SUSTAINABILITY OF LOWER RANGITAIKI RIVER EEL FISHERY: ASSESSMENT OF HISTORIC ANTHROPOGENIC IMPACTS USING THE MAURI MODEL

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Abstract:

Eels, especially longfin eels, are important to commercial and customary fishing in New Zealand, and are also especially valued by indigenous Māori for cultural reasons. As such, the decline of the eel fishery along the Rangitaiki River has been met with much concern, and mitigation and restoration efforts have been pursued in recent decades. Using the drainage of the Rangitaiki Plains, construction of Matahina Dam, and implementation of the Kokopu Charitable Trust's elver trap and transfer programme as important historic markers, I divide the history of the lower Rangitaiki River eel fishery into distinct phases. A decision-making framework, the Mauri Model, measures the change in *mauri* (binding force) – and thereby, sustainability – over time and revealed significant decreases in *mauri* from the drainage of the Rangitaiki Plains and dam construction, but a shift to positive scores after eel stock remediation efforts. Projections into the future estimate that losses in the *mauri* of the fishery throughout the last century may be offset by gains after roughly 160 years. I recommend for future studies to expand the scope of this analysis to address more factors stemming from anthropogenic modification of the land.

Key Words:

Mauri Model, sustainability, eel, fishery, decision making framework, *mana*

Introduction:

Like all indigenous peoples, the indigenous Māori of New Zealand sustain an intimate relationship with the environment (1, 2, 3) and employ sustainable and responsible practices in the harvesting of resources from their environment. Such systems are becoming increasingly important on the world stage as examples of how we may interact with the environment sustainably (1, 2, 4, 5). These practices are exemplified in Māori culture by the concept of *kaitiakitanga* (guardianship/stewardship of the land) and are applied to all agricultural and food-gathering practices, including eel fisheries, which are of especial importance to Māori, as evidenced in *matauranga* (wisdom from knowledge passed down through generations) and traditions. Since the arrival of Europeans to New Zealand, several major anthropogenic changes to the geography in and around the Bay of Plenty region have occurred. I apply the Mauri Model (1, 5) to the Rangitaiki River and surrounding areas with a focus on the Matahina Dam to assess the anthropogenic impacts on this eel fishery.

Previous environmental assessments involving the Matahina Dam have glossed over its impact on the local eel fishery since the dam's construction in the early 1960s (6). Other assessments of the Matahina situation and elsewhere underscore the potential dangers to eel fisheries by anthropogenic-derived changes to the environment, with special attention to impacts on recruitment (7, 8, 9), or the number of individuals that reach a specified stage in their life cycle; in this case, adult. However, all of these reviews discount impacts on cultural aspects in favour of biological and other social ones. In this way, previous studies remain important to any considerations of impacts on the environmental impact, but fail to fully encompass the entire scope of the problem. Of major focus among anthropogenic impacts are the extensive drainage of the wetlands formerly surrounding the lower Rangitaiki River and the construction of hydroelectric dams on the river beginning in the 1960s (Matahina) (7).

As catadromous fish, eels have a life cycle that begins in the ocean, takes them up rivers to grow and mature, and returns to open waters in order to spawn and die (8). Three species of freshwater eel call New Zealand home today: the longfin eel (*Anguilla dieffenbachii*), shortfin eel (*A. australis*), and Australian longfin (*A. reinhardtii*), the last of which is newly arrived and present only on the North Island (9). Due to the newly-introduced status of *A. reinhardtii*, we will restrict our attentions to only *A. dieffenbachia* and *A. australis*. Furthermore, the status of the longfin eel is especially scrutinised by those concerned with the sustainability of the fishery (9, 10, 11, 12, 13, 14, 15), as it is longer-lived, may take as long as several decades to attain reproductive maturity, and is slower-growing than its shorter-finned cousin. Eel surveys and elver trap and transfer data gathered from water bodies above the Matahina dam as well as local knowledge will serve as indicators of eel fishery health and remediation.

Mauri (binding force) describes the inextricable link between the physical and spiritual aspects of all things, and serves as a suitably holistic measure of sustainability (5). “The use of *mauri* as the common yardstick” (5) by the Mauri Model marries sustainability to the four well-beings identified by New Zealand legislation, especially the Resource Management Act (RMA): social, economic, environmental, and cultural. It recognises and integrates indigenous perspectives to address sustainability challenges, thereby increasing the acceptability and holistic aspect of assessment. The Mauri Model is a decision-making framework (DMF) that uses a number of indicators as proxies for each of the well-beings and a coarse scale that scores each indicator between -2 and +2, as illustrated in Figure 1. Scores are assigned based on comparisons to a baseline level. Positive effects on *mauri* based on an indicator give a score of +1 or +2. Negative effects give -1 or -2. No effect gives 0. The original Mauri Model paper indicates that the relative importance weightings of the four dimensions may be determined in a case-by-case manner (5). In New Zealand, planners and engineers have assigned a 70% weighting to economic well-being and 10% to social, cultural, and environmental well-beings. In contrast, typical Māori allocations give 35% environment, 30% cultural, 20% social, and 15% economic (2). In theory, a truly holistic perspective would assign equal weightings to the four well-beings.

