Lake Tahaaroa Customary Tuna Research

Prepared for Tahaaroa Lakes Trust

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Prepared by:
Ngahuia Herangi
Shannan Crow
Tekiteora Rolleston-Gabel
Siohban Nuri
Fleur Passau
Rhonda Tuaupiki-Kerr
Taituwha King

For any information regarding this report please contact:

Ngahuia Herangi
Environmental Researcher
Te Kūwaha
+64 7 838 8356

New Zealand Institute for Earth Science Limited
PO Box 11115
Hamilton 3251

Phone +64 7 856 7026

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	Approved for release by:	Michael Bruce

Operation Tuna. [Keith Kana, Ngaati Mahuta ki te Hauaauru]

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Executive summary

The Tahaaroa Lakes (Lakes Tahaaroa, Numiti, Rotoroa, Piopio, Rototapu and Harihari) are a distinctive group of shallow coastal dune lakes located on the west coast of Aotearoa-New Zealand's North Island, within the rohe of Ngaati Mahuta ki te Hauaauru (Ngaati Mahuta). These roto are taonga tuku iho, central to the identity and hauora of the hapuu, and Lake Tahaaroa in particular, sustains an important customary tuna fishery. For many years, however, the aspirations of mana whenua for a thriving tuna population have not been met. Tikanga reminds us that this decline is not only an ecological issue but also a wero to our mana whakahaere, our relationship with the roto, and the intergenerational transmission of maatauranga and practice.

The customary fishery has been impacted by declining tuna availability, degraded lake conditions, eutrophication, parasites, and reduced recruitment. The scale and timing of these changes are not fully understood, creating a critical knowledge gap. Guided by tikanga and carried out in partnership with kaitiaki, this study sought to restore clarity. Karakia and kawa anchored each step of the mahi, ensuring that tuna were treated with respect as taonga, handling and harvest were minimised, and remains were returned in accordance with customary practice. Scientific tools including fyke-netting, otolith ageing and parasite assessments were applied within this tikanga-led framework.

The aim was to quantify the current health of the tuna population in Lake Tahaaroa and understand how the customary stock has changed over 17 years. To achieve this, we repeated the 2007 survey by Chisnall & Ruru (2008) and compared population measures (catch rates, sizes, condition, growth) between 2007 and 2025.

Key findings show that tuna catch rates have increased since 2007 and are now comparable with other sites across Aotearoa. However, the stock is dominated by older, slower-growing individuals. Shortfin growth rates declined from 33 mm/year in 2007 to just 17 mm/year in 2025, meaning eels of the same size are now often twice as old. Despite reduced growth, shortfin condition has improved. A major concern is the sharp rise in parasite prevalence, 74% of shortfin were infected, mainly with shagworm (*Eustrongylides* spp.), which was virtually absent in 2007. This shift likely reflects changes in host bird populations such as black swan, paradise duck, and Canadian geese. Recruitment continues, but its success remains constrained by uncertainties around the Wainui Stream fish pass and barriers at Lake Harihari.

The wider environment shows clear signs of stress. Water quality has deteriorated, with sedimentation and nutrient enrichment shifting Lake Tahaaroa from oligotrophic to eutrophic/supertrophic status. Algal blooms and habitat decline signal urgent need for riparian restoration, stock exclusion, and wetland rehabilitation. Continuous monitoring is required to better understand the drivers of tuna health and resilience.

From a cultural perspective, these ecological stressors compromise the mauri of the fishery and the suitability of tuna for customary harvest. The scarcity of longfin tuna and high parasite loads support recommendations for a hapuu-declared raahui on longfin harvest. Hauanga kai strategies must evolve to uphold tikanga: protecting taonga species while sustaining customary practice. Ensuring fish passage at Wainui Stream and Lake Harihari is critical for the return of juvenile tuna.

Looking forward a tikanga-based roadmap for research and restoration is proposed. This includes regular fyke-net surveys, otolith ageing, parasite assessments, recruitment monitoring and the continued integration of maatauranga Maaori. It also calls for strong hapuu authority over data governance, co-designed restoration, and actions that give effect to Te Tiriti o Waitangi.

Ultimately, this mahi has been carried by *'Ngaa Hau o Te Hauaauru'*, the guiding winds of Ngaati Mahuta. The winds of the past, '*Hautupua*', anchor us in whakapapa and koorero tuku iho. The winds of change, *'Haumaiangi'*, bring new tools and insights, and the all-encompassing wind, '*Hauaawhio'*, unites our people across generations. Together these winds restore the mauri of Tahaaroa lakes, uphold mana whakahaere, and carry forward the tikanga and hauanga kai practices of Ngaati Mahuta ki te Hauaauru moo ngaa uri whakaheke.

1 Introduction

1.1 Background

Tuna (freshwater eel) are taonga species of immense ecological, cultural, and customary importance with a fascinating life history. Three species are found in Aotearoa, the longfin (*Anguilla dieffenbachii*), shortfin (*A. australis*) and Australian longfin (*A. reinhardtii*), but the Australian longfin is only occasionally found. Shortfin eels generally inhabit lowland lakes and rivers, and reach up to 1.1 m in length and weigh up to 3 kg. Longfin eels prefer the mid-upper reaches of catchments and may reach lengths of 2.0 m and weights over 20 kg. Longfins are also more long-lived than shortfins (Jellyman, 2003; Beentjes et al. 2020). Both of these tuna are catadromous, which means they must migrate between the ocean and freshwater systems to successfully complete their life cycle. Longfin and shortfin spawning occurs in tropical ocean waters far from Aotearoa, likely in the southwest Pacific, but the exact location remains unknown (Jellyman & Bowen 2009). After hatching, larvae (leptocephali) drift on ocean currents for several months before metamorphosing into glass eels as they reach the coastline (Figure 1-1). Upon entering the estuaries and freshwater systems, the glass eels metamorphose into elvers and begin migrating further inland (McDowall, 1990).

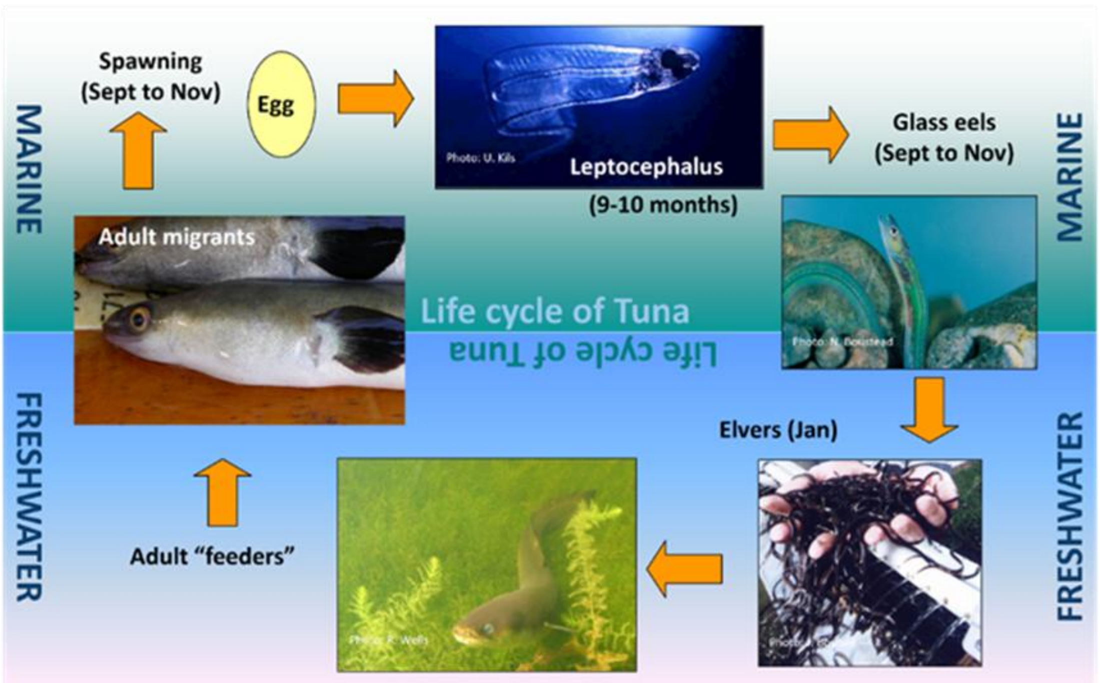


Figure 1-1: Life cycle of (Anguilla spp) showing key marine and freshwater stage: spawning (Sep-Nov), leptocephalus larva (9-10 months), glass eel migration (Sep-Nov), elver recruitment (Jan), adult feeding phase, and adult migration. Images used with permission or under educational licence from ESNZ, DOC, and contributors. [Credits: U. Kils, N. Boustead, R. Wells, and Bobbee].

The Tahaaroa Lakes (Lakes Tahaaroa, Numiti, Rotoroa, Piopio, Rototapu and Harihari) are a distinctive group of shallow coastal dune lakes located on the west coast of New Zealand's North Island, within the rohe of Ngaati Mahuta ki te Hauaauru (Figure 1-2). Lake Tahaaroa, Numiti and Rotorua are interconnected and drain to the ocean via Wainui Stream which is the outlet of lake Tahaaroa. Lake Harihari is located further South from the three interconnected lakes and has a separate outlet to the sea. These freshwater taonga have long sustained tangata whenua, providing tuna, koura, and other kai resources that underpin customary practices, cultural identity, and the wellbeing of hapuu. Lake Tahaaroa in particular remains a cornerstone of local food sovereignty and whaanau connection to the taiao. Unfortunately, the Tahaaroa Lakes have been subjected to a series of degradation pressures over the last four decades. For example, the water quality has degraded with high levels of sediment resuspension, fish passage through Wainui Stream has been blocked (Chisnall & Ruru 2008), and there has been a largescale invasion of pest weed lagarosiphon (*Lagarosiphon major*) (Herangi et al. 2025a). From a cultural perspective, these environmental issues directly affect the ability of tangata whenua to uphold customary practices such as hiinaki placement and whaanau-led tuna harvests. The erosion of hauanga kai and disruption to intergenerational knowledge transmission have prompted renewed calls for localised, culturally grounded responses. This aligns with broader movements to restore mana whakahaere and uphold kaitiakitanga across Aotearoa's freshwater taonga (Ruru et al. 2017).

This map depicts Ngaati Mahuta ki te Hauaauru's tribal boundaries, inclusive of areas and sites that are of cultural and historical significance to our hapuu. Ngaati Mahuta ki te Hauaauru recognizes that there are areas where there are common interests and shared mana with neighboring iwi that reflect mutual historical association and whakapapa relationships.

Figure 1-2: The indicative rohe boundaries of Ngaati Mahuta ki te Hauaauru extend south from Te Puia Springs in Kaawhia to Motunau Rocks south of Lake Harihari, and out to sea to Karewa or Gannet Island. [Graphic: Ruby Mckenzie Sheat, Earth Sciences New Zealand (ESNZ)].

In the 1970s an iron sand mining operation was established near the Tahaaroa Lakes. The operation was established by New Zealand Steel (NZ Steel) with a large harvesting area established on the seaward side of the Tahaaroa lakes. The mining operation required fresh water as part of their iron ore extraction process, so a dam was constructed at the outlet of Lake Tahaaroa (Wainui Stream). Wainui Stream provides the only access for diadromous fishes such as tuna, to enter Lake Tahaaroa and the interconnected Lakes Numiti and Rotoroa. Fish passage into Lake Harihari also been restricted by the construction of a perched culvert (Chisnall & Ruru 2008). To mitigate the impacts of the Wainui Stream dam on fish recruitment, a fish pass structure was installed to ensure that recruitment of fish into the Tahaaroa Lakes could be maintained. Unfortunately, the fish pass was ineffective which led to impacts on the health and wellbeing of the tuna population (Chisnall & Bellingham, 1998; Chisnall & Ruru, 2008). In response to these concerns 6,600 small eels (<220 g) were introduced into Lake Tahaaroa in 1997 as way of supplementing the dwindling tuna stocks (Chisnall 1998). The fish pass was then upgraded in 2010 (Bennet 2022), but it is still unknown if this new structure can sustain tuna recruitment into the Tahaaroa Lakes. In 2017, Tahaaroa Mining Investments Ltd brought the site and has continued to operate the mine but the ecological and cultural integrity of the Tahaaroa Lakes remains at risk (Chisnall & Ruru, 2008; New Zealand Steel, 2014). Community members continue to report diminished tuna availability and degraded lake conditions, including turbid waters, eutrophication, and the ongoing presence of parasites such as shagworm. The long lifecycles of tuna make them particularly susceptible to population decline and recruitment limitation, as any impacts on the population and/or recruitment can take decades to reverse (Jellyman, 2012).

1.2 Aims

Ngaati Mahuta are seeking to understand the current health and wellbeing of the tuna population in Lake Tahaaroa. The research is grounded in the principle of kaitiakitanga, the obligation of care and guardianship, and shaped by the tikanga and kawa of Ngaati Mahuta. Whaanau are actively engaged across all stages of the mahi, from design and sampling through to interpretation and dissemination of results. This approach honours intergenerational knowledge, as reflected in the paatere:

"Whaatoro atu ki te ruku hiinaki ki te roto o Tahaaroa"
Stretch forth to place the hiinaki into Lake Tahaaroa

This phrase speaks to the enduring relationship between tangata whenua and their freshwater taonga, a relationship rooted not only in sustenance, but in whakapapa, identity, and tino rangatiratanga.

The aim of the present study is to quantify the current tuna population health in Lake Tahaaroa and identify how the customary tuna stock has changed over the last 17 years. To address these aims we repeated a 2007 tuna survey that was completed by Chisnall & Ruru (2008) in Lake Tahaaroa, then compared population metrics (catch rates, sizes, condition and growth rates) between 2007 and 2025. The outcomes provided insights into the key concerns identified by Ngaati Mahuta and Chisnall & Ruru (2008) relating to the status of the tuna stock in Lake Tahaaroa. Additionally, we also explored tuna parasite loadings within Lake Tahaaroa. The original survey of Chisnall & Ruru (2008) identified the presence of shagworm in Lake Rotoroa but commented that it was uncommon in the other lakes.

Ngaati Mahuta wished to understand how prevalent shagworm (and other parasite) was in Tahaaroa which and if the infestation rate had changed from 2007 to 2025.

The current research initiative was funded by the Customary Fisheries Research Fund, which is administered by the Fisheries New Zealand (FNZ). The research represents a timely opportunity to address the interconnected challenges and concerns raised by Ngaati Mahuta and builds on the foundational 2007 tuna population survey by Chisnall & Ruru (2008). The renewed focus, driven by whaanau aspirations and grounded in tikanga, seeks not only to re-establish a robust knowledge base, but to embed maatauranga Maaori and hapuu priorities in contemporary freshwater management. Ultimately, they will inform restoration efforts that are ecologically sound, culturally affirming, and strategically aligned with national commitments to uphold Te Tiriti o Waitangi in environmental governance (Waitangi Tribunal, 2011; MPI, 2024).

1.3 Data Custodianship and Tikanga Protocols

The Trust considers all data collected during this mahi, including measurements, photos, species samples, and analysis outputs to be taonga. These materials were collected under hapuu oversight and are to be held in accordance with tikanga. No data may be shared, published, or reproduced without the consent of the Trust. As noted in the Catchment Plan.

> *All data and research related to the Tahaaroa Lakes must be handled with the same reverence as one would treat a waka huia, a vessel of treasures, held close to the heart.*
> — Herangi et al., 2025b.

Future environmental monitoring efforts must continue this approach, embedding cultural safety and data sovereignty into all project phases from design through to storage and reuse.

These standardised sampling and processing methods provide a robust basis for interpreting the status of Lake Tahaaroa’s tuna population.

2 Methods

2.1 Tikanga and Cultural Protocols

All field activities were conducted under the guidance of kaitiaki from Ngaati Mahuta in accordance with tikanga. A karakia was undertaken each morning before fieldwork commenced, and all tuna were handled respectfully to minimise stress. Any tuna not retained for further analysis were returned to the water near their point of capture. This oversight ensured that scientific procedures aligned with cultural values and the exercise of mana whakahaere over the lakes. These tikanga-based protocols are discussed further in Section 4.7.

