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The feasibility and risks of using brown trout and longfin eel as biocontrols for brown bullhead catfish in Lake Rotoiti

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by

Brendan J. Hicks and Cindy Baker[1]

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Email: b.hicks@waikato.ac.nz

Environmental Research Institute
Faculty of Science and Engineering
University of Waikato, Private Bag 3105
Hamilton 3240, New Zealand

[1]National Institute of Water and Atmospheric Research Ltd,
Hamilton, New Zealand

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Cover picture: Brown bullhead catfish, *Ameiurus nebulosus*. Fork length 415 mm, 1035 g. Photo: Brendan Hicks.

Reviewed by:

University of Waikato

Approved for release by

John Tyrrell

University of Waikato

Executive summary

The aim of this study was to evaluate the risks and feasibility of using brown trout (*Salmo trutta*) and longfin eel (*Anguilla dieffenbachii*) as biocontrols for brown bullhead catfish (*Amieurus nebulosus*) in Lake Rotoiti. This question arose because of the recent discovery and spread of catfish in Lake Rotoiti. Several factors will constrain predation of catfish by longfin eels or brown trout, and these are summarised below.

Lakes Rotoiti and Rotorua together have a current wild brown trout abundance of at least 2,000-3,000 adults that has not prevented the spread of brown bullhead between 2016 and 2018. Catfish breeding can overwhelm the ability of predators to control them.

The abundance of brown trout could be increased by stocking but they are likely to have minimal interaction with catfish because of their very different preferred temperatures. Warm water temperatures in summer in the littoral habitats that catfish typically inhabit would likely be avoided by brown trout. Brown trout could, however, be a risk to taonga species such as kōura and and kōaro.

Catfish have a window of vulnerability for predation that probably lasts for as little as six months after spawning. After this, their antipredator defences (stout spines) and size (>100 mm) probably means that they cannot be eaten by piscivorous fish. This remains to be tested definitively.

Longfin eels have similar temperature preferences to catfish, so should be able to occupy the same habitat, leading to the potential for predation of catfish by eels. However, the diet of longfin eels is similar to shortfin eels, which are abundant in Waikato lakes where they do not effectively control catfish abundance.

Eels stocked into the Waikato hydro lakes appear to have vastly reduced the abundance of kōura, suggesting that the risk of kōura predation outweighs the potential benefit of catfish control.

Warm summers, which are especially conducive to catfish spawning, are likely to occur more frequently with climate change, increasing the success of catfish reproduction and reducing the likelihood of biocontrol of juvenile catfish by brown trout.

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Introduction

The aim of this study is to evaluate the risks and feasibility of using brown trout (*Salmo trutta*) and longfin eel (*Anguilla dieffenbachii*) as biocontrols for brown bullhead catfish (*Amieurus nebulosus*) in Lake Rotoiti. This question arose because of the recent discovery and spread of catfish in Lake Rotoiti. Several factors should be considered in evaluating whether predation by longfin eels or brown trout can control catfish abundance, including:

- The habitat and thermal preferences of catfish, eels, and trout
- The thermal environment available in the lake, including fluctuations with season and depth
- The abundance of the species in the lake now
- Evidence of successful biocontrol in other environments
- Antipredator defences in catfish in the period during which they might be most vulnerable to predation
- The risks posed to other species by increased populations of brown trout and longfin eels

Abdundance of catfish, brown trout, and longfin eels

Catfish abundance, recruitment, and growth

Between March 2016 and September 2018 brown bullhead catfish have spread around the western end of Lake Rotoiti (Figure 1). Fyke netting has caught over 33,000 catfish, with a strong recruitment pulse beginning in December 2017 (Figure 2). Since that time, numbers of catfish have exploded. The most likely cause of this unprecedented increase in catfish reproduction was the extremely warm summer of 2017 – 18 (Figure 3). A monitoring buoy in Lake Rotoiti at the Narrows recorded a temperature anomaly of almost 5°C above from the mean temperature for 2008 to 2017 for the same period. This was followed by an almost 4°C increase above normal in February 2018. These temperature increases are within the spawning and rearing periods for brown bullhead catfish.

Catfish exhibit rapid growth in Lake Rotoiti compared to other environments. Over 77 days between January and June 2017 a cohort of catfish, principally from Te Weta Bay, grew from means of 35 mm to 75 mm, i.e., a growth rate of 0.52 mm day^{-1}. With this growth rate, a catfish that was 35 mm fork length in January would be 100 mm long 125 days later (~4 months).

Brown bullhead catfish have stout spines on their pectoral and dorsal fins as an antipredator adaptation. While brown trout may be able to consume juvenile catfish, growth of catfish will eventually limit predation. During their first year in Lake Rotoiti, catfish are 15 to 100-mm long (Francis 2019), and within that size range are likely to be susceptible to predation. In their second year, Lake Rotoiti catfish are 100 to 150-mm long and are probably inaccessible to predation by trout or eels, though shags have been observed swallowing 150-mm catfish

(Hicks, unpub. observation). This means that the window of vulnerability of catfish to predation by piscivorous fish is probably short.