Figure 1

Previous uses of the Mauri Model have included evaluations of sustainability in geothermal development, pollution and wastewater management, and watershed restoration. This study will retrospectively evaluate impacts to sustainability, measured by *mauri*, in and around the lower Rangitaiki River spanning from pre-1910 to the present. As such, this will be the first use of the Mauri Model to assess past impacts for retrospective analysis, as opposed to potential future scenarios for decision-making.

The true impact of anthropogenic changes to the environment with drainage of wetlands around the lower Rangitaiki River and the construction of the hydroelectric dam at Matahina has been underrepresented (6, 16, 17). While several hydroelectric dams have been erected along the Rangitaiki River and its tributaries over the past several decades, my focus will be on the Matahina Dam and the surrounding area. It is the first hydroelectric dam obstacle for migrating eels on the river, its location provides an interesting habitat contrast between the lower and upper reaches of the river, I have established a close collaboration with Bill Kerrison, a *kaitiaki* (guardian) who is foremost in those involved in elver transportation efforts, and consultation from Michael Kearney, who is in the midst of a biomass study on the local eel fishery, will aid analysis. I will use the Mauri Model to integrate information from an ongoing study at Matahina Lake, *matauranga*, and historical accounts and considerations. Because the Mauri Model takes into account effects on indigenous culture and practices, this reassessment will represent a more holistic and accurate look at the impacts to the eel fishery along the Rangitaiki River.

Background:

Beginning in 1910, industrial and agricultural pressures in the Rangitaiki Plains initiated drainage of wetlands for conversion to land suitable for modern residential and commercial infrastructure, notably for grazing of livestock. While these changes enabled significant development, especially in agriculture, to occur, they also signaled huge losses for the environment. As with any conversion from undeveloped nature to agriculture or the like, there were observed decreases in biomass and habitat loss (20). Specifically for freshwater eels, changes to the land meant huge losses in habitat, as these wetlands had been ideal habitats for these fish (19).

The commercial eel fishery commenced in the late 1960s, grew rapidly over the next several years, and peaked in the early 1970s (21). Eventually, concerns over the sustainability and overexploitation of stocks, especially longfin stocks, resulted in total allowable catch (TAC) settings in 1978 (21). North Island eels became integrated into the Quota Management System (QMS) in 2004, with 14% of the TAC set aside for customary use (21). Non-fishing activities that may affect the fishery fall under the jurisdiction of the Resource Management Act of 1991 (22). Since its beginnings in the 1960s, the eel fisheries in the North Island of New Zealand has evolved into a valuable industry, and concerns over fishery health have produced regulations to curb overexploitation of the resource, though “it is considered unlikely that such measures will be sufficient to arrest a predicted substantial decline in the recruitment of this [longfin] species” (21). Longfin eels in the Rangitaiki River are included in the Waikato/Poverty Bay jurisdiction and are managed under the QMS as LFE21, while shortfins are managed as SFE21. Recently in 2008, total allowable commercial catch (TACC) was decreased for both species.

Figure 2

The construction of the hydroelectric dam at Matahina in the 1960s created Matahina lake, which is a “long, thin and deep lake formed in an incised river gorge with a limited littoral zone" (Figure 2). The Matahina Dam is one of several hydroelectric dams along the Rangitaiki River and its tributaries, the closest one being the Aniwhenua Dam, upriver. Matahina Dam is the closest dam to Whakatane (Figure 2). In 1992, an elver passage was installed for the intended purpose of allowing for migratory passage of these juvenile eels up the river. This early effort proved to be mostly ineffective due to poor maintenance and construction flaws (23), and in 1997 an improved device was set up by the Kokopu Charitable Trust and administered by Bill Kerrison. Estimates have since recorded 1.1 million or more elvers relocated above Matahina Dam annually (7, 23).

