National SCIENCE Challenges

SUSTAINABLE SEAS

Ko ngā moana whakauka

Report

A novel approach to aquaculture in Aotearoa New Zealand: growing community wellbeing with pātiki tōtara

Report prepared for the Sustainable Seas National Science Challenge.

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About the Sustainable Seas National Science Challenge

Our vision is for Aotearoa New Zealand to have healthy marine ecosystems that provide value for all New Zealanders. We have 75 research projects that bring together around 250 scientists, social scientists, economists, and experts in mātauranga Māori and policy from across Aotearoa New Zealand. We are one of 11 National Science Challenges, funded by the Ministry of Business, Innovation & Employment.

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Executive Summary

This study aimed to identify whether aquaculture of pātiki tōtara, or yellowbelly flounder, could help develop new blue economy opportunities in coastal communities in New Zealand.

Global flatfish aquaculture has experienced rapid growth due to market demand and dwindling wild resources. Various production methods such as land-based tanks, outdoor ponds and indoor recirculating systems have been used to farm a range of high value species. New Zealand's aquaculture industry, aspires to reach $3 billion in annual sales by 2035, and currently revolves around mussel, oyster, and salmon farming. The recent emergence of new entrants to land-based aquaculture signals industry diversification and innovation. Despite most organisations having revenue-driven structures, aquaculture could also offer opportunities for preserving cultural traditions and enhancing social well-being in coastal communities. Pātiki tōtara is a culturally significant species and currently faces declining stocks, this has prompted an interest in aquaculture to ensure its sustainable management and help develop local economies.

Imagining kaupapa Māori pātiki economies

This study partnered with two coastal Māori communities, Matakana and Rangiwaea hapū, and Whakatōhea iwi. Both communities identified an interest in pātiki aquaculture, which reflects their deep-rooted connection to their land, sea, and cultural heritage. Effects of colonisation, including the loss of access to traditional resources like kaimoana, increased fishing pressure, and environmental degradation have fuelled an urgent need to restore and protect their marine ecosystems, including pātiki stocks.

Matakana and Rangiwaea hapū express aspirations centred around tino rangatiratanga, emphasizing the importance of self-determination and control over their resources. They seek to implement pātiki aquaculture with a focus on hapū-level decision-making and adherence to traditional knowledge (mātauranga), cultural practices (tikanga), and environmental stewardship (kaitiakitanga). Their goal is to balance cultural, social, environmental, and commercial imperatives, ensuring that any aquaculture operations benefit their community while preserving their cultural heritage.

Similarly, Whakatōhea iwi aspire to incorporate tikanga, mātauranga, and kaitiakitanga into pātiki aquaculture, recognising their responsibilities as kaitiaki (guardians) of their taonga (treasures). Primarily, they seek to preserve and sustain their relationship and tikanga with wild pātiki. Aquaculture could assist through the development of a stock enhancement program supported through commercial cultivation of pātiki. Whakatōhea whānau are interested in leveraging aquaculture to create positive outcomes for their people, including employment opportunities and educational initiatives, while maintaining access to wild pātiki stocks and honouring traditional food gathering practices.

Both communities identified potential concerns around aquaculture of pātiki. These concerns include:

- the possibility of a different, and potentially inferior, taste of farmed pātiki
- potential barriers imposed by government policies
- the challenge of maintaining tikanga in a commercial aquaculture setting.

In addition, the need to prioritise the mauri of the fish themselves, in a farm operation would necessitate as natural culture environment as possible. These concerns reflect communities' commitment to preserving the integrity and authenticity of their cultural practices and environmental relationships.

The aspirations and concerns of Matakana and Rangiwaea hapū, and Whakatōhea iwi underscore the complex interplay between cultural, social, environmental, and economic factors that would shape any future aquaculture development of pātiki. While each community recognises the potential benefits of aquaculture for their people, they also emphasize the importance of ensuring that future initiatives align with their values, aspirations, and responsibilities as kaitiaki.

Preliminary business analysis

Pātiki tōtara commanded premium prices in both export and domestic markets in comparison to the average seafood export price. Wild catch volumes have decreased largely due to regulatory constraints, but consumer demand appears to remain strong, indicating an opportunity for sustainable aquaculture product to meet market demand. Additional market analysis to understand consumer preferences and substitution behaviours will be crucial to identify market niches and optimise product positioning.

Potential revenue per hectare

Preliminary economic analysis highlighted the lack of specific data relevant to pātiki tōtara aquaculture and key values were often substituted from other farmed flatfish species. Land-based production of pātiki tōtara was assumed to be sustained at least 40 kg/m^2 of fish per year with harvest at approximately two years of age. Considering the 2020 port price index, such production levels could generate NZD 1.66 million in revenue per hectare annually. This compares favourably with local kiwifruit returns, of NZD 137,524/ha (SunGold) and NZD 57,636/ha (Zespri Green) in 2022/23.

Capital cost of establishment

Expenses related to land acquisition, earthworks, and equipment would be necessary to establish a land-based aquaculture operation. Factoring in consenting and project management expenses, the total cost for land, earthworks (NZD 120/m3), and pond-liners was estimated at approximately NZD 1.5 million/ha. Equipment costs, including pumps, filters, and storage tanks, are estimated at NZD 700,000/ha. Comparisons with kiwifruit orchard establishment costs reveal that the estimated pātiki aquaculture setup expenses could be three-to-four times higher per hectare.

Operating Costs

The inflation-adjusted production cost per kilogram of harvested fish based on estimates from European flatfish data translates to approximately NZD 21.96/kg in 2024, equating to NZD 8.78 million per hectare. Estimates based on European data for fingerlings, feed, and labour were the greatest projected expense. Comparatively, kiwifruit orchards incur significantly lower operating costs, highlighting a significant economic disparity between the two ventures.

Conclusions

While the projected revenue from pātiki aquaculture appears promising, it falls short of covering the estimated acquisition costs of juvenile fish and total production expenses. However, despite the current economic impracticality, avenues for cost reduction and optimisation may still exist. Future research priorities include methodologies to:

- reduce juvenile production costs
- enhance feed conversion efficiency
- minimise labour and energy requirements.

Innovative approaches, such as low or semi-intensive mesocosm production, might offer solutions to mitigate operational expenses and improve overall financial viability.

Broodstock technology to support hatchery development of pātiki tōtara

In commercial aquaculture, bottlenecks during the hatchery phase create challenges for the supply of juveniles to the wider industry. Wild caught broodstock often experience stress-related reproductive failure which leads to a shortage of eggs for larval production. Hormonal interventions, such as GnRHa injection, effectively stimulate reproduction and synchronize ovulation, to overcome reproductive failure in captive fish. GnRHa induces final maturation in oocytes (developing eggs). This is a critical developmental stage at which reproductive failure commonly occurs. Controlling broodstock reproduction is an essential step for securing juvenile supply.

Induced reproduction in pātiki tōtara

The current study aimed to establish a method for inducing reproduction in wild-caught pātiki tōtara to advance hatchery broodstock technology. A captive experimental broodstock was established in land-based recirculating seawater systems, and fish were administered one of three different treatments: a saline control, and two doses of GnRHa hormone. Ovarian tissue biopsies were collected at regular intervals, and fish were monitored daily for signs of ovulation.

Results indicated that reproductive failure occurred in wild-caught pātiki tōtara following capture. Saline-injected control fish showed no sign of progressive oocyte development. However, treatment with GnRHa showed promise in stimulating ovarian development, with a majority of fish in the 50 µg kg-1 group and some in the 100 µg kg-1 group progressing through final oocyte maturation stages. Ovulation occurred only in fish from the GnRHa treatment groups. The mean fecundity per ovulated batch of eggs was approximately 34,000 per 100g of bodyweight. These findings suggest that GnRHa injection stimulated ovarian development, while untreated fish did not continue to develop or ripen ovaries.

Treatment with GnRHa yielded good quality eggs with fertilization rates ≥ 80% although this was not consistent for all egg batches. The best response in terms of oocyte maturation and ovulation was observed in the 50 µg kg^{-1} treatment group. GnRHa treatment did not, however, guarantee ovulation. Histological evidence suggested that some of the fish already exhibited oocyte degradation, or atresia, before the study began. Stress-related factors and the amount of time that the fish were held prior to the experiment may have impacted treatment efficacy. While the study primarily focused on female pātiki tōtara, milt production appeared low in males even with GnRHa treatment. This result may indicate a challenge for future hatchery development.

In summary, GnRHa may be an effective short-term treatment for overcoming capture-related reproductive failure in pātiki tōtara broodstock and advancing hatchery technology. Best practice involves capturing broodstock close to the breeding season and administering treatment as soon as possible to minimise stress-related oocyte atresia. Long-term goals should focus on broodstock acclimation to promote natural ovulation without hormonal intervention. This approach is likely to yield optimal gamete quality.

Future perspectives

The study shows that significant interest in pātiki aquaculture exists within the partnering communities. This interest is primarily focused on stock enhancement and commercial production. However, preliminary economic analysis suggests operational costs may outweigh returns. If there were to be further interest in developing pātiki aquaculture, then targeted research is needed to address the feasibility of pursuing these aspirations.

If a stock enhancement program were to be developed, it would be essential to ensure that the release of hatchery-reared fish does not negatively impact existing populations. Understanding trophic interactions, managing broodstock genetics, and initiating small-scale trials to assess program effects would be important research avenues. This research would also involve estimating ecosystem carrying capacity, and the best ways to obtain social license and regulatory consent.

It would be essential to establish a hatchery for both stock enhancement and commercial aquaculture purposes. But significant capital and operational costs would be involved, and economic analysis casts doubt over the viability of such a venture. To provide more accurate economic data for this species, further research needs to validate juvenile production under low- and high-intensity models. If this species-specific data improves the economic prospects, then further research should:

- assess grow-out performance using sustainable production systems
- identify suitable locations
- manage broodstock genetics
- evaluate disease management strategies.

Based on the limited data at hand, the most promising future for pātiki aquaculture may lie with extensive, low-intensity production methods. Aside from the benefits of lower production costs, this approach is most likely to align with community values.

Contents

Introduction

The blue economy seeks to foster economic prosperity, social equity, and community wellbeing by harnessing marine resources and simultaneously prioritising environmental sustainability. Quadruple bottom line (QBL) reporting advocates for the consideration of social, cultural, and environmental factors alongside financial elements in business operations. While companies embrace QBL values to varying extents, there tends to be an emphasis on the financial aspects. In contrast, traditional Indigenous economies have historically thrived in non-monetary cultures, where humans exist as an integral element within nature. Here, the wellbeing of the people was inherently intertwined with that of the environment. Despite coexisting within capitalist frameworks and contributing to local economies, these cultural values remain deeply ingrained today. Including Indigenous stakeholders and their unique perspectives should be considered vital to fully realising the blue economy.

Aquaculture presents an avenue for sustainable production of nutritious, high-value protein. As populations continue to grow, the strain on environmental resources underscores the importance of food security, sustainability, and community wellbeing. Consequently, most seafood production has shifted from wild capture to aquaculture, making it the fastest-growing primary industry globally. In regions like Aotearoa, New Zealand, fin-fish aquaculture predominantly revolves around salmon and, more recently, land-based yellowtail kingfish farming. However, these ventures entail significant infrastructure costs which necessitate corporate-scale investment. These financial barriers can exclude rural coastal communities that aspire to become stakeholders in the industry.

Reimagining the conventional aquaculture model to align with traditional cultural values holds promise for enhancing community wellbeing while also rebalancing the QBL outcomes that are rarely seen in corporate entities. When guided by sustainable principles, aquaculture can safeguard wild stocks, bolster food security, and offer education, skills, and employment opportunities, thereby encouraging self-determination. These practices enable Indigenous communities to fulfill their custodial responsibilities towards the environment and foster a deeper cultural connection and contribute to overall community well-being.

