleys surrounded by steep hills. Approximately 32% of the harbour is intertidal. The coastline is predominantly rocky and whilst mangroves have generally thrived in the upper Whangaroa Harbour where stock have not intruded, the area of saltmarsh is small, possibly because of the extensive reclamations carried out in earlier years. Freshwater wetlands are also rare. (DOC 1999 Ecological District Report).

The northern and western shores of the harbour (including the entrance headlands) are volcanic outcrops with steep cliffs to sea level whilst the southern and eastern shores have more gentle terrain composed of sedimental shale. The land use is mainly pastureland to the south and west, with bush and scrubland forming the northern and eastern coastal margins.

The head of the inner harbour comprises a series of deltas, mantled with fine grained sediments associated with the three main contributing streams: Kaeo, Pupuke and Iwitawa. The sands and gravels in the outer harbour are derived from shells from within the harbour itself. Harbour entrance reefs are likely to support rich encrusting assemblages given their exposure to strong tidal streams. The seafloor channel immediately outside the harbour is flat with much shell gravel, a few large scallops, and little in the way of epifauna (M. Morrison, pers. observ.)[1]

The narrow harbour entrance means that tidal motion dominates and being offset to the northeast, little swell enters the harbour except from that direction or travels much beyond Peach island (Ohauroro). The tidal range is 2m and strong tidal currents come through the entrance channel which act as a pump for the interior. There is a dominant clockwise current movement throughout the tidal cycle. The catchment drains through ~132 sub-catchment rivers and streams to the harbour delivering an estimated average of around 9.5 m^3/s of freshwater inflow. Over 65% is drained through the catchments of the Kaeo and Pupuke Rivers. Water inflow is 5-15cumecs into the harbour in summer and winter respectively.

The Kaeo River, the largest on the south-eastern side of the harbour has numerous streams flowing into the harbour and is 18kms long with its headwaters at the confluence of the Waiare and Upokorau Streams and at a maximum elevation of 456m above sea level. Surface runoff varies with rainfall and high intensity rainstorms can produce extremely large floods at any time of year. Flushing in the Whangaroa Harbour is approximately 39,000,000 m^3 of seawater on a rising spring tide. (Whangaroa Harbour Study, 1985.)

[1] Dougan, C.M. (1984). Sediment and hydrology of Whangaroa Harbour. Unpubl. MSc thesis, University of Auckland. 89 pp.

The Northland Climate

Most of the region lies below 150m elevation although some points in the central ranges are above 600m. Together these factors give Northland a climate that is warm and humid in the summer and mild in the winter. Rainfall is highest in winter while dry spells tend to occur in summer and autumn. Tropical cyclones that reach Northland and still retain very low pressures and hurricane force winds are very rare. However, other storms of tropical origin (which may never have been fully developed tropical cyclones) affect Northland about once or twice each year, mainly between the months of December and April. They usually bring heavy rain and strong easterly winds. The airflow over Northland is predominantly from the southwest (Tomlinson, 1975). This is particularly so in winter and spring, but in summer the proportion of winds from the easterly quarter, especially in eastern districts, about equals that from the southwest.

Northland is a narrow peninsula with no part more than 50kms from the sea. This causes winds to be very moist with abundant rainfall ranges throughout the region. Distribution patterns are related topography: rainfalls range from about 1000mm in low-lying coastal areas, to approximately 2000mm at higher elevations. Figure A1.1 shows the distribution of median annual rainfall based on the 1981-2010 period. The Kaeo township has one of the highest annual rainfalls regionally with 1596mm on average. The Whangaroa catchment falls within a high annual rainfall area shown in blue.

Northland has experienced numerous extreme weather events, with significant damage and disruption caused by flooding and high winds. Kaeo has been affected on multiple occasions by those extreme events, for example the 2012 floods triggered by rainfall of over 280mm in 24 hours (Figure A1.2).