Differences in the biology of longfin (*A. dieffenbachii*) and shortfin (*A. australis*) have accordingly led to different results based on respective species. Eels are known to exhibit species-specific habitat preference; shortfins prefer such slower-flowing areas as lowland lakes, swamps, and other wetland habitat, while longfins prefer faster-flowing habitats, greatly favour stream banks, and may be found further inland than shortfins (11, 12, 18, 19). Because of these habitat preferences, the gradual and eventual elimination of lowland wetland habitat had differential effects on longfins and shortfins (11, 19). Decreases in total biomass of eel stocks were predictable, though analysis of records shows that the proportion of longfins to shortfins has declined with time (7). Some researchers believe that shortfin eels are more aggressive in migration and that their range may hinge upon habitat availability (11, 15, 24). Thus, it could be that shortfins have resorted to less-ideal areas in lieu of their now-absent lowland habitat, have pressured resident longfin eels with interspecies competition, and are getting the upper hand. Whereas longfins were known to have dominated the upper reaches of Rangitaiki tributaries in the past, species ratio has been altered over time. This trend is speculated to have been exacerbated by the indiscriminate transport of both longfin and shortfin eels through elver migration mitigation efforts, which may have resulted in an artificial displacement of shortfins that may otherwise have settled in lower reaches of the river (20).

Longfins constituted 12-14 percent of the 9.5 million elvers transferred above Matahina Dam from 2002-2008 (25). Furthermore, only 8 percent of adults handled along the Rangitaiki River in a 2008 catch-and-release survey were longfins. Variable numbers have been recorded for elver transfer operations: 4.5 million total elvers with 12% longfins in 2008-2009 (23), down to 1 million elvers with 8% longfins in 2009-2010(26), and 1.8 million elvers with only 5.5% longfins in 2010-2011 (27). Adult eel transfers are also being undertaken at Aniwhenua Dam in hopes of enabling adults ready to breed to swim out to sea (23, 26, 27). Additionally, the Bay of Plenty Regional Council's consent decisions have provided for a study of the biodiversity of the flora and fauna below Matahina Dam (16) in response to concerns over effects of increased turbidity and quicker flow on aquatic life (20).

While a large hydroelectric dam has the obvious potential to disrupt eel migration, other unexpected phenomena have also come from the placement of dams along the Rangitaiki River (28). Growth rates of longfin eels, indicated by variable banding in otoliths (inner-ear hard structures commonly used for aging fish), in Lake Aniwhenua, above the Aniwhenua dam, were among the fastest recorded for Anguilla species (14, 20). Shortfins also exhibited quicker maturation (20). Further otolith analysis indicated that longfin eels occupied habitats that conferred variable rates of growth over time, while shortfins generally stayed in the lake habitat, which conferred the highest rate of growth (14). These increased growth rates in the lake habitat created by the construction of a dam on the Rangitaiki River could possibly be a result of low population densities due to impediments to migration, increased availability of habitat, decreased intraspecies and interspecies competition, and so on (14).

The apparent benefit of increased levels of growth exhibited above the Aniwhenua Dam, and likely above the Matahina Dam as well, must however be viewed in the light of the severe detriment these huge barriers have for eel migration. Eels are catadromous, and so make two migrations in their lifetime: one as juveniles from spawning grounds in the sea to freshwater riparian habitat, and the other as reproductively mature adults from inland habitat to their spawning grounds at sea, which interestingly has as of yet never been found (8). The limitation on migration has obvious repercussions on the recruitment and cohort strength of eels, which in turn determines stock size (8, 29). Female longfin eels are known to grow to weigh over 60kg and live to over one-hundred years before migrating to sea to spawn (19, 30). Furthermore, for each 1.2kg a female carries in weight, an estimated 1,000 elvers will make their way from the ocean spawning grounds (19). Also, both commercial and customary harvests remove females almost exclusively (21), which may have an effect on the future health of the fishery. Therefore, the full effects of dams in disrupting migration may not have yet been felt due to the longevity of the species. Optimistic conclusions suggest that the quick growth rates experienced by longfins above the dam may provide enhancement opportunities for the fishery (14).

In addition to the biological impacts these punctuated environmental changes have had to the region, social and cultural effects have been far from minor. Damage to the *mauri* of the land has been severe; from draining of the lowlands, to the disruption of the natural flow of the river, to the inundation of all the lands that now lie beneath the reservoirs behind hydroelectric dams.

> Maori have frequently expressed concern that commercial fishing has compromised their own ability to harvest sufficient quantities of large eels for ceremonial purposes, and that such land-use practices as wetland drainage and stream clearance have led to a significant degradation of eel habitat. (21)

There have surely been gains to the *mauri* as well, however, such as increased wealth from development, food from agriculture, and a higher standard of living conferred by hydroelectric power. In terms of the eel fishery, a social impact lies in the role eels have in the culture of local *iwi* (tribe). While each local *iwi* has different specific traditions and customs, it is common among *iwi* all around New Zealand for eel to be regarded as of great importance – for basic food, *mana* (social status/prestige), *matauranga*, belief in *taniwhas* (monster of legend), etc. It is also for abstract tags of importance such as these that we must sustain this important fishery. In decision-making frameworks used in New Zealand in the past, planners have greatly prioritised economics in their calculations at the expense of cultural, environmental, and social considerations (2). Māori weigh these well-beings more holistically, and we must join these two views in order to move forward.