Background

Global flatfish aquaculture

Flatfish have been an important component of human diets for centuries. Their high nutritional profile and sought-after white flesh (Puvanendran et al., 2003) have fueled overexploitation, leading to stock declines since global wild capture fisheries peaked in the 1970s (Cheung & Oyinlola, 2018). Market demand, however, has not abated with the global flatfish market currently valued at USD 1.1B (Food and Agriculture Organisation of the United Nations, 2020). The majority (85 %) of these fish are supplied from wild capture fisheries. Major export markets span three continents with Japan, Italy and the United States, featuring as key consumers. Primary exporters include China, South Korea, and Norway with typical market prices of approximately NZD $13-31/kg (Tridge: Global Food Sourcing & Data Hub, n.d.), with current market trends indicating an increase in demand for flatfish products (Nelson, 2020).

Flatfish aquaculture has evolved to become a high-value industry in a diverse range of countries, due to market demand and the associated decrease in wild caught resources. Several key species are commercially farmed, including European turbot (*Scophthalamus maximus*), olive flounder (*Paralichthys olivaceus*), Atlantic halibut (*Hippoglossus hippoglossus*), Senegalese (*Solea senegalensis*), and the common sole (*Solea solea*). Many other species are in varying stages of production or industry development across several continents.

Production methods

A range of systems from simple, low-cost methods to expensive technology-driven solutions can be used for the commercial production of flatfish species. Flatfish have been farmed using different holding environments. Their flattened body-plan has evolved to suit a benthic lifestyle. This adaptation means that they spend comparatively less time actively swimming in the water column and have a reduced energy demand compared to most cultured round-fish. As a result, flatfish also tend to require less water depth in a farmed environment. European turbot and olive flounder are typically farmed in outdoor land-based tanks or raceways with less than 1m of water depth (Watanabe & Daniels, 2010; Øiestad, 1999).

To increase production efficiency in Europe, turbot are increasingly produced indoors using recirculating aquaculture systems (RAS). This allows a more stable temperature to be maintained, improving growth and only requiring as little as 5-10% water exchange per day. In China, plastic tunnel houses may be used to help moderate winter temperatures. In contrast to these techniques, Atlantic halibut require greater depth, and are farmed in outdoor tanks of approximately 1.2 – 3m depth or in coastal sea cages (Brown, 2010). Unlike most flatfish, halibut appear to readily settle on shelves, which can be used in both tanks and cages to optimise the volume of the environment. In most outdoor situations the production environment is covered with netting and shade-cloth to reduce predation, UV damage, and swimming activity.

Extensive or semi-intensive systems based on earthen ponds are used to rear Senegalese sole in Portugal and Spain (Brown, 2002). This is a simple, low infrastructure system, which may use either tidal exchange of water or pumping. These farms are usually integrated with other fish species such as European seabass (*Dicentrarchus labrax*) or gilthead seabream (*Sparus aurata*) (Colen, Ramalho, Rocha, & Dinis, 2014). Intensive production of Senegalese sole can also be achieved using recirculating aquaculture systems (RAS).

New Zealand's aquaculture industry

Although the domestic aquaculture industry is small on a global scale, it possesses significant potential for regional economic, cultural, and social development. The New Zealand government outlined a vision in the 2019 Aquaculture Strategy to leverage industry growth to $3 billion in annual sales by 2035. With total sector revenue of NZD 671m reported in 2022 (Aquaculture New Zealand, 2022), significant expansion of the industry in terms of existing scale, technology, skilled labour, and diversity of production will be required to attain this goal.

Coastal aquaculture forms the cornerstone of the domestic industry, with approximately 1,200 marine farms in existence producing one of three key species. The sector has been dominated by the longline farming of Greenshell mussels, intertidal farming of Pacific oysters, and cage farming of Chinook salmon. Production of the latter accounted for NZD 300m of revenue in 2022 (Aquaculture New Zealand, 2022). Salmon are also produced to a lesser extent using inland freshwater canals that form part of the national hydroelectric power generation network.

Commercial-scale land-based aquaculture operations represent an underdeveloped aspect of the domestic industry. While there are established land-based hatcheries supporting the mussel and salmon industries, few grow-out operations currently exist. At present these include yellowtail kingfish RAS and pāua in Northland and in southern New Zealand, whitebait, or native larval galaxiid, production and a new pāua farm in Bluff. An advantage of land-based aquaculture is the possibility to contain and treat waste products as well as the ability to actively manage water quality within the farm environment. While these operations currently account for a much smaller proportion of the overall industry revenue, they underscore the diversification and innovation developing within New Zealand's aquaculture industry.

Developing the domestic blue economy

While sustainability may be an important pillar of the New Zealand aquaculture industry, most operations are primarily focused on profit generation. This relates to the scale of capital investment and the company structure requiring returns on shareholder investment. While this is a legitimate goal for companies operating within a competitive economic environment, other potential stakeholders exist who view aquaculture as an opportunity to deliver different outcomes. Coastal Indigenous communities have strong cultural and social connections to the marine environment. In many cases, declines in local marine resources have been witnessed during the period of rapid population growth and development associated with the modern post-colonial society. In these rural communities, the ability to exercise kaitiakitanga, or stewardship, over the marine environment as well as the appropriate tikanga (traditional practice) around food gathering is an integral aspect of cultural identity and freedom. Moreover, many of these communities struggle with economic deprivation and experience reduced health and well-being (hauora and oranga).

Aquaculture could provide an avenue to help preserve specific tāonga species of high cultural value and enhance opportunities for coastal communities to continue integral customary practices. In many instances, the key species of interest will also have commercial value and offer the opportunity for local revenue generation to further assist community self-determination (mana motuhake). Under this model, the primary focus of aquaculture is to enhance the social wellbeing of a community of stakeholders. This aspiration strongly aligns with those defined for the blue economy by the World Bank; '*The need to balance the economic, social, and environmental dimensions of sustainable development in relation to oceans*', where; '*sustainable development implies that economic development is both inclusive and environmentally sound, and to be undertaken in a manner that does not deplete the natural resources that societies depend on in the long term'*. The development of an equitable blue economy that includes the needs of coastal communities in New Zealand should investigate how aquaculture might contribute to this outcome.

The value of endemic yellowbelly flounder

Pātiki tōtara, or yellowbelly flounder (*Rhombosolea leporina*) are a right-eyed flatfish species endemic to New Zealand. They are widely distributed around the country but are mostly found in North Island waters, where they inhabit shallow muddy bays, estuaries, and harbours. They may also be found along open sandy coasts down to 30 m depth (Colman, 1973). Pātiki eat relatively low on the food-chain, consuming a range of benthic invertebrates including small crustaceans and worms. Growth differs according to sex (sexually dimorphism), males reach 24 cm and females 29 cm total length (TL) in northern New Zealand after two years (Colman 1974). The maximum size is believed to be approximately 45 cm TL which may be attained after three years.

The high flesh quality of this species has seen significant commercial and recreational fishing pressure develop over recent decades. At present, retail value fluctuates between approximately NZD 25 – 35/kg for a whole (gilled and gutted) fish. This is a high price-point in comparison to other popular high-value species based on whole weight. Moreover, local observations report that the number of pātiki tōtara are declining in many harbours around the country which may relate to a combination of human-related factors. Anecdotal reports suggest that the commercial fishing industry may also be struggling due to increasing compliance costs. If these factors lead to decreased market-supply then the commercial value of this species can be expected to remain high.

The cultural value of pātiki tōtara, however, is historic and does not fluctuate. For many coastal Māori communities, pātiki tōtara are considered a tāonga species and are an important traditional food resource (Wham, 2020). For many coastal communities, declining stocks directly affect their ability to exercise kaitiakitanga over the environment and the tikanga of food gathering which are deeply embedded in culture. Ensuring that local pātiki tōtara stocks endure sustainably, is strongly linked to social well-being.

Aims and objectives

This report investigates the possibility of developing aquaculture of pātiki tōtara in coastal communities in New Zealand. The primary aim was to identify how flatfish aquaculture might be used to develop an inclusive local blue economy to improve the overall well-being of these communities. This was approached through three key objectives.

1. The co-development of a vision for kaupapa-based pātiki economies

2. A preliminary business analysis of pātiki aquaculture

3. The development of hatchery techniques to produce a supply of quality eggs from broodstock fish to support future hatchery advancement

To meet these objectives, the study partnered with coastal Māori communities in the Bay of Plenty, specifically the hapū of Matakana and Rangiwaea islands and Whakatōhea, It was anticipated that this work may indicate an opportunity for a unique aquaculture vision that could lead to new stakeholders entering the inductry to help diversify and strengthen the existing aquaculture industry.

Imagining kaupapa Māori pātiki economies

Aotearoa pātiki relations, rights, and responsibilities

Pātiki (flounder) are a culturally important species in Aotearoa-New Zealand (Ellis-Smith, 2022) and are considered taonga by many Māori groups. The definition of taonga varies across Aotearoa, but generally, taonga can be defined as "treasured possessions, including property, resources, and abstract concepts such as language, cultural knowledge and relationships" (Waitangi Tribunal, 2011, p. 749). Pātiki have been a part of Māori mahinga kai (food gathering and stewarding) practices mai rānō (for a very long time). Groups that hold these long-term kin-based relationships with pātiki include whānau, hapū, and iwi in the Ōtaki area (Best, 2005), Kopupātiki village (Robin-Middleton, 2019), Aotea harbour (Moana Rāhui o Aotea, n.d.), Waipawa River and Papanui stream (Wakefield et al., 2013). Rangitane (Walker, 2017), Ngāi Rārua (Sutton et al., 2022), Ngāti Maniapoto (Maniapoto Māori Trust Board, 2015) and Ngāi Tahu (Tahu, 2015) also have long-term relations with pātiki. The two case study groups in this report Matakana and Rangiwaea hapū and Whakatōhea also consider pātiki taonga.

The importance of pātiki is highlighted in whakataukī (proverbs), pūrākau (narratives) and toi Māori (Māori art) that have been used by Māori groups to express and share mātauranga and tikanga across generations. For example. Whaanga et al (2018) studied environment-related whakatauki and found six pertaining to pātiki. One of the most well-known is; *E kore te pātiki e hoki ki tona puehu - The flounder does not go back to the mud it has stirred.* Elder (2020) posits that this is related to human fears of the unknown as well as the fact that sometimes it is best to walk away from our mistakes rather than address them. Diamond-shaped pātiki designs are common in Toi Māori. Ngati Porou attribute their prevalence to the fact that pātiki are able to provide sustenance for a large number of people (Ngā Puna Waihanga - Waitaha Tai Poutini, 2003). Pātiki designs are also common in kōwhaiwhai (Potaka, 2021) and tukutuku (Te Kanawa, 2013) (Māori patterns). Whakatōhea Māori Trust Board for example, have a pātiki design on the tukutuku panels in their boardroom (Figure 1).

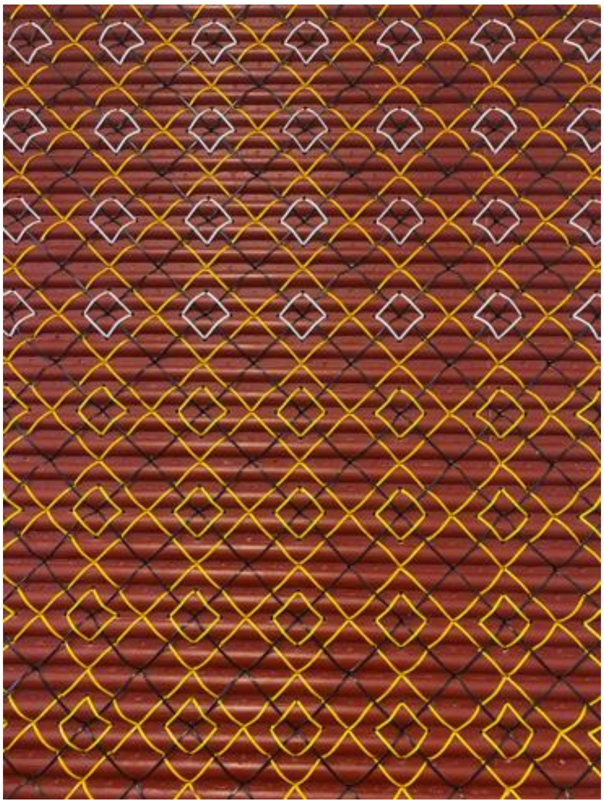

Figure 1: Pātiki pattern on tukutuku design in the Whakatōhea Māori Trust Board boardroom (Photo credit: Georgia Mcllelan).

