THE USEFULNESS OF EXISTING SCIENCE MODELS IN TERMS OF CULTURAL HEALTH INDICATORS IN THE ROTORUA TE ARAWA LAKES

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Introduction

Within science there is a wide range of modelling approaches that are increasingly being applied to understand ecological systems and to allow for better management of those systems. The three most commonly used modelling approaches in the Rotorua Te Arawa lakes are: water quality models, knowledge networks and regression analysis.

Water quality modelling involves water quality-based data using mathematical simulation techniques. Use of models has become standard practice to support community and management decision-making for managing water quality in the Rotorua Te Arawa lakes.

Knowledge Networks (KNs, graphical conceptual models) however, foster a more holistic approach, summarising, in one diagram, diverse knowledge on the linkages between key cultural values (e.g., fisheries, swimming safety), pressures, restorative actions and facilitating cross-cultural understanding of complex issues (Quinn & Rowe, 2014). The use of KNs can be helpful for organising traditional ecological knowledge into a framework that can interface with western science methods (Collier et al. 2014). In the Rotorua Te Arawa lakes, KNs have previously been developed for five taonga species (i.e., kōura, kākahi, kōaro, common smelt, and tuna (NIWA 2007, Kusabs 2015).

Regression is a statistical technique that has long been used in environmental management and ecological decision-making (Collier et al. 2014). Regression analysis is a set of statistical methods used for the estimation of relationships between a dependent variable and one or more independent variables. It can be utilised to assess the strength of the relationship between variables and for modelling the future relationship between them. Linear regression has been used to model kōura and kākahi population characteristics in lakes Rotorua and Rotoiti and runs of wai inanga in the Ōhau Channel (Kusabs 2020).

Te Arawa cultural health indicators

Te Tūāpapa o ngā wai o Te Arawa (Te Arawa Cultural Vales Framework) outlines seven aspirations in the *health and wellbeing* of the Rotorua te Arawa lakes, these are:

1. Lakes in a healthy state
2. Kua mā te mauri o te wai
3. To be able to swim, drink the water and collect kai in all lakes again
4. Healthy, plentiful food resources
5. Pest free, and pollution free
6. Kōura on the table
7. Healthy and balanced ecosystem of the lakes

No cultural health indicators are specified but the seven aspirations can be grouped into three main categories:

(a) *Taonga species* - to be able to collect kai, kōura on the table, healthy and plentiful resources.

(b) *Water quality* - lakes in a healthy state, safe to swim and drink, pollution free and,

(c) *Holistic values* - combination of mauri, water quality and taonga species i.e., kua mā te mauri o te wai, healthy and balanced ecosystem of the lakes.

These categories are described in more detail below.

(a) Taonga species

Background

The social and economic wellbeing of Māori has long relied on the sustainable utilisation, conservation and management of their local natural resources. Freshwater species like kōura (crayfish; *Paranephrops planifrons*) and kākahi (mussels; *Echyridella menziesii*), wai inanga (common smelt; *Retropinna retropinna*), koaro (*Galaxias brevipinnis*), toitoi (*Gobiomorphus cotidianus*) and tuna (eels; *Anguilla* species), support important customary fisheries for Te Arawa iwi (tribal members) in the Rotorua Te Arawa lakes. Historically, kōura and koaro were the most important with large numbers harvested for consumption and trading (Kusabs and Quinn 2009). However, koaro were decimated following the introduction of trout and smelt in the early 20th century and now only small, relict populations remain. In contrast, kōura are considered a taonga species and continue to support important customary fisheries in lakes Ōkataina, Rotomā, Rotoiti and Tarawera where large populations of kōura still exist.

Kōura

Freshwater crayfish are increasingly used as indicator species because of the important role they play in aquatic ecosystems and their iconic and heritage values. Kōura are arguably the most suitable cultural indicator as they are affected by multiple environmental stressors including introductions of exotic fish which prey upon kōura (Kusabs & Quinn 2009), exotic plant species which likely hinder movement and accumulate large amounts of fine organic detritus, as well as reduced concentrations of dissolved oxygen in the bottom waters of lakes owing to eutrophication (Kusabs et al 2015).