Methods:

I visited Matahina Dam in February, 2012, where I assisted Bill Kerrison (19) in transporting elvers from the trap below the dam to Matahina Lake. I then met with Michael Kearney to familiarise myself with the methods of his data collection used to compile biomass information for the eel fishery at Matahina Lake. I also met with Mr. Kerrison once more to gain his opinion, from a *kaitiaki* standpoint, of the state of the eel fishery on the Rangitaiki River and how anthropogenic influences have affected it since farmers first began to drain the Rangitaiki Plains.

In our analysis of the myriad factors needed to holistically examine the environmental impact of the Matahina Dam on the eel fishery of the Rangitaiki River, I consulted literature of eel biology and ecology, literature addressing integration of science with indigenous knowledge, experts on the state of the eel fishery and the region, local *kaitiaki*, and previous assessments done by governmental organizations and independent parties, resource consent reports, and other primary literature including claims made on the basis of the Treaty of Waitangi Act of 1975. Though I hoped to consult more Māori leaders and experts to glean more information on the cultural significances and impacts in regards to the eel fishery, the opportunity did not present itself and I supplemented information from Mr. Kerrison and others with secondary sources and Māori knowledge databases.

Mauri Model Analysis:

I chose three indicators for each of the well-beings – environmental, cultural, social, and economic: habitat, eel life history traits, and biomass for environmental; *mana*, *kaitiakitanga*, and *mahinga kai* for cultural, recreation, health, and family interactions for social, and allocation of resources, resource harvest, and exploit availability flow for economic. In the future, the third environmental indicator may be changed to biomass/biodiversity, in accordance with the biodiversity study currently being undertaken (16).

Table 1

Based on three identified significant events in the history of the eel fishery in and around the lower Rangitaiki River, four phases were chosen to represent the periods before and after the respective events: ‘pristine’ (baseline), post-plains drainage (PPD), post-dam construction (PDC), and post-eel trap & transfer (PET). The ‘pristine’ phase serves as a baseline and first point of reference to put subsequent Mauri Model results in perspective. The scores illustrate conditions experienced by Māori before extreme anthropogenic impacts affected the area. PPD marks the period after the drainage of the Rangitaiki Plains from wetlands to lands suitable for commercial, residential, and mainly agricultural development, which began in 1910. PDC marks the period after the construction of Matahina Dam in 1967, which is the second main anthropogenic impact and one of the focuses of this study. Because commercial operations began in earnest at about the same time, in the late 1960s, PDC also marks the period in which the commercial fishery developed, peaked, and declined. PET describes the period after the 1997 construction of the Kokopu Trust’s elver trapping station and beginning of adult transport efforts until the present. I focus on the Kokopu Trusts’ efforts because the 1997 improvements to transfer protocols were significantly more effective than past efforts (23). PET also marks the decline of the commercial eel fishery, as harvests have declined substantially since 1997; the general consensus is that stocks, especially longfin, have been overexploited and the fishery is unsustainable (21). Because of the relatively short time-span over which the three major events described took in comparison to the lengths of the gaps in-between each, they are denoted in the final analysis as distinct points along a timeline. The Mauri Model analysis focuses on the spaces before and after each point.

Results:

Values ranging from -2 to +2 were assigned to each indicator for the four phases described based on the criteria illustrated in Figure 1. Based on Table 2, the 'pristine' phase – the baseline for this study – received the highest *mauri* rating (+1.75). Drainage of the Rangitaiki Plains and construction of the Matahina hydroelectric dam produced negative Mauri Model values (-1.00 and -0.83), indicating diminished *mauri* stemming from these two events. Establishment of an effective elver trap and transfer procedure increased *mauri* (+0.50). The general trend since the steep drop in Mauri Model values after the drainage of the Rangitaiki Plains is increasing (Fig. 3)

Table 2

Figure 3

Similar trends are seen in three of the four well-beings: environmental, cultural, and social. However, the economic trend for the Mauri Model shows a slightly altered trend, following an increase after the construction of the Matahina dam and remaining unchanged after implementation of elver trap and transfer efforts (Fig. 4)

Figure 4

By assessing the area beneath and above the Mauri Model graphs, I quantified the total losses and gains to *mauri*. I projected current levels of *mauri* restoration into the future to produce estimates of how long it will take until the negative impacts to *mauri* are balanced by gains to *mauri*. Based on current (PET) Mauri Model scores, losses to *mauri* will be neutralised after 158.7 years. Breakdown of projections into respective well-beings are as follows: 294.4 years (environmental), 76.8 years (cultural), and 123.2 years (social). Because there are currently no gains for the economic well-being, losses to this category will not be offset if current conditions are kept constant.