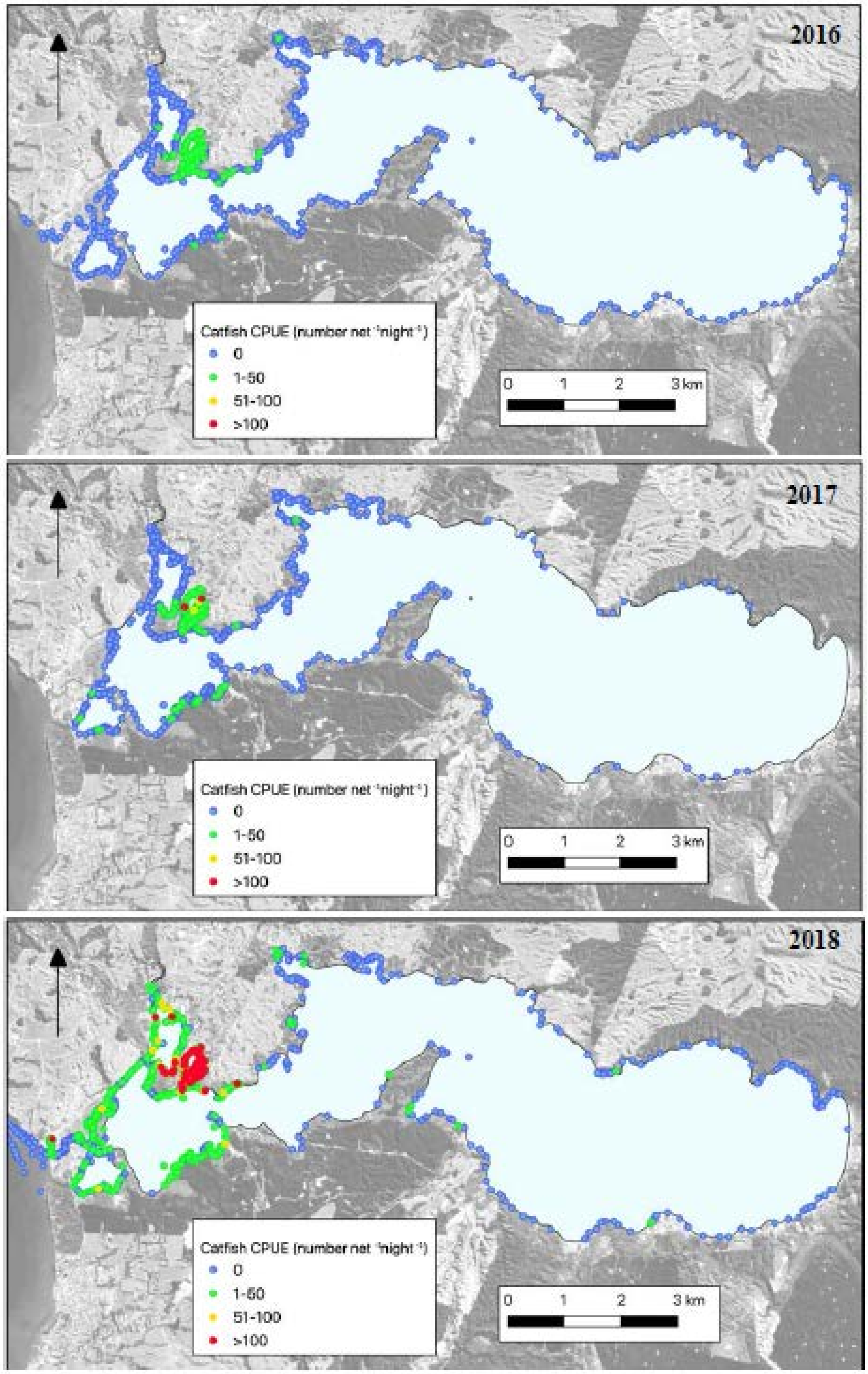

Figure 1. Catfish catch rates (number net^{-1} night^{-1}) for all net types set in Lake Rotoiti between 2016-18 during routine monitoring for catfish. Source: Francis (2019).

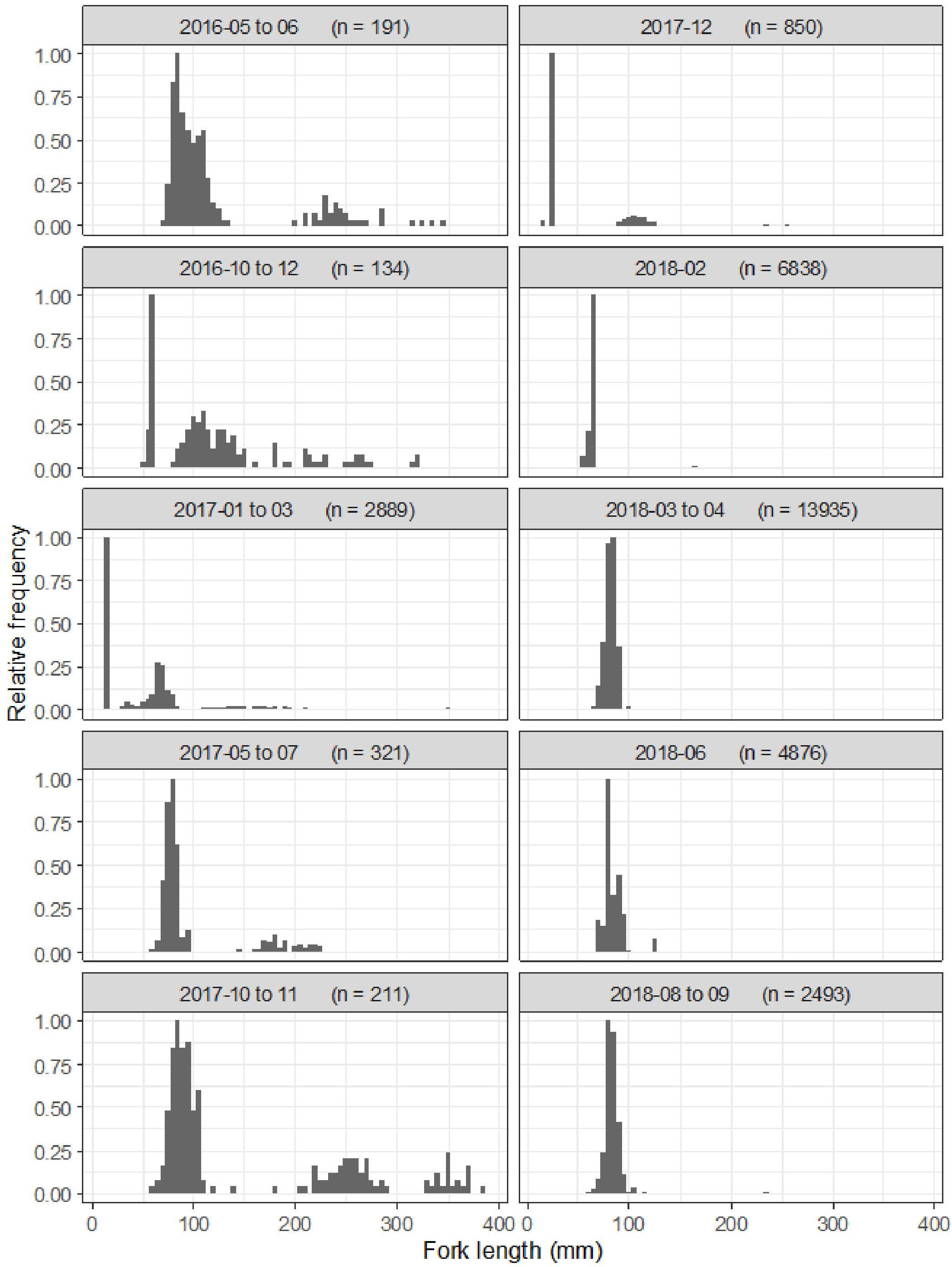

Figure 2. Length frequencies of catfish (*n* catfish = 32,738) caught in Te Weta Bay between 5 May 2016 and 27 September 2018 by fyke netting (*n* net nights = 6,955). Relative frequency normalises the modal frequency to 1. Source: Francis (2019).