The absence of kōura in four of the Rotorua Te Arawa Lakes (i.e., Ōkaro, Ngāpouri, Ngāhewa and Tutaeinanga) is directly attributable to eutrophication, which results in rapid and prolonged hypolimnetic deoxygenation (>ca. 5 m depth) (Kusabs et al 2015, Kusabs 2017). Furthermore, kōura are excluded from the deoxygenated hypolimnion of mesotrophic lakes; Ōkāreka, Rotokakahi, Rotoehu, Rotoiti, and Tikitapu in late summer and autumn when the lakes were stratified and concentrations of DO <5 mgL^{-1}. Periodic stratification events also cause intermittent hypolimnetic deoxygenation in polymictic lakes -Rotorua and Rerewhakaaitu, which leads to the movement of kōura into shallower water (Kusabs and Butterworth 2011).

Kōura are also a useful indicator of the establishment of benthic fish predators. For example, in lakes Rotorua and Rotoiti changes to the kōura populations were apparent well before (7 -10 years) brown bullhead catfish, well known predators of kōura, were officially recorded. The progressive decline in relative kōura abundance and biomass and an increase in kōura mean size indicated that brown bullhead catfish had been present for quite some time but at densities too low to be detected using standard trapping methods (Kusabs 2018).

Other taonga species

Kākahi are similarly affected by hypolimnetic deoxygenation but are a less useful indicator as they are absent, or present in very low numbers, in some of the of Rotorua Te Arawa lakes (e.g., Tikitapu and Ōkareka) due to water chemistry. Lake Tikitapu is exceptionally low in calcium (0.7 mg l^{-1}; Forsyth, 1978) and also low in silica and all major ions (McColl, 1972). Wai inanga and toitoi are reasonably tolerant species and are present in all of the Rotorua Te Arawa lakes and most abundant in the eutrophic lakes. Tuna are also tolerant of poor water quality and their usefulness as a cultural health indicator is further limited by their naturally-low numbers in the Rotorua Te Arawa lakes.

Native aquatic plants

LakeSPI (Lake Submerged Plant Indicators) is based on the principle that New Zealand lakes can be characterised by the composition of native and invasive plants growing in them, and the depths to which these plants grow. Submerged aquatic plants are highly suitable biological indicators because they are easy to observe, reflect environmental conditions within a lake over an extended period of time, and bring a focus to the edges of a lake, where the greatest public interaction occurs.

LakeSPI is carried out using scuba diving to record key information features about aquatic plant structure and composition within a lake. LakeSPI scores can be used to monitor trends over time within a single lake and/or for assessing or comparing the ecological condition of lakes within New Zealand. The maximum depth of plant growth is particularly useful as it has long been recognised as a direct indicator of water clarity in lakes. LakeSPI can contribute directly to reporting of lake environmental trends at the local, regional and national levels.

Potential cultural health monitoring methods

A number of traditional Māori methods can be used to monitor the taonga species outlined above, these include; tau kōura, ruku, and hinaki (Table 1). Monitoring these species will also provide These methods will not only provide information on the taonga species but also provide information on many biophysical parameters (Table 1). For example, the abundance and depth distribution of kōura and kākahi provides insights into low dissolved oxygen concentrations, as they are generally absent when DO concentrations <5 mg/l. Similarly, the absence of kākahi and snails is an indicator of unusual water chemistry, whereas the maximum depth of aquatic plants (native and exotic) is an excellent indicator of water clarity (Table 1).

Table 1. Potential cultural health indicators with methods, measures and models to assist in decision-making.