Māori have inherent rights and responsibilities related to their taonga. Both Te Tiriti o Waitangi signatory and non-signatory groups hold mana motuhake (indigenous autonomous power) over their taonga (Simon, 2016), including pātiki. Here, we attempt to depict what mana motuhake-driven aquaculture economies might look like for our partnering communities. We draw from kōrero about their concerns and aspirations for pātiki aquaculture in their respective rohe.

Pātiki aquaculture aspirations: Matakana and Rangiwaea hapū

Matakana and Rangiwaea are two neighbouring islands located under the shadow of Mauao (Mount Maunganui) in Tauranga Moana. Five hapū whakapapa back to these islands; Te Whanau a Tauwhao, Te Ngare, Ngāi Tamawhariua, Ngati Tauaiti and Ngāi Tuwhiwhia (Matakana & Rangiwaea Island, 2012). Many whānau who reside on the islands have lived there their whole lives (Matakana & Rangiwaea Island, 2012). There is a strong hapū presence on the islands and they hold deep connections with their whenua and the moana that surround them: Te Awanui (Tauranga Harbour) and Te Moana-nui-ā-Toi (coastal waters) as well as various freshwater bodies (Matakana & Rangiwaea Island, 2012). Mana whenua refer to these water bodies as their pātaka kai (food cupboards). Kaimoana, including pātiki is a fundamental food source that has served whānau on these islands, mai rānō, for a very long time (Matakana & Rangiwaea Island, 2012).

Like other Māori groups throughout Aotearoa, Matakana and Rangiwaea hapū have suffered greatly due to colonisation and the ongoing effects of settler-colonialism, which, among other things, have affected their access to kaimoana, including pātiki (Matakana & Rangiwaea Island, 2012). The hapū have expressed their concerns about a) dredging of the Tauranga harbour and b) the increasing number of recreational and commercial fishers around the islands, which are both impacting their access to kaimoana (Matakana & Rangiwaea Island, 2012). The hapū have identified restoring kaimoana breeding grounds as a priority (Matakana & Rangiwaea Island, 2012). This intent speaks to their interest in taking part in Pātiki aquaculture, especially its potential to positively impact wild pātiki stocks. The following sections consider the aspirations and concerns that Matakana and Rangiwaea hapū hold around the implementation of pātiki aquaculture in their rohe.

Key aspiration 1 - Tino rangatiratanga (self-determination)

"For many years we have allowed outsiders to dictate our needs ... to service our industries, maintain our roads, develop our land and use our resources. This has led to a gradual loss of control over tribal land and resources while outside interests have benefited with minimal returns to the island community to reassert itself and consolidate our control over its remaining resources. We must look at buying back land, leases, and industries as we are able; we must enclose all services and industries. We must restore our mana and independence and face up to the challenge of social change." Sonny Tāwhiao, (Matakana & Rangiwaea Island, 2012, p. 20)

Sonny Tāwhiao's quote above shows Matakana and Rangiwaea hapū have, in the past, experienced a loss of tino rangatiratanga over their taonga, whenua, and moana. In setting up pātiki aquaculture, Matakana and Rangiwaea hapū wish to ensure that they maintain complete control over their resources as their right as tangata whenua. Matakana and Rangiwaea hapū posited that, if pātiki aquaculture on the islands was to implement tino rangatiratanga, it would be guided by both:

- hapū level (rather than iwi or trust board level) decision-making and control
- Matakana and Rangiwaea-based mātauranga, tikanga and kaitiakitanga.

Implementing Matakana and Rangiwaea-based mātauranga, tikanga, and kaitiakitanga means allowing and enabling the hapū to carry out their responsibilities as tangata whenua (Matakana & Rangiwaea Island, 2012). For mātauranga, the hapū have noted that they want a healthy synergy of local mātauranga and Western science to be used when setting up and operating pātiki aquaculture on the islands. Kaitiakitanga practices, in this instance, might involve aquaculture operations that work to protect and preserve indigenous species and retain the traditional character of the Islands (Matakana & Rangiwaea Island, 2012). Adhering to tikanga means that pātiki aquaculture operations work to reinstate and/or maintain whānau access to traditional food sources, including pātiki.

Key aspiration 2 - Balancing cultural, social, environmental and commercial imperatives

"*The economic well-being of hapū cannot be measured in monetary terms alone. Our economic health is inextricably linked to our cultural, social, and environmental well-being*" (Matakana & Rangiwaea Island, 2012, p. 19).

As outlined in the quote above, it is vital for any pātiki aquaculture that may take place on the islands to contribute to cultural, social, and environmental outcomes for whānau. Matakana and Rangiwaea hapū are intent on developing an aquaculture economy that is as environmentally sustainable as possible. Whānau discussed three main aspects of a sustainable pātiki aquaculture operation. Firstly, one whānau member discussed the possibility of a venture that puts half of its stock produced into the wild and sells the other half. Secondly, whānau discussed setting up a circular aquaculture system that would reduce waste. Lastly, whānau were interested in sustainable pātiki feed. An aquaculture system that incorporates these three aspects would enhance whānau access to pātiki (both wild and farmed), enhance the mauri of the environment, and generate revenue. In turn, it would allow whānau to fulfil their responsibilities as kaitiaki and contribute to cultural, social, environmental, and commercial outcomes.

For their commercial goals, Matakana and Rangiwaea hapū have made it clear that they want any commercial benefits from pātiki aquaculture operations to filter back into their community. One of the main points highlighted in their hapū management plan is the lack of employment opportunities on the islands. Whānau members have been leaving the islands since the 1950s to seek employment elsewhere, and some of them would now like to return to the islands but are unable to due to the lack of job opportunities (Matakana & Rangiwaea Island, 2012). On top of this, wages on the islands are generally less, and expenses are higher, than on the mainland. This discrepancy is largely due to elevated operational costs, which makes it even harder for whānau to live on the islands (Matakana & Rangiwaea Island, 2012). Hapū-run pātiki aquaculture could increase living-wage employment opportunities on the islands so that more whānau are able to live on their whenua. Alongside generating employment, whānau may view pātiki aquaculture as an opportunity to generate funding for infrastructure and support services, education and training, marae facilities, hauora services, recreation and sporting activities, and durable housing on the islands (Matakana & Rangiwaea Island, 2012).

Matakana & Rangiwaea - Pātiki aquaculture concerns

Matakana and Rangiwaea hapū discussed four key concerns with the potential implementation of pātiki aquaculture on their islands.

a) *Taste* - the first concern pertained to the taste of farmed pātiki as opposed to wild-caught pātiki. Taste is a very important part of the significance of pātiki for whānau. They know and value the specific taste of flounder that they have grown up eating.

b) *Western science* - the second main concern voiced by hapū surrounded Western science that might be used within the implementation of pātiki aquaculture on the islands. Some of the conventional aquaculture techniques discussed, such as the use of hormones and selective breeding, were considered potentially confronting as they did not feel natural. This is where it is important to address whānau aspirations around blending mātauranga and Western science.

c) *Transport costs* - the third main concern had to do with the cost involved in transporting infrastructure to and from the islands. Costs to operate businesses on the islands are also understandably higher than on the mainland (Matakana & Rangiwaea Island, 2012).

d) *Land use* - another concern is related to land where pātiki aquaculture might take place. Across the islands, multiple Māori trusts administer Māori land blocks with multiple owners. There are also many land blocks without trusts or formal admin (Matakana & Rangiwaea Island, 2012). Attempting to establish administration over these blocks and use them for purposes such as aquaculture may be difficult as it will involve working with several owners who don't necessarily reside on the islands (Matakana & Rangiwaea Island, 2012).

It will be important to address whānau aspirations and concerns about the implementation of pātiki aquaculture in their rohe if further research is to continue and if pātiki aquaculture is to be actualised on the islands.

Pātiki aquaculture aspirations: Whakatōhea

Whakatōhea are an iwi located in the Ōpōtiki area approximately 150 kilometres southeast of Matakana and Rangiwaea islands. Whakatōhea is made up of six hapū Upokorehe, Ngāti Patumoana, Ngāti Ira, Ngāti Ngahere, Ngāti Rua, and Ngāi Tamahaua. For Whakatōhea, taonga are, *"anything tangible or intangible that contribute to the tribes' intellectual (taha hinengaro), physical (taha tinana), and spiritual wellbeing (taha wairua)" (Whakatōhea, 1993, p. 9)*. Whakatōhea relationships with taonga are based on both whakapapa relations and *"long-form physical associations and experiences"* (Whakatōhea, 1993, p. 5). In this way, pātiki can be considered taonga as they are a sustainable source of kai that has been harvested by whānau mai rānō.

Whakatōhea have a set of customary rights and responsibilities, exercised through tino rangatiratanga and kaitiakitanga, which allow them to harvest and manage their taonga, including fisheries, in a way that reflects their aspirations (Whakatōhea, 1993). Whakatōhea have made clear their need to *"ensure absolute protection of customary fishing rights, traditional fisheries resources and habitats."* (Whakatōhea, 1993, p. 36). Whakatōhea rights and responsibilities in relation to their taonga are confirmed and guaranteed by Te Tiriti o Waitangi, which was signed by several Whakatōhea chiefs on the 27th of May 1840 (Whakatōhea, 1993). However, much like Matakana and Rangiwaea hapū, these rights and responsibilities have been eroded over time through colonisation and subsequent settler-colonialism.

Over time, Whakatōhea have lost a significant amount of access to their traditional fisheries resources due to *"overharvesting, overfishing, and mismanagement of traditional fisheries resources by government, commercial, and recreational interests"*, among other things (Whakatōhea, 1993). Awa (rivers) in the Whakatōhea area have slowly degraded due to the many environmental effects of settler colonialism (Mclellan, 2020; R. Walker, 2007). Whānau also suspect that commercial fishing negatively impacts pātiki. Subsequently, pātiki numbers have dropped over time, but they are still a prominent source of kai in the rohe. Whakatōhea whānau harvests pātiki via several methods, including plonking, net setting, spearing, and with their feet. Below, we discuss some of Whakatōhea's aspirations and concerns about potential pātiki aquaculture in their rohe.

Key aspiration 1 - Tikanga and mātauranga and kaitiakitanga

For Whakatōhea, any pātiki aquaculture that takes place in the rohe must acknowledge and implement Whakatōhea-based tikanga, mātauranga, and kaitiakitanga, including whakapapa-based relations. Incorporating mātauranga-a-Whakatōhea might mean taking into account Whakatōhea specific whakataukī, pūrākau, waiata and place names that highlight their relations with the pātiki. For example, Kōpua Pātiki is a popular area for catching pātiki at Tōrere near Ōpōtiki. Furthermore, a famous Whakatōhea haka called *Te Tapu o Muriwai* makes mention of pātiki. Local knowledge pertaining to taniwha, tidal currents, seasons and māramataka (lunar cycles) should also be acknowledged and implemented.