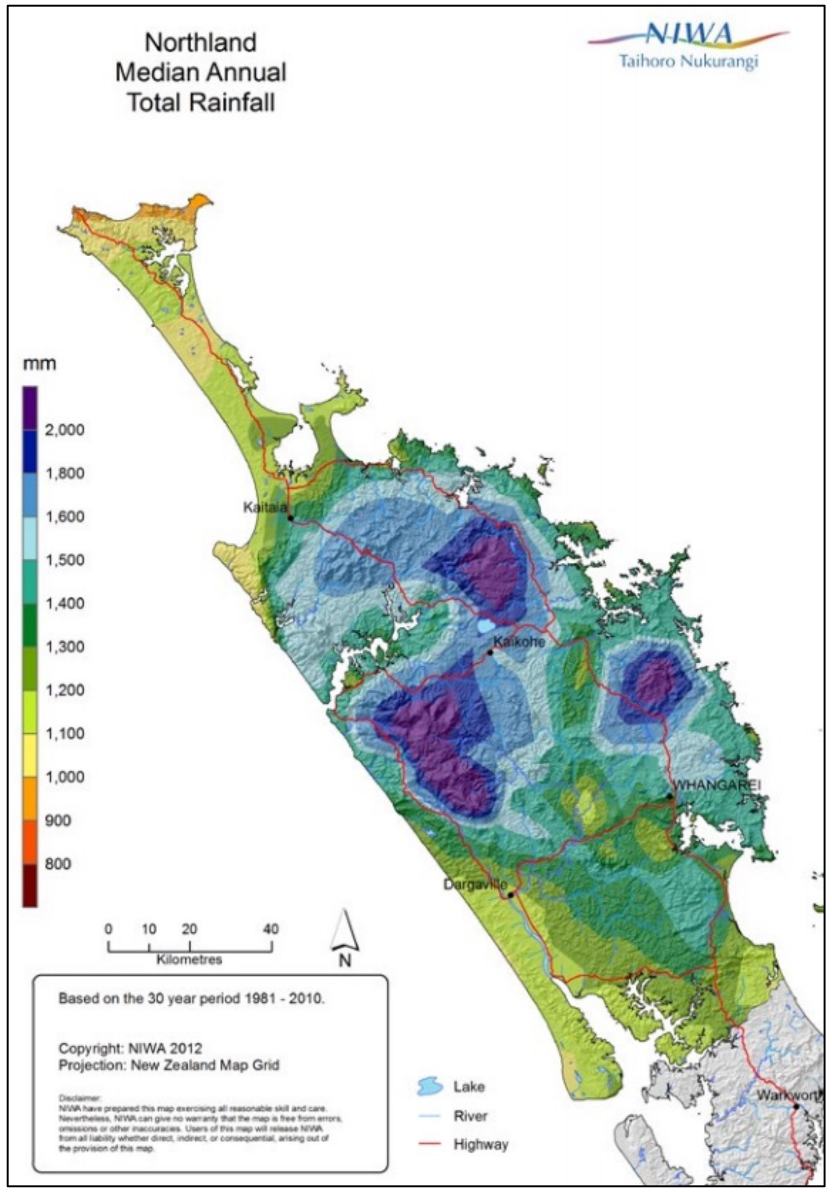


Figure A1.1. Northland median annual rainfall, 1981-2010

Natural History

Prior to European settlement the whole area was covered by mixed podocarp hardwood forest. Kauri was abundant, especially around the southern harbour. It would appear that Māori occupation had little effect on the vegetation cover. From the earliest contact with Europeans the area appealed for its safe harbour and access to timber for ship building. Selective tree felling, then clearing, then conversion to pasture followed European settlement, significantly in the early 1900s. In the late 1970s pine plantations began being established.

Biodiversity

The area has some important biodiversity with several bird species in the Berghan Point/Whakaangi area at or approaching their northern limit, including miromiro/pied tit, North Island brown kiwi and hard beech. Extensive areas of regenerating forests provide habitat for the Northland green gecko and pūpū rangi/kauri snails. Scallop beds were present in the harbour in 1984, and those remaining are highly valued by recreational fishers. Dive surveys were undertaken in the 1970–80s but were very poorly documented. In 1984 other dominant benthic communities in the middle to outer harbour contained fan scallops Chlamys zealandiae, the bivalves T. spissa and Myadora striata, and the gastropods Penion adusta, Struthiolaria paulosa, and Trochus tiaratus (Dougan 1984). The harbour is not a stopover for migratory waders although New Zealand dotterel, Australasian bittern, brown teal, North Island fernbird, and banded rail breed around the harbour (Shaw & Maingay 1990)[2].