Discussion:

While some Mauri Model score assignments are intuitive, such as -1 (diminishing) for all environmental indicators after the drainage of the Rangitaiki Plains, others may require some explanation. It is clear that the *mauri* of the environmental well-being would diminish through destruction of habitat. The baseline scores were mostly +2, as most aspects pertaining to the eel fishery existed at a ‘restored’ state, since they had not been strongly impacted in hundreds of years. For the most part, environmental, cultural, and social scores speak for themselves. Scores for the economic indicators may need some explanation, however.

‘Allocation of resources’ denotes decision-making for daily living (Table 2). Since eel fishing was well-integrated into the social and cultural lives of Māori, eel resource allocation considerations were not pressures to the extent in the past that they are today. With the diminishing of eel stocks, these pressures manifested themselves and resources had to be devoted to obtaining food, where in the past it had always been in abundance. Focusing on ‘resource harvest,’ the PDC phase was given a +2 score because, while the commercial eel fishery has since declined significantly, commercial harvests began and reached their historical maximum in this historical period. ‘Exploitable resources’ track the availability of resource that harvestable in an economic sense, and therefore follows a similar trend to the environmental indicators.

Using environmental well-being as an example, eel life history traits and biomass were affected indirectly by habitat loss in the second phase (PPD), but nevertheless were impacted to an equally extreme extent. It is important to observe that, though indicators used in the Mauri Model are intended to be scored individually and without consideration to other indicators, they all measure aspects of the same greater whole; that is, sustainability. In this way, all indicators used in this study are all linked, though substantial effort was spent making sure scoring was done on a case-by-case basis.

The Mauri Model is vulnerable to subjectivity, as it requires the scorer to both choose appropriate indicators and assign values based on his/her intuition and knowledge. Balance to this subjectivity is the coarseness in scoring. The rigid -2 to +2 scoring criteria (Figure 1) make for objective evaluations of subjectively-chosen indicators. The coarseness of the model may be frustrating – the construction of Matahina dam undoubtedly had a negative effect on habitat, *mana*, etc. but the score must still be -1 – but this drawback of the Mauri Model is also a strength. Lack of a more continuous scoring system makes less room for subjectivity in assigning scores compared to a model in which the scorer must choose a value from a gradient. Thus, the Mauri Model, while rigid, thereby provides for a carefully objective analysis.

Three of the four well-beings – environmental, cultural, and social – largely followed the same trend (Figure 4). Economic well-being challenged the otherwise prevailing trend, producing the slight upward movement in 1967 (Figure 3). This phenomenon was expected, as the construction of a hydroelectric dam would predictably produce economic benefits.

The most notable feature of the results is the extreme dip in *mauri* following the drainage of the Rangitaiki Plains (Figures 3 and 4). This drop was predictable, as it marked the first extreme land alteration for the eel fishery in the lower regions of the Rangitaiki. More unexpected in the visual representation is the apparent lessened negative pressure after the construction of the Matahina hydroelectric dam, which indicates that economic factors alleviated and more than offset exacerbations to environmental well-being (Figure 4). While it should be noted that this may not have been the case had a less coarse model been introduced, this feature should not be discounted, as it shows the ability of gains in one well-being to offset or outweigh losses in another. Also notable is the historically recent shift from a negative to positive Mauri Model score due to the Kokopu Trust's elver trap and transfer programme (Figure 4). These gains came from environmental, cultural, and social sources.

Projected length of time at which increases in *mauri* would equal historic losses and thereby neutralise or offset these losses was based on current Mauri Model scores (PET). This unrealistically assumes that no change impacting any of the four well-beings will occur in the future. However, projections are useful in underscoring the negative impacts anthropogenic pressures have placed on the eel fishery; approximately 160 more years will be required to offset the past effects of half that many (1910-1997). These figures are rough at best, but they go a long way in implying that we must be vigilant in preserving natural resources and managing them sustainably. Furthermore, the estimates must be viewed in light of the length of time before 1910, pre-drainage of the Rangitaiki Plains, when the status of the fishery could be considered 'pristine. Maori arrived in New Zealand hundreds of years ago – rough estimates of arrival are debated and float around 700-1000 years ago – so the 'pristine' phase of positive *mauri* lasted for far longer than any of the other phases.