Cultural Health Indicator	Methods	Parameter	Measure	Model
Kōura	Tau kōura	Dissolved oxygen	Depth distribution, whakaweku decomposition/smell	Linear regression relative abundance vs time
		Aquatic weed distribution	Presence of aquatic weeds on tau kōura	
		Pest fish	Kōura abundance and size distribution	
		Fine sediment	Whakaweku condition	
		Koaro	Present in whakaweku	
		Water chemistry	Absence of snails on tau kōura are an indicator of unusual water chemistry	
Kākahi	Ruku kākahi Bathyscope counts	Sedimentation	Sediment depth	Linear regression density vs time
		Periphyton and algae growth	Observations	
		Water clarity	Black tube	
		Water chemistry	Absence of kākahi/snails an indicator of unusual water chemistry	
	Ruku kākahi – kākahi transects	Aquatic plant distribution	Diver observations	Linear regression density vs time
		Dissolved oxygen	Depth distribution of kākahi	
		Sediment quality	Diver observations	
		Water clarity	Diver observations – secchi disc	
		Water chemistry	Presence/absence of kākahi/snails an indicator of unusual water chemistry	
Tuna/koaro/wai inanga/toitoi	Hinaki -fine mesh fyke net	Pest fish	Abundance, distribution & population characteristics of pest fish, tuna common smelt, kōaro & kōura	Linear regression relative abundance vs time
Native aquatic plants charophytes	Ruku – Lake SPI surveys	Aquatic plants - species composition & distribution	Diver observations	Lake SPI indices vs time
		Water quality	Vegetation maximum depth - indicator of water clarity and lake condition	Linear regression max depth vs time
		Dissolved oxygen	Presence and depth distribution of kōura and kākahi indicator of DO concentrations	
Western Values	Water quality monitoring	Water temperature, water clarity, pH, water chemistry, bacterial counts	Water Quality monitoring buoy & in-lake monitoring surveys	Coupled-lake ecosystem models Trophic level index vs time

Conceptual models

Knowledge network conceptual models have been developed for the taonga species kōura, kākahi, kōaro, wai inanga (common smelt) and tuna in the Rotorua Te Arawa Lakes (Phillips 2007, Kusabs 2015). These models define three key factors (habitat quality, food supply and predation) which collectively contribute to the abundance of taonga species in the lakes. Each of the key factors is described by a range of variables (boxes), while the arrows describe the relationships between the variables.

The Rotorua Te Arawa Lakes KN (Figure 1) is based on Kusabs (2015) and summarises the key influences on taonga species and, in particular, kōura and includes lake management interventions, land use management, factors affecting food safety (cyanobacteria blooms, heavy metals and pesticides), the effects of lake bed substrates, influence of macrophytes and climate change.