Figure A1.2. Flooding in Kaeo, March 2012

[2] An information review of the natural marine features and ecology of Northland. NIWA Client Report: AKL2005-30. May 2005. NIWA Project: DOC05101

The People

According to Māori traditions, the waka Mahuhu-ki-te-rangi explored the Whangaroa harbour and the area was settled by descendants of Te Mamaru and Mataatua waka crews. The Whangaroa catchment encompasses the two census units Kaeo and Magapa-Matauri. The 2013 census showed 459 and 2517 people were present in the Kaeo and Mangapa-Matauri units respectively. This is a decrease in 246 people since the last 12-year sanitary survey (2001 census). The population density is 0.04 persons per hectare.

History of the Region

The region has an abundance of historical features, particularly the Māori-influenced landscapes of Motukawanui, Mahinepua Peninsula and Ranfurly Bay. Typical of rich coastal areas, a wide variety of defended and undefended pā, archaic middens, terraces, gardening systems, urupā, wāhi tapu and other archaeological features are present. The larger islands of the Cavalli group were extensively occupied in pre-European times. Residence was probably seasonal, with gardening and kaimoana supplementing the diet. The Reverend John Butler noted 18 villages in the outer Whangaroa harbour area alone in 1823 with an estimated 6000 people living in the area overall. The first recorded European visitors were from whaling and other ships, which started calling at Whangaroa from 1805 to 1809, including the *General Wellesley and Commerce* in 1806 and *Elizabeth* in 1809. In December 1809, the brigantine *Boyd*, a 395 ton vessel with a complement of 70 persons, including some New Zealanders returning from Australia, called at the harbour to collect timber. A conflict between Captain Thompson and a Māori greeting party ended with the captain and 66 Europeans killed and the vessel set alight. European visits resumed when the *Dromedary* loaded timber in 1820. Europeans later also settled around the harbour in the 1840s, and a Catholic mission was established at Waitaruke. The first Wesleyan mission in New Zealand was founded at Kaeo in June 1823. Hongi Hika attacked local Māori to gain control of millable kauri on 27th January 1827. Although he did not attack the mission, its inhabitants took fright and it was abandoned. In 1828, Hongi Hika died at Whangaroa from a wound suffered 14 months earlier in the Hokianga.

Kauri logging developed into a major industry in the region during the 1830s and continued to thrive until the early 1900s. By the time the Kauri Timber Company operations burnt down in 1905 its output was about 3 million feet of sawn timber per year with the remaining kauri resources then estimated at 14million feet. 25 years later the same company was still bringing vast quantities of kauri from inland Northland (above Pupuke) to Auckland. Acacia Cottage, the oldest extant, and first private timber house in Auckland (the first home of John Logan Campbell) was built of kauri sourced from Whangaroa in 1841. The harbour was a centre for milling and gum digging and shipyards were established at Totara North in 1872 with Whangaroa Harbour having the busiest shipyard in New Zealand in the late 1800's. Kauri was so plentiful in the hills around the harbour, that many logs were sent to Auckland to be milled. The logs were floated down river then chained together to form rafts and towed to Auckland. Some of the logs were so big and heavy that it took 12 bullocks to drag them.

In the early 20th century there was a whaling station at Sea Sick Bay near the south head. By the 1920s it had moved to Ranfurly Bay, near the north head. During World War 2, Army, Navy and Airforce bases were set up around the harbour to protect it from the threat of Japanese invasion. After the Mangamuka Gorge road became sealed in 1961, State Highway 1 became the main route north from Whangarei to Kaitaia and beyond, bypassing Whangaroa. State Highway 10 runs through Kaeo and on through Waitaruke on the south side of the harbour and onwards Mangonui. The village of Whangaroa is on the east of the harbour and Totara North is on the west. The township of Kaeo is built on the flood plain of the Kaeo river which flows into Whangaroa harbour. Kaeo is named from a Māori word meaning "a freshwater shellfish". Kaeo takes its name from a type of freshwater shellfish found in the river there.