While the results of this study seem to indicate that historic decreases in the *mauri* of the eel fishery may be neutralised by recent and future increases, this is not necessarily true. Elders of local *iwi* lamented the loss of history and spiritual places when Matahina dam was built and the area behind it was flooded to form Matahina lake (25). These important places are now completely lost to Māori and the *mauri* lost with them can also not be recouped. Among Māori, “there is also a general desire for eel stocks to be rebuilt to pre-commercial fishing levels, although unfortunately this would seem to be impossible because of irreversible land-use changes” (21). Eel stocks may never return to what they once were, but mitigation and remediation efforts have been invaluable. Eel populations in Rangitaiki reservoirs remain low even after 1997 due to a plethora of possible effects – recruitment trouble, fishing pressure, transfer survival, competition, and predation – but there is a belief that efforts of the Kokopu Charitable Trust and others are playing a massive role in at least maintaining eel stocks and preventing even further losses to the fishery (7).

Conclusions:

Severe impacts to the sustainability of the eel fishery in the lower Rangitaiki have been sustained since 1910 following the drainage of the Rangitaiki Plains and construction of the Matahina hydroelectric dam. This negative trend changed for the better at the end of the 20th century, notably from the sustained and continued efforts of Bill Kerrison and the Kokopu Charitable Trust in their elver trap and transfer scheme. While fishery recovery efforts may not replace important environmental and cultural losses, the current state is much improved from just several decades ago. The future is promising in this respect, and continued and expanded efforts to restore the *mauri* to the eel fishery will surely yield positive results.

This study’s Mauri Model analysis illustrates much information regarding the evolution of influences on *mauri* of the lower Rangitaiki eel fishery, however they also reveal the limited scope of this study. I focused solely on the sustainability of the eel fishery in the lower Rangitaiki River, and previously in the Rangitaiki Plains, especially emphasizing the impact of the Matahina dam. Had the scope of this study been of the whole length of the Rangitaiki River in all its respects or the entire Rangitaiki watershed, influential factors such as the impacts of land use change towards agriculture, electricity produced by the hydroelectric dams, and other facets of eel fishery restoration efforts could be included. This study, while including negative impacts of hydroelectric dam construction, for example, does not give positive economic gains and consequent social benefits from electricity production. I recommend that this study be expanded to include a larger geographic area and wider range in scope.

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*I will look more into papers of Chisnall, Glova, and Jellyman

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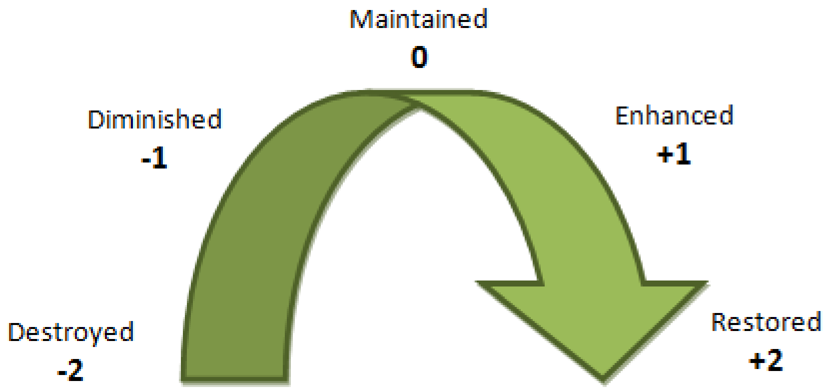

Fig. 1. Mauri Model sustainability meter for *mauri*.