2.2 Study Area

Fieldwork was carried out at Lake Tahaaroa from 10–13 February 2025. Fieldwork was conducted by ESNZ in partnership with the Trust and representatives of Ngaati Mahuta. All fieldwork was carried out under approved Health and Safety protocols, including a site-specific Health and Safety Plan, Fieldwork Plan, Boat Safety Plan and Standard Operating Procedures (SOPs) developed by ESNZ. These protocols were designed to ensure the wellbeing of all participants and safe deployment of field equipment under varying lake and weather conditions.

2.3 Site Selection

We aimed to sample the same sites in 2025 that were used in Chisnall & Ruru (2008). Unfortunately, exact locations of the sites were not available, so we utilised Figure 1 from Chisnall & Ruru (2008) combined with GIS software to match the sampling locations. All sites were georeferenced in the present study and then reviewed during planning to ensure spatial alignment with the previous survey (Figure 2-1)(Appendix A). In some instances, the lagarosiphon beds were so thick that the boat could not access the exact location used by Chisnall & Ruru (2008). Due to boat access restrictions, nets were set at the nearest accessible location along the lake edge.

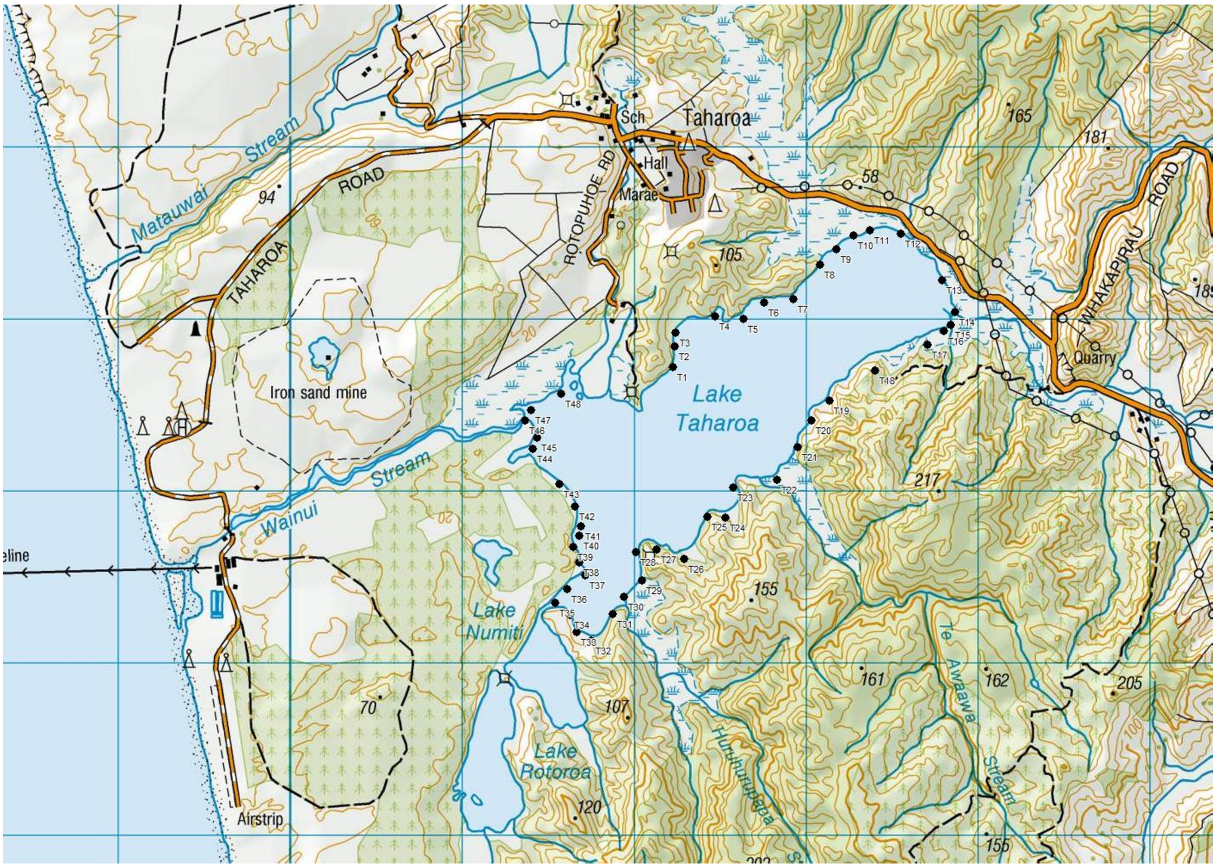


Figure 2-1: Locations of the 48 sampling sites around the perimeter of Lake Tahaaroa. The coordinates of each site are available in (Appendix A).

2.4 Tuna Sampling

Coarse mesh (8 mm stretched mesh) fyke nets were used to sample the tuna population in Lake Tahaaroa from 11-15 February 2025. The tuna survey was completed at a similar time to Chisnall & Ruru (2008) which maximised comparability between the two surveys. The coarse mesh fyke nets used in the present study have previously been shown to be an effective sampling technique for tuna >400 mm (Jellyman and Graynoth 2005). To prevent any smaller eels being predated by larger ones, all fyke nets were fitted with a size excluder section at the end of the net which allows eels <400 mm to enter this area but not larger fish. All fyke nets were un-baited because baiting nets has been shown to make no difference to catch rates within lake areas where flow is limited (Don Jellyman, pers. comm.), and bait was not used in the survey of Chisnall & Ruru (2008).

Each morning, the fyke nets were retrieved and transported to an onshore processing station (Figure 2-2, Figure 2-3). The catch from each net was then transferred into catch bags and tuna were anaesthetised using AQUI-S® which minimised handling stress and allowed the fish to be accurately identified and measured for length (mm) and weight (g).

Figure 2-2: The onshore processing station set up beside Lake Tahaaroa where the team conducted species identification, biometric measurements, parasite checks, and sample preparation. [Photo: Keith Kana, Ngaati Mahuta]

A sample of approximately 50 shortfins were collected for ageing. Following Chisnall & Ruru (2008) the ageing sample was size-stratified with ten shortfin tuna being collected from each of five 100 mm length classes (0–99 mm, 100–199 mm, 200–299 mm, 300–399 mm, >500 mm). The 50 tuna were humanely euthanised with an overdose of AQUI-S®. Otoliths were then extracted from all 50 shortfins. Otoliths are small, calcified structures located in the inner ear of fish. Much like the rings in a tree trunk, otoliths from distinct layers over time as the fish grows. These layers, called annuli, form due to seasonal changes in growth rate where tuna grow faster in summer compared to winter. The winter bands appear denser and darker than the summer growth bands, making it possible to count the number of years a tuna has lived for. Otoliths were prepared for ageing using the method of Hu and Todd (1981), which was subsequently modified by Graynoth (1999). All otolith reading was completed following FNZ approved methodology outlined in Walsh et al. (2016). Counts of annual growth increments combined with length data were used to calculate annual freshwater growth rates for aged shortfins. Freshwater growth was calculated as (total length – 60 mm)/total age, where 60 mm is the mean length of glass eels (Jellyman and Lambert 2003). This was the same annual growth calculation used in Chisnall & Ruru (2008), which means the growth increment estimates were directly comparable between the two studies.

Figure 2-3: The field team setting fyke nets and gee-minnow traps and transiting across open water to reach sampling locations on Lake Tahaaroa. [Photos: Keith Kana, Ngaati Mahuta]

2.5 Parasite load assessment

Parasite load assessments were completed on the 50 shortfin tuna that were sacrificed for ageing and an additional 43 shortfin were collected for customary harvest. A visual health assessment was carried out on these individuals, including the outside of the tuna and the internal organs to identify the presence of any visible parasites. In some cases, the stomach lining and contents were also examined. The tuna were then assigned the parasite infestation index of Richardson (1998), which provides a structured, repeatable method for assessing tuna health and enables comparisons with other studies. The parasite infestation index score was based on the following criteria:

0 = no parasites present
1 = one or two parasites
2 = numerous parasites
3 = heavy parasite infestation

The average infestation score was later converted into a parasite index percentage using the following formula:

$$Parasite\ index\ score = \left(\frac{mean\ value\ of\ parasite}{3}\right) \times 100$$

Handling protocols mirrored those used in Chisnall & Ruru (2008) survey and were carried out in accordance with ethical approvals and tikanga. This included hapuu oversight of sampling activities and the integration of maatauranga Maaori alongside scientific methods. Kaitiaki from the Trust and Ngaati Mahuta supported daily operations, ensuring cultural safety, access, and coordination throughout the fieldwork.

2.6 Data Analysis

The 2007 survey did not record length and weight measurements from all eels, which makes comparisons with the present study challenging because we measured every tuna captured. In 2007, only a sub-sample of tuna was measured for length, and an even smaller sub-sample was measured for both length and weight.

To assess whether these two sub-samples were representative of the lake population, we compared the size distributions of shortfin and longfin eels in the length-only group (i.e., tuna only measured for length) and the length–weight group (i.e., tuna measured for length and corresponding weight) (Appendix A). The results showed that shortfin data was consistent across the length and length-weight sub-samples, so we assumed that it was valid to compare these against what we recorded in the present study. However, due to low replication in the longfin length–weight sub-sample, we decided in was only appropriate to compare longfin length data with the present study [i.e., weight and condition comparisons between the two studies were not possible because the outcomes could be influenced by an un-representative sample measured in Chisnall & Ruru (2008) rather than changes in the population structure] (Appendix C).

The 2007 survey also used a variety of net types, including fine-meshed fyke nets, commercial fyke nets with escapement tubes and commercial fyke nets without escapement tubes. These nets are no longer available and have since been replaced by standardised fyke nets that are now commonly used by regional councils and research institutions. In the present study, we used these standardised fyke nets (8 mm mesh, no escapement tubes) to ensure consistency with current best practice and comparability with national datasets. To support meaningful comparisons with 2007, we used data collected in 2007 with standard commercial fyke nets (standard fyke nets hereafter) without escapement tubes. Although the mesh size used in the present study (8 mm) was slightly smaller than the 2007 fyke nets (13 mm), this was considered to have a minimal impact on the sizes and numbers of fish that were captured.

2.6.1 Length Distributions

Length–frequency plots were used to compare the size distribution of shortfin and longfin tuna between 2007 and 2025. For completeness, we also included a separate plot showing the full 2007 length–frequency data from all fyke net types. A two-sample t-test was used to compare length and weight of shortfins between 2025 and 2007. A two-sample t-test was used to compare length and weight of longfins between 2025 and 2007. In both cases, the measurements taken from the individual fish were treated as the unit of replication.

2.6.2 CPUE and condition

The condition factor (k) is an indicator of how fat the fish are, which was calculated from the relationship between length and weight. Condition factor was calculated using:

$$k = \text{weight (g)} * 1000000/\text{length (mm)}^3$$

Condition was calculated from all shortfins and longfins individually measured in the present study. Condition was calculated using the same approach in the present study and Chisnall & Ruru (2008).

Fyke-netting data collected in the present study were converted into two catch-per-unit-effort (CPUE) indices: CPUE biomass (kg/net/night) and CPUE abundance (no./net/night). CPUE is a comparable index of abundance that is commonly used to examine and compare the status of fish populations (Jellyman and Graynoth 2005). Both CPUE indices were calculated separately for longfin and shortfin. CPUE abundance for shortfin and longfin tuna was compared between 2007 and 2025 with a two-sample t-test, using the site-level CPUE values as the unit of replication.

Because only catch numbers (not weights) were available from 2007, CPUE weight could not be compared between the two surveys. We also used two-sample t-tests to compare the condition of shortfin tuna only (insufficient longfin data available from 2007), drawing on all individual condition estimates from the present study and the 2007 dataset where both length and weight measurements were recorded.

2.6.3 Age

Ageing data for shortfin tuna were obtained from the 2007 Lake Tahaaroa survey and compared with the 50 shortfin collected in the present study. Boxplots were used to examine annual freshwater growth rates and identify outliers; one extreme value (65.6 mm/year, more than double the next highest rate) was removed from the analysis because it was considered to be spurious. Growth rate in freshwater was then calculated for shortfins collected in 2007 and in 2025 as:

$$\text{Growth rate} = (\text{total length} - 60\ \text{mm})/\text{total age}$$

Where 60 mm represents the average length of glass eels (Chisnall et al. 2007). This method was consistent with that used in 2007, allowing direct comparison of growth increments between studies. Mean annual growth was used as the basis of comparison, since eel growth in freshwater is considered linear (Jellyman, 1997). All aged fish from Chisnall et al. (2008), regardless of sampling method, were included, with the mean annual growth rate of each fish treated as the unit of replication. A two-sample t-test was then used to compare freshwater growth rates between the two surveys.

3 Results

A total of 92 (32.2 kg) longfin and 815 (193 kg) shortfin were captured from fyke nets during the present study across the 42 net-nights of sampling (Table 3-1). Shortfin made up 90 % of the total catch number and 87 % of the total catch weight. Compared to 2007, the present study captured roughly double the numbers and weight of shortfin and longfin with fewer net-nights of sampling (42 net-nights in the present study vs. 51 net-nights in 2007).

Table 3-1: Total numbers, mean length, weight and condition of shortfin and longfin captured in 2007 and 2025. Standard error (SE) is shown for each of the mean calculations. Total count and total weight for 2007 data were taken from Table 1 and Table 2 in Chisnall & Ruru (2008). Weight and condition calculations were not completed for longfin from the 2007 data because raw weight data were not representative of the population and there was low replication (see Appendix A).

Study	Species	Count	Total weight (kg)	Mean length (mm)	SE Length (mm)	Mean weight (g)	SE Weight (g)	Mean condition (k)	SE Condition (k)
2007 all nets	Longfin	44	52.70	585.6	42.0	NA	NA	NA	NA
2007 all nets	Shortfin	466	84.70	533.6	5.0	296.0	12.6	1.91	0.03
2007 standard fyke-nets	Longfin	35	NA	588.7	49.7	NA	NA	NA	NA
2007 standard fyke-nets	Shortfin	161	NA	533.1	6.7	276.7	15.5	1.84	0.03
2025	Longfin	92	32.24	459.5	15.1	358.2	54.7	2.69	0.15
2025	Shortfin	815	193.11	453.7	3.6	243.5	18.2	2.44	0.25

3.1 Size Distributions of Tuna

Shortfin captured in 2025 showed a clear peak around 400-460 mm, with the percentage of the catch gradually declining with increasing size above 460 mm (Figure 3-1). Most of the shortfin captured were between 400-560 mm with an average length of 454 mm recorded from the 815 shortfin measured (Table 3-1). The 2007 study recorded higher proportions of larger fish compared to the present study (Figure 3-2). In 2007 all nets and standard fyke nets both showed size distributions with a strong peak around 520-600 mm (Appendix C). The mean length of shortfin was approximately 70 mm longer in 2007, which was significantly larger than the mean length of shortfin captured in the present study ($t=10.43$, $DF=262.97$, $P<0.001$).

Longfin captured in 2025 showed similar size structure to shortfin captured in 2025. Longfin showed a peak around 440-460 mm with a mean length of 460 mm (Table 3-1). The percentage of the catch above 460 mm gradually declined with increasing size. The only obvious difference between the shortfin and longfin size distribution was the presence of a few larger (>1m) fish. The size distribution of longfin captured in 2007 showed higher proportions of larger fish compared to the present study. In 2007, standard fyke nets and all fyke nets showed a peak longfin catch around 380 mm and then declining catch with increasing size. A key difference was the presence of more longfin between 800-1300 mm in 2007 compared to 2025. Similarly, the mean length of longfin was approximately 120 mm longer in 2007, which was significantly larger than the mean longfin length captured in the present study ($t=2.49$, $DF=40.42$, $P=0.017$).