Whakatōhea have a specific set of tikanga related to stewarding and distributing their taonga, including tikanga-driven limits on production. Whanau discussed some important tikanga, including manaakitanga, i.e. distributing pātiki to kaumatua and mahinga kai, i.e. enhancing whānau access to pātiki as a traditional food source. Whakatōhea's hapū management plan (Whakatōhea, 1993) highlighted tapu and rāhui as useful tools for managing taonga as well as the importance of working to balance the taha tinana, taha hinengaro, and taha wairua of taonga. Serving the collective interest over the individual and prioritising the rights of individual hapū were also emphasised in the iwi management plan (Whakatōhea, 1993). These are all significant Whakatōhea tikanga that should be taken into account within the implementation of pātiki aquaculture in the rohe.

For Whakatōhea kaitiaki, responsibilities include observing tikanga, protecting the mauri of all things, passing down high-quality taonga to their mokopuna and opposing all developments that have the potential to adversely affect taonga (Whakatōhea, 1993). In modern times, Whakatōhea kaitiakitanga practices incorporate both traditional and Western approaches because; a) contemporary contaminants require contemporary solutions and; b) Te Tiriti o Waitangi incorporates both sets of knowledge (Whakatōhea, 1993). Part of being kaitiaki is also recognising that, in order for pātiki to thrive in the wild, the whole ecosystem needs to be healthy. It is vital that any pātiki aquaculture that takes place in the rohe enables Whakatōhea whānau to carry out their obligations and responsibilities as kaitiaki.

Key aspiration 2 - Balancing cultural, social, environmental, and commercial imperatives

Whakatōhea's resource management plan highlights their wish to *"restore and sustain the economic base of Whakatōhea for the collective political, social, and cultural wellbeing of Whakatōhea"* (Whakatōhea, 1993, p. 23). Both Matakana and Rangiwaea hapū and Whakatōhea want to find the right balance between cultural, social, and environmental outcomes when it comes to pātiki aquaculture. While Whakatōhea pursue commercial goals with pātiki aquaculture, it is vitally important to them to:

- be able to carry out their responsibilities as kaitiaki
- maintain whānau access to wild pātiki stocks.

For Whakatōhea whānau, the benefits of wild harvest far outweigh the benefits of purchasing pātiki from a shop. To this extent, Whakatōhea have a strong interest in the possibility of using pātiki aquaculture for stock enhancement in their rohe.

Whakatōhea whānau must be able to carry out an environmentally focused pātiki operation alongside any commercial operation that might take place in the rohe. Whānau discussed some environmental goals they have for pātiki that might become part of this operation. Firstly, they are eager to partake in pātiki monitoring, sampling, and habitat testing in different parts of the rohe to track the mauri of the pātiki, including the quality of their habitat and their access to healthy food. In relation to this, whānau are curious about what impacts the recent Ōpōtiki Harbour and upcoming marine precinct development (Ōpōtiki District Council, 2023) might have on the mauri of pātiki. Whakatōhea are in the process of setting up an iwi research centre that could potentially be involved in this monitoring process. Secondly, as mentioned above, whānau are interested in implementing a hatchery programme to release juvenile pātiki back into the environment to replenish and enhance the wild stock.

Whakatōhea realise that establishing and operating a stock enhancement program will incur financial cost. They have identified that commercial pātiki production could provide an income stream to help support such a program. Whakatōhea whānau are not interested in developing a typical profit-maximising business. Rather, they wish to use revenue generated to create positive outcomes for their people and the environment. One way to do this is through employment; pātiki aquaculture could provide opportunities for employing Whakatōhea whānau. Two specific initiatives to enhance whakatōhea livelihoods through pātiki aquaculture were mentioned by whānau.

1. Revenue could be used to provide whānau with free and/or subsidised pātiki.
2. Revenue could be used for educational purposes to teach whānau how to harvest pātiki themselves or set up their own whānau and/or hapū level pātiki aquaculture system.

Whakatōhea students could also study towards an aquaculture or aquaculture-related degree at an iwi pātiki farm. One whānau member discussed their desire to incorporate traditional methods of exchange, including trading and bartering, into pātiki aquaculture in the rohe. Another Whakatōhea whanaunga discussed the potential for linking pātiki aquaculture to Whakatōhea's successful commercial mussel venture, suggesting that mussel slurry might be used for pātiki feed.

Pātiki aquaculture concerns

Whakatōhea whānau have three key concerns over the potential implementation of pātiki aquaculture in their rohe.

a) *Taste* - like the Matakana and Rangiwaea hapū, Whakatōhea whānau are also concerned about the taste of farmed pātiki and how it would compare to the taste of the wild-caught pātiki they're used to.

b) *Crown-related barriers* - whānau are also concerned about crown-related barriers, including policy and legislation that may inhibit pātiki aquaculture in the rohe and/or make it very expensive to implement.

c) *Tikanga in a factory setting* - Perhaps what Whakatōhea whānau are most concerned about is maintaining tikanga in a factory or farm setting. Farming pātiki fundamentally changes the relationship between Whakatōhea whānau and their taonga, the pātiki, a gift from Tangaroa. It is vital for the people of Whakatōhea that the mauri and the mana of the pātiki is maintained during the aquaculture process. Thinking about pātiki living in a sterile, commercial environment is challenging for some whānau. Whānau would like the aquaculture environment to replicate the pātiki's natural environment as much as possible.

For a local pātiki aquaculture operation to succeed it will be essential to consider and implement these aspirations and concerns expressed by whānau.

Conclusion

The above kōrero has summarised the aspirations and concerns of the two partnering communities in respect to pātiki aquaculture in their rohe. Matakana and Rangiwaea hapū aspirations for pātiki aquaculture revolve around maintaining and enhancing tino rangatiratanga and balancing environmental, cultural, social, and commercial imperatives. They have concerns regarding pātiki taste, Western science, transport costs, and land use. The Matakana and Rangiwaea hapū members that we met were, understandably, unsure about whether they wanted to pursue pātiki aquaculture on their islands. They are taking the time to discuss the idea with their wider whānau members to fully consider their potential priorities for such a project. They would only pursue this further if a strong appetite for this concept exists around the islands.

Whakatōhea whānau’s aspirations are similar; they aspire to incorporate mātauranga, tikanga, and kaitiakitanga into pātiki aquaculture operations, and like Matakanana and Rangiwaea hapū, they wish to balance environmental, cultural, social, and commercial imperatives. Their primary interest in pātiki aquaculture is toward stock enhancement with a secondary focus on commercial production. They harbour concerns about the taste of farmed pātiki as well as crown-related barriers and how tikanga may work in a factory setting. The aquaculture environment should be as natural as possible to uphold the mauri of the fish. The Whakatōhea whānau members with whom we have had kōrero, are interested to further explore the potential for pātiki aquaculture in their rohe but also recognise the need for more information in the meantime.

Preliminary business analysis of a potential pātiki industry

The New Zealand aquaculture industry is relatively small and has remained largely undiversified over the last 50 years in comparison to many of its international competitors. This limits the scope of expertise and scale of infrastructure that may otherwise be available in a more mature primary industry. Access to research, breeding programmes, fish health experts, local feed industry, equipment suppliers, market pathways, and other technical support and expertise is affected. There is, however, a growing recognition that New Zealand aquaculture presents an opportunity to use our innovative culture and unique provenance, including the incorporation of Te Ao Maori, to develop commercially viable aquaculture opportunities. As highlighted previously, these may be led by cultural values and principles. As a tāonga species that also commands a high commercial value, pātiki tōtara present an interesting model with which to innovate and diversify the New Zealand aquaculture industry. These fish provide a niche product that is recognised for its quality within the domestic seafood market. And with inconsistent seasonal supply and increasing compliance costs impacting the wild-capture industry, demand is likely to outstrip supply in the future.

High market value and demand are only two important qualities that a new aquaculture candidate must associate with to be considered viable. An independent scoping review that was commissioned as part of this study identified additional criteria that determine the potential for economic success in a new aquaculture venture.

1. *Best product*: species, quality, food safety, sustainable, competitive pricing, consistent availability, taste profile, and good provenance.

2. *Best place*: site and technology that suits the biology, allowing good growth performance, accessibility to markets, setup and operational cost structure, low risk from natural disaster (flooding, earthquakes) and disease, as well as the legal and social setting.

Furthermore, the review highlighted five common constraints influencing the success of new aquaculture ventures in New Zealand:

1. *Market positioning*: finding a point of difference which the consumer will value over and above more traditional alternatives and which ensures margins are sufficient to ensure profitability.

2. *Productivity*:

    a. Broodstock – necessary to provide consistent reliable access to quality stock at a reasonable cost or price (see Section 5).

    b. Feed – consistent and reliable access to a food source.

3. *Environment or growing site*: in common with most primary industries, a level of vulnerability exists with operations in the natural environment including the risks of pests and diseases.

4. *Regulatory constraints*: this is particularly critical in the public water space of the marine environment, but land-based aquaculture can also encounter resource consenting, social license, and compliance constraints that need to be considered.

5. *Workforce constraints*: aquaculture, as a relatively immature but developing industry in New Zealand, has recently experienced workforce issues at both the expert and lower-skilled worker levels for a variety of reasons.

Many of the key factors highlighted above are yet to be analysed in depth for pātiki and the extent to which the associated constraints would impact a specific aquaculture venture remains unknown. However, before such research is commissioned and resources committed, it is useful to carry out a preliminary assessment of the viability of a venture based on the available data. The following analysis is based on the concept of commercial land-based pond systems that are used for fish production in some parts of the world.

Requirements for flounder aquaculture

No flatfish aquaculture ventures exist in New Zealand, despite great international interest in flatfish farming. Land-based pātiki tōtara aquaculture is a permittable activity pursuant to Regulation 2 of the Freshwater Fish Farming Regulations 1983 (Ministry for Primary Industries, 2020). Wild caught pātiki tōtara are sold into both the domestic retail and export markets and they occur as a seasonal item on local restaurant menus. Although it is not a large species, they exhibit relatively fast growth to attain plate size. In the wild, females reach a mean length of 30 cm after 2 years (Colman, 1974). Fish growth is related to temperature, genetic heritage, and other factors, such as diet. The possibility of enhancing growth performance in land-based facilities exists through regulation of environmental temperature, improved dietary food conversion ratio (FCR), and selective breeding. Studies in commercially produced salmonids have shown that genetic gains in growth of approximately 10% have been achieved with each subsequent generation (Neira et al. 2006). Considering that yellowbelly flounder can become reproductive after two years, there may be great potential to rapidly 'breed-in' advantageous traits such as enhanced growth and disease resistance. It should be noted however, that developing a selective breeding program would need to be carefully considered as this may not align with stakeholder interests, values or aspirations and would need to be a matter for stakeholder consultation.

Flatfish have been successfully farmed in various production systems based on species and location. Due to their sedentary benthic nature, cultured flatfish have been reported to perform well in shallow, land-based raceway systems (Merino et al., 2007; Øiestad, 1999).

Shallow raceways present a cost effective and sustainable culture system due to the possibility of excavating simple ponds and the ability to remove and treat organic waste before it can enter the environment. Trials with flatfish culture in other countries indicate moderately-high stocking densities (30 to 80 kg/m^2 in European turbot; Person-Le Ruyet, 2002) can be achieved without limiting growth rates compared to conventional land-based tanks (Labatut & Olivares, 2004). The possibility of producing yellowbelly flounder in land-based aquaculture eliminates many of the barriers and risks associated with ocean-based aquaculture, particularly because the ability to recirculate water can greatly reduce the demand for large volumes of fresh sea or brackish water. Land-based RAS commonly recirculate 90-99% of water (Badiola et al., 2012). This enables greater control over environmental effects and water quality parameters. It should be noted, however, that the cost of achieving a high-performance RAS system escalates rapidly with scale and production intensity. Another advantage for developing flatfish culture in New Zealand is the possibility to transfer existing technologies and research from the range of commercial flatfish species that are already cultured around the world.