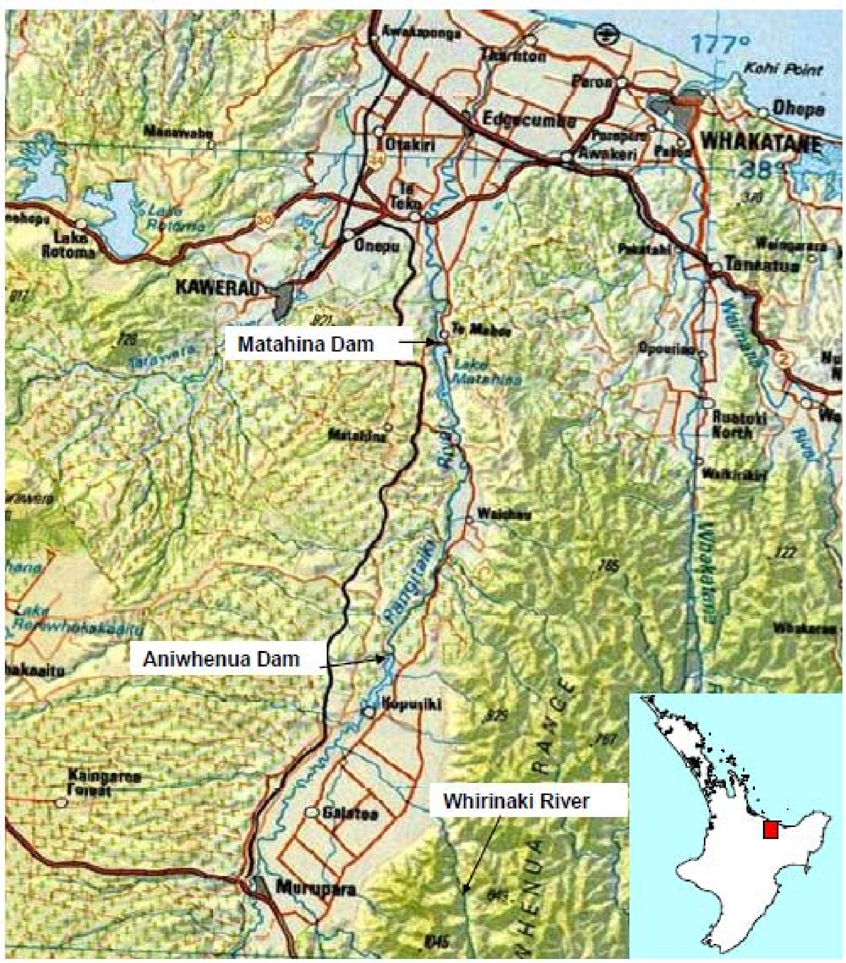

Fig. 2. Locations of Dams along the lower Rangitaiki River and surrounding area (7).

Category	Indicator	Description
Environmental	Habitat	Habitat suitable for eels, differentiated by species preference
	Eel Life History Traits	Aspects of the life history of eels, namely eels' stages of life and behaviours and requirements to achieve the stages
	Biomass	Abundance of eels in the fishery
Cultural	*Mana*	Status/prestige bestowed upon local *iwi* (tribe/confederation of tribes) based on the status of the eel fishery
	Kaitiakitanga	Guardianship of the environment by *kaitiaki*, who are entrusted with protection of all aspects of the environment, including the eel fishery
	Mahinga Kai	The ability of local Māori to freely harvest food from their lands and waters; well-integrated into Māori culture
Social	Recreation	Use of the eel fishery for recreational purposes
	Health	Changes in health stemming from impacts to fishery health
	Family Interactions	Family outings and cultural norms centered around the fishery
Economic	Allocation of Resources	Economic allocation of resources for daily living, especially those pertaining to food and diet
	Resource Harvest	Trading and profits from the eel fishery, especially pertaining to commercial fishing operations
	Exploit Availability	Extent and availability of the pool of exploitable resource

Table 1. Indicators by category and descriptions in relation to the eel fishery.

		Phase			
Category	**Indicator**	'Pristine'	PPD	PDC	PET
Environmental	Habitat	+2	-1	-1	-1
	Eel Life History Traits	+2	-1	-2	+1
	Biomass	+2	-1	-1	+1
Cultural	*Mana*	+2	-1	-1	+1
	Kaitiakitanga	+2	-1	-1	+1
	Mahinga Kai	+2	-1	-1	+1
Social	Recreation	+2	-1	-1	+1
	Health	+2	-1	-1	0
	Family Interactions	+2	-1	-1	+1
Economic	Allocation of Resources	0*	-1	-1	0
	Resource Harvest	+1**	-1	+2	-1
	Exploitable Resources	+2***	-1	-1	+1
	Results:	**+1.75**	**-1.00**	**-0.83**	**+0.50**

Table 2. Mauri Model assessment for the given indicators in each of the four well-beings. Criteria for scoring is given in Figure 1 and descriptions for indicators are given in Table 1. Phases are as follows: 'pristine' (baseline), post-plains drainage (PPD), post-dam construction (PDC), and post-Kokopu Trust eel trap & transfer (PET).