The Names Whaiangaroa and Whangaroa

The traditional spelling of Whangaroa was Whaingaroa however the 'i' was removed to avoid confusion with Whaingaroa in Raglan in the Waikato. The name comes from the lament "whaingaroa" or "long wait" of a woman whose husband had left for a foray to the south. In te reo Māori, "whanga" means "harbour" and "roa" means "long". Matauri Bay is named from the Māori words "ma" meaning "stream" and "tauri" meaning "feathered ornament". *"Named from the river being well stocked with shellfish resembling the pipi, but slightly larger and called by the Maoris 'Kaeo'. They used to come long ago and gather it, and so in time going to the Kaeo meant to this particular section of the river, where most of this fish was found."*[3] At this point in time, the Kaeo mussel bed has disappeared.

Education

Te Kura o Hato Hohepa Te Kamura is a full primary (years 1-8) school in Waitaruke. It has a decile rating of 1 and a roll of 25. Totara North School is a contributing primary (years 1-6) school with a decile rating of 3 and a roll of 37. Kaeo Primary School, a contributing primary (years 1-6) school, has a decile rating of 1 and a roll of 117. This school dates back to 1877 and was moved to its current site from Old School Gully Road some years later. From 1941 to 1969 it became Kaeo District High School, taking both primary and secondary students. After the opening of Whangaroa College in 1969, Kaeo School became a primary school. Whangaroa College, a co-educational secondary (years 7-13) school, has a decile rating of 2 and a roll of 110[4] . Matauri Bay Primary School is a contributing primary (years 1-6) school with a roll of 72 students. It opened in 1895. Te Kura Kaupapa Māori o Whangaroa is a composite (years 1-13) school with a roll of 50 students. Both have a decile rating of 2.

[3] Wise's New Zealand Index to Every Place in New Zealand (1912)

[4] https://www.fndc.govt.nz/files/assets/public/objectivedocuments/community-development-cdv/community-plans/whangaroa/whangaroa-cdp-adopted.pdf