Overall market potential

According to Seafood New Zealand (2023), flounder exports in all forms during 2023 totaled 173.4 metric tonnes (MT) with a value of NZD 2.31 million, or NZD 13.33/kg on average. This translates to an appreciable premium when compared to the mean seafood export value of NZD 9.07/kg for the same year. Most of the flounder exports went to Australia and almost all was exported chilled rather than frozen. Confidential data on NZ auction prices for yellowbelly flounder during 2023 and 2024 to date indicate that the domestic market price is on average, at least as high as that of the export market. However, as predicted above, price varied appreciably with the season.

The commercial availability of pātiki has declined over previous decades. According to MPI (2023, p. 335), landings of flatfish, including flounder, in 2021/22 totaled 1583 MT, which was down from 5160 MT in 1983/84. The Total Allowable Commercial Catch (TACC) for flatfish was reduced to 4546 MT per year in 2021/22, from 6670 MT per year between 1990/91 to 2006/07. This reduction was due to concerns about sustainability of the fishery. According to MPI's 2020 discussion paper (p. 11); *The average price paid by fishers during the 2019/20 fishing year for one kilogram of FLA 2 ACE was $0.92. The 2019/20 port price index of FLA 2 was $4.14kg.* So, approximately 22% of the landed price of wild flatfish caught in FLA 2 (MPI, 2023, p. 333) (flatfish management area 2, under the quota management system) was paid by commercial fishers to purchase their annual catch entitlement (ACE).

Based on this information, it is important to consider the following points.

- Flatfish landing volumes were historically much higher than at present, and these presumably supported significantly greater domestic and export sales volumes. The reduction of current landings is due to regulation rather than market change.
- A high acceptance by commercial fishers to pay for flatfish ACE implies continued demand for the product.
- Flounder secure a premium export price compared to the average seafood price.

Collectively, these points suggest that the market is likely to be open to additional supply of flounder through sustainable aquaculture, assuming that flounder can be produced at costs comparable to that of wild catch (including ACE).

An important step to establish market interest for additional flounder supply is to assess which existing food products consumers would consider substituting with flounder. This will most likely be another fish species, at least initially; identifying the criteria that customers use to select between flounder and other products is invaluable for market analysis. A preliminary market analysis could be carried out by interviewing consumers of fish using stated choice methods (Louviere et al., 2000).

Potential revenue per hectare

We estimate that harvesting flounder from land-based aquaculture at about two years of age should produce at least 40kg/m2 of fish per year. For comparison, density trials on Greenback flounder (Rhombosolea taparina), which is native to NZ and closely related to pātiki tōtara, showed that greenback flounder have similar growth performance at densities from 15.9kg/m2 to 61.1 kg/m2 (Hart, 2010).

Based on the 2020 port price index noted above, production at 40kg/m2 would provide NZD1.66 million in revenue per hectare per year.

If we assume that pātiki aquaculture would be carried out in the Bay of Plenty, it would be reasonable to compare this potential revenue with the average return for Zespri's highest-returning kiwifruit, SunGold. SunGold returned NZD137,524/ha to growers in 2022/23, compared to NZD57,636/ha for Zespri Green (Zespri, 2023).

In practice, effective pātiki aquaculture would require dry access to raceways, space for equipment and potentially space in which to grow food for the fish, so less than 100% of each hectare would be available for production. However, if the per-hectare revenue potential from aquaculture is approximately an order of magnitude more than that from kiwifruit, this would suggest that the concerns about high land costs expressed in the ADL report to WaikatoLink are not likely to be critical. The cost of the land is considered later in this chapter, along with the capital cost of establishing the aquaculture operation on that land.

Capital cost of establishment

For the three months ending July 2023, the median price of dairy and finishing farms in New Zealand was NZD38,850/ha and NZD34,690/ha respectively (REINZ, 2024). These farms typically include a combination of flat and rolling land, in which the flat land could be converted to land-based aquaculture while the rolling land could be leased to other farmers for dairy stock replacement or beef finishing.

According to Builder Connect (Guy, 2024), earthworks costs are typically between NZD30 and NZD120/m3, including excavation, soil removal, and grading. Similarly, as of 2023 according to Earthmoving Auckland, bulk earthworks may range from NZD70 to NZD90/m3 plus NZD30/m3 to remove soil (Earthmoving Auckland, 2023). So, conservatively assuming a total of NZD120/m3 for 1 ha of raceways dug 1 m deep, earthworks costs would total NZD1.2 million/ha. The cost of a dam liner to make the earthworks watertight would range from NZD521.64 to NZD1737.88 incl GST for a 10x8 metre sheet (Permathene New Zealand, 2024), or NZD5.67 to NZD18.89/m2 for a 300 to 1000 micron liner, i.e. NZD56,700 to NZD188,900/ha respectively.

Allowing for liner installation, consenting and project management costs, this would bring the land, earthworks, and liner total cost to about NZD1.5 million/ha.

Based on the costs of equipment (pumps, filters, data logging, storage tanks, electrical services, etc.) for a recirculating aquaculture system of about 0.2 hectare in size developed by colleagues of the author with a commercial partner, we estimate the equipment cost at about NZD700,000/ha, giving a total establishment cost for land-based flounder aquaculture of about NZD2.2 million/ha.

For comparison, costs to establish a hectare of kiwifruit production were estimated in 2019 at: NZD290,000 for a Gold3 fruit license (there is no license fee to produce green kiwifruit), NZD150,000 for site preparation, shelter development, trellis, and tree and planting costs, rising to NZD400,000 for very intensive operations that may include irrigation (Tupu.nz, 2024) (which would produce greater volumes of fruit and greater revenue). This gave a total establishment cost for a kiwifruit orchard of NZD480,000 to NZD730,000/ha.

This comparison indicates that the establishment cost for land-based flounder aquaculture is likely to be three to four times higher than for kiwifruit on a per-hectare basis. However, due to the potential annual revenue being more than ten times higher than for kiwifruit on a per-hectare basis, the ratio of annual revenue to establishment cost for land-based flounder aquaculture may, in fact, be more than *twice* that of a kiwifruit orchard, i.e. 0.75 for aquaculture vs. 0.29 to 0.19 for gold kiwifruit.

To understand the economic attractiveness of land-based aquaculture compared to other land-uses, however, we would have to understand the likely *profitability* of aquaculture, so would have to understand its operating costs.

Operating costs

The production costs for land-based summer flounder aquaculture in the United States were estimated in 2003 (Yates et al., 2020) (excluding building and equipment costs, which have been counted separately above).

- Fingerlings, 46%
- Feed, 17%
- Labour, 16%
- Electricity, 9%
- Interest, 4%
- Insurance, 4%
- Other, 4%

A 2014 analysis of sole farming in Europe (Bjørndal & Guillen, 2014) estimated an average cost of production of €9.62 per kg of harvested fish with juvenile costs at €1.20 per juvenile or €3.77 per kg of harvested fish (39% of the total) and feed at €1.52 per kg of harvested fish (or 16% of the total), Assuming a feed conversion ratio of 1.1 and an assumed 9.1% mortality over an 18-month growth cycle to a harvest weight of 350g per fish.

Feed conversion for Olive flounder is close to 1:1 (Seikai et al. 2010), and the ratio for European turbot is 1:1.2 - 1.3 (Person-Le Ruyot, 2010), but these are much more developed aquaculture species than yellowbelly flounder is today, and so have rapid growth.

Inflation in the Euro area since 2014 has been about 27.81% (Alioth Finance, 2024) and the Euro per NZ dollar exchange rate at present is about 0.56 Euro per NZD (Bank of New Zealand, 2024, May 24), which would make the production cost based on the European analysis about NZD21.96 per kg of harvested fish in 2024, or about NZD8.78 million per ha, using the production per square metre that was assumed earlier.

This clearly compares unfavourably with the operating costs for a kiwifruit orchard of NZD40,000 to NZD50,000/ha. The time from planting to first harvest can be as little as 3 years with a mature harvest after 5 to 7 years. Break-even for establishing a kiwifruit orchard can be as soon as 8 years and averages 12 to 15 years (Tupu.nz, 2024).

Conclusions

While having a superficially attractive revenue per hectare of NZD1.66 million based on the 2020 port price index or NZD3.63 million based on the 2023 export price for yellowbelly flounder, this projected revenue would be lower than the cost of acquiring juvenile fish, according to both the European and United States models mentioned above, and far lower than the estimated total cost of production. While this certainly suggests that people would be unwise to invest in land-based yellowbelly flounder aquaculture today, we should not conclude that the case is hopeless, given the very early stage of development for the industry.

The models outlined above suggest three priorities for future research.

1) Development of a methodology to reduce the likely cost of juvenile production by 80+ %
2) Optimisation of the feed conversion efficiency of pātiki tōtara to achieve similar values to that of other farmed flatfish (this was assumed in the current analysis)
3) Identification of methodologies to reduce labour and energy requirements for land-based aquaculture operations by 50+ %

While these figures are undoubtably challenging, potential solutions may still exist. For example, much of the cost of juvenile fish in modern aquaculture is based on high-tech intensive hatchery production of larvae. This is labour intensive and requires expensive feeds. Semi-intensive or extensive mesocosm production of juveniles may offer a low-tech and cost-effective solution. These techniques are based on large volume, low density production systems, where an ecosystem of phytoplankton and zooplankton are created to support larval development. Ideally, these systems are self-sustaining, requiring only fertilisation of nutrients and the addition of fish embryos. In practice, some additional zooplankton may also need to be supplemented, but the potential exists to source this from wild supplies. In Europe, mesocosm production of larval fish is associated with high survival rates and enhanced juvenile quality (Shields, 2001). Economic evaluation of milkfish (*Chanos chanos*) fry production concluded that the cost of semi-intensive production methods were approximately 25 % in comparison to intensive production (Lee et al, 1997). Moreover, the same study demonstrated that intensive fry production only became economically viable at larger scale. At present, the true cost of producing juvenile pātiki tōtara remains unknown and needs to be identified for accurate analysis.

Broodstock technology to support hatchery development of pātiki tōtara

Our co-development work with partners from Matakana and Rangiwaea islands and Whakatōhea has demonstrated their interest in developing pātiki aquaculture for stock enhancement and commercial production. This would require a hatchery to produce juvenile fish. Ensuring a consistent supply of juvenile stock for grow-out is a common constraint for new aquaculture ventures. These bottlenecks typically occur when either, broodstock fail to reproduce, or larval culture techniques cannot provide the appropriate diet or environmental conditions for survival and growth. The ability to control broodstock reproduction is therefore an essential first step towards ensuring a consistent supply of offspring for further industry development. The current study set out to develop techniques to provide viable eggs from wild caught pātiki broodstock.

Reproduction of pātiki tōtara

To effectively manage reproduction in captive broodstock it is important to have a comprehensive understanding of the reproductive biology of the species. This knowledge is still lacking for pātiki tōtara. Observations indicate that in northern New Zealand, spawning occurs over approximately six months of the year between June and December (Colman, 1973, Koverman, 2018). Anecdotal reports from commercial fishers suggest that bi-modal spawning peaks may exist within this six-month window. Our observations also support this, with fish close to reproductive maturity being caught at the beginning of winter and the peak of spring. Data from Colman (1973) strongly indicates that peak spawning occurs around September – October. Whether individual fish can spawn across this entire period or if the population contains groups of individuals that spawn earlier or later within the season remains to be determined. The closely related greenback flounder (*Rhombosolea taparina*), which is native to southern New Zealand and Tasmania, also shows an extended breeding season with little evidence of breeding synchrony within populations (Pankhurst & Fitzgibbons, 2006; Sun & Pankhurst, 2004). From an aquaculture perspective, a protracted breeding season may provide the advantage of extended access to gametes (eggs and sperm) for larval production. However, until a captive broodstock is successfully established, a long breeding season could create logistical challenges for captive reproduction. Wild fish that are in reproductive condition may prove difficult to access as spawning individuals tend to migrate from shallow mudflats into deeper water between 12–30m during winter months (Colman, 1973). Access to healthy wild broodstock is essential in the early stages of industry development for any aquaculture species.