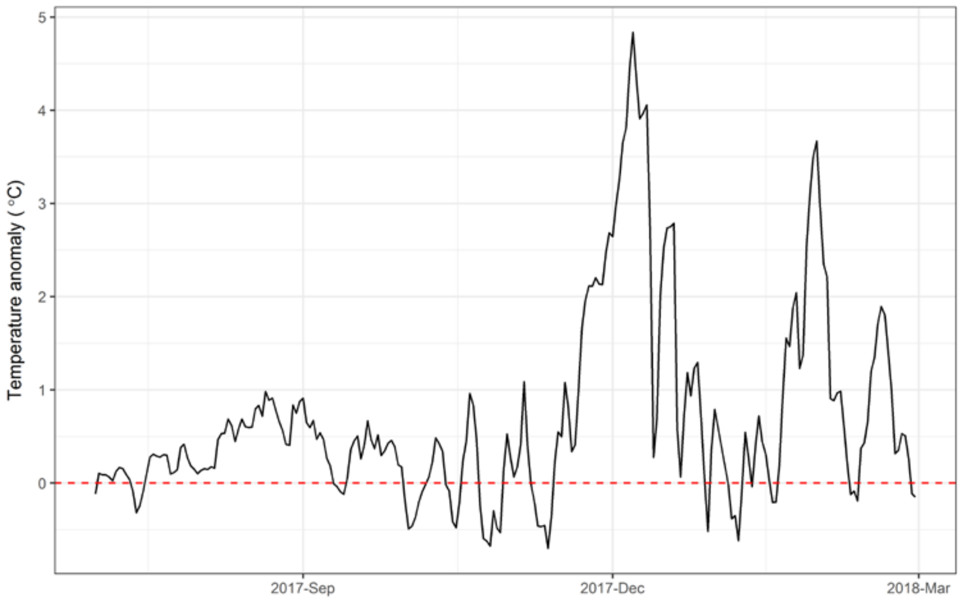

Figure 3. Temperature anomaly of surface water in Lake Rotoiti from July 2017 to March 2018 compared to the daily means of data from the Lake Rotoiti Narrows lake buoy for 2008-2017. Source: unpublished data, Chris McBride, University of Waikato (Hicks and Allan 2018).

Brown bullhead catfish have unusual nest guarding behaviour that protects eggs and juveniles from predators. Juveniles remain in schools guarded by an adult for an average of five days (Figure 4, Blumer 1985, Blumer 1986a, 1986b, Guth 2011).

Figure 4. Adult brown bullhead catfish guarding a school of juveniles in Lake Rotoroa (Hamilton Lake). Photo credit: Jim Bannon.

Brown trout abundance

Before considering the wisdom of adding brown trout by stocking we need to establish their current abundance in Lake Rotoiti. Brown trout abundance has not been specifically estimated but two unrelated sources of information allow inferences to be made about their relative abundance in the Rotorua and Rotoiti lakes system.

Brown trout were the subject of an intensive management campaign based around a fish trap on the Ngongotaha Stream, which is a major spawning tributary of the lakes Rotorua and Rotoiti system. This management campaign was documented in the records of the Wildlife Service of the Department of Internal Affairs, the then managers of the Rotorua trout fisheries. Between 1959 and 1963, 2,200-3,300 adult brown trout formed 23-31% of the spawning run of brown and rainbow trout into the Ngongotaha Stream (24,400 to 29,900 adults; Figure 4, Mill 2000). A culling programme conducted by the Wildlife Service attempted to eradicate brown trout between 1963 and 1979 by killing all adults during their upstream spawning run through the Ngongotaha Stream trap. The aim was to increase rainbow trout returns to anglers. This programme almost wiped out the brown trout run into the Ngongotaha Stream; from 1977 to 1980 no brown trout were recorded at the Ngongotaha Stream trap. However, rainbow trout numbers did not increase as expected so the brown trout cull was ended. In 1981 and 1982, brown trout numbers had started to recover (569 and 392 adult brown trout, respectively; Figure 5).

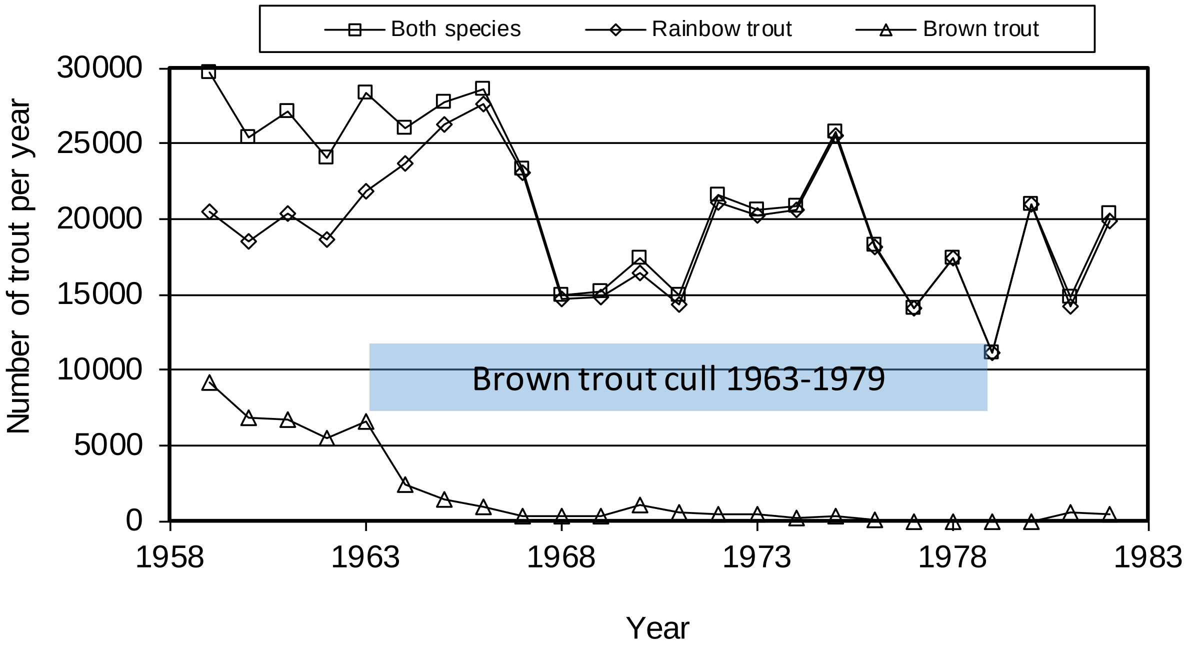

Figure 5. The number of upstream migrant rainbow and brown trout in the Ngongotaha Stream throughout the years 1959 to 1982. Source: Mill (2000).