A2. Oyster farming history and current farming landscape

Oyster Farming in Northland

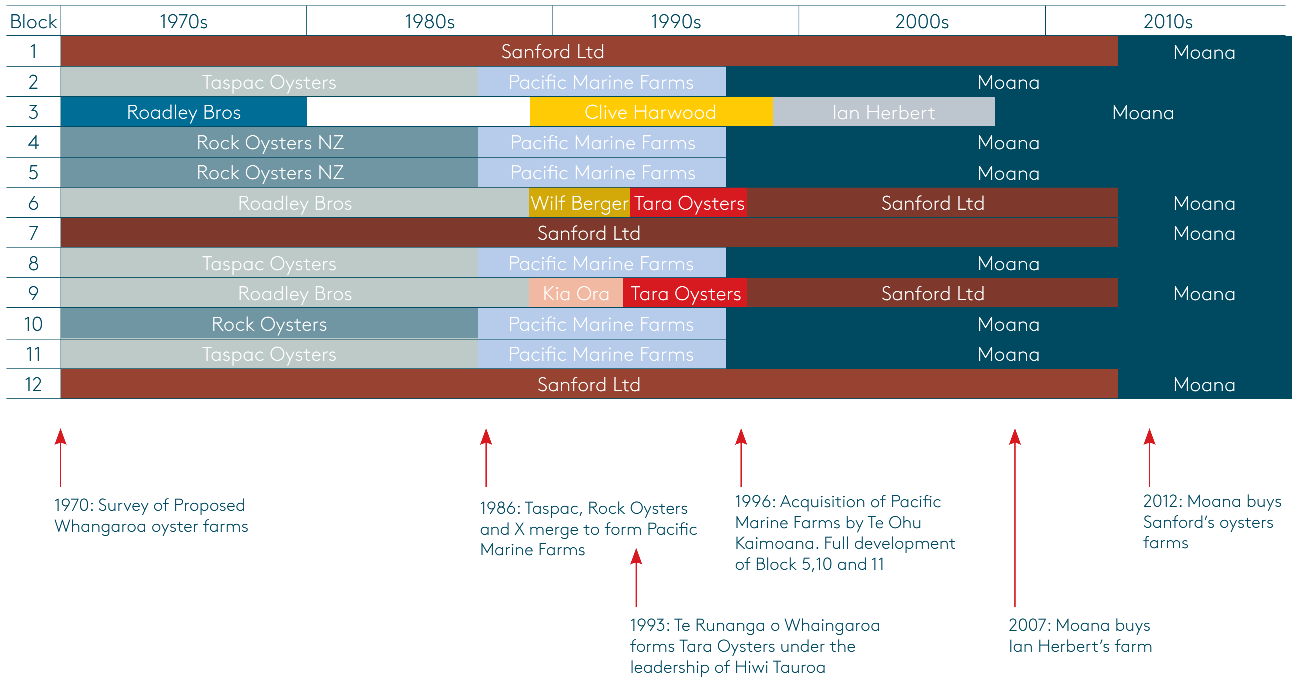
Pacific Oysters (*Crassostrea gigas*) are native to Japan and were first observed in New Zealand in 1971 although they may have arrived as early as 1958 in ship ballast water (Cawthron 2009). Intertidal cultivation of Pacific oysters began in New Zealand on the tidal flats of Northland harbours in the mid-1970s and in favour of an industry at that time based on cultivating native rock oysters (*Saccostrea glomerata*). Pacific oysters have been farmed in Whangaroa Harbour since 1979. To date most Northland Harbour oyster farms have used wooden racks embedded in the seabed in the lower intertidal zone. Juvenile oyster spat used to be attached to sticks which were laid across racks that were spaced several metres apart for farm barge access and elevated above the sediment. Today Moana New Zealand has removed all the sticks and racks and is using a suspended line between two posts on which oyster baskets hang, and which are turned over by a barge moving along the line, instead of people doing so from within the water. Northland Regional Council is responsible for aquaculture permitting with the Coastal Plan Change 4 recognising Whangaroa Harbour as a Marine 2 (Conservation) Management Area (MM2) and prohibiting any additional aquaculture in the harbour beyond the current leases.

Moana New Zealand's Whangaroa Oyster Farm

Moana New Zealand began farming oysters in the Whangaroa Harbour with the purchase of existing farms from Pacific Marine Farms in 1996.

Oyster Growing Areas

The oyster growing lease sites in Whangaroa Harbour correspond to Shellfish Growing Areas (GA) number 202 except for Lease 77 in Touwai bay (GA202A). MNZ occupies leases: 3, 79 and the "Main block"in GA202. (Figure A2.1)