The current scientific literature suggests that pātiki tōtara spawn a single clutch of eggs per season (Colman, 1973; Mutoro, 2001). This suggestion is unlikely, however, based on the histological evidence from our previous work (Koverman, 2018) and the spawning trials in the current study. The simultaneous presence of distinct groups of oocytes (developing eggs) at different developmental stages indicates a multiple batch-spawning strategy of reproduction. In other words, female fish are likely to spawn several batches of eggs per breeding season. To this effect, we also observed that individual fish ovulate more than once within a period of 3–5 days. While this provides the opportunity to obtain repeat batches of eggs from a single fish, it also increases the likelihood of asynchronous spawning within a broodstock group containing many females. These unpredictable spawning events would increase the logistical demand on hatchery operations.

Establishing an effective captive broodstock with a balanced sex ratio, requires being able to identify the sex of individual fish. Male and female pātiki tōtara have few distinguishing macroscopic features other than size. Male pātiki tend to grow slower and reach sexual maturity at a smaller size than females (Colman 1973; Colman 1974). However, size alone is not an effective method to determine sex. In this study, sex was rapidly determined through visual identification of gonad shape using a strong LED light. When backlit from underneath, the ovarian and testicular outlines clearly differ in sexually mature fish. The ovary appears longer and fuller in comparison to the short, triangular shape of the testis (Fig. 2).

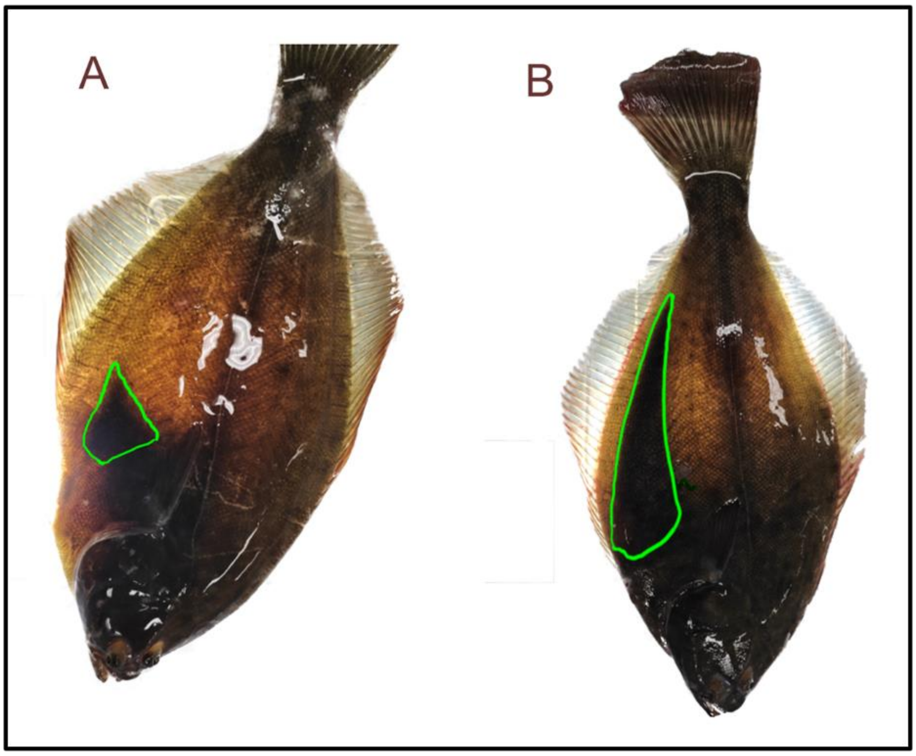

Figure 2: Gonadal silhouette of (A.) male and (B.) female adult pātiki tōtara.

Reproductive failure in farmed fish

Perhaps the greatest risk of using wild caught broodstock in a hatchery setting, is their predisposition to reproductive failure (Zohar & Mylonas, 2001). The lack of natural environmental cues and the stress of capture, often leads to elevated levels of the stress hormone, cortisol. This typically impairs the function of the reproductive endocrine axis, or in other words, the coordinated release of reproductive hormones necessary to drive normal reproductive function. In female fish, this usually results in the premature arrest of oocyte development (Zohar & Mylonas, 2001). This stress ultimately results in the failure to obtain viable eggs from broodstock fish and creates a bottleneck in the supply of juvenile fish for grow-out. One solution to this issue is to replace the key reproductive hormones that have been inhibited by stress. It is important to understand the precise stage of oocyte development at which the dysfunction occurs to successfully guide an appropriate treatment.

One of the most effective ways to overcome reproductive failure in fish is through the injection of a gonadotropin releasing hormone agonist (GnRHa). This reproductive brain hormone stimulates the production and release of luteinizing hormone (LH) from the pituitary gland, beneath the brain (Nagahama, 1994). Once released into the circulatory system, the naturally produced LH binds to its receptor on the follicle cells in the ovary to activate final oocyte maturation (FOM) (Nagahama & Yamashita, 2008). The process of FOM is essential for the successful ovulation of viable eggs prior to spawning. If the developing oocytes do not complete FOM then ovulation will not occur. While the use of treatments like GnRHa are not necessarily a long-term goal for the development of pātiki tōtara aquaculture, they do provide a helpful short-term solution to advance the current hatchery-related knowledge in this species.

Induced reproduction in pātiki tōtara

The current study aimed to develop a methodology for producing viable eggs from wild-caught pātiki tōtara to advance hatchery broodstock technology. A captive experimental broodstock was established in three 1600 litre land-based recirculating seawater systems. Fish were injected with one of three different treatments to induce reproduction.

1) Saline 'sham' control (no hormone)

2) 50 µg kg^{-1} bodyweight (bw) GnRHa

3) 100 µg kg^{-1} bw GnRHa

Ovarian tissue biopsies were collected from the fish using a plastic catheter in the first three days of the experiment and then weekly after day seven for four weeks. Fish were checked daily for signs of ovulation. Ovulated fish showed distinct swelling over the gonadal region and eggs were easily expressed with gentle pressure on the abdomen (Figure 3). When backlit, the gonads of peri-ovulatory pātiki also appeared somewhat translucent compared to fish with less developed ovaries. Fish were handled in accordance with New Zealand National Animal Ethics Advisory Committee guidelines.

Figure 3: Gravid female pātiki tōtara. The swollen and distended appearance of the abdomen (top, centre of image) reflects the presence of final stage, hydrated oocytes. Ovulated eggs are easily expressed with gentle pressure over the abdomen.

The results of the study indicate that wild caught pātiki tōtara suffer from reproductive failure following capture. None of the saline-injected control fish ovulated or showed signs of oocyte development progressing through the final stages of oocyte maturation (FOM). There was evidence, however, to indicate that this reproductive failure can be treated with GnRHa. The majority (75 %) of the fish in the 50 µg kg^{-1} and some (38 %) of the 100 µg kg^{-1} GnRHa treatments, progressed into and through FOM. This was evident by the presence of late stage FOM oocytes in the ovarian tissue samples taken in the days and weeks after injection (Figure 4). Moreover, ovulation only occurred in fish from the 50 µg kg^{-1} and 100 µg kg^{-1} GnRHa treatments. The mean fecundity (number of eggs) per ovulated batch of eggs was approximately 34,000 per 100 g of bodyweight. Collectively, these results indicate that GnRHa injection stimulated ovarian development while the ovaries of fish that did not receive GnRHa did not continue to develop or ripen. Treatment with GnRHa did not guarantee ovulation and viable egg collection.

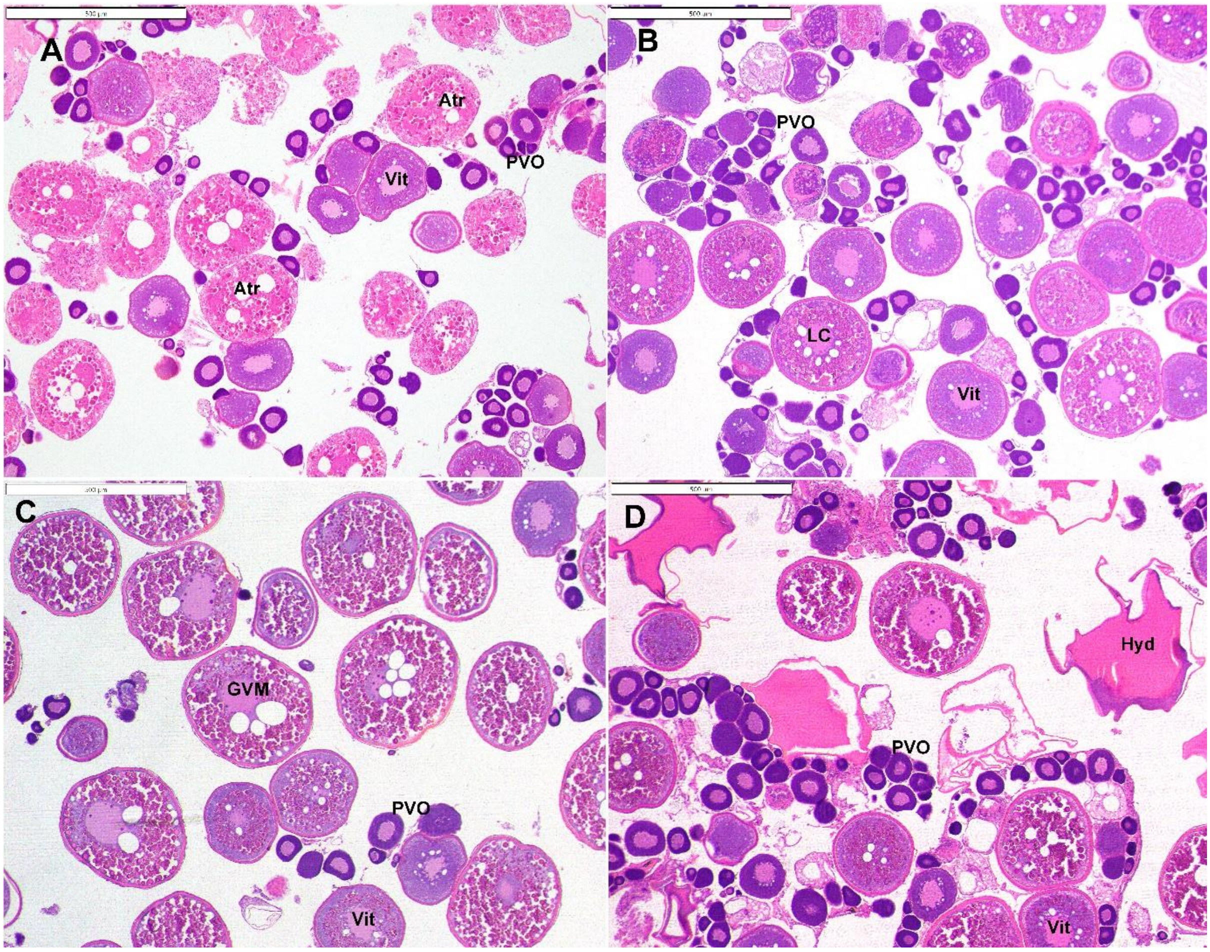

Figure 4: Progression of oocyte development after administration of gonadotropin releasing hormone analogue (100 µg kg-1 bw) at:

A: Day 0 fish showing apparently healthy oocytes in the mid-stages of development (vitellogenesis) with the simultaneous presence of late-stage (FOM) oocytes that have started to break down (atresia)

B: Day 7 post injection, distinct cohorts of healthy oocytes at early-stage (previtellogenic), mid-stage (vitellogenic) and recent late-stage (FOM) development

C: Day 14 post injection, the ovary is characterised by the presence of a cohort of late-stage (FOM) oocytes prior to ovulation

D: Day 21 post injection, all stages of oocyte are present including hydrated oocytes and post ovulatory follicles, indicating that ovulation has recently occurred.