The second source of information is the Ohau Anglers' Club (OAK) Fish Records. Of the 5,675 trout caught by member anglers between 2002 and 2015, 557 or 9.9% were brown trout (Figure 6). The proportion reached a maximum of 17.2% in 2009. We predict that since 1979, when the Wildlife Service cull ended, brown trout have returned to their former natural abundance in the system, which is at least 2,000 and 3,000 adults, judging from their original spawning run in Ngongotaha Stream. The OAK records of brown trout, most of which were caught in the Ohau Channel, support the contention of a thriving brown trout population.

Though the number of brown trout in Lake Rotoiti is unknown, rainbow trout pass freely from Lake Rotorua to Lake Rotoiti (Blair and Hicks 2009) and brown trout are likely to do the same.

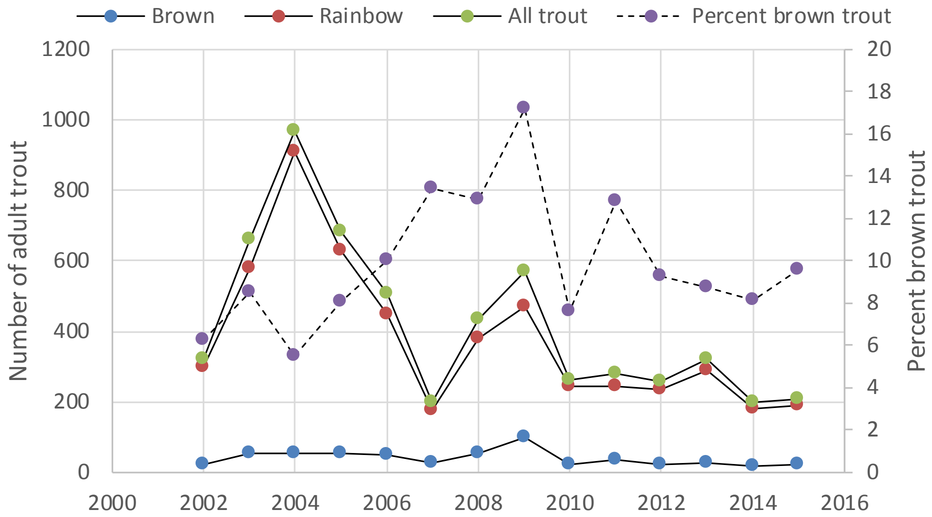

Figure 6. Ohau Channel angler records and creel census data for angler-caught trout. Source: Matt Osborne, Eastern Region Fish and Game, OAK Club Fish Records.

Longfin eel abundance

Waterfalls on the Kaituna River probably prevent most if not all of the natural upstream migration of eels into Lake Rotoiti, so longfin eels are found at very low densities in the lake and the eels that do occur there have most likely been transferred by humans (Martin et al. 2007). Boat electrofishing in the Ohau Channel between 2007 and 2015 caught 12 longfin and 2 shortfin eels (Hicks et al. 2018). Fyke netting for catfish between 5 May 2016 and 27 September 2018 in Lake Rotoiti caught 106 longfin eels in 6,955 net nights, confirming their low abundance (BOP RC, unpublished data).

Fyke netting for catfish between 5 May 2016 and 27 September 2018 in Lake Rotoiti caught 1,159 longfin eels in 6,955 net nights, confirming their low abundance (BOP RC, unpublished data).

Habitat and thermal preferences of catfish, trout, and eels

Catfish temperature and depth preferences

Catfish prefer warm water temperatures (26-29°C) with an optimum growth temperature of 29-30°C (Table 1; Figure 7). Catfish spawn in spring in water temperatures >14°C (Figure 6, Collier et al. 2015). In Lake Rotoiti, surface waters do not exceed 14°C until late October on average (Figure 15). November is likely to be the peak of catfish spawning in Lake Rotoiti, as shown by the discovery of gravid females in November 2016 (Figure 8).

Table 1. Mean optimum growth temperature (OGT), final temperature preferendum (FTP), upper incipient lethal temperature (UILT), critical thermal maxima (CTMax), optimal spawning temperature (OS), and optimum egg development temperature (OE) data for eels, catfish, trout, and common smelt. A dash (-) indicates that no data were found.

			Temperature (°C)						
Family	Common name	Scientific name	OGT	FTP	UILT	CTMax	OS	OE	Source
Anguillidae	Longfin eel	*Anguilla dieffenbachii*	-	25	35	-	-	-	Richardson et al. (1994)
Anguillidae	Shortfin eel	*Anguilla australis*	-	27	36	-	-	-	Richardson et al. (1994)
Ictaluridae	Brown bullead catfish	*Ameiurus nebulosus*	30.0	26.2	33.4	37.9	21.1	22.8	Hasnain et al. (2010)
Salmonidae	Brown trout	*Salmo trutta*	12.6	15.7	25.0	28.3	7.8	7.5	Hasnain et al. (2010)
Salmonidae	Rainbow trout	*Oncorhynchus mykiss*	15.7	15.5	25.0	22.1	7	8.9	Hasnain et al. (2010)
Retropinnidae	Common smelt	*Retropinna retropinna*	-	16.5	28.5	-	-	-	Richardson et al. (1994)