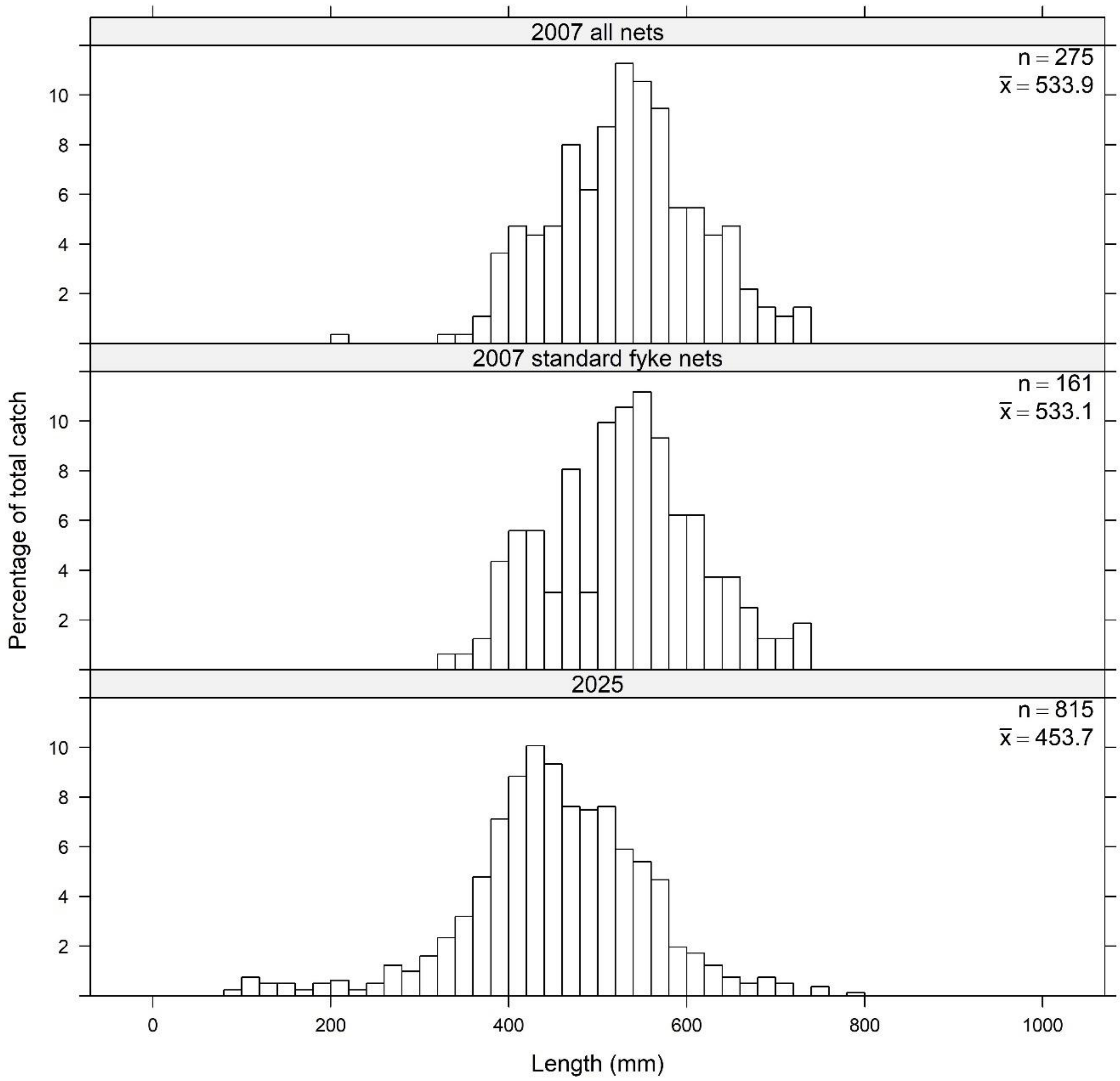


Figure 3-1: Length-frequency distributions for shortfin captured from Lake Tahaaroa in 2007 (Chisnall & Ruru 2008) and in 2025. Length-frequency distributions for shortfin captured from Total number captured (n) and mean length (x̄) are shown in the top right corner of each plot. Catches from standard fyke nets used in 2007 are shown (similar to the nets used in the present study) along with all fyke-nets used in 2007 (fine mesh, commercial fyke nets with and without escapement tubes)..

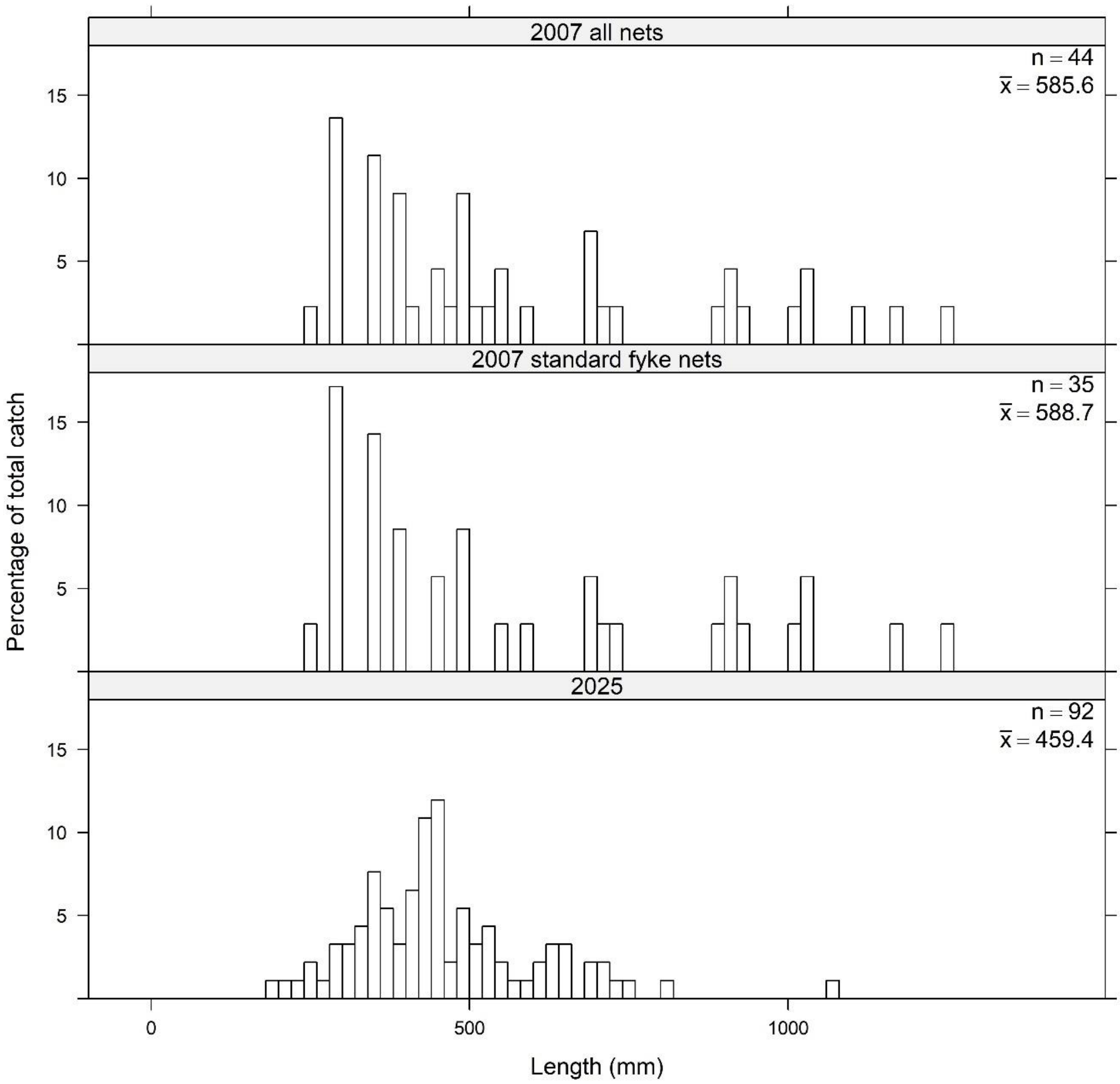


Figure 3-2: Length-frequency distributions for longfin captured from Lake Tahaaroa in 2007 (Chisnall & Ruru 2008) and in 2025. Total number captured (n) and mean length ($\bar{x}$) are shown in the top right corner of each plot. Catches from standard fyke nets used in 2007 are shown (similar to the nets used in the present study) along with all fyke-nets used in 2007 (fine mesh, commercial fyke nets with and without escapement tubes).

3.2 Catch-Per-Unit-Effort

On average (±SE), 5.39 (±0.66) kg of shortfin and 0.73 (±0.16) kg of longfin (total of 6.12 ± 0.72 kg) was captured from each net/night of fishing in 2025 (Figure 3-3, Table 3-2). Unfortunately, there was no weight data available from 2007 to compare CPUE weight with the present study. In terms of catch rates for tuna numbers, an average (±SE) of 25.04 (±2.78) shortfin and 2.07 (±0.32) longfin (total of 27.11 ± 2.78 eels) were captured from each net/night of fishing (Figure 3-4, Table 3-3). Significantly higher numbers of longfin (t=3.18, DF=70.64, P=0.002), shortfin (t=-5.13, DF=59.58, P<0.001) and both species (t=-5.42, DF=62.60, P<0.001) were captured from each net in the present study compared to 2007 (Figure 3-4, Table 3-3).

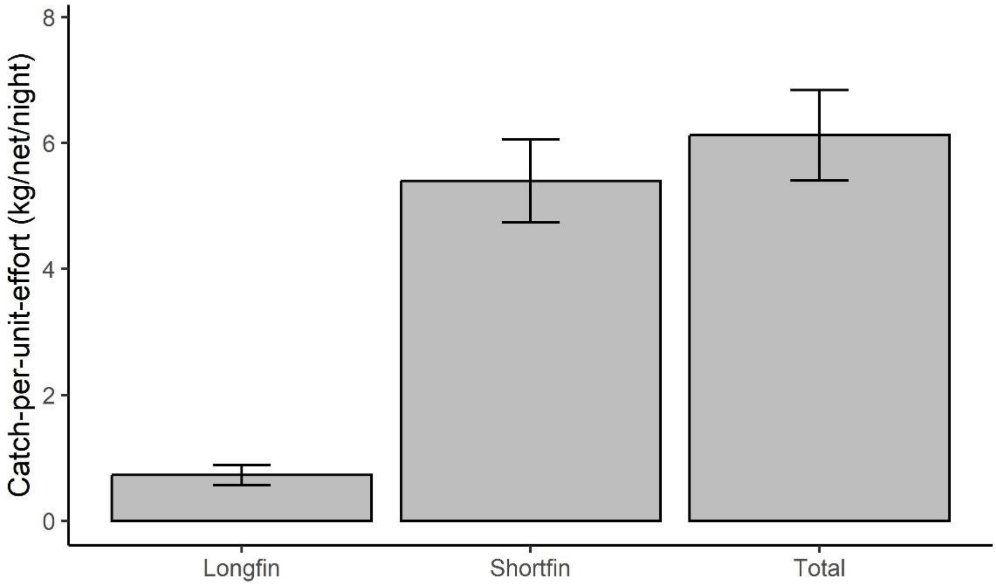


Figure 3-3: Mean (+- standard error) catch-per-unit-effort [average weight of eels (in kg) captured each night from each net] from of longfin, shortfin and both species (total) form Lake Tahaaroa in 2025. This could not be calculated from the raw data available from the dataset collected by Chisnall & Ruru (2008).

Table 3-2: Mean (+- standard error) catch-per-unit-effort [weight of eels (in kg) captured each night from individuall nets] of longfin, shortfin and both species (total) form Lake Tahaaroa in 2025.

Species	Mean weight (kg) of eels captured/net/night	Standard error for the weight (kg) of eels captured/net/night
Longfin	0.73	0.16
Shortfin	5.39	0.66
Total	6.12	0.72

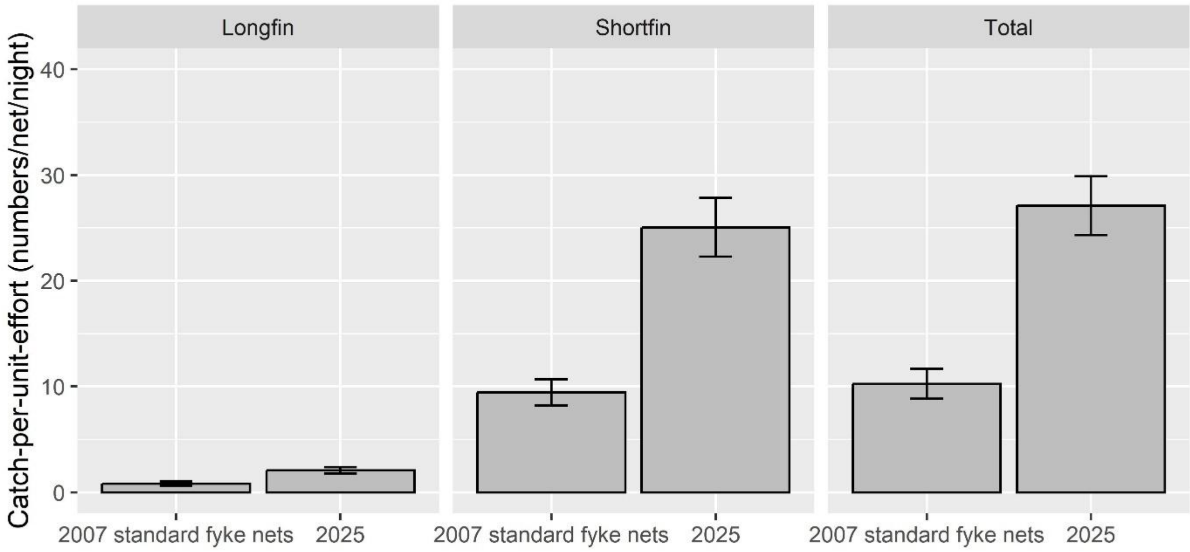


Figure 3-4: Mean +- standard error catch-per-unit-effort (number of eels captured each night from individuall nets) of longfin, shortfin and both species (total) form Lake Tahaaroa in 2007 (Chisnall & Ruru 2008) and in 2025.

Table 3-3: Mean and standard error (SE) catch-per-unit-effort (number of eels captured each night from individuall nets) of longfin, shortfin and both species (total) form Lake Tahaaroa in 2007 (Chisnall & Ruru 2008) and in 2025.

Species	Study	Mean number of eels captured/net/night	SE for the number of eels captured/net/night
Shortfin	2007 standard fyke nets	9.43	1.25
Shortfin	2025	25.04	2.78
Longfin	2007 standard fyke nets	0.82	0.23
Longfin	2025	2.07	0.32
Total	2007 standard fyke nets	10.25	1.40
Total	2025	27.11	2.78

3.3 Condition of Shortfin

Shortfin condition was significantly higher in the present study compared to the 2007 study (t=-2.39, DF=813.05, P=0.017; Figure 3-5).This indicates that the shortfin in 2025 were significantly fatter at any length compared to 2007.

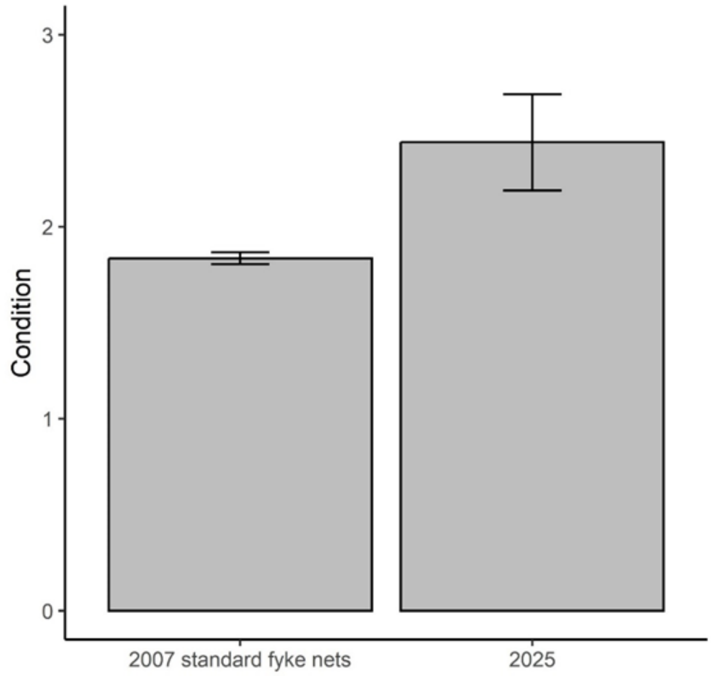


Figure 3-5: Mean +- standard error of shortfin condition measured in 2007 (Chisnall & Ruru 2008) and 2025 (present study). Mean and SE calculations for 2007 were made from 44 longfin and 276 shortfin that were individually weighed and measured. Condition could not be compared between the two studies for longfin because length and weight data were not available from Chisnall & Ruru (2008).