Scale bars represent 500 µm. Abbreviations; Atr, atretic oocyte; GVM, germinal vesicle migration stage of final oocyte maturation; Hyd, hydration stage of final oocyte maturation; LC, lipid coalescence stage of final oocyte maturation; PVO, previtellogenic oocyte; Vit, vitellogenic oocyte.

Hormonal treatments often require careful refinement to identify optimal dosage. Inappropriate dosage can reduce egg quality (Setiawan et al. 2016). Initial indicators showed that good quality eggs can be obtained from pātiki tōtara using either 50 µg kg^{-1} or 100 µg

kg^{-1} GnRHa. This was evident in terms of both egg viability and fertilization rates. Although, variable, fertilization rates ≥ 80 % were achieved in both GnRHa treatments. This indicates that the doses used were not unduly excessive. However, the greatest effect on oocyte maturation and ovulation was observed in the 50 µg kg^{-1} treatment group. Fish that were treated with 100 µg kg^{-1} tended to show a slower ovarian response. Subsequent experimental work that we have conducted on the short-term pituitary response to GnRHa, indicates that 25 µg kg^{-1} and 50 µg kg^{-1} may be more appropriate dosages. Further refinement should examine the effects of 0–100 µg kg^{-1} GnRHa on ovulation and egg quality to identify an optimal dose.

The study recorded a limited number of ovulated fish. It is possible that some ovulated fish may have gone undetected between sampling days due to the difficulty of seeing in the reduced light of the tank environment. In addition, the stress from repeat handling of the fish could have impacted oocyte development and led to atresia or oocyte degradation (Corriero et al. 2021; Mylonas et al. 2010). GnRHa treatment is typically only effective once oocytes have met a threshold level of development (vitellogenesis). Histological evidence showed that the most developed oocytes in some fish had started atresia by the time the experiment started. In some cases, fish were held for over 14 days prior to experimentation due to the logistics of field capture. This may have exacerbated stress-related atresia and reduced the likelihood of successful response in the remaining less-developed oocytes. Ensuring adequate access to well-conditioned broodstock and rapid treatment with GnRHa is crucial for successful hormonal intervention.

The current study focused primarily on female pātiki tōtara, but our observations indicated that only comparatively small volumes of milt could be obtained from male fish. This could highlight a future challenge for captive breeding of this species. We trialed GnRHa on a small number of male pātiki tōtara with limited success. Pankhurst and Fitzgibbon (2006) found that greenback flounder also have low milt volumes but this increased when treated with human choriogenic hormone (hcg) rather than GnRHa. Ensuring an adequate supply of high-quality milt would be essential for future development of pātiki aquaculture.

In summary, this work has indicated that wild-caught pātiki tōtara broodstock suffer reproductive failure after capture. Due to their naturally timid nature, acclimation to captive conditions can take months and is associated with concurrent loss of body condition which negatively impacts reproduction. Our work suggests that treatment with 50 µg kg^{-1} GnRHa activates the reproductive axis to stimulate oocyte maturation. For optimal ovulation, best practice is to capture wild broodstock near the onset of the breeding season when they are in prime condition and responsive to GnRHa. These fish should be treated as soon as possible following capture to circumvent unwanted stress-related oocyte atresia. While hormonal intervention can accelerate the development of a pātiki tōtara breeding program, the best quality gametes in captive fish are typically achieved through natural spawning events without hormones. We have found that wild-caught pātiki tōtara can acclimate to captivity and successfully complete maturation when provided a low disturbance environment and wild-type diet. This can take up to 12 months to achieve.

Next steps and recommendations

This study aimed to identify whether aquaculture of pātiki tōtara could help develop new blue economy opportunities in coastal communities in New Zealand. The co-development work with partners from Matakana and Rangiwaea islands and Whakatōhea has highlighted strong interest in aquaculture of pātiki. This was expressed primarily as a desire to consider using aquaculture to support stock enhancement of customary pātiki fisheries as well as a secondary interest in commercial operations. However, while our preliminary economic analysis indicated that pātiki farming might offer good revenue opportunities, the cost of operations is likely to outweigh these returns. It is therefore important to identify what the next steps should be, if aquaculture of these fish were to be pursued any further.

Future considerations for stock enhancement

It is important that any wild release of hatchery-reared fish should not impact the growth and productivity of existing wild populations. The release habitat, therefore, must not only be suitable for pātiki, but would also need to have sufficient food resources to support the additional introduced fish. Moreover, seasonal aspects of the wild food resources also need to be timed to suit the size-related feeding ecology of the released fish. It should be acknowledged that the full extent of trophic interactions between pātiki and their ecosystem are yet to be understood. Another critical issue is the management of broodstock genetics to avoid genetic dilution. In Denmark, hatchery-reared turbot were released in different areas using only locally sourced broodstock (Støttrup & Sparrevohn, 2010). Such careful planning has not always been the case in other stock enhancement programs. The effects of a pātiki stock enhancement program cannot be fully predicted. If it were to be explored, then small-scale trials using tagged fish would need to be conducted. The following research questions should also be considered.

- What is the carrying capacity of the local ecosystem and what are the key drivers of the declining customary fishery? To answer these questions will likely require population estimates of both pātiki and other species including key food resources, as well as identification of local habitat change.

- What would be necessary to achieve both community and regulatory consent for the development of a stock enhancement program? How should such a program be funded considering the existing regulatory environment and the various stakeholders who may benefit from the program?

- What is the survival rate of hatchery-reared juveniles after release into the wild? What is the optimal size at release and how can hatchery-reared juveniles best be conditioned to maximise survival?

- What is the genetic variation between and within local pātiki tōtara stocks? This information would be useful to help manage local breeding programmes to ensure diverse, healthy fish heritage that reflects the lineage of local wild stock. It would also enable tools to identify hatchery reared fish for monitoring.

Commercial aquaculture of yellowbelly flounder

Both a pātiki stock enhancement program and commercial aquaculture, would necessitate the development of a hatchery. As highlighted in the economic analysis, this would carry significant capital and operational costs. The lack of research into native flatfish species means that many technical and financial questions that directly influence the viability of an aquaculture operation remain unanswered. Our preliminary analysis indicated that commercial pātiki aquaculture would be unviable, primarily due to the cost of juveniles, feed, and labour. It's difficult to verify exactly how accurate these estimates are without a pilot study to identify the performance of these fish through the hatchery and grow-out phases. This would provide accurate production cycle times and associated costs. Now, it is impossible to accurately predict whether pātiki aquaculture could ever be financially viable.

To address this critical lack of information, the following outcomes would be necessary.

- Validation of larval performance under low-intensity versus high-intensity rearing conditions, to accurately assess juvenile survival, quality, production time, and cost.

- Economic modelling of the cost of juvenile production under the different production models and scalability of hatchery operations. In addition, market analysis to identify the most effective channels to reach domestic and export customers.

If economic viability of juvenile production could be demonstrated, then the following outcomes would also be valuable.

- Quantitative assessment of grow-out performance (growth, FCR, mortality, health, quality). Investigation of the feasibility of sustainable ingredients such as insect meal.

- Exploration of efficient and sustainable production systems that align with stakeholder aspirations. Identification of whether extensive, low-intensity mesocosm culture could be developed with natural *in situ* food production?

- Identification of the best locations to meet operational requirements and maximise cooperative benefits, such as lowered cost of production.

- Identification of key diseases and development of effective screening methodologies.

- Exploration of plans to manage broodstock genetics that align with stakeholder production goals.

This information would be invaluable to guide the development of a future pātiki industry. However, before committing significant resources toward this aspiration, it is important to prioritise research that can directly help determine and validate whether pātiki aquaculture is financially viable. Based on the current financial analysis, investigating low-intensity juvenile production methods and the possibility of extensive 'wet-land' type mesocosms for grow-out, might prove to be the most cost-effective model. This remains to be determined and it may not be the most efficient model if maximum profit was to be the primary objective. However, the current study makes clear that both partnering communities value social and environmental priorities over and above profit. Interestingly, the qualities associated with low-intensity, extensive-scale aquaculture are also most likely to align with the key cultural values that were identified as priorities for the production environment — that the environment should be as natural as possible to uphold the mauri of the fish.

The current study highlights the desire and community interest toward innovating aquaculture solutions that can help preserve traditional cultural practices. If realised, locally developed aquaculture promises coastal communities the opportunity to create their own blue economy with a unique focus on social wellbeing.

References

Alioth Finance, Official Inflation Data. (2024, May 15). *Value of 2014 Euros today | Euro Inflation Calculator*. https://www.officialdata.org/europe/inflation/2014.

Badiola, M., Mendiola, D., & Bostock, J. (2012). Recirculating aquaculture systems (RAS) analysis: Main issues on management and future challenges. *Aquacultural Engineering, 51*, 26-35.

Bank of New Zealand. (2024, May 24). *Exchange rates*. https://www.bnz.co.nz/personal-banking/international/exchange-rates

Best, E. (2005). *Māori Religion and Mythology: Being an Account of the Cosmogony, Anthropogeny, Religious Beliefs and Rites, Magic and Folk-Lore of the Māori Folk of New Zealand*. Te Papa Press.

Bjørndal, T, Guillen, J. (2014). The Future of Sole Farming in Europe: Cost of Production and Markets, *Aquaculture Europe, vol. 39*(2), 5-13.

Brown, N. (2002). Flatfish Farming Systems in the Atlantic Region. *Reviews in Fisheries Science*, 10:3-4, 403-419, DOI: 10.1080/20026491051712

Brown, N. (2010). Halibut aquaculture in North America. In Daniels, H.V & Watanabe, W.O. (Eds), *Practical flatfish culture and stock enhancement*, (1st ed, pp 3 – 29), Wiley-Blackwell.

Cheung, W. W., and Oyinlola, M. A. (2018). Vulnerability of flatfish and their fisheries to climate change. *Journal of Sea Research*, 140, 1-10.

Colen, R., Ramalho, A., Rocha, F., & Dinis, M. T. (2014, February 18). *Solea spp. (S. solea, S. senegalensis)*. Food and Agricultural Organisation of the United Nations. https://firms.fao.org/fi/website/FIRetrieveAction.do?dom=culturespecies&xml=Solea_spp.xml&lang=en

Colman, J. A. (1973). Spawning and fecundity of two flounder species in the Hauraki gulf, New Zealand. *New Zealand Journal of Marine and Freshwater Research*, *7*(1-2), 21-43. https://doi.org/10.1080/00288330.1973.9515454

Colman, J. A. (1974). Growth of two species of flounders in the Hauraki Gulf, New Zealand. New Zealand Journal of Marine and Freshwater Research, 8(2), 351-370. https://doi.org/10.1080/00288330.1974.9515510

Corriero, A., Zupa, R., Mylonas, C.C., Passantino, L. (2021). Atresia of ovarian follicles in fishes, and implications and uses in aquaculture and fisheries. *Journal of fish diseases*, 44, 1271-1291.

Cram, F., Prendergast, T., Taupo, K., Phillips, H., & Parsons, M. (2010). *Traditional knowledge and decision-making: Maori involvement in aquaculture and biotechnology.* Proceedings of the Traditional Knowledge Conference (2008) Te Tatau Pounamu: The Greenstone Door Auckland: Te Pae o te Maramatanga

Earthmoving Auckland. (2023, July 30). *How much does excavation cost in Auckland*? Understanding excavation costs in Auckland. https://earthmovingauckland.co.nz/how-much-does-excavation-cost-in-auckland-understanding-excavation-costs-in-auckland/

Elder, H. (2020). *Aroha - Māori wisdom for a contented life lived in harmony with our planet*. Penguin.