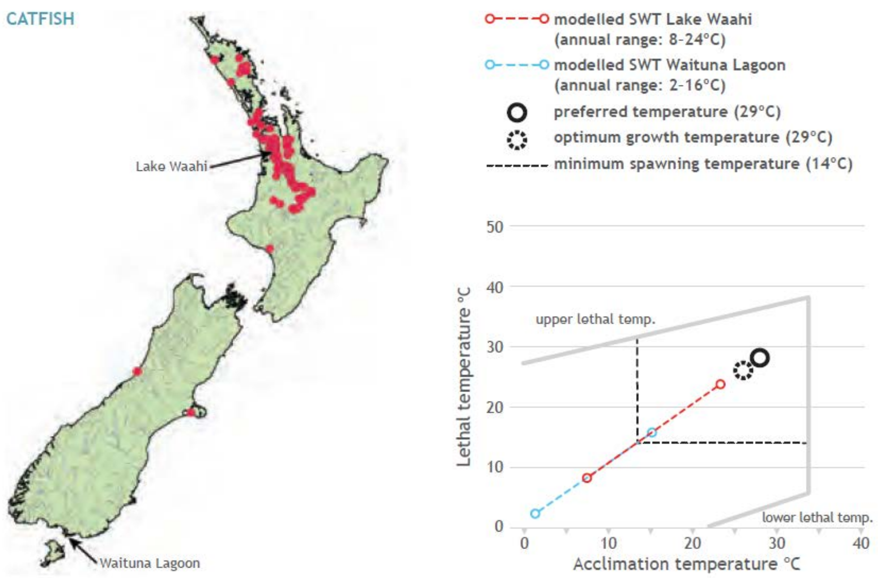

Figure 7. Thermal tolerance polygon, minimum spawning temperature, and New Zealand distribution for catfish, *Ameiurus nebulosus*. SWT = surface water temperature. Source: Collier et al. (2015).

Figure 8. Large gravid female catfish caught in Okere Arm on 11 November 2016. Photo: Shane Grayling, BOP RC.

In response most likely to falling seasonal temperatures, catfish move from the warmer littoral zones in summer in depths less than 6 m to deeper depths (2-10 m) in winter. Catfish are nocturnal, occupying shallower depths at night in deeper depths during the day (Figure 9).

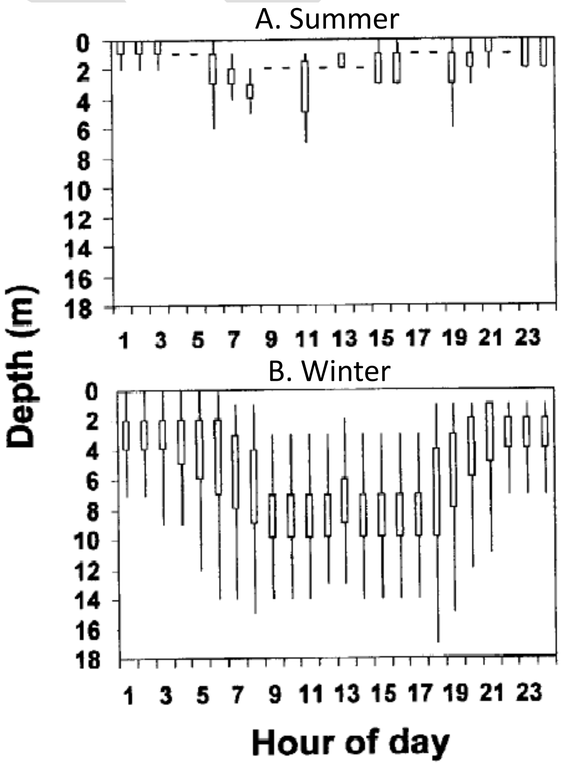

Figure 9. Depths occupied by brown bullhead catfish in Lake Taupo in A. summer and B. winter as recorded by acoustic tracking. The boxes give the 25th and 75th percentiles of the values around the medians. Whiskers indicate the 10th and 90th percentiles of the observations. Source: Modified from Dedual (2002).

Temperature preferences of brown trout

Trout, like most fish, are metabolic conformers, which means their internal body temperature is controlled by their environment. Increasing temperatures will therefore increase their metabolic scope, swimming speed, foraging efficiency and digestive capability (Kristensen et al. 2018). However, trout are also cool-water stenotherms, which means that their metabolism can only accommodate a narrow range of cool temperatures. In laboratory experiments with a range of acclimation temperatures, the optimum for growth in brown trout (*Salmo trutta*) has been established as 14^{o}C, with no growth occurring below 2^{o}C or above 19^{o}C (Elliott and Hurley 1999). Maximum energy conversion occurs at 9^{o}C, but brown trout in lakes may have a choice of temperatures at different depths, and are able to feed in warmer surface waters and then convert the energy consumed into growth in cooler deeper waters with temperatures (Elliott and Hurley 2000b). Optimum temperature for growth was higher for brown trout on a fish diet (mean 17.0°C, range 16.6-17.4 °C) than for brown trout feeding on invertebrates (mean 13.9 °C, range 16.6-17.4 °C; Elliott and Hurley 2000a).

Brown trout in Denmark that were implanted with temperature recording tags showed a clear preference for water temperatures between 10 and 15^{o}C (Figure 10), seeking warmer or cooler water in response to seasonal changes in surface water temperature. This implies that brown trout can forage in cool water in winter and warm water in summer provided that 10-15^{o}C water, their reported optimal growth temperature, is accessible to act as a refuge. Brown trout appear to avoid temperatures above 17°C, which is the upper range reported as optimal for growth in the species (Kristensen et al. 2018). Choice-chamber experiments confirmed the conclusion that brown trout will seek water less than 18^{o}C (Figure 11, Larsson 2005).