3.4 Shortfin Age, Growth and Sex Ratio.

A total of 50 shortfin otoliths were extracted and aged using Fisheries New Zealand–approved protocols (Table 3-4) (see Appendix D for examples). One otolith showed irregular growth patterns that made age estimation unreliable and was excluded from analysis. The remaining 49 shortfin were successfully aged and included in the present study (Appendix D).

For any given length, shortfin in 2025 were approximately twice the age of the same sized fish from 2007 (Figure 3-7). Both studies aged similar sized fish, but the mean (±SE) growth rate of shortfin in 2007 (33.37 ± 1.16 mm/year) was approximately twice what it was in 2025 (17.22 ± 0.47 mm/year). These results show that shortfin growth rate has significantly declined in Lake Tahaaroa from 2007 to 2025 (t=-15.33, DF=62.89, P<0.001) (Figure 3-7).

Sex was determined for most of the 50 shortfin tuna aged, with 28 identified as female, 13 as male, and 9 undetermined.

Table 3-4: Ageing results from the present study and 2007. We used age data from all shortfin tuna captured by Chisnall & Ruru (2007) regardless of sampling method. Standard errors (SE) are shown for all mean calculations.

Study	Mean growth rate (mm/year)	SE growth rate (mm/year)	Mean length (mm)	SE length (mm)	Number aged	Mean age (years)	SE age (years)	Min Age	Max age
2007	33.37	1.16	512.20	17.55	20	13.65	0.44	10	18
2025	17.22	0.47	564.57	11.96	49	30.20	0.98	17	47

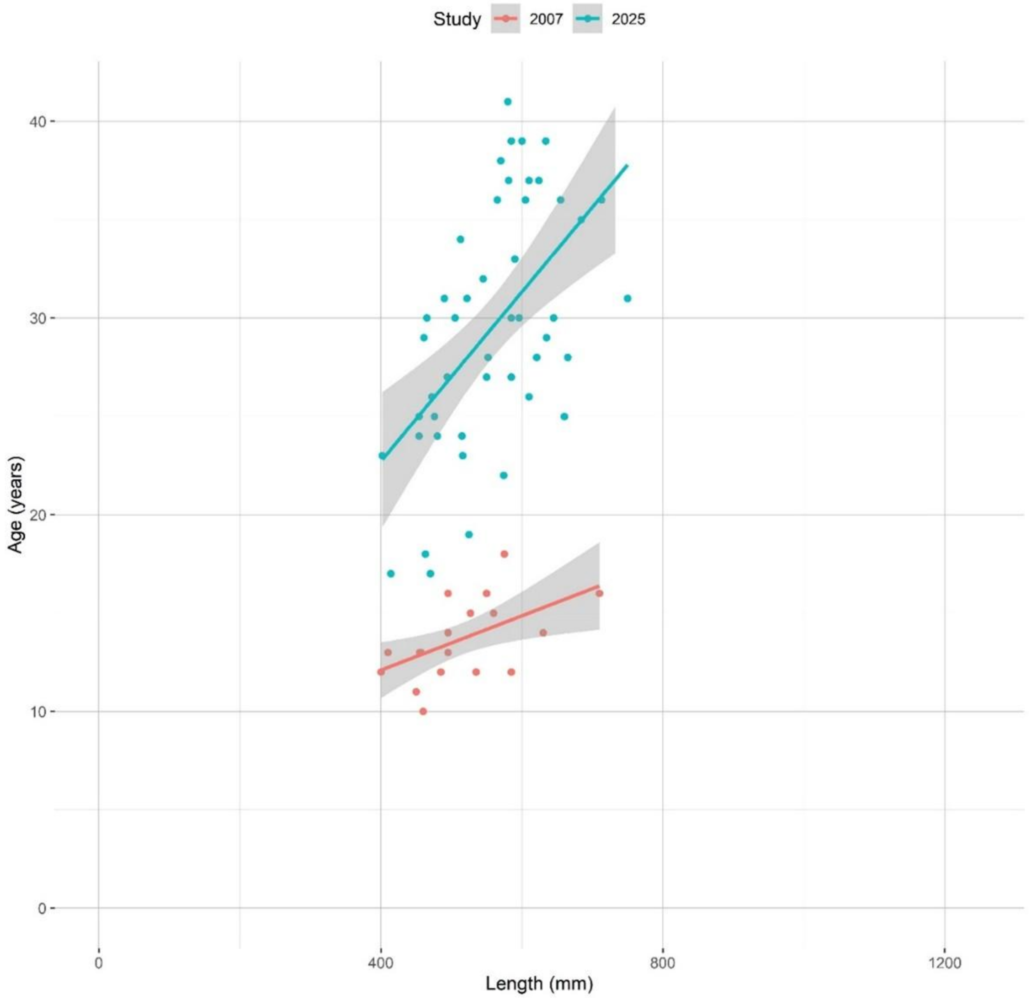


Figure 3-6: Relationship between age and total length of shortfin tuna sampled from Lake Tahaaroa in 2007 (Chisnall & Ruru 2008) and in 2025. Each point represents the age and corresponding length of an individual eel. The positive trend reflects increasing length with age.

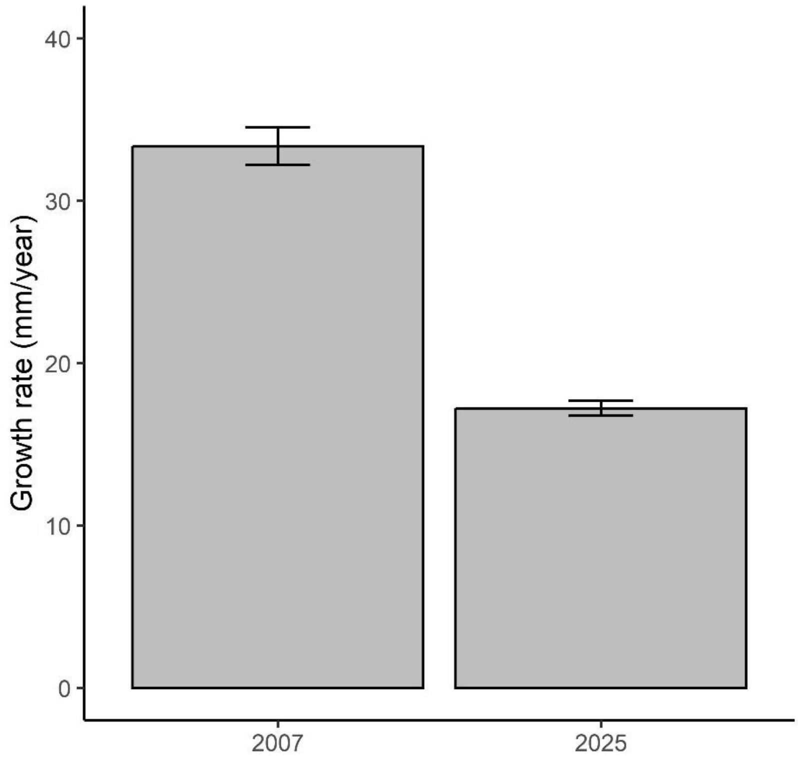


Figure 3-7: Mean +- standard error of shortfins annual freshwater growth rate from fish collected in 2007 (Chisnall & Ruru 2008) and in 2025.

3.5 Parasite and Pathogen Observations

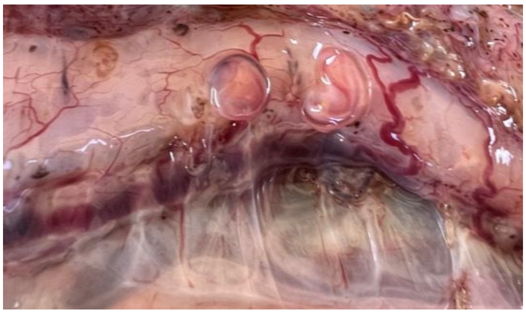
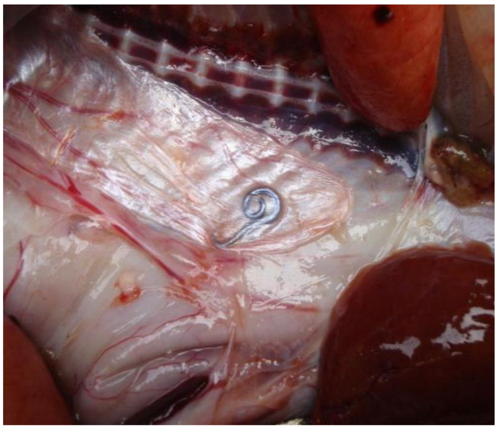
As part of the tuna health assessment, 93 shortfin individuals were examined for visible parasites, internally and externally, using Richardson's (1998) parasite infestation index (Table 3-5, Table 3-6).

Four types of parasites were identified in tuna from Lake Tahaaroa for the first time:

- Shagworm (Eustrongylides spp.): Prevalent in the stomach/intestine of many eels.
- Nematodes (Anguillicola spp.): Found in the swim bladders of two individuals.
- Putative trematodes: Unidentified worm-like organisms embedded in stomach linings.
- Unidentified black markings: Observed in several shortfin body cavities.

Overall, 74.1% of shortfin displayed parasites. The mean parasite index score was 37.0, which is well above the acceptable range of 0–2.7 (Richardson, 1998). This suggests that there is a high level of infestation and raises questions about potential effects on tuna fitness and suitability for harvest.

Table 3-5: Examples of parasite and pathogen infestations observed in shortfin during the lake Tahaaroa tuna survey (February 2025). All photos were taken of tuna caught in Lake Tahaaroa except for the nematode image, which was sourced from a 2008 observation in the Kaikou River (Williams et al. 2017).

Description	Photos
Pathogen/parasite Shagworm, *Eustrongylides* sp. **Site of infection** Stomach, intestine Shagworm were prevalent in the shortfin caught in Lake Tahaaroa. The intermediate stage of this worm is typically found in the body cavity and flesh of fish, reaching maturity in predatory birds (Williams et al 2017). The immature worms are red in colour and can grow up to about 60 mm in length. Shagworms are typically coiled in cysts attached to various organs within the fish's body cavity, most commonly on the outer surface of the stomach (Stokell, 1936). It also appeared that shagworms were encysts deep within the stomach wall of some eels.	 
Pathogen/parasite Nematode, *Anguillicola spp.* **Site of infection** Swim bladder Nematodes were observed in the swim bladder of two shortfin assessed. Nematodes are ingested by tuna and move from the digestive tract to the swim bladder. A severe infestation of nematodes may result in symptoms such as bleeding lesions and swim bladder collapse. As it affects its swim bladder, it can also hamper a tuna's ability to swim and reach its spawning grounds. (Source: Wikipedia).	 Nematode in the swim bladder of a longfin found in Kaikou River in 2008. Photo credit: Erica Williams, Jacques Boubée. (Williams et al. 2017).
Pathogen/parasite Unidentified/putative trematode **Site of infection** Stomach, intestine Unidentified parasite. White worm-like structure encysted in the stomach/intestine of shortfin. It is likely a digenean trematode due to its location within the eel and description. Further assessments required for accurate identification.	

Description		Photos
Pathogen/parasite	Unidentified	
Site of infection	Stomach wall/Body cavity	
Unidentified black markings were observed along the body cavity and the stomach wall of shortfin. Potential pathogen. These markings have also been observed in other eels (Williams et al 2017).		

Table 3-6: Summary of parasite load observed in shortfin.

Parasite load	Number of tuna	% of tuna
0	14	25.9
1	12	22.2
2	16	29.6
3	12	22.2

4 Discussion

This section interprets the results in the context of ecological processes, cultural knowledge, and long-term lake health. It examines potential drivers behind observed trends and considers the implications for customary fisheries management and restoration planning.

4.1 Changes in the Tuna Population from 2007 to 2025

4.1.1 Catch rates

Catch rates (both CPUE abundance and CPUE weight) have increased in Lake Tahaaroa from 2007 to 2025. CPUE abundance of tuna (both species) in 2025 was more than double what was recorded in 2007 with similar nets and more than four times higher than the 2007 catches recorded from all net types (Chisnall & Ruru 2008). CPUE abundance for longfin and shortfin was also more than double what was recorded in 2007. In December 2001, 26 commercial fykes (standard fyke nets with escapement tubes) were set in Lake Tahaaroa and an average CPUE abundance of 25.3 eels/net/night was recorded (Chisnall & Ruru 2008), which was similar to the 27.11 recorded in the present study. Another fine-meshed fyke net survey from 2001 in Lake Tahaaroa recorded an average of 18.1 eels/net/night (see discussion in Chisnall & Ruru 2008), which is lower than the present study. Given that the catch rates from the two studies in 2001 (18.1-25.3 eels/net/night) were higher than 2007, the higher catch rates observed in the present study suggest that the numbers of tuna in Lake Tahaaroa suffered a decline in the mid-late 2000s and may have returned to pre-2000s level now. While no data on CPUE weight were available from 2007, a fine-meshed fyke net survey in 2001 recorded a mean CPUE weight of 3.1 kg/net/night (Chisnall & Ruru 2008). This 2001 CPUE weight figure was less than half what was recorded in 2025, again indicating that the current stock in Lake Tahaaroa may be higher than it was in the mid 2000s. It is important to note that in the late 1990s the customary fishery was unable to meet the needs of Ngaati Mahuta (Chisnall & Ruru 2008), so even though there has been a potential recovery to early 2000 levels, the current tuna stock is still unlikely to meet the aspirations of mana whenua.

The current catch rates in Lake Tahaaroa were similar to those recorded throughout the Waikato River Catchment. Chisnall & Ruru (2008) reported a series of unpublished CPUE data in Appendix 1 of their report that was collected with fine-meshed fyke nets (Table 4-1). Chisnall & Ruru (2008) suggested that catch rates from these fine-meshed fyke nets were higher than the standard commercial fyke nets used in their 2007 survey. Presumably the same rationale holds true for the nets used in the present study, and that catches from fine-meshed fyke nets would be higher than the nets used in the present study. The mean (±SE) CPUE abundance of 27 (±3) tuna recorded in the present study was broadly comparable to the fine-meshed catches in the Waikato region (31.1 ± 5.3) (Table 4-1). This suggests that catch rates were high in the present study considering that the nets we used were likely to capture lower numbers than fine-meshed fyke nets. Similarly, the mean (±SE) weight of tuna captured in the present study was 6.12 ± 0.72 kg/net/night which was higher than the 4.6 kg/net/night recorded from fine-meshed fyke nets throughout Waikato, also suggesting catch rates in Lake Tahaaroa were high compared to other areas in the Waikato River basin. Similarly, the mean (±SE) CPUE weight of 6.12 ± 0.72 kg/net/night recorded in the present study is similar to the 7.5 ± 1.2 kg/net/night recorded from several locations in the South Island (Table 4-2), suggesting the catch rates in Lake Tahaaroa are consistent with other areas in Aotearoa.

Table 4-1: Mean catch-per-unit-effort (CPUE) data of tuna (both species) from locations in the Waikato River basin. Data from Appendix 1 (Chisnall & Ruru 2008) were from fine meshed fyke nets, while the data from Chisnall & Ruru (2008) were from all fyke nets used. Mean, standard error, min and max values are reported separately for Appendix 1 Chisnall & Ruru (2008) and with the combined results from Appendix 1 Chisnall & Ruru (2008) and results from the Chisnall & Ruru (2008) survey.