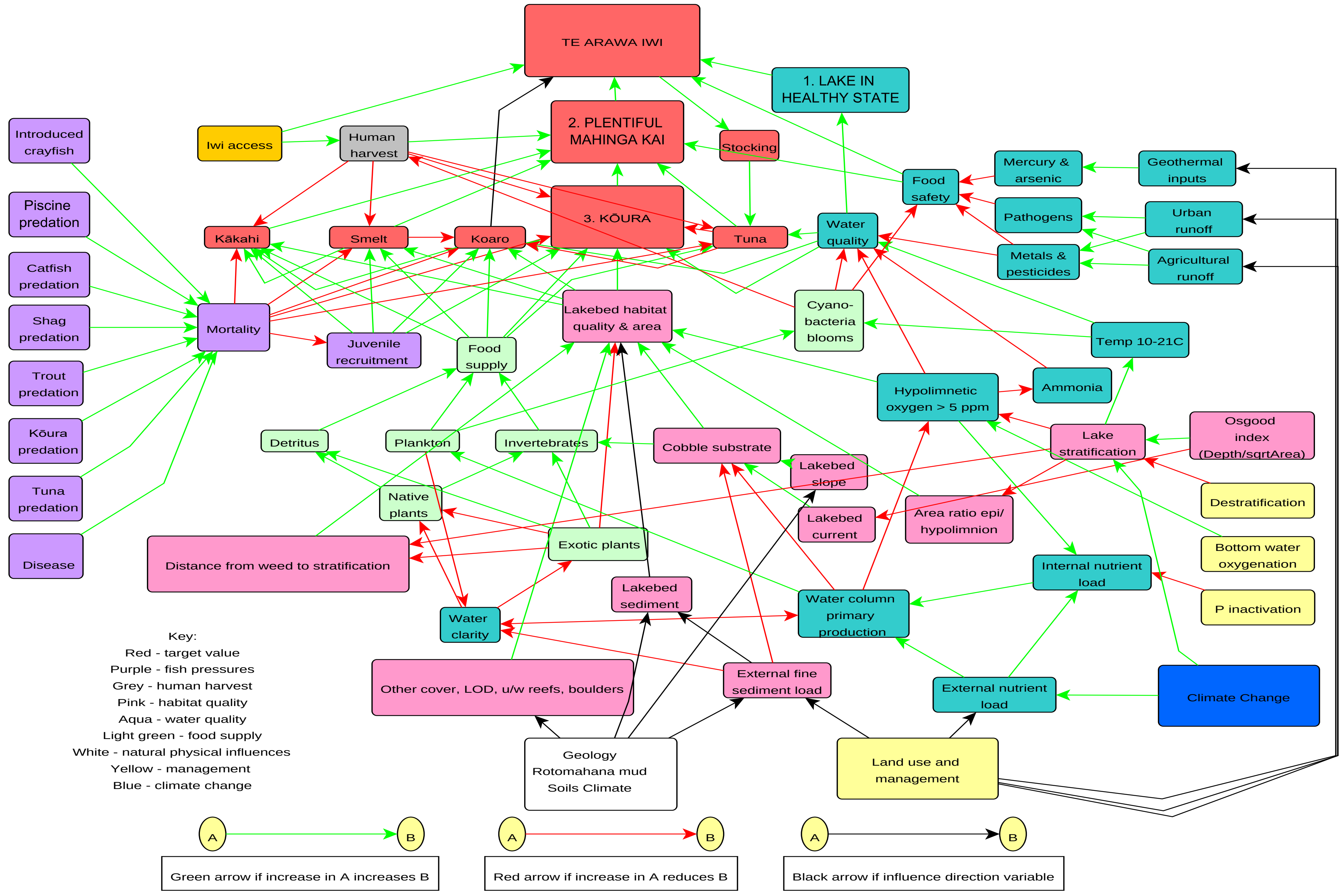

Figure 1. Rotorua Te Arawa Lakes knowledge network

Regression analysis

Regression is a standard statistical technique that has long been used in environmental management and ecological decision making. In its simplest form it involves relating a single environmental variable to record population measures. Regression analysis includes several variations, such as linear, multiple linear, and nonlinear. The most common models are simple linear and multiple linear. Nonlinear regression analysis is commonly used for more complicated data sets in which the dependent and independent variables show a nonlinear relationship. Despite its simplicity, regression methods can be very useful and easy to understand with a clear assessment of predictive ability (Fig. 2). Linear regression is currently used to model kōura and kākahi population characteristics in lakes Rotorua and Rotoiti and runs of common smelt in the Ōhau Channel (Kusabs 2020).