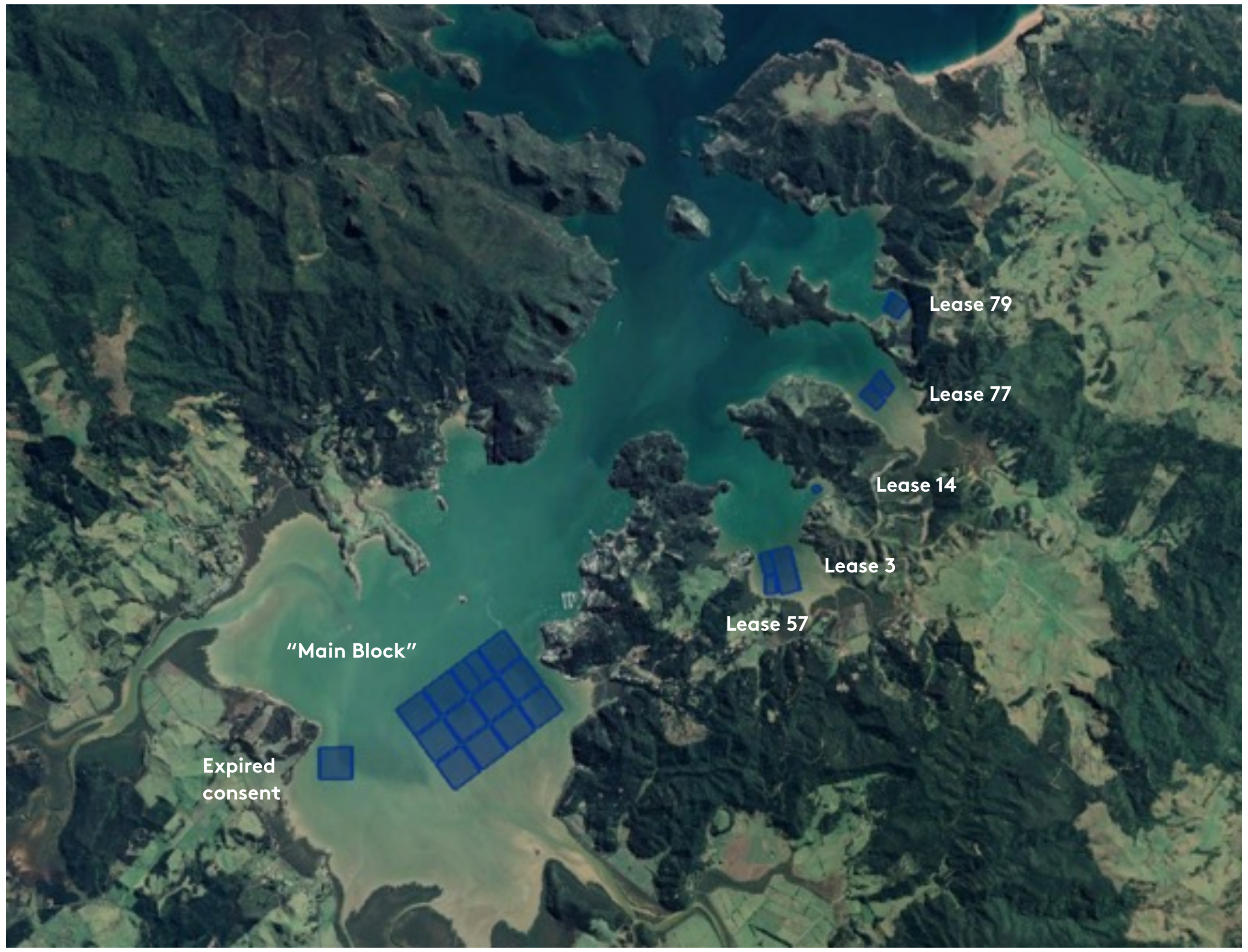


Figure A2.1. Location of oyster farms in Whangaroa harbour. Leases owed by Moana are shown in blue text.

Whangaroa Harbour Shellfish Growing Areas (GA202 and GA202A) are open or closed for harvest using different criteria:

- the "Main block" owned by Moana relies on salinity monitoring with any significant drop denoting freshwater input and the risk of E.coli contamination, which then requires the area be temporarily closed for oyster harvesting.
- The Eastern arms farms (Waitapu bay, Touwai and Pumanawa bay) rely on the monitoring of rainfall gauges. Rain above 17mm over a rolling 24h period will close the area for harvesting.

Water and shellfish quality samples collected between 2003 and 2015, when GA202 was open for harvest, show that the growing area complies with the Ministry for Primary Industries (MPI) Bivalve Molluscan Shellfish Regulated Control Scheme (BMSRC) regulations for a conditionally approved area. The GA has been successfully managed using salinity and rainfall criteria although the current determination of rainfall closures is cumbersome, requiring data retrieval and rainfall calculations each morning after rain, and from multiple gauges. Historically GA202 was closed voluntarily for harvest between January and March which coincided with *Crassostrea gigas* spawning and increased summer boating periods. However, the introduction of sterile *Crassostrea gigas* oysters, which are being on-grown to market size, offers the opportunity to harvest product throughout the year. It also means that the farm no longer facilitates pacific oysters becoming wild in the harbour.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