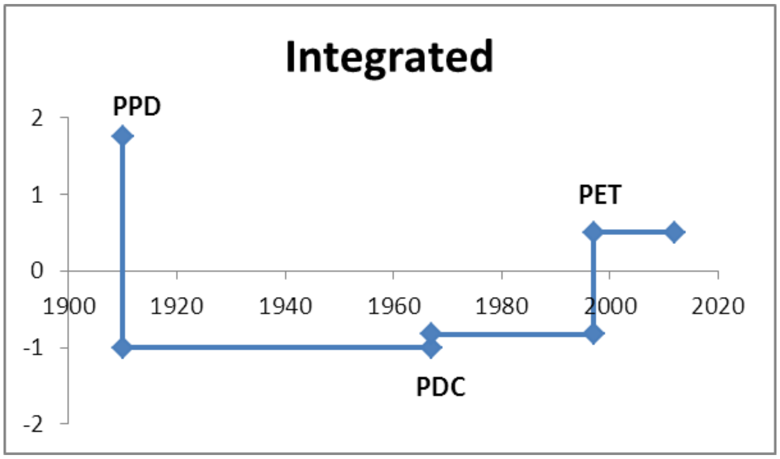

Fig. 3. Graphical representation of Mauri Model analysis showing delineated changes in *mauri* between phases, as marked by phase transition dates. Dates of phase transition events are as follows: drainage of the Rangitaiki Plains (PPD) beginning in 1910, construction of Matahina Dam (PDC) beginning in 1967, and Kokopu Trust eel trap and transfer work (PET) beginning in 1997.

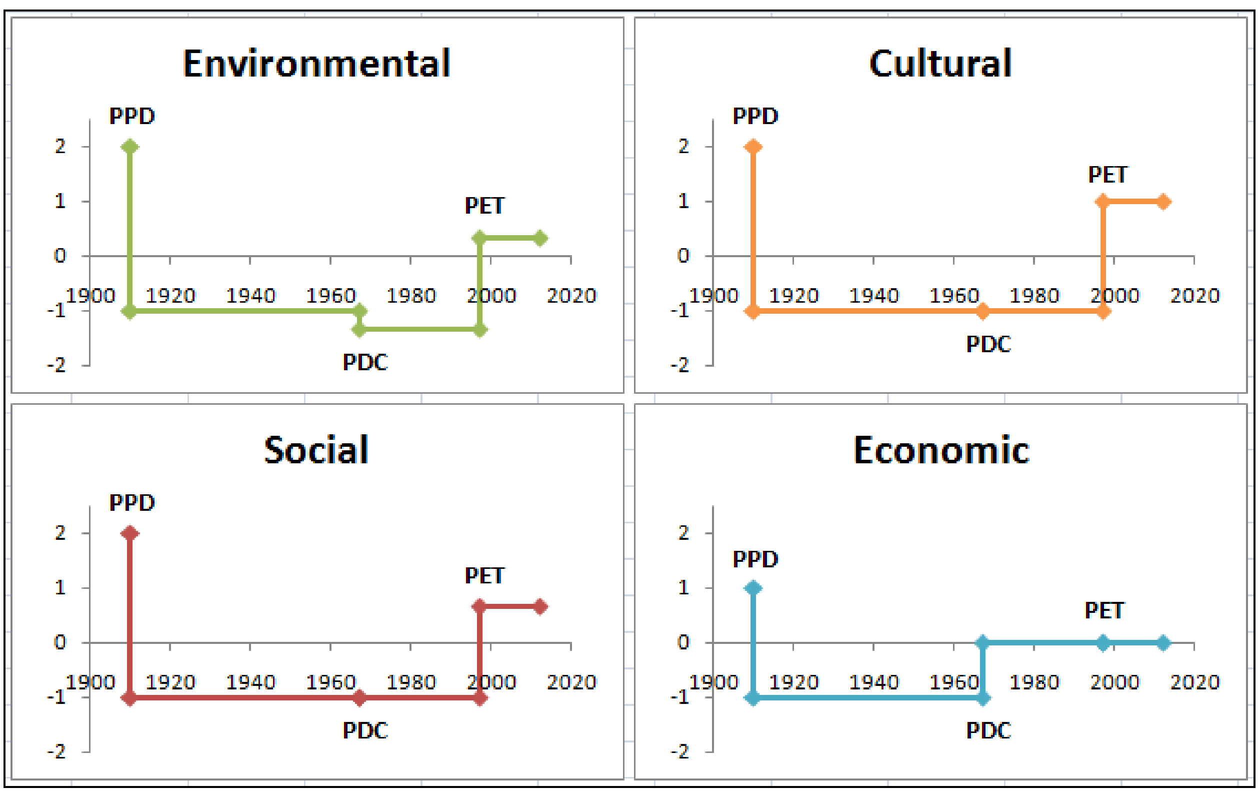

Fig. 4. Graphical representation of Mauri Model analysis broken down by well-being. Dates of phase transition are as follows: drainage of the Rangitaiki Plains (PPD) beginning in 1910,

construction of Matahina Dam (PDC) beginning in 1967, and Kokopu Trust eel trap and transfer work (PET) beginning in 1997.