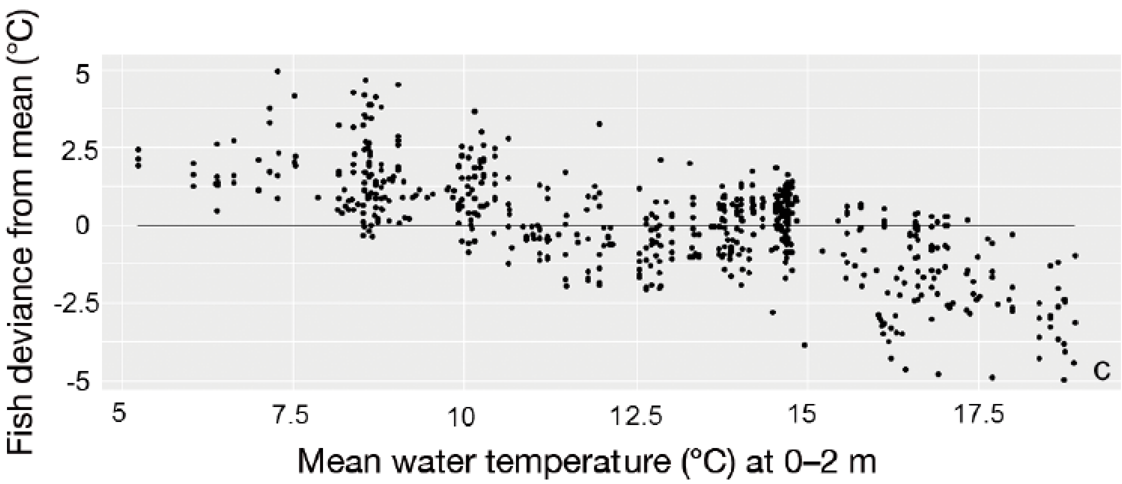

Figure 10. Deviance of the internal temperature of brown trout (when residing at 0−2 m for a minimum of 20 min) from mean surface water temperatures at 0−2 m. Source: Kristensen et al. (2018).

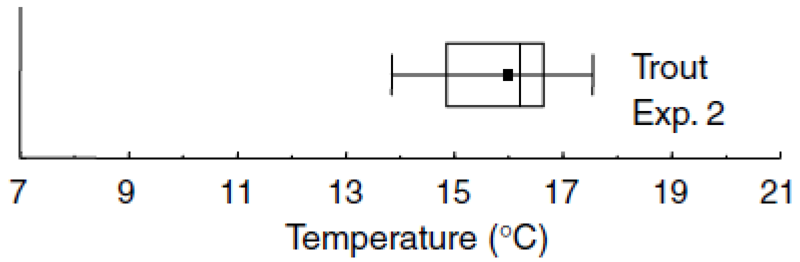

Figure 11. Distribution of preferred temperatures of 11 individual brown trout from Scandinavian lakes determined from choice chamber experiments. Within the box, the vertical line and black square indicate the median and the mean preferred temperature. Source: Larsson (2005).

Temperature preferences longfin eels

Longfin eels have a preferred temperature that is similar to catfish and somewhat cooler than shortfin eels (Table 1, Figure 12).

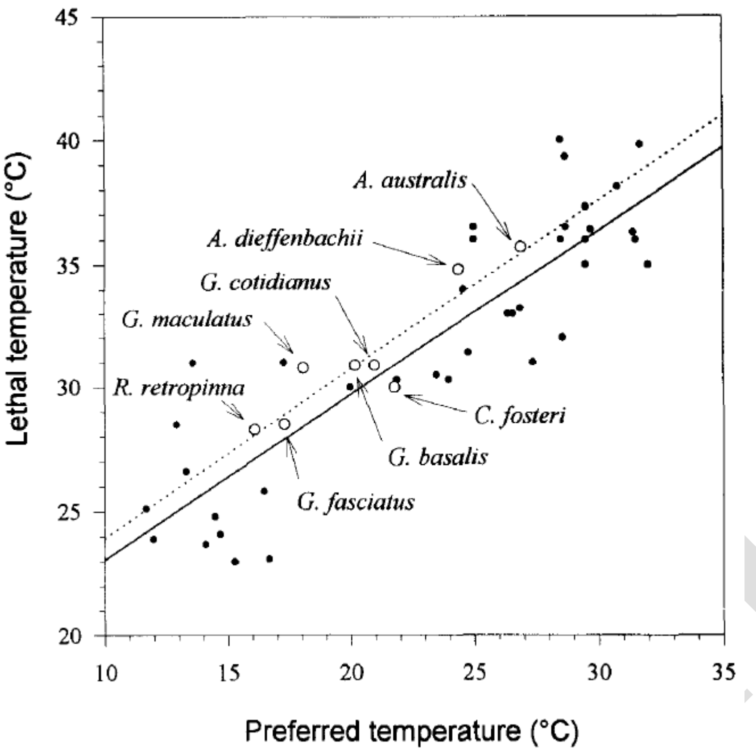

Figure 12. Relationship between preferred and lethal temperatures for eight native fish species (open circles, dashed line) together with the regression line developed by Jobling (1981) for 38 other fish species (solid circles, solid line). Source: Richardson et al. (1994).

Thermal environment of Lake Rotoiti and its fluctuations with depth and season

Water temperature of Lake Rotoiti varies considerably with depth and season. Measurements at three sites (Figure 13) from June 2004 to June 2005 show that in its deeper parts the lake is stratified in summer and fully mixed in winter (Figure 14). From late November to mid-April, surface water temperatures in Lake Rotoiti exceed 18°C (Figure 15), which brown trout are likely to avoid. Brown trout will seek cooler water when catfish occupy warm surface waters in littoral zones, so are unlikely to interact with catfish during summer when catfish are most active. Warmer summers, such as November 2017 to February 2018, will accentuate the separation of brown trout and brown bullhead catfish and increase the likelihood of successful catfish spawning.

Brown trout are likely to be restricted to depths of >10 m in summer to find their preferred temperatures (Figure 14). In winter, however, when the lake is fully mixed and when catfish retreat to deeper depths, they could be vulnerable to predation by brown trout. When catfish can find rocky habitat with crevices, however, they will use rocky substrate to avoid predation. A clear preference for rocky substrates over sand and macrophytes was identified in Lake Taupō (Barnes and Hicks 2003) and in Lake Rotoiti (Francis 2019).