Location	Year collected	Mean numbers/net/night	Mean weight/net/night	Data source
Waikato River estuary	1992-1994	21.3	2.3	Appendix 1 Chisnall & Ruru (2008)
Lake Rotongaro	1992-1994	45.3	5.7	Appendix 1 Chisnall & Ruru (2008)
Lake Rotongaroiti	1992-1994	45	4.4	Appendix 1 Chisnall & Ruru (2008)
Lake Whangape	1992-1994	37.8	5.5	Appendix 1 Chisnall & Ruru (2008)
Lake Waahi	1992-1994	69	3	Appendix 1 Chisnall & Ruru (2008)
Lake Waikare	1992-1994	46	5.7	Appendix 1 Chisnall & Ruru (2008)
Lake Okowhaeo	1992-1994	8.5	1.7	Appendix 1 Chisnall & Ruru (2008)
Lake Kainui	1992-1994	8.6	1.5	Appendix 1 Chisnall & Ruru (2008)
Lake Ngaroto	1992-1994	43.3	7	Appendix 1 Chisnall & Ruru (2008)
Lake Tahaaroa	1992-1994	18.1	3.1	Appendix 1 Chisnall & Ruru (2008)
Lake Numiti	1992-1994	9.8	3.3	Appendix 1 Chisnall & Ruru (2008)
Lake Rotoroa	1992-1994	37.4	13.2	Appendix 1 Chisnall & Ruru (2008)
Lake Harihari	1992-1994	14.3	3.5	Appendix 1 Chisnall & Ruru (2008)
Lake Tahaaroa	2007	5.4	NA	Chisnall & Ruru (2008)
Lake Numiti	2007	6.3	NA	Chisnall & Ruru (2008)
Lake Rotoroa	2007	5.8	NA	Chisnall & Ruru (2008)
Lake Harihari	2007	2.3	NA	Chisnall & Ruru (2008)
Mean		25.0	4.6	All data
Standard Error		5.3	0.9	All data
Max		69.0	13.2	All data
Min		8.5	1.5	All data
Mean		31.1	4.6	Appendix 1 only
Standard Error		5.3	0.9	Appendix 1 only
Max		69.0	13.2	Appendix 1 only
Min		8.5	1.5	Appendix 1 only

Table 4-2: Mean catch-per-unit-effort (kg/net/night) of tuna from areas in the South Island. ANG14 refers to the MPI reporting area for commercial fishing that covers South Canterbury.

Location	Mean CPUE (kg/net/night)	Reference
ANG14 rivers	13.7	Jellyman (2012)
ANG14 rivers excluding Dead Arm	11.9	Jellyman (2012)
Aparima	7.5	Jellyman and Graynoth (2005)
Mataura – reserve	6.4	Jellyman et al. (2009)
Mataura – commercially fished	2	Jellyman et al. (2009)
Kaikōura rivers	10.6	Crow and Jellyman (2009)
South Canterbury Rivers 1983–1989	4.7	Jellyman (1993)
South Canterbury, Waitaki, 1990–1999	4.7	Beentjes and Bull (2002)
Wainono Lagoon East	5.19	Jellyman and Sykes (1998)
Wainono Lagoon West	7.99	Jellyman and Sykes (1998)
Mean ± SE	7.5 ± 1.2	All studies

4.1.2 Growth rate and condition

The growth rates observed in the 2025 survey provide critical insight into the changing dynamics of the tuna population in Lake Tahaaroa. Shortfin growth rate has dropped from 33.4 mm/year in 2007 to 17.2 mm/year in 2025. Shortfins can grow up to 30–50 mm/year under ideal conditions (Beentjes et al. 2020), suggesting that the current growth rates in Tahaaroa are very low. In a South Island lowland lake Te Waihora/Lake Ellesmere, shortfin growth rates average 33 mm/year (Graynoth et al.2008) also suggesting that growth rates of shortfins from a similar habitat are much lower in Tahaaroa.

The reduced growth rate from 2007 to 2025 suggests that there has substantial shift in environmental and/or ecological conditions within the lake over the intervening 17 years. Interestingly, despite this slower growth, shortfin captured in 2025 had a higher mean condition factor (2.44) than those from 2007 (1.91), indicating better body mass relative to length. This could reflect a shift in energy allocation, from somatic growth to fat storage, potentially as an adaptive response to environmental stressors or as an indicator of delayed migratory readiness. It is possible that the growth rate decrease may simply be associated with age estimation differences between otolith reader methods and/or readers. Despite Earth Sciences New Zealand completing the ageing in both studies, there are now new approaches and methodologies being used to complete age estimates of eels under the Fisheries New Zealand guidelines (Walsh et al. 2016). These new estimates could have resulted in inconsistent/incompatible age estimates being generated between the two studies. The best approach to addressing this problem is for the otolith readers from the present study to re-age a random selection of the 2007 otoliths. Unfortunately, the original 2007 otoliths are not available (not held by NIWA and authors have stated that all samples were provided to FNZ at the completion of the study).

Environmental changes that may have caused the reduced growth rate in Lake Tahaaroa are difficult to identify and further work is required to conclusively identify the drivers. Changes to the environmental conditions and/or food accessibility could be a reason for the decreased growth rate.

Growth rates in European eels have been shown to be associated with temperature (Vaughan et al. 2021), which impacts on growing seasons. Kuhlman (1979) also showed that 26.5 °C was the optimum temperature for growth of European eels (*Anguilla anguilla*) fed to excess in captivity, with growth rates reducing at temperatures above and below this optimum. Similarly, salinity has also been shown to interact with temperature and influence growth of shortfin and longfin (Kearney et al 2008). It is possible that the water temperature in Lake Tahaaroa spends less time around the optimum growth temperature in 2025 compared to 2007. This would mean that growing conditions for eels are less favourable for longer periods each year, reducing the growing season for eels. Unfortunately, no long-term temperaurte data from Lake Tahaaroa are available to explore this. Food accessibility may also be impacting on growth rates, but prey fish abundance (inanga, smelt, bullies) is likely to be higher now that there is improved fish passage. Very high numbers of bullies were indeed observed in the lake (>5000 bullies counted from some fyke nets). However, more research is required before any conclusions can be made about differences in the drivers of shortfin growth between 2007 and the present study.

The presence of tuna nearing 50 years old affirms the long-lived nature of this taonga species. The age structure indicates that Lake Tahaaroa continues to support adult tuna critical for both ecological integrity and customary harvest. Continued monitoring will be essential to detect trends in recruitment and assess potential pressures on population resilience. The presence of older, slower-growing individuals aligns with whaanau observations of declining tuna health and further highlights the need for catchment-wide interventions to support recruitment, feeding conditions, and habitat restoration. Together, these findings reflect a shift from a growing, replenishing population to an ageing population under stress, with implications for both ecological resilience and customary harvest sustainability. If slow growth persists without adequate remediation the long-term viability of the Lake Tahaaroa tuna fishery may be at risk.

4.2 Freshwater Fish Recruitment

The fish passage into Lake Tahaaroa appears to have maintained tuna recruitment at similar levels to the mid-2000s, but further work is required to conclusively examine the effectiveness of the Wainui Stream fish pass. The fish pass at Wainui Stream was regarded to not be functioning efficiently prior to 2010, when it was upgraded. Looking at the growth rates in the present study of 17 mm/year, fish larger than shortfins entering the lake after 2010 should be smaller than 315 mm on average (assuming they entered freshwater at 60 mm and then grew at the mean rate for 15 years). Looking at the shortfin length-frequency data, 759 of the 815 (93 %) shortfins captured in the current study were larger than 315 mm and entered Lake Tahaaroa prior to the fish pass upgrade in 2010. The data suggests that there has been continued recruitment of eels prior to 2010, and that recruitment should increase over the coming years if the 2010 upgrades have helped improve the efficacy of the structure. Other diadromous fishes were also observed in the fyke nets that must have entered the lake through the fish pass, such as high numbers of common bullies[1] (>2000 individuals were counted in several fyke nets), smelt (<50 individuals), grey mullet (3 captured in a single net) and redfin bullies (2 captured). While common bullies can form landlocked populations, the rest of these species are diadromous and must have entered the lake through the Wainui fish pass.

[1] Common bullies can also form self-sustaining land-locked populations, so these fish could have been non-diadromous. Further work would be required to identify if the common bullies are land-locked or recruited from the ocean.

The present study only aimed to identify changes in the tuna population and did not examine the efficiency of the Wainui Stream fish pass, which would require further work. To fully assess the efficacy of the new fish pass, the design could include:

- Mapping the flow regime for the fish pass and site and comparing this with swimming speeds of diadromous fishes.
- Mark and recapture trials of diadromous fish. This involves externally tagging fish with a non-invasive dye and then releasing them at the bottom of the dam, then examining what proportion of the fish are recaptured at the top of the dam over several days.
- Continuously monitoring catch rates of fish from a trap located at the bottom and at the top of the fish pass.
- Comparing catch rates and/or densities of diadromous fish from areas above and below the fish pass.

4.3 High Parasite Burden and Implications

The high prevalence of parasites, particularly shagworm (*Eustrongylides* spp.), in tuna from Lake Tahaaroa raises both ecological and cultural concerns. In this survey, 74.1% of shortfin tuna examined were infected, indicating that parasites are now widespread across the population. This contrasts with the 2008 survey, which reported shagworm primarily in Lake Rotoroa and largely absent from Lake Tahaaroa (Chisnall & Ruru, 2008). The increase in prevalence suggests that parasite transmission has expanded across the lake system. Known avian hosts such as black swan and paradise duck (Chisnall & Ruru, 2008) likely contributed to this spread, and since 2008, Canadian geese have also become a pest in the Tahaaroa lakes, adding further pressure through grazing, fouling, and potential parasite spreading pathways. Regular bird culling was previously suggested as a strategy to reduce shagworm transmission (Chisnall & Ruru, 2008), which remains a viable option to limit parasite spread.

While parasite presence is common in wild fish populations (Williams et al. 2017), the levels observed in 2025 were unusually high and pose a risk to tuna growth, reproductive capacity, and migratory behaviour (Duignan et al. 2003; Richardson, 1998). From a cultural perspective, such high parasite prevalence, combined with heavy parasite burdens in some individuals, reduces the suitability of tuna for customary harvest and undermines whaanau confidence in the health and mauri of the fishery. These findings reinforce the need for regular parasite surveillance and targeted ecological interventions, particularly through bird population management that includes not only black swan and paradise duck, but also the more recent presence of Canadian geese.

4.4 Implications for Customary Use and Hauanga Kai Strategies

The findings from this survey have significant implications for the ongoing implementation of customary rights and the maintenance of hauanga kai traditions at Lake Tahaaroa. While catch-per-unit-effort suggests tuna abundance is comparable to other sites nationally, the stock is now dominated by older, slower-growing individuals with high parasite burdens. These conditions undermine the suitability of tuna for customary harvest and weaken whaanau confidence in the mauri of the fishery.

For hauanga kai strategies, this means: Customary harvest practices may need to be adapted to ensure sustainability. In particular, the scarcity and advanced age of longfin tuna in the catch strongly suggest that these individuals are a taonga cohort requiring protection. Ngaati Mahuta could consider a raahui on longfin tuna, whereby:

- Longfin harvest is temporarily restricted across the lake system.
- The raahui is regularly reviewed in conjunction with monitoring results, allowing for adaptive management if recruitment improves.
- Exceptions may be permitted under tikanga in extraordinary cultural circumstances, subject to collective decision-making by kaitiaki.
- Communication of the raahui is embedded in whaanau waananga, signage at key access points, and engagement with external agencies (MPI, WRC, DOC) to reinforce its legitimacy.
- Knowledge transmission is at risk if whaanau are unable to safely and confidently harvest tuna for hui, tangihanga, or everyday sustenance. Revitalising customary harvest under controlled conditions, supported by monitoring, would maintain intergenerational skills and narratives.
- Whaanau wellbeing is compromised if taonga species are unsuitable for kai. High parasite prevalence, particularly shagworm, diminishes trust in the safety of tuna for consumption. Hauanga kai strategies must therefore extend beyond harvest regulation to include catchment restoration, parasite surveillance, and bird host management.
- Rangatiratanga and mana whakahaere require that decision-making about harvest and restoration is led by Ngaati Mahuta. This study reaffirms the importance of hapuu authority over when, how, and under what conditions customary harvest may occur.

Overall, the sustainability of hauanga kai at Lake Tahaaroa will depend not only on protecting tuna populations, but on ensuring that whaanau can continue to engage in safe, tikanga-based harvest practices that reaffirm whakapapa connections and food sovereignty.

4.5 Relevance of Findings for Local Environmental Management

The 2025 tuna survey highlights a number of urgent management issues for the Tahaaroa lakes system. These results provide a clear evidence base for local interventions and underline the need for hapuu-led environmental authority to be recognised and upheld.

- **Bird culling and parasite management**
  The extremely high prevalence of shagworm (74.1% of shortfin) indicates an urgent need to manage host bird populations such as black swan, paradise duck and Canadian geese. Regular bird culling, as previously recommended, could reduce parasite transmission and restore tuna health. This must be undertaken under hapuu oversight to ensure cultural safety and ecological integrity.
- **Habitat restoration**
  Slower growth rates and declining water quality point to catchment degradation as

a key stressor. Priority actions include riparian planting, fencing stock from waterways, and sediment/nutrient management in surrounding farmland. Wetland restoration should also be pursued, recognising their role in buffering nutrients and sediment.

- **Fish passage improvements**
  Effective juvenile recruitment remains uncertain. Further assessment and potential upgrades to the Wainui Stream fish pass and perched culverts (e.g., at Lake Harihari) are required to secure long-term stock resilience.

- **Water quality monitoring**
  Sporadic monitoring over the past decade has left significant data gaps. Continuous data loggers for temperature, dissolved oxygen, and turbidity would allow direct links to be made between tuna health and environmental conditions. This should be paired with seasonal sampling of nutrients and algal biomass to track trophic status.

- **Recognition of raahui and customary protocols**
  A critical implication of this survey is the vulnerability of longfin tuna. Their scarcity, older age profile, and ecological importance warrant a hapuu-declared raahui on longfin harvests. From a local management perspective, agencies including WRC, DOC, and MPI have a responsibility to:

  - Formally recognise the raahui as a legitimate regulatory tool, in line with Te Tiriti o Waitangi obligations.
  - Embed the raahui into fisheries management frameworks, resource consents, and lake management plans to ensure its enforceability and visibility beyond whaanau networks.
  - Support monitoring and enforcement, by aligning compliance mechanisms (e.g., customary permit systems, environmental bylaws) with hapuu directives.
  - Resource hapuu governance to lead the design, communication, and review of the raahui, ensuring that tikanga and maatauranga Maaori remain central.

- **Integrated monitoring framework**
  A hapuu-led monitoring programme should combine standardised fyke netting, otolith ageing, and parasite checks with maatauranga-based tohu such as changes in water clarity, bird behaviour, or seasonal fish movements. This integrated approach would ensure that ecological and cultural indicators are considered together in management responses.

In summary, the survey findings point to a need for catchment-scale interventions, addressing parasites, restoring habitats, securing recruitment, and embedding hapuu authority in monitoring and management. Formal recognition and resourcing of a Ngaati Mahuta-led raahui on longfin would represent both a pragmatic management measure and a Treaty-consistent expression of mana whakahaere.

4.6 Upholding Mana Whakahaere in Research Partnerships

As tangata whenua and kaitiaki of the Tahaaroa lakes, Ngaati Mahuta hold the right and responsibility to lead research, restoration, and environmental decision-making in their rohe. This report has been developed under the governance of the Tahaaroa Lakes Trust (The Trust) and reflects a maatauranga-led approach to customary fisheries monitoring.

Future research and restoration efforts must shift from extractive or externally driven models to partnerships grounded in tikanga, co-design, and data sovereignty. This includes recognising that all information gathered through environmental monitoring, including biological samples, images, datasets, and whakapapa koorero, constitutes taonga.

Funders and research agencies including MPI, DOC, NIWA, and WRC have an obligation under Te Tiriti o Waitangi to support hapuu governance of research and monitoring processes. This includes recognising Ngaati Mahuta's authority to set priorities, define tikanga-aligned methods, and retain kaitiaki control over data and outcomes.

> *The Trust asserts that all information and data generated from research... constitutes taonga and remains under the stewardship of the Trust... Effective collaboration must begin with recognition of the Trust's authority to lead research agendas.*
> — Herangi et al., 2025b.

4.7 Integrating Maatauranga Maaori and Science

This assessment demonstrates the value of bringing together maatauranga Maaori and scientific methods in understanding the health of Lake Tahaaroa's tuna fishery. Ngaati Mahuta's relationship with the lake is intergenerational and guided by tikanga, with customary practices shaping how tuna are caught and handled. Hapuu oversight ensured that all fieldwork upheld cultural protocols, including karakia and the respectful treatment of taonga species.