Ellis-Smith, B. (2022). *Induced reproduction in Pātiki (Rhombosolea leporina), a novel endemic aquaculture candidate* [Master of Science in Ecology and Biodiversity, The University of Waikato]. https://researchcommons.waikato.ac.nz/bitstream/handle/10289/15564/thesis.pdf?sequence=4&isAllowed=y

Food and Agriculture Organisation of the United Nations. (2020). *Global Aquaculture Production 1950-2018*. Retrieved 20.08.20 from http://www.fao.org/statistics/en/

Hart, P.R. (2010). Culture of greenback flounder. In Daniels, H.V & Watanabe, W.O. (Eds), *Practical flatfish culture and stock enhancement*, (1st ed, pp 169– 184), Wiley-Blackwell.

Koverman, R. (2018). Reproductive biology of yellowbelly flounder Rhombosolea leporina (Günther, 1862) and Rhombosolea spp [Masters thesis, The University of Waikato].

Lee, C.S., Leung, P.S., Su, M.S. (1997). Bioeconomic evaluation of different fry production systems for milkfish (*Chanos chanos*). *Aquaculture*, 155, 367-376.

Louviere, J. J., Hensher, D.A., Swait, J.D. (2000). *Stated Choice Methods*. Cambridge, U.K., Cambridge University Press.

Maniapoto Māori Trust Board. (2015). *He Mahere Ika - Maniapoto Upper Waipā River - Fisheries Plan 2015*. https://researchspace.auckland.ac.nz/bitstream/handle/2292/25512/Maniapoto%20Upper%20Waipa%20River%20Fisheries%20Plan%202015.pdf?sequence=7

Matakana & Rangiwaea Island. (2012). *Matakana and Rangiwaea Island's Hapū Management Plan - Part 1*. https://www.boprc.govt.nz/media/285431/HMP-Matakana-Rangiwaea-Hapu-Management-Plan-as-submitted-on-7-November-2012-FINAL_Part1.pdf

Mclellan, G. (2020). *Balancing Moni Hua and Mana Motuhake Iwi Commercial Food Ventures and Māori Food Sovereignty A Whakatōhea Case Study*. University of Auckland.

Ministry for Primary Industries. (2020). *Notice specifying fish species which may be farmed (2020) (notice no. MPI 1134) - 2020-GO1484 - new zealand gazette*. New Zealand Gazette. https://gazette.govt.nz/notice/id/2020-go1484

Ministry for Primary Industries. (2022). *Review of Sustainability Measures for Flatfish (FLA 2) for 2021/22.* https://www.mpi.govt.nz/dmsdocument/43015/direct

Ministry for Primary Industries. (2023). *Fisheries Assessment Plenary May 2023 Volume 1 – FLATFISH (FLA).* https://fs.fish.govt.nz/Page.aspx?pk=113&dk=25430

Moana Rāhui o Aotea. (n.d.). *Pātiki (Flounder)*. Aotea Harbour. Retrieved November 22, 2023, from https://aotea.maori.nz/catching-and-drying-patiki-flounder

Mutoro, D. B. (2001). *Life of a flatfish, the yellowbelly flounder, Rhombosolea leporina Günther, 1873, in Auckland's sheltered waters* [Doctoral thesis, University of Auckland].

Mylonas, C.C., Fostier, A., Zanuy, S. (2010). Broodstock management and hormonal manipulations of fish reproduction. *General and Comparative Endocrinology* 165, 516-534.

Nagahama, Y. (1994). Endocrine regulation of gametogenesis in fish. *Int. J. Dev. Biol*., 38, 217-229.

Nagahama, Y., and Yamashita, M. (2008). Regulation of oocyte maturation in fish. *Develop. Growth. Differ.,* 50, 195-219.

Nelson, A. (2020, November 25). Demand for flat fish on the rise. Supermarket Perimeter. https://www.supermarketperimeter.com/articles/5929-demand-for-flat-fish-on-the-rise

Neira, R., Diaz, N.F., Gall, G.A.E., Gallardo, J.A., Lohrente, J.P., Manterola, R. (2006). Genetic improvement in Coho salmon (Oncorhynchus kisutch). I: Selection response and inbreeding depression on harvest weight. *Aquaculture*, 257, 9–17.

New Zealand Government (2019). *Aquaculture Strategy*. Retrieved from: https://www.mpi.govt.nz/growing-and-harvesting/aquaculture/strategy/

Ngā Puna Waihanga - Waitaha Tai Poutini. (2003). *Puawaitanga o te Ringa - Fruits of our busy hands*. https://christchurchcitylibraries.com/Maori/Puawaitanga/Puawaitanga.pdf

Øiestad, V. (1999) Shallow raceways as a compact, resource-maximizing farming procedure for marine fish species. Aquaculture Res. 30:831-840

Ōpōtiki District Council. (2023). *Te Ara Moana a Toi*. Ōpōtiki District Council. https://www.odc.govt.nz/repository/libraries/id:2bpcqtp1b1cxby3k9b0b/hierarchy/sitecollectiondocuments/our-council/Reports%20%26%20Studies/Reports/Te%20Ara%20Moana%20a%20Toi%20-%20Initial%20Benefits%20Assessment.pdf

Pankhurst, N.W., and Fitzgibbon, Q.P. (2006). Characteristics of spawning behaviour in cultured greenback flounder *Rhombosolea tapirina*. *Aquaculture*, 253, 279-289.

Person-Le Ruyet, J. (2010). Turbot culture. In Daniels, H.V & Watanabe, W.O. (Eds), *Practical flatfish culture and stock enhancement*, (1st ed, pp 125– 139), Wiley-Blackwell.

Potaka, M. (2021). *Whakarongo* [Masters of Māori Visual Arts, Massey University]. https://mro.massey.ac.nz/server/api/core/bitstreams/7154c565-67c9-43ce-ba44-02400066a746/content

Puvanendran, V., Boyce, D., & Brown, J. (2003). Food ration requirements of 0+ yellowtail flounder Limanda ferruginea (Storer) juveniles. Aquaculture, 220(1-4), 459-475.

Robin-Middleton, J. (2019). *How to prep a hāngi - A framework for end-user engagement within the design process* [Master of Architecture]. Victoria University of Wellington.

Seafood New Zealand. (2023, January). *Export stats - January 2023*. Export Stats - January 2023 - Seafood NZ. https://www.seafood.co.nz/detail/export-stats-january-2023-provisional

Seikai, T., Kikuchi, K., Fujinami, Y. (2010). Culture of Japanese flounder. In Daniels, H.V & Watanabe, W.O. (Eds), *Practical flatfish culture and stock enhancement*, (1st ed, pp 144–155), Wiley-Blackwell.

Setiawan, A.N., Muncaster, S., Pether, S., King, A., Irvine, G.W., Lokman, P.M., Symonds, J.E. (2016). The effects of gonadotropin-releasing hormone analog on yellowtail kingfish *Seriola lalandi* (Valenciennes, 1833) spawning and egg quality. *Aquaculture Reports*, 4, 1-9.

Shields, R.J. (2001). Larviculture of marine finfish in Europe. *Aquaculture*, 200, 55-88.

Simon, H. H. (2016). Te Arewhana Kei Roto i Te Rūma: An Indigenous Neo-Disputatio on Settler Society, Nullifyling Te Tiriti, “Natural Resources” and Our Collective Future in Aotearoa New Zealand. *Te Kaharoa*, *9*. https://www.tekaharoa.com/index.php/tekaharoa/article/view/6/4

Støttrup, J.G., and Sparrevohn, C.R. (2010). Stock enhancement Europe: turbot *Psetta maxima*. In Daniels, H.V & Watanabe, W.O. (Eds), *Practical flatfish culture and stock enhancement*, (1st ed, pp 219 – 236), Wiley-Blackwell.

Sun, B., and Pankhurst, N.W. (2004). Patterns of oocyte growth, vitellogenin and gonadal steroid concentrations in greenback flounder. *J. Fish Biol*., 64, 1399-1412.

Sutton, N., Jennings, C., Greig, K., & Walter, R. (2022). *Archeological Assessment for Coring in the Wairau Lagoons*. University of Otago. https://www.rangitane.org.nz/wp-content/uploads/2022/03/20220316-GNS-Wairau-Lagoons-Assessment.pdf

Tahu, N. (2015, September 3). *Pātiki - Ngāi Tahu Mahinga Kai*. Youtube. https://www.youtube.com/watch?v=tRQN2Qolj2s&t=28s

Te Kanawa, K. (2013). *Māori weaving and tukutuku – te raranga me te whatu - Tāniko and tukutuku*. Te Ara - the Encyclopedia of New Zealand; Ministry for Culture and Heritage Te Manatu Taonga. https://teara.govt.nz/en/interactive/43489/types-of-tukutuku-designs

Tridge: Global Food Sourcing & Data Hub. (n.d.). *Global price trends*. https://www.tridge.com/trades

Tupu.nz. (2024). *Kiwifruit - Land use fact sheet*. https://www.tupu.nz/en/fact-sheets/kiwifruit

Waitangi Tribunal. (2011). *Ko Aotearoa Tēnei*. Waitangi Tribunal. https://play.google.com/store/books/details?id=hssvygAACAAJ

Wakefield, B., Gregory, B., Hape, M., & Hepere, J. (2013). *Cultural Impact Assessment of the Ruataniwha Water Storage Scheme*. Hawkes Bay Regional Council. https://www.hbrc.govt.nz/assets/Document-Library/RWSS-Final-RMA-Reports/Assessment-Reports/RWSSA5b-Zone-M-CIA-Addendum-Taiwhenua-o-Tamatea-April-2013.pdf

Walker, K. (2017, May 2). *Rangitane Mahinga Kai - Patiki*. Youtube. https://www.youtube.com/watch?v=ZsvGq8uY5ps

Walker, R. (2007). *Ōpōtiki-Mai-Tawhiti: Capital of Whakatōhea*. Penguin Books.

Wham, C. (2020). New Zealand and Mãori nutrition and health. In S. Croxford, C. Itsiopoulos, A. Forsyth, R. Belski, A. Thodis, S. Shepherd & A. Tierney (Eds.), Food and Nutrition Throughout Life: A comprehensive overview of food and nutrition in all stages of life (pp. 276-289). Routledge.

Whaanga, H., Wehi, P., Cox, M., Roa, T., & Kusabs, I. (2018). Māori oral traditions record and convey indigenous knowledge of marine and freshwater resources. *New Zealand Journal of Marine and Freshwater Research*, *52*(4), 487–496.

Whakatōhea. (1993). *Tawharua o nga hapu o Whakatōhea - Whakatōhea Resource Management Plan*. Whakatōhea. https://atlas.boprc.govt.nz/api/v1/edms/document/A3557765/content

Watanabe, W.O., and Daniels, H.V (2010). Summary & Conclusions. In Daniels, H.V & Watanabe, W.O. (Eds), *Practical flatfish culture and stock enhancement*, (1st ed, pp 323 – 357), Wiley-Blackwell.

Yates, J. K., Dumas, C. F., Watanabe, W. O., Carroll, P. M., & Losordo, T. M. (2020, March 9). Production economics of flounder aquaculture - responsible seafood advocate. Global

Seafood Alliance. https://www.globalseafood.org/advocate/production-economics-of-flounder-aquaculture/

Zespri. (2023, May 30). Zespri’s 2033/23 Financial Results Reflect Challenging Season. https://www.zespri.com/en-NZ/publications/newsroomdetail/2022-23-financial-results

Zohar, Y., and Mylonas, C.C. (2001). Endocrine manipulations of spawning in cultured fish: from hormones to genes. *Aquaculture*, 197, 99-136.