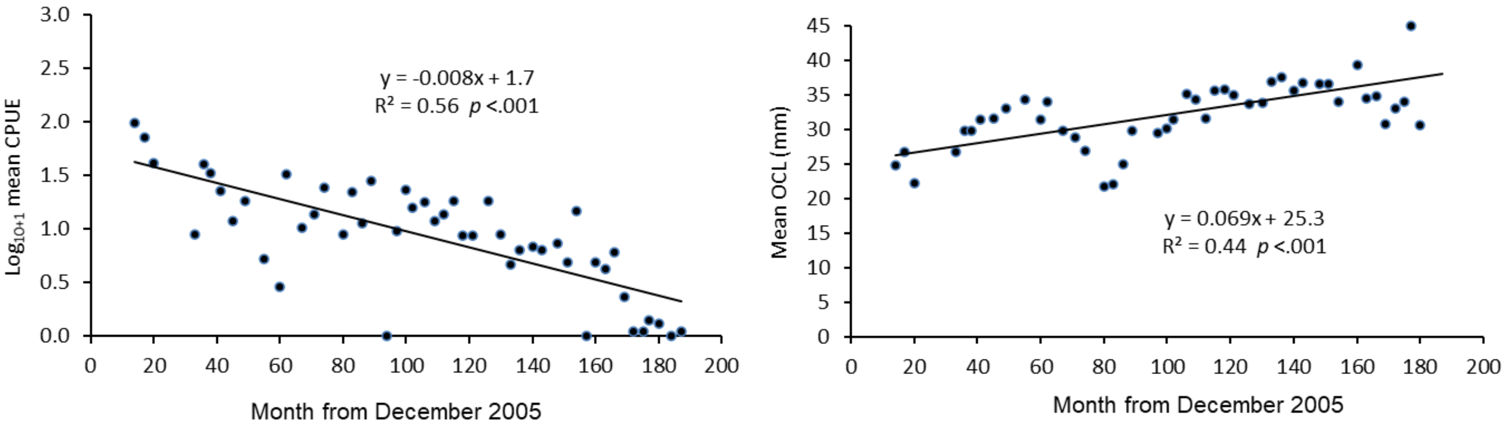

Figure 2. Relationship between mean relative abundance (catch per unit effort, CPUE) and size (mean orbital carapace length; mm) at Te Ākau Bay, Lake Rotoiti (Kusabs 2020).

(b) Water quality

Water quality is a key Te Arawa value in Te Tūāpapa o ngā wai o Te Arawa as outlined in the following statements *"lakes in a healthy state, safe to swim and drink, pollution free"*. A key part of the strategy to manage water quality in the Rotorua Te Arawa lakes is the application of lake water quality (process) models. For example, model simulations of Lake Rotoiti demonstrated how diversion of the Ōhau Channel inflow from Lake Rotorua to Lake Rotoiti would lead to a significant reduction in cyanobacteria (blue-green algae) through reduced nutrient loads (Hamilton 2012). A combination of aquatic ecosystem models is currently used to simulate lake responses to management activities affecting catchments and in-lake nutrient recycling processes (Fig. 3). No single model is capable of coupling climate, nutrient loads and lake water quality (Hamilton 2012). For this reason, different system-specific models have been linked together through their respective model inputs and outputs, in order to simulate time-varying TLI responses to changes in nutrient loads and climate. These models include:

- ROTAN (the Rotorua Taupō Nitrogen model) is used for the prediction of nitrate inputs to lakes for various land use, rainfall, and mitigation scenarios to inform land use policy and decision making for improving environmental outcomes.
- SimCLIM: a model developed in the International Global Change Institute at the University of Waikato, that downscales data from atmosphere-ocean general circulation models used by the International Panel for Climate Change (IPCC) to hindcast past climates and predict a future climate, up to 2100.
- CLUES: The Catchment Land Use for Environmental Sustainability (CLUES) model developed by NIWA. This model produces annual average total phosphorus loads in streams.
- DYRESM-CAEDYM is a coupled hydrodynamic-ecological model that has been applied to lakes and reservoirs around the world to simulate the one-dimensional (vertical) distribution of water temperature and chemical and biological constituents of water that are relevant to lake trophic state. In a review of internationally-available lake water quality models it was considered to be the leading model of its type for water quality predictions (Trolle et al 2011). DYRESM resolves the vertical distribution of temperature, salinity, and density, and the vertical mixing processes in lakes and reservoirs. CAEDYM simulates time-varying fluxes that regulate biogeochemical variables (e.g., nutrient species, phytoplankton biomass).

These dynamic process-based lake ecosystem models require complex configuration and calibration/verification for each new application. In addition, these models are mainly focussed on water quality and do incorporate taonga species or their habitat requirements. However, they do provide a basis for discussions of habitat relating to fisheries management (e.g., DO concentrations in the bottom waters that can affect kōura and kākahi distibution). An advantage of these models is that they can be used for testing future management scenarios which has the potential to more effectively engage stakeholders.