Whaanau puuraakau and lived experience provide tohu that complement measured ecological indicators. These tohu include changes in water clarity, the abundance or absence of key species, and shifts in bird and insect behaviour all signalling changes in lake health. As articulated in Ngaa taonga tuku iho o ngaa roto o Tahaaroa.

> *Ngaati Mahuta understand lake health not only through scientific measures, but through the condition and behaviours of taonga species, seasonal patterns, and the mauri of places. This knowledge is embedded in the lived experience of whaanau who actively engage with the lakes for kai, waananga, and ceremony.*
> — Herangi et al. 2025b.

Embedding these cultural indicators into future monitoring frameworks affirms mana whakahaere and strengthens the alignment between ecological science and cultural values. This integrated approach offers a more holistic understanding of tuna health, habitat quality, and the long-term resilience of the lake system.

The insights gained from this analysis form the basis for the recommendations in the next section, which outline immediate actions, identify critical knowledge gaps, and set a roadmap for future research and monitoring.

4.8 Maintaining Mauri: Water Quality Challenges and Ecological Resilience to Ensure a Thriving Tuna Population

The lake-edge wetlands buffer the fringes of the lake from erosion and wind formed waves. Importantly, as water enters wetlands and the level of the lake rises, nutrients will be taken up by plants and algae and thus the wetlands likely assist to maintain lake water quality. Gully wetlands play a key role in filtering water from the catchment, reducing sediment and nutrients entering the lakes (Bayler et al. 2020). Bayler et al. (2020) describes three forms of water pollution impacting Tahaaroa lakes:

- Nutrients: specifically, nitrogen and phosphorus. When these nutrients are present in excessive amounts, they contribute to the decline of water quality by promoting algal blooms.
- Sediment: which comes from soil erosion and accumulates in rivers, lakes, streams, and estuaries. This build-up of mud and suspended particles reduces water clarity and can suffocate aquatic organisms.
- Bacterial contamination: especially faecal coliforms, which often originate from livestock either entering waterways directly or through runoff from agricultural land.

4.8.1 Nutrients

The Trophic Level Index (TLI) is a method of characterising the ecological health of lakes based on the amount of nutrients and algae growing in them ((Burns et al. 2000) (Table 4-3). It provides an integrated measure of water quality that can be tracked over time and used to estimate biological productivity. TLI is presented as a score, the lower the score the better the condition of the lake (Burns et al. 2000; LAWA, 2024).

Table 4-3: The trophic level index values are calculated according to the methods described by Burns et al. (2000) involving commonly measured lake variables, including chlorophyll a (Chla), secchi depth, total phosphorus (TP), total nitrogen (TN), hypolimnetic volumetric oxygen depletion rate and phytoplankton species and biomass. TLI values provide a measure of the nutrient status of water bodies and are critical indicators of lake water quality.

Trophic Status	Trophic Level	Trophic Description
Oligotrophic	2.0 - 3.0	Low – the lake is clear and blue, with low levels of nutrients and algae.
Mesotrophic	3.0 - 4.0	Medium – the lake has moderate levels of nutrients and algae.
Eutrophic	4.0 - 5.0	High – the lake is murky, with high amounts of nutrients and algae.
Supertrophic	5.0 - 6.0	Very high – the lake has very high amounts of phosphorous and nitrogen and can be overly fertile and often associated with poor water clarity. Excessive algae growth can occur. Suitability for recreational purposes is often poor.

Trophic Status	Trophic Level	Trophic Description
Hypertrophic	6.0 - 7.0	Extremely high – the lake is highly fertile and supersaturated in phosphorus and nitrogen. Excessive phytoplankton growth contributes to poor water clarity, poor suitability for recreational uses, and restricts habitat for desirable fish.

Lake Tahaaroa was classified as oligotrophic in 1982, indicating low nutrient and high-water clarity levels at that time (David et al. 2014; Dean-Speirs et al. 2014). However, monitoring conducted under Waikato Regional Council's Shallow Lake Indicator Programme between 2006 and 2012 showed a decline in lake condition, with TLI scores ranging from 5.1 to 4.1 over that period (Dean-Speirs et al. 2014) (Table 4-4). These results signalled a marked deterioration in water quality, with rising algal concentrations leading to the lake's reclassification as eutrophic by 2012 (David et al. 2014). Despite these changes, David et al. (2014) noted that Lake Tahaaroa still supported extensive native macrophyte beds and populations of kaiaua. Since 2012, no further data appears to be available, suggesting that WRC's monitoring programme for Lake Tahaaroa may have ceased.

In contrast, monitoring data from 2014 onwards for Lakes Numiti and Rotoroa are available through the LAWA website, as part of WRC's shallow lakes monitoring programme (Table 4-4). Additionally, the Tahaaroa Data Deficient Shallow Lakes Survey by David et al (2014) provides baseline physico-chemical, submerged plant and ecological information for Lakes Numiti, Rotoroa, Rototapu and Piopio (David et al. (2014). At the time of the 2014 survey, the TLI values for Lakes Numiti and Rotoroa indicated high nutrient enrichment with both lakes showing a shift from eutrophic to supertrophic status. By contrast, a previous assessment in 1982 had classified these lakes as oligotrophic, with low nutrient enrichment (Dean-Speirs et al. 2014).

The Tahaaroa lakes are particularly vulnerable to nutrient enrichment, invasive species and climate-driven fluctuations (Waikato Regional Council, 2023). Key risks include elevated levels of total nitrogen and phosphorus, the potential for a regime shift to persistently turbid conditions (Waikato Regional Council, 2023). Notably, the lakes may exhibit signs of hysteresis, where ecological recovery is not immediate or guaranteed, even after the removal of stressors, highlighting the importance of early intervention and sustained management.

Table 4-4: The following table provides an indication of the trophic levels for Lakes Tahaaroa, Numiti and Rotoroa ranging in TLI results over a period of years from 2006 to 2023. Lake Tahaaroa TLI values have been sourced from the Waikato region shallow lakes management plan: Volume 2 (Dean-Speirs et al. 2014) and the TLI values for Lakes Numiti and Rotoroa have been sourced from the LAWA website (David et al. 2014). https://www.lawa.org.nz/explore-data/waikato-region/lakes

	TLI Values		
	Lake Tahaaroa	Lake Numiti	Lake Rotoroa
2006	4.8	-	-
2007	5.1	-	-
2008	5.1	-	-

	TLI Values		
	Lake Tahaaroa	Lake Numiti	Lake Rotoroa
2009	4.0	-	-
2010	3.8	-	-
2011	4.4	-	-
2012	4.1	-	-
2014	-	5.2	5.2
2020	-	5.9	5.8
2021	-	5.2	5.7
2022	-	5.3	5.4
2023	-	5.3	5.5

4.8.2 Sediment

The drivers behind the decline in water quality at Lake Tahaaroa remain uncertain. However, it is likely that land use changes such as deforestation, increased erosion, and sediment runoff from the surrounding catchment have played a role (Dean-Speirs et al. 2014; Bayler et al. 2020). Encourageingly, the lake possesses key ecological features that help maintain its mauri including well-established native aquatic vegetation (and viable seed banks), as well as substantial populations of kaiaua (Dean-Speirs et al. 2014). Lake Tahaaroa and a tributary of Lake Rotoroa was identified as a Priority 1 Stock Exclusion Waterbody in the Waikato Regional Plan (Dean-Speirs et al. 2014).

4.8.3 Bacterial contamination

Despite efforts to fence some of these lakes, livestock still gain direct access, and runoff from farmland carries sediment and nutrients straight into the lakes. The severe eutrophication events currently affecting the Tahaaroa lakes (e.g., Lake Rotoroa[2] and Numiti[3]) poses the greatest risk to their long-term viability as critical habitats for native aquatic plants and animals. As nutrient levels reach super-trophic levels, the resulting increase in algal blooms may disrupt the ecological balance, potentially rendering the lakes unsuitable for aquatic vegetation and certain native fish species (National Oceanic and Atmospheric Administration, 2024; NIWA, 2010).

Environmental data for the Tahaaroa lakes system is patchy and it is difficult to get a clear picture on the historical and current state of the dune lake system. Of these lakes, only Lake Harihari has had regular water quality data gathered between 2009 and the present[4].

[2] https://www.lawa.org.nz/explore-data/waikato-region/lakes/lake-rotoroa-south-of-kawhia
[3] https://www.lawa.org.nz/explore-data/waikato-region/lakes/lake-numiti
[4] https://www.lawa.org.nz/explore-data/waikato-region/lakes/lake-harihari

In 2014 several Tahaaroa lakes were identified by the Waikato Regional Council (WRC) as being "data deficient" meaning that there was insufficient information known about them to inform management efforts and interventions (David et al. 2015). At that time several surveys were conducted to better understand the water quality, terrestrial and aquatic plant, bird, invertebrate and fish communities in lakes Numiti, Rotoroa, Rototapu, and Piopio. These datasets complemented other workstreams previously commissioned by WRC and Fisheries NZ which have focused on the macrophyte and tuna populations in selected Tahaaroa lakes (e.g., Edwards et al. 2010, Burton et al. 2014, Chisnall & Ruru 2008).

5 Summary and Recommendations

The findings of this study confirm that Lake Tahaaroa continues to support a culturally and ecologically significant population of longfin and shortfin tuna. The tuna catch rates have increased since 2007 and are similar to other areas around Aotearoa, but the current population is dominated by older, slower-growing individuals high parasite loadings and the lake continues to display habitat degradation. These pressures are consistent with long-term trends observed by whaanau and highlight the need for coordinated catchment-scale responses to preserve the integrity of Lake Tahaaroa. The following sections cover a series of options that will ensure better information is collected on the ecology and customary values supported by Lake Tahaaroa.

5.1 Environmental Monitoring

Information on environmental conditions of Lake Tahaaroa are required to understand what factors may be driving changes in tuna populations, condition, growth patterns, and parasite prevalence. A series of changes to the tuna population have been identified in the present study, but the drivers are unknown and there is limited environmental data currently available to explore what may be driving these changes. Sporadic monitoring over the past decade indicates signs of eutrophication, declining water clarity, and seasonal algal blooms in parts of the lake. Total nitrogen and phosphorus levels have remained elevated, while sediment inputs from the catchment continue to degrade nearshore habitat quality. In summer, thermal stratification is likely to occur, reducing dissolved oxygen availability in deeper zones. These processes will all effect the health and well-being of mahinga kai, but we need more information to allow conclusive drivers to be identified. The information needs to be collected continuously over several years, so continuous data loggers (e.g. recording lake height, temperature, sediment) should be installed.

5.2 Monitoring Spawner Escapement

Nationally, a range of indicators are used to assess the state of freshwater tuna populations. These include elver recruitment at hydroelectric dams, commercial catch-per-unit-effort (CPUE), and habitat impact assessments. However, the unique biology and migratory lifecycle of tuna make conventional stock assessment methods (like those used in marine fisheries) inappropriate for longfin and shortfin (Dunn et al. 2009; MPI, 2012). Notably, there is no national monitoring programme for spawner escapement, and the Fisheries New Zealand Eel Working Group has acknowledged this data limitation. In response, the International Longfin Eel Review Panel recommended greater inclusion of iwi- and hapuu-led monitoring to fill knowledge gaps (Haro et al. 2013). This underscores the importance of place-based, culturally grounded research such as the present study at Lake Tahaaroa. Developing a customary monitoring programme for spawner escapement would address this critical knowledge gap and allow Ngaati Mahuta to monitor the ongoing health of the tuna fishery.

5.3 Value of Historical and Local Knowledge

Maatauranga Maaori should be integrated into the decision-making frameworks that govern the management of Lake Tahaaroa. The consolidation of historical information is essential for designing effective long-term monitoring programmes. Local datasets, including those from neighbouring catchments with similar environmental conditions, can provide important context for interpreting change.

Relevant sources include:

- Published literature (e.g., reports, books and published scientific papers).
- Maatauranga Maaori and local ecological knowledge.
- Customary, recreational and commercial catch information.

Maatauranga Maaori is a dynamic and evolving knowledge system that enriches our understanding of the environment. The degradation of ecosystems such as mahinga kai not only disrupts ecological processes but also fragments cultural identity and practice (Tipa, 2011). This in turn weakens the transmission of intergenerational knowledge. Differences in values, beliefs, and learning styles between generations can further challenge the continuity of maatauranga (Moller et al. 2009).

Efforts to collect and revitalise maatauranga Maaori, particularly through the co-production of knowledge, strengthen both cultural and environmental outcomes. Capturing the knowledge of kaumaatua and ruruhi offers long-lasting benefits for whaanau, hapuu, and iwi. Numerous case studies across Aotearoa demonstrate how maatauranga and science can be integrated to improve environmental management and co-governance outcomes. For example:

- Maatauranga-informed indicators have revealed historical changes in species abundance (e.g., titi: Lyver, 2008; kererū: Lyver et al. 2008; kanakana: Kitson et al. 2012).
- Long-term harvest records (e.g., titi diaries) have been used to identify ecological trends and climate patterns such as the El Niño–La Niña Southern Oscillation (Lyver et al. 1999).
- Studies have shown that Maaori cultural indicators of river health align closely with science-based indicators, supporting their joint use in setting benchmarks and understanding freshwater conditions (Harmsworth et al. 2011).
- Monitoring frameworks based on customary harvest methods and catch rates have proven effective for assessing abundance and prioritising future research (Kitson, 2004; Kusabs & Quinn, 2009; Newman & Moller, 2005).

The integration of maatauranga Maaori into the design and evaluation of tuna monitoring programmes provides a more holistic picture of environmental health and enhances the relevance and longevity of management actions.

5.4 Future Pathway for Restoring and Sustaining Lake Tahaaroa

Informed by the results and discussion, this section sets out a strategic pathway for restoring and sustaining Lake Tahaaroa's tuna fishery. It distinguishes between immediate priority actions, emerging gaps in knowledge or capability, and long-term research and monitoring needs.

The table below outlines priority recommendations arising from the study. These actions are framed to restore the mauri of the lake, strengthen the resilience of the tuna population, and uphold mana whakahaere for Ngaati Mahuta. Each recommendation includes a clear rationale and identifies the organisations best placed to lead or support implementation.

The aim is to support a long-term, hapuu-led restoration strategy that integrates maatauranga Maaori with scientific evidence, honours Te Tiriti o Waitangi, and sustains the hauanga kai traditions that are central to iwi and marae wellbeing.

Table 5-1: Priority 1 recommendations for restoring tuna habitat and water quality in Lake Tahaaroa. Actions include riparian planting, stock exclusion, sediment and nutrient management, and ongoing lake water quality monitoring with basic field measurements. These measures aim to address degraded water quality, improve habitat conditions, and strengthen the link between environmental health and tuna growth, parasite prevalence, and recruitment.

Priority	Action	Why it matters?	Responsibility
1. Restore tuna habitat and water quality	Riparian planting to reduce sedimentation Fencing stock from waterways Sediment and nutrient management in the catchment Ongoing lake water quality monitoring, including basic field measurements during tuna surveys ((e.g., temperature, dissolved oxygen, Secchi depth)	Degraded water quality (eutrophication, sedimentation, algal blooms) limits food availability, habitat quality, and growth of tuna. Ensures fish health and environmental conditions are measured at the same time, enabling stronger links between habitat quality and tuna growth, parasite prevalence, and recruitment.	**WRC** – enforce freshwater farm plans, provide funding for restoration. **The Trust** – lead riparian restoration aligned with tikanga. **Landowners and leaseholders** – adopt best practice land management. **ESNZ** – provide technical and analytical support.
2. Improve Fish Passage for Recruitment	Assess and upgrade fish passage infrastructure at Wainui Stream and culverts (especially at Lake Harihari) Monitor elver recruitment	Low juvenile recruitment remains a critical bottleneck in population recovery.	**Department of Conservation (DOC)** and **WRC** – lead infrastructure assessments and upgrades. **Ministry for Primary Industries (MPI)** – fund elver surveys through customary research streams. **The Trust** – monitor access barriers and support design to fit local tikanga.