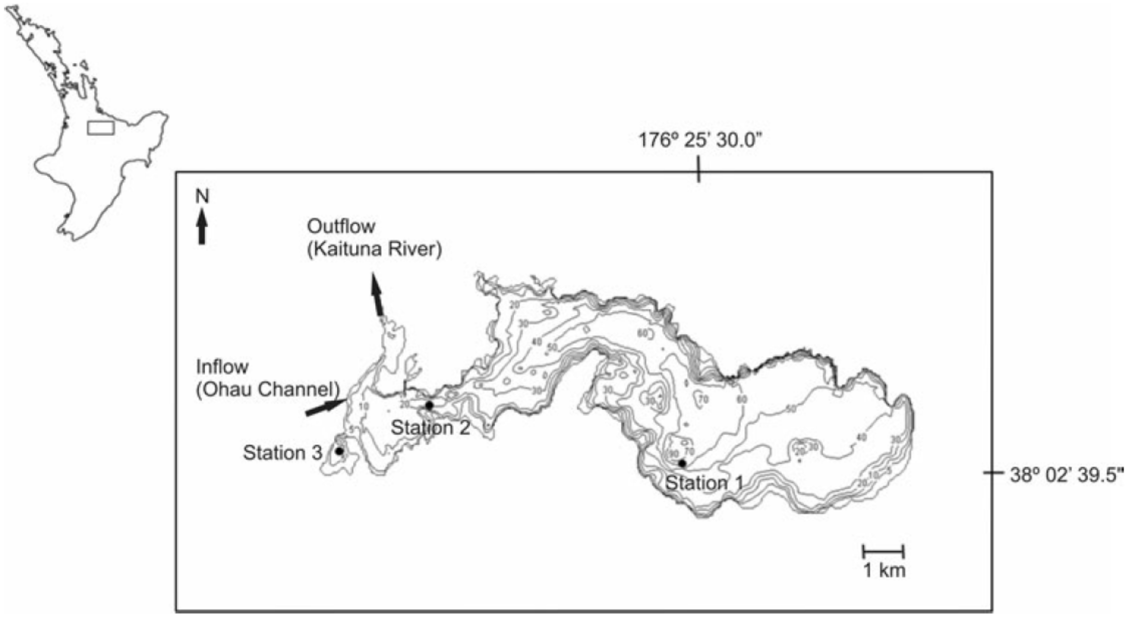

Figure 13. Location map of Lake Rotoiti, North Island, New Zealand with depth contours 5, 10, 20, 30, 40, 50, 60, 70, 80 and 90 m, showing the location of sampling stations 1, 2 and 3. Source: von Westernhagen et al. (2010).

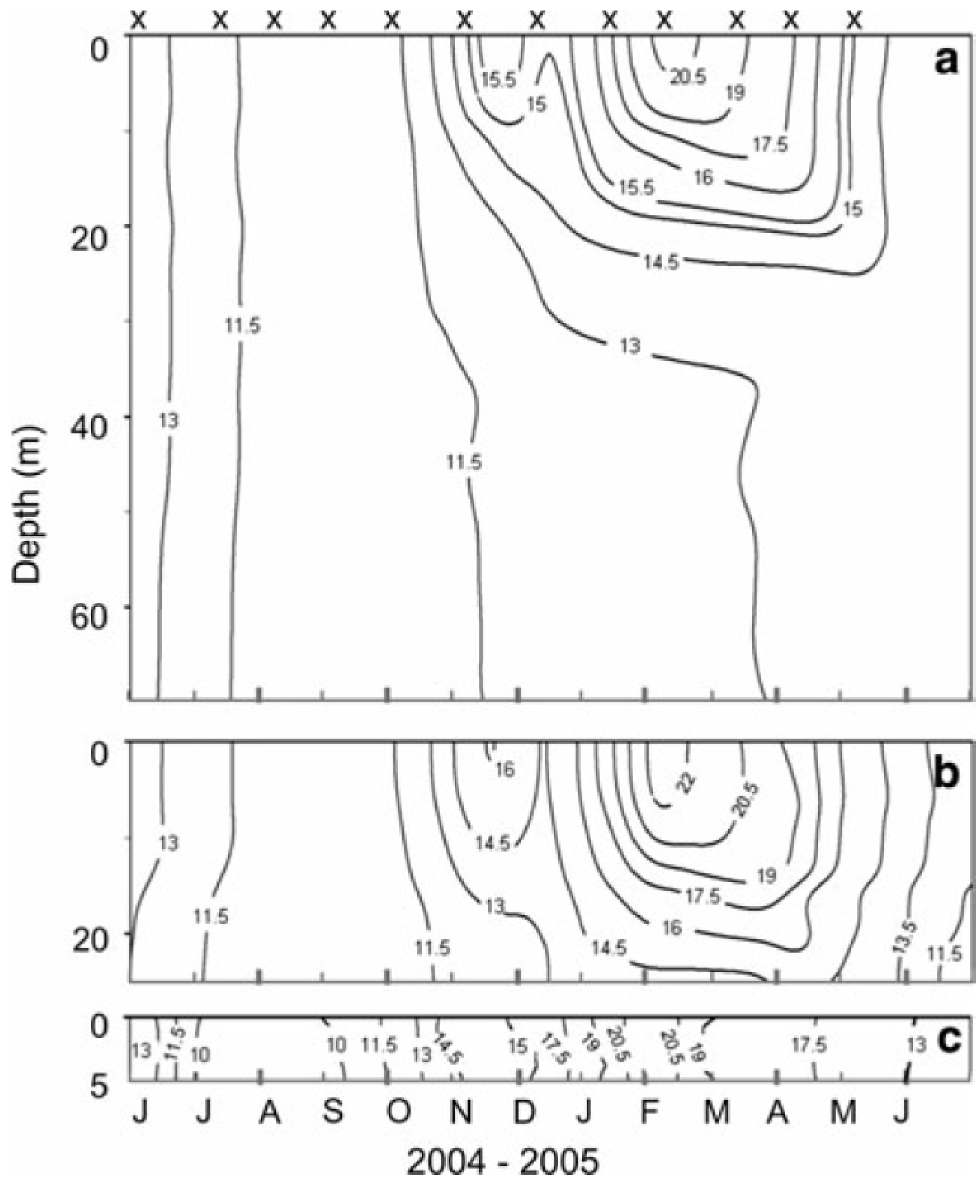

Figure 14. Contour plot of temperature (°C) for a) Station 1, b) Station 2 and c) Station 3 from June 2004 to June 2005. a) and b) are from thermistor chain records at 15-min intervals and c) from monthly CTD profiles. Field sampling dates are marked with x. See Figure 13 for the location of sampling sites. Source: von Westernhagen et al. (2010).