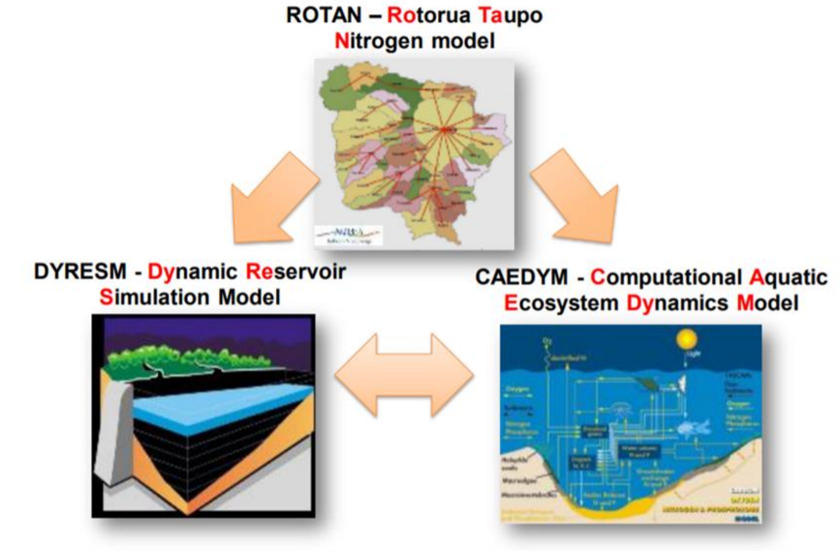

Figure 3. Coupled lake ecosystem models from Hamilton (2012).

(c) Holistic values

The holistic values outlined in Te Tūāpapa o ngā wai o Te Arawa can possibly be represented as a combination of mauri, water quality and taonga species e.g., '*kua mā te mauri o te wai, healthy and balanced ecosystem of the lakes.'* Knowledge Networks are holistic, summarising, the diverse knowledge on the linkages between key cultural values, pressures, restorative actions and facilitating cross-cultural understanding of complex issues.

Knowledge Networks are also useful for identifying and resolving complex environmental issues because they can incorporate the effects of multiple influences on a wide range of values and can include information from a variety of sources. These make them particularly useful for integrating cultural health indicators and science information. However, conceptual linkage diagrams lack statistical information on the relative strengths of individual and combined effects of parent nodes (from which arrows start) or child nodes (where arrows finish). This may mean that they are inadequate to support some levels of decision making in which case development of a full BBN is required using BBN development software.

Regression models are useful in determining relationships and trends for specific variables however they rely on those variables being strongly affected by one or two variables (either directly or indirectly). Examples could include the effect of benthic substrate size on or hypolimnetic deoxygenation on kōura distribution.

Water quality models (DYRESM-CAEDYM) are focussed mainly on water temperature and chemical and biological constituents of water that are relevant to lake trophic state. Currently, coupled aquatic lake ecosystem models are used to simulate lake responses to management activities affecting catchments and in-lake nutrient recycling processes.

Conclusions

Knowledge network (incorporating cultural health indicators) and water quality (process models) are complementary to each other and a combination of the two model types offers the most potential for Te Arawa to assess, manage and protect the health of the Rotorua Te Arawa lakes. Decisions with respect to protection, management and restoration of the Rotorua Te Arawa lakes rely on water quality (process) models to determine appropriate and effective management actions to achieve desired outcomes. Incorporating key cultural health indicators (e.g., the habitat requirements of kōura) would make the water quality (process) models more relevant to Te Arawa iwi, particularly if they are on a user-friendly, open-access platform. An advantage of these models is that they can be used for testing future management scenarios which has great potential for engaging stakeholders. Such a modelling approach (*An ecosystem modelling platform to assist New Zealand lake- management*) has been proposed by the University of Waikato and has been submitted to the 2021 Endeavour Fund (Smart Ideas).

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