Priority	Action	Why it matters?	Responsibility
3. Manage Parasite Load via Host Species Control	Develop and implement a bird population management strategy (e.g. black swan, paradise ducks and Canadian geese control) Carry out regular parasite surveillance of tun	74% of shortfin tuna showed parasitic infestation (mostly shagworm), compromising their fitness and suitability for customary harvest.	**DOC** – lead bird population assessments and ecological controls. **The Trust** – coordinate with whaanau, ensure cultural safety and oversight. **ESNZ** – support design of monitoring programme.
4. Develop and Fund a Long-Term Tuna Monitoring Programme	Standardise methods and timing (e.g. fyke nets, February survey window) Include age, growth, condition, and parasite health assessments Incorporate maatauranga Maaori indicators	Consistent, hapuu-led monitoring is essential for detecting trends and informing hauanga kai decisions over time.	**The Trust** – lead design and implementation. **MPI Customary Fisheries Research Fund** – fund long-term monitoring. **WRC / DOC** – align with wider freshwater state of environment monitoring.
5. Advance Co-Governance and Te Tiriti-Based Decision Making	Formalise a Mana Whakahono aa Rohe or co-management agreement over the lake system Ensure hapuu-led priorities guide regulatory, conservation, and fisheries decisions	Restoration efforts will only be durable if tangata whenua are empowered to lead decision-making and exercise mana whakahaere.	**Ngaati Mahuta/ The Trust** – negotiate agreements. **WRC** – honour statutory obligations and support co-design. **MPI / DOC** – incorporate cultural evidence into policy and funding frameworks.
6. Restore Hauanga Kai Practices and Knowledge Transmission	Create opportunities for whaanau-led tuna harvests under controlled conditions Run waananga on traditional harvest methods, tohu, and ecological whakapapa Explore temporary raahui or size-based restrictions where needed	The revival of cultural practices is essential for intergenerational transmission of knowledge, whaanau wellbeing, and the exercise of rangatiratanga.	**The Trust/Ngaati Mahuta** – design and deliver initiatives. **Te Puni Kōkiri / MPI** – provide funding support through Maaori development and fisheries programmes. **Ngaati Mahuta** – embed learning in everyday community life.

Priority	Action	Why it matters?	Responsibility
7. Uphold Mana Whakahaere and Hapuu Research Leadership	Recognise the Trust's authority to lead research agendas, protect data as taonga, and ensure hapuu-led research design and tikanga-based oversight	Empowering tangata whenua as research leads affirms Te Tiriti obligations, supports intergenerational kaitiakitanga, and ensures cultural safety in science.	**MPI, DOC, NIWA, WRC** – commit to co-design, data sovereignty, and cultural protocols. **The Trust / Ngaati Mahuta** – lead and govern research kaupapa.

All data and research related to the Tahaaroa Lakes must be handled with the same reverence as one would treat a waka huia, a vessel of treasures, held close to the heart.
— Herangi et al. 2025b.

5.4.1 Setting Measurable Restoration Targets

Currently, the report outlines strategic actions but lacks specific outcome indicators or timelines. The absence of setting measurable restoration targets (SMART) makes it difficult to assess progress or hold agencies accountable over time. Future planning should include measurable benchmarks, such as reducing parasite prevalence or improving elver recruitment rates by a target year.

5.5 Future research and monitoring opportunities for Lake Tahaaroa

5.5.1 Monitoring Elver Recruitment and Migration

Despite long-standing concerns about access for juvenile tuna, there is no dedicated elver or glass eel monitoring programme in place. Regular monitoring at key inflows like Wainui Stream is essential for understanding whether recruitment is occurring and whether past fish passage upgrades have been effective.

5.5.2 Customary Harvest Guidelines and Adaptive Management

The dominance of older, slow-growing tuna suggests limited recruitment and possible over-reliance on a dwindling stock. Yet there is currently no recommendation addressing harvest limits, raahui, or size-based restrictions. Hapuu-led development of adaptive harvest protocols would help safeguard remaining stocks while revitalising tikanga-based management.

5.5.3 Climate Change Preparedness

While habitat degradation and poor habitat quality has been reported in Lake Tahaaroa, there are no resources identifying the potential impacts of climate change, including increasing lake temperatures, drought cycles, and altered seasonal flows. These changes may affect tuna habitat, growth, and migration triggers. Future work should include hydrological and climate monitoring as part of a broader adaptation strategy.

5.5.4 Food Web and Dietary Analysis

Another opportunity lies in incorporating dietary analysis into future tuna research. Gut content examination and stable isotope analysis can help determine whether food limitation, suspected to be a driver of reduced growth, is occurring in Lake Tahaaroa. While not part of the 2025 survey, these tools could be introduced in future work to explore trophic changes, prey availability, and energy allocation in ageing tuna populations.

Future work should include hydrological and climate monitoring as part of a broader adaptation strategy. In addition, future tuna surveys should include basic field measurements (e.g. temperature, dissolved oxygen, Secchi depth) collected concurrently with fish sampling. This will strengthen the ability to link habitat conditions directly to tuna health, growth, and recruitment.

5.5.5 Maatauranga and Seasonal Knowledge

Embedding tohu and maatauranga into future monitoring programmes affirms mana whakahaere and strengthens the alignment between ecological indicators and cultural values. Incorporating these intergenerational observations, such as tohu indicating tuna migration, changes in insect and bird life, or signs of imbalance in the lake, into monitoring frameworks will strengthen the cultural integrity of restoration efforts. This maatauranga can sit alongside tools like stable isotope analysis or parasite monitoring to provide a more holistic picture of ecological health over time.

> *Ngaati Mahuta understand lake health not only through scientific measures, but through the condition and behaviours of taonga species, seasonal patterns, and the mauri of places. This knowledge is embedded in the lived experience of whaanau who actively engage with the lakes for kai, waananga, and ceremony.*
> — Herangi et al. 2025b.

5.5.6 Cultural Indicators and Tohu

Puuraakau and lived experience highlight tohu as a legitimate and necessary basis for environmental monitoring. These include changes in water clarity, absence of certain species, shifts in bird and insect behaviour, and other sensory or experiential markers that signal imbalance or resilience. Unlike conventional scientific sampling, tohu are continuous, intergenerational, and deeply place-based.

> *Tohu as a legitimate and necessary basis for environmental monitoring... changes in water clarity, abundance or absence of specific species, shifts in bird and insect behaviour, and other sensory or experiential markers that signal imbalance or resilience.*
> — Herangi et al., 2025b.

Incorporating these cultural indicators into future tuna monitoring programmes would strengthen the responsiveness of management decisions and reflect the mana whakahaere of Ngaati Mahuta.

5.5.7 Data Sovereignty and Long-Term Storage

As customary monitoring and maatauranga Maaori are increasingly central to lake management, the need for secure, hapuu-controlled data storage becomes critical. A clear data governance plan, respecting Maaori data sovereignty principles, would ensure that tuna data are managed in culturally appropriate and future-proofed ways.

This approach must also recognise that data is taonga, and that Ngaati Mahuta, through the Trust, maintains authority to lead research design, interpretation, and application in line with their mana whakahaere. These gaps present not only risks but opportunities. They offer a pathway for Ngaati Mahuta and the Trust to lead the development of an intergenerational strategy that is grounded in tikanga, informed by science, and resilient in the face of environmental and institutional change.

5.6 Future Research and Monitoring Roadmap

The knowledge gaps identified throughout this report highlight where current knowledge or capability is insufficient to fully protect and restore Lake Tahaaroa's tuna populations. These include the absence of targeted recruitment monitoring, limited climate and habitat data, no harvest guidelines, and the need for deeper integration of maatauranga Maaori into ecological assessment. Building on the findings of the 2025 survey, the following roadmap sets out priority areas for ongoing research and monitoring to safeguard Lake Tahaaroa's tuna fishery. These priorities reflect both ecological needs and cultural responsibilities, recognising that healthy tuna populations depend on well-managed habitats, secure migration pathways, and the integration of maatauranga Maaori alongside scientific methods.

The roadmap identifies key focus areas that, when implemented together, will create a comprehensive, long-term dataset. This will allow trends in tuna health, habitat condition, and recruitment to be tracked over time, inform adaptive management, and strengthen Ngaati Mahuta's ability to exercise mana whakahaere. Importantly, these actions will also ensure that restoration and management decisions are grounded in both intergenerational knowledge and robust ecological evidence.

Table 5-2: Proposed future research and monitoring roadmap for Lake Tahaaroa's tuna fishery. Priority areas include annual tuna monitoring, water quality and habitat assessment, elver recruitment and passage, migration tracking, food web and diet analysis, integration of maatauranga Maaori, and secure data governance. Each focus area outlines specific methods to build a comprehensive, long-term dataset that integrates ecological and cultural indicators.

Priority Area	Focus
Annual Tuna Monitoring	Repeat fyke netting, otolith ageing, parasite assessments, and biometric surveys to build a long-term dataset.
Water Quality and Habitat Monitoring	Seasonal measurements of temperature, dissolved oxygen, clarity, and nutrient levels; mapping of spawning and feeding habitat.
Elver Recruitment and Passage	Annual elver monitoring at inflows; fish passage assessment and restoration at Wainui Stream and Lake Harihari culverts.
Migration and Movement Tracking	Trial PIT tagging, acoustic telemetry, and tohu-based observations to study silver eel migration triggers and pathways.
Food Web and Diet Analysis	Stable isotope and gut content analysis to assess trophic position and investigate whether food limitation is affecting growth.
Maatauranga Maaori Integration	Document tohu, seasonal knowledge, and intergenerational observations; run waananga to embed cultural indicators in monitoring.
Data Sovereignty and Storage	Establish hapuu-governed digital infrastructure; treat all data as taonga, protected under tikanga and managed by the Trust.

6 Conclusion

This research reaffirms the ecological significance of tuna and the cultural responsibility of Ngaati Mahuta to protect them. The ongoing exercise of mana whakahaere, grounded in maatauranga and supported by science, will ensure that the wellbeing of the lake and its people are sustained for generations to come.

"E rere ana te mauri o ngaa wai o ngaa roto o Tahaaroa hei oranga moo te roto, moo ngaa koiora katoa, moo te whenua, moo te tangata, aa, hei painga hoki moo ngaa uri whakaheke o Ngaati Mahuta ki te Hauaauru."

The mauri of the waters of the Tahaaroa lakes flows to sustain the lake, all living beings, the land, and the people, and to uphold the wellbeing of future generations of Ngaati Mahuta ki te Hauaauru. — Herangi et al. 2025b (unpublished draft).

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To the kaitiaki and Trustees of the Tahaaroa Lakes Trust, thank you for your leadership, guidance, and commitment to protecting our tuna and taonga species. Your maatauranga and presence throughout this mahi ensured that the research was grounded in tikanga and reflective of the values of Ngaati Mahuta ki te Hauaauru. *Kaare he hau e rite ana ki te hauaauru, ka pupuhi, ka ngaro katoa ngaa hau. There are no winds like the westerly winds, when it blows all other winds succumb.*

To the field team from ESNZ, thank you for your professionalism, expertise, and collaboration in delivering the survey safely with care and precision. Your respect and dedication to the cultural and scientific integrity helped uphold our kaupapa. E mihi ana ki a Paul Lambert, Alex Rose, and Kristy Hogsden for completing the ageing and analysis process, efforts that are truly appreciated. *Kaiaua piritahi – united in movement and strong in purpose.*

Ka huri tooku aro ki te hau kaainga, ki te hau-aa-uru, ki Te Tahaaroa a Ruaputahanga – e kore rawa te puna aroha e mimiti. Ehara too taatou aroha moo te whenua me ngaa wai Maaori anake, i te mea, ko taatou te whenua, ko taatou anoo te wai Maaori. Your presence reaffirmed the importance of our research and the exercise of mana motuhake in environmental monitoring. *Huri Taiaawhio Ko Ngaati Mahuta E!*

We also acknowledge the support of the Ministry for Primary Industries, Customary Fisheries Research Fund, whose contribution enabled this important work to proceed. Your investment has helped restore the knowledge base required to protect our freshwater taonga for future generations. *Toituu te mana, toituu te whenua, toituu te wai, toituu te tangata.*

Noo reira, ngaa mihi nui ki a koutou katoa. Maa te tuna e hoki mai ai ngaa koorero o tua whakarere, hei oranga moo ngaa uri whakaheke.

8 Glossary of abbreviations

D.O.	Dissolved Oxygen
DOC	Department of Conservation
CPUE	Catch Per Unit Effort
ESNZ	Earth Sciences New Zealand
GIS	Geographic Information System
MPI	Ministry for Primary Industries
NIWA	National Institute of Water and Atmospheric Research
PIT Tag	Passive Integrated Transponder Tag
SE	Standard Error
TP	Trophic Position (used in stable isotope analysis)
WRC	Waikato Regional Council

8.1 Glossary of Cultural Terms

Hauanga Kai	Customary food gathering and the associated practice and rights.
Kaitiaki	Guardian(s) responsible for protecting taonga (treasures) and natural resources.
Mana Whakahaere	Authority to manage and make decisions over a particular area or resource.
Maatauranga Maaori	Maaori knowledge systems, including traditional environmental knowledge.
Raahui	A temporary restriction or closure on resource use to allow recovery.
Tohu	Environmental indicators observed and interpreted through cultural knowledge.

8.2 Glossary of Scientific Terms

AQUI-S®	A fish anaesthetic approved for use in New Zealand that safely sedates fish during handling or transport. It minimises stress and harm to fish during scientific sampling and is especially useful when precise measurements or biological samples (e.g., otoliths) are required. AQUI-S® breaks down quickly in water and leaves no residue, making it suitable for both research and aquaculture (AQUI-S New Zealand Ltd, 2023).

Catch Per Unit Effort	A standardised measure of how many fish are caught relative to the amount of effort used to catch them. In this study, CPUE is calculated as the number or weight of tuna caught per net per night. It is commonly used to track population abundance over time and allows comparison between different years, locations, or fishing methods (Maunder & Punt, 2004).
Otolith	Small calcium carbonate structures located in the inner ear of fish. Otoliths help fish maintain balance and hearing, and they grow in layers over time. Scientists use otoliths like tree rings to determine the age of a fish. In tuna research, otoliths are extracted and examined to assess growth rates and age structure of populations (Jellyman & Graynoth, 2005).
Parasite Infestation Index	A scoring system used to assess the level of parasite burden in fish, developed by Richardson (1998). Each fish is visually inspected and assigned a score from 0 to 3: **0** = no parasites present **1** = one or two parasites **2** = numerous parasites **3** = heavy infestation The average score across a sample can be converted to a percentage to provide an overall infestation index. It is used to monitor fish health and compare conditions between populations or over time (Richardson, 1998).
Customary fisheries	Fisheries that are managed and used in accordance with the tikanga (customs and practices) of Maaori. Customary fisheries relate to the non-commercial harvest of fish and other aquatic species for cultural purposes such as hui, tangihanga, and sustenance. They are protected under New Zealand law and often governed by tangata whenua through mechanisms like maataitai reserves or customary permits (Ministry for Primary Industries, 2021).
Eutrophication	Nutrient enrichment of a water body, often leading to algal blooms and reduced water quality.
Fyke Net	A funnel-shaped fish trap used to capture eels and other fish in freshwater.
Longfin Tuna (*Anguilla dieffenbachii*)	Native New Zealand freshwater eel species, long-lived and slow-growing.
Shortfin Tuna (*Anguilla australis*	Native New Zealand freshwater eel species, faster-growing and more common in lower elevation waters.
Otolith	A calcified structure in the inner ear of fish used to determine age.
Parasite Prevalence	The proportion of individuals in a population infected with a parasite.

Recruitment	The addition of new individuals (e.g., juvenile tuna) into the fishable population.
Secchi Depth	A measure of water clarity based on how far a black-and-white disk can be seen underwater.
Stable Isotope Analysis	A technique to study diet and trophic position by examining chemical signatures in tissues.
Thermal Stratification	Layering of water in a lake based on temperature differences, which can limit oxygen in deeper layers.

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Appendix A Coordinates of sampling locations used in Lake Tahaaroa

Location	Lat	Long	NZTM East	NZTM North	NZMG East	NZMG North
T1	-38.16253981	174.7375325	1752219	5774724.2	2662412.4	6336426.9
T2	-38.16144635	174.7376312	1752229.9	5774845.4	2662423.5	6336548.1
T3	-38.16073256	174.7376556	1752233.5	5774924.6	2662427.2	6336627.2
T4	-38.15981179	174.7402993	1752467.1	5775022.4	2662660.9	6336724.8
T5	-38.15992741	174.7421474	1752628.7	5775006.5	2662822.5	6336708.7
T6	-38.15904751	174.7435347	1752752.1	5775101.9	2662946	6336803.9
T7	-38.1588508	174.7454224	1752917.9	5775120.6	2663111.9	6336822.4
T8	-38.15702705	174.7471986	1753077.4	5775320	2663271.6	6337021.6
T9	-38.15620508	174.7482405	1753170.4	5775409.5	2663364.7	6337111
T10	-38.15548483	174.7493397	1753268.2	5775487.6	2663462.6	6337189
T11	-38.15518053	174.7504624	1753367.2	5775519.5	2663561.6	6337220.7
T13	-38.15773895	174.7552979	1753785.5	5775227.6	2663979.6	6336928.3
T12	-38.15530582	174.7524802	1753543.8	5775502.3	2663738.2	6337203.3
T14	-38.15938631	174.7561963	1753860.8	5775043.3	2664054.6	6336743.9
T15	-38.1600516	174.7559025	1753833.6	5774970	2664027.4	6336670.6
T16	-38.16038108	174.7554792	1753795.9	5774934.1	2663989.5	6336634.8
T17	-38.16111804	174.7544231	1753701.8	5774854.1	2663895.3	6336554.9
T18	-38.16252421	174.7509629	1753395.7	5774703.8	2663589	6336405
T19	-38.16414703	174.7479419	1753127.6	5774528.7	2663320.8	6336230.3
T20	-38.16518609	174.7468217	1753027.3	5774415.3	2663220.3	6336116.9
T21	-38.16659483	174.745917	1752945.1	5774260.4	2663137.9	6335962.2
T22	-38.16832069	174.7445688	1752823.4	5774071.1	2663015.9	6335773.1
T23	-38.16878076	174.7416897	1752570.2	5774024.8	2662762.7	6335727.1
T24	-38.17036341	174.7412249	1752526.2	5773850	2662718.5	6335552.3
T25	-38.17034517	174.7399968	1752418.6	5773854	2662610.9	6335556.5
T26	-38.1725777	174.7385519	1752287.4	5773608.7	2662479.4	6335311.3
T27	-38.17211531	174.7366646	1752123	5773663.1	2662315.1	6335365.9
T28	-38.17225968	174.7352988	1752003.1	5773649.3	2662195.1	6335352.3
T29	-38.17374684	174.7357698	1752041.2	5773483.5	2662233.1	6335186.5
T30	-38.17459616	174.7345897	1751936.1	5773391.2	2662127.8	6335094.3
T31	-38.17550708	174.7338473	1751869.2	5773291.3	2662060.8	6334994.5
T32	-38.17691661	174.7324778	1751746.3	5773137.1	2661937.7	6334840.5
T33	-38.1764918	174.7314738	1751659.2	5773185.9	2661850.7	6334889.4
T34	-38.17562724	174.7310316	1751622.3	5773282.6	2661813.9	6334986.1
T35	-38.17499784	174.7300224	1751535.2	5773354.1	2661726.9	6335057.7

Location	Lat	Long	NZTM East	NZTM North	NZMG East	NZMG North
T36	-38.17427198	174.730814	1751606	5773433.3	2661797.8	6335136.9
T37	-38.17351922	174.7319555	1751707.6	5773515	2661899.5	6335218.4
T38	-38.17285248	174.7315793	1751676	5773589.6	2661868	6335293
T39	-38.17206573	174.7311667	1751641.5	5773677.6	2661833.6	6335381.1
T40	-38.17146192	174.7315432	1751675.7	5773744	2661867.9	6335447.4
T41	-38.17096151	174.7316102	1751682.6	5773799.4	2661874.9	6335502.8
T42	-38.16993458	174.7312141	1751650.1	5773914	2661842.5	6335617.5
T43	-38.16876442	174.7301494	1751559.2	5774045.6	2661751.8	6335749.2
T44	-38.16694988	174.7283397	1751404.4	5774249.9	2661597.3	6335953.7
T45	-38.16634095	174.728614	1751429.7	5774317	2661622.7	6336020.8
T46	-38.16548455	174.7278084	1751360.9	5774413.4	2661554	6336117.2
T47	-38.16493535	174.728185	1751395	5774473.7	2661588.2	6336177.5
T48	-38.16404137	174.7301712	1751570.9	5774569.6	2661764.2	6336273.2

Appendix B Length and weight measurements recorded in Chisnall & Ruru (2008)

Not all the raw size (length and weight) data were discoverable within the original dataset available for Chisnall & Ruru (2008). Raw length data were measured from a sub-set of the shortfin and longfin captured, which we have assumed is representative of the total catch from Lake Tahaaroa in 2007. A smaller sub-set of fish were measured for both length and weight from Lake Tahaaroa in 2007. The present study aims to explore changes in sizes of eels from 2007 to 2025, which will be valid for length comparisons but we needed to explore if the smaller sub-sample measured for length-weight was also representative of the lake population. To understand how representative the length-weight sub-sample was of the lake population, we prepared a length-frequency plot of the fish measured for lengths only, and fish measured for both length and weight. We then made a visual assessment of how similar the length-frequency plots were for the two datasets. We assumed that similar length-frequency plots indicated that the weight sub-sample was representative of the lake population, while differing length-frequency plots indicated that some sizes were misrepresented in the weight sub-sample and that it was not representative of the lake population.

Shortfin length measurements were recorded from 162 shortfin while length and weight data were recorded from 114 shortfin (Figure B-1). While the shortfin measured for length and weight showed a slightly smaller mean size (11 mm), generally similar proportions of each size class were measured in both datasets. The slightly larger size of the shortfin only measured for length, seems to be associated with slightly more smaller fish in the 300-350 mm being included in the length-weight. Overall, the length and length-weight datasets for shortfin were similar and we included length and weight comparisons between 2007 and 2025 in the present report.

Longfin length measurements were recorded from 38 fish while length and weight measurements were only recorded from six fish (Figure C-1). Moreover, the mean size of fish recorded for length and weight was much larger than fish where only length was recorded, and smaller fish (less than c. 450 mm in length) were not measured for both length and weight. Given the differences in sizes between the two datasets we only included longfin length comparisons between 2007 and 2025 and excluded any weight or condition comparisons between 2007 and 2025. This is because the weight data had low replication and overrepresented larger fish, which makes the weight and condition estimates from 2007 biased towards larger fish.

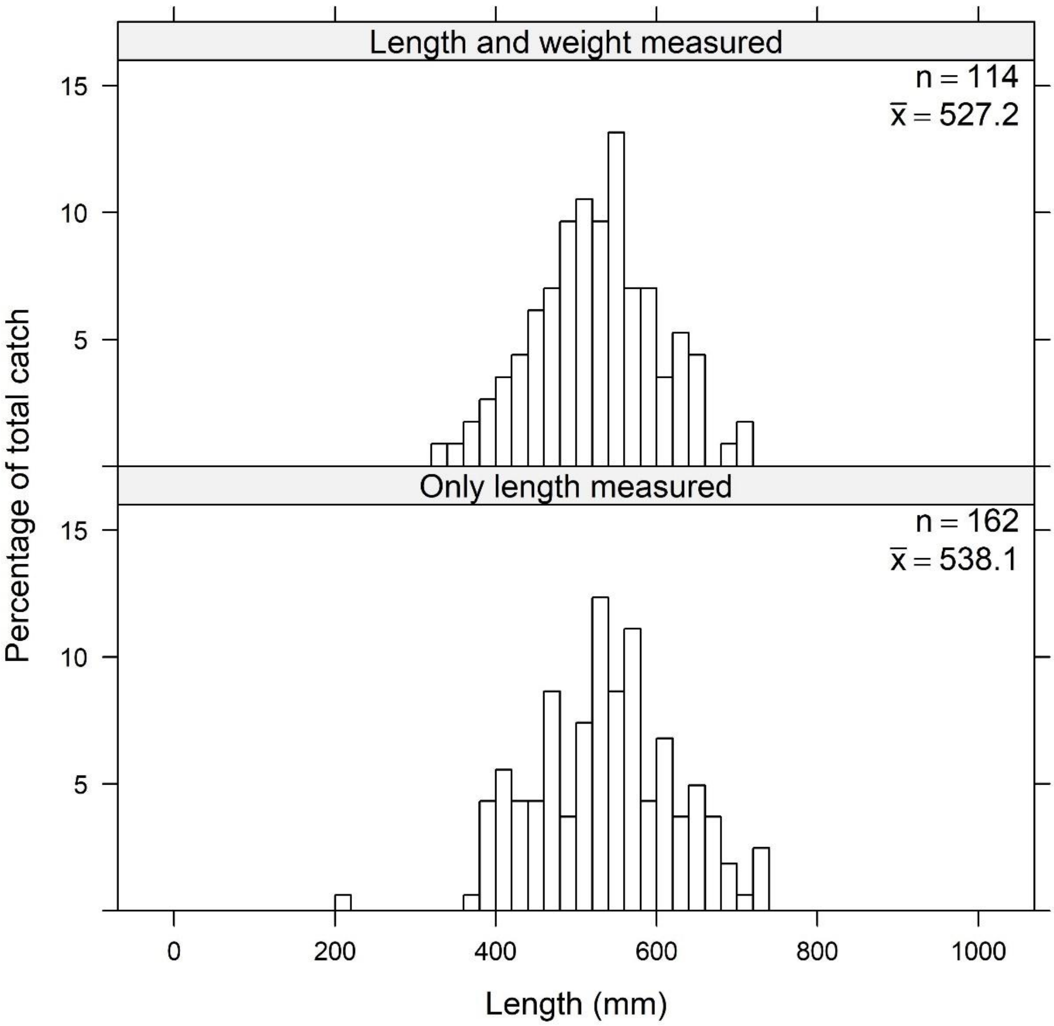

Figure B-1: Length-frequency of shortfin captured from Lake Tahaaroa by Chisnall & Ruru (2008) that were measured for length only, and for both length and weight. Total number captured (n) and mean length (x̄) are shown in the top right corner of each plot.

Appendix C Length of shortfin captured from the different net types used by Chisnall & Ruru (2008)

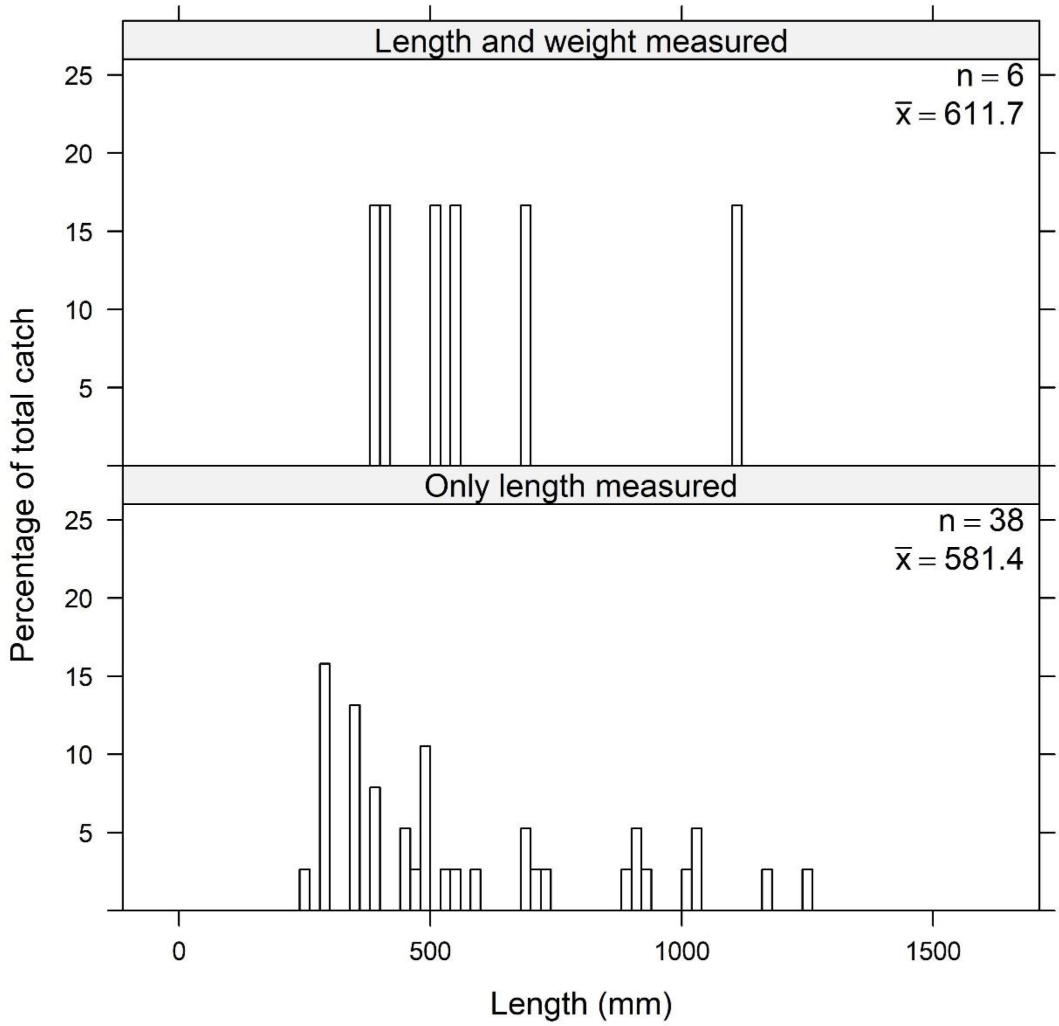

Figure C-1: Length-frequency of longfin captured in Lake Tahaaroa by Chisnall & Ruru (2008) with the three different net types used. Standard meshed fykes had no escapement tubes, while the commercial fyke nets had the same mesh size as the standard nets but also included a 30 mm escapement tube. Fine meshed fyke nets contained much smaller mesh size than the standard and commercial fyke nets.

Appendix D Examples of Otolith Ageing Results

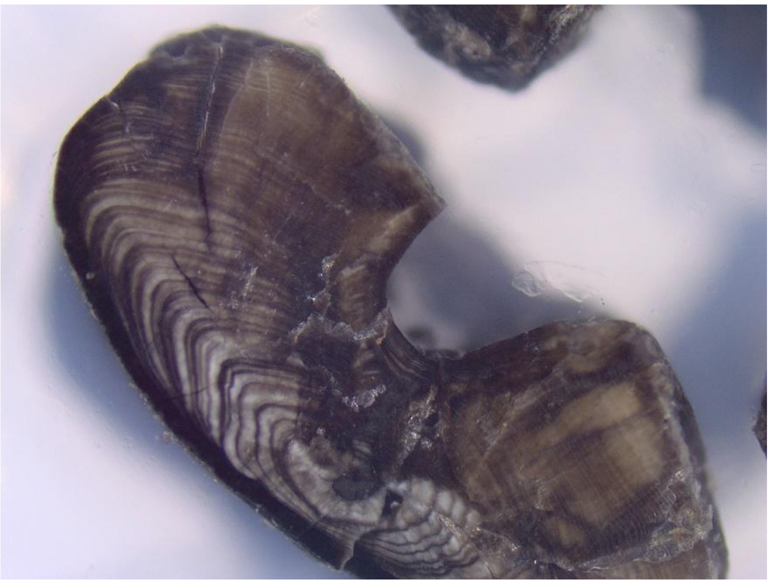

Figure 9-1: Shortfin otolith from Lake Tahaaroa, showing distinct annual growth rings (annuli). Each dark/light band represents one year of growth in freshwater. This specimen was 654mm and aged at 47 years. T34-I75#2, 13/02/25, SFE, 654mm, Age 47. [Ageing: Paul Lambert, Alex Rose, Kristy Hogsden]

Figure 9-2: Paired otolith halves from Lake Tahaaroa shortfin. Multiple tightly spaced annuli are visible, with outer bands indicating slower growth in later life stages. Estimated age 14 years at 454mm. T24-I82#1, 11/02/25A, SFE, 454mm, Age 14. [Ageing: Paul Lambert, Alex Rose, Kristy Hogsden]

Figure 9-3: This shortfin otolith from Lake Tahaaroa. Despite fracturing, annuli remain visible and readable. This specimen was 505mm and aged at 30 years. T23-EX09#2,11/02/25A, SFE, 505mm Age 30. [Ageing: Paul Lambert, Alex Rose, Kristy Hogsden]