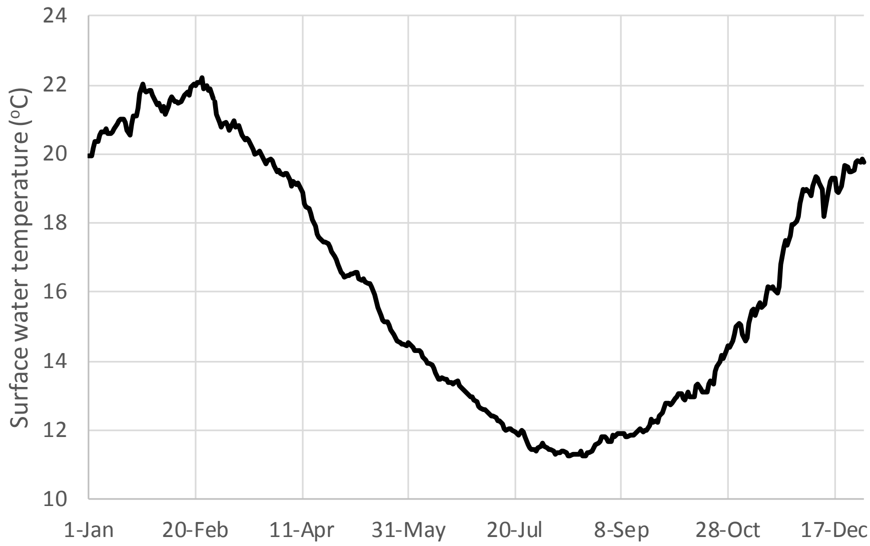

Figure 15. Daily mean surface water temperature in Lake Rotoiti from 2008-2018. Source: Chris McBride, Narrows lake buoy (Station 2 in Figure 13).

Impact of brown trout on native fish

Brown trout will almost certainly eat kōaro in Lake Rotoiti, judging from their predation of galaxiids of similar sizes in South Island streams (Figure 16; Jones and Closs 2018). However, both brown trout, rainbow trout and kōaro currently exist in Lake Rotoiti (e.g., Francis 2019), so the risk of additional brown trout is probably small. Nevertheless, brown trout can reduce kōaro abundance in lakes (Figure 17, Jellyman et al. 2018).

Figure 16. A brown trout caught in a South Island stream with six juvenile adult *Galaxias anomalus* in its stomach. (Photo credit: D. Jack.) Scale bar: approx. 10 cm. Source: Jones and Closs (2018).

Figure 17. Schooling kōaro (*Galaxias brevipinnis*) in a troutless lake in the South Island of New Zealand. Such phenomena are very rarely observed in lakes containing brown trout. Source: Jones and Closs (2018). Source: Jellyman et al (2018).

Effect of trout on kōura

The effect of brown trout on benthic invertebrates in lakes has received almost no attention (McDowall 1990). This remains true today (Jellyman et al. 2018). Anecdotal evidence suggests that trout introductions are likely responsible for declines in the abundance of two large-bodied freshwater invertebrates (crayfish, 'kōura,' *Paranephrops planifrons* and crabs, *Halicarcinus lacustris*) from North Island lakes, although quantitative data are not available (McDowall, 1990).

Though we have no data for brown trout in lakes, adult rainbow trout in Lake Rotoiti eat kōaro and kōura (Figure 18; Blair et al. 2012).

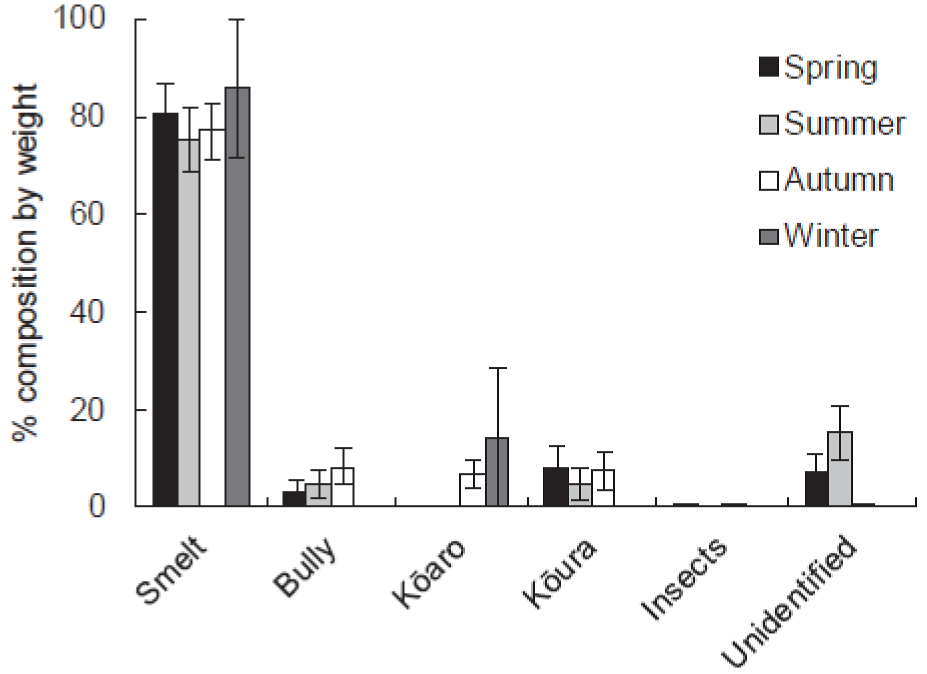

Figure 18. Seasonal changes in percentage composition of prey by wet weight eaten by adult rainbow trout (>400 mm) from Lake Rotoiti (mean±SE). Source: Blair et al. (2012).

Effect of eels on kōura

The Waikato hydro lakes provide evidence of the effect of eels on kōura (Clearwater and Kusabs 2014). Kōura were abundant in tributaries with no longfin eels, and absent or at low abundance where eels were present. One exception with abundant kōura and longfin eels had a large amount of cover available for kōura.

In the hydro lake, netting from before 1988 to 2014 showed that kōura disappeared as eels were introduced to the hydro lakes beginning in 1992. A trap and transfer programme in which eels are caught at the Karapiro Dam and released into all Waikato hydro lakes except Aratiatia has transferred an estimated 26,878,000 elvers between 1992 and 2014. Kōura, which were once abundant in all hydro lakes, declined in abundance between 1996 and 2000, disppearing from lakes Ohakuri, Atiamuri, Whakamaru, Maraetai, and Waipapa and present only in low abundance in lakes Karapiro, Arapuni, and Aratiatia (Clearwater and Kusabs 2014).

Eels are the only native freshwater fish that are capable of exerting significant predation pressure on kōura in streams. For example, 25-32% of longfin eel stomachs in Waikato streams contained kōura (Hicks 1997).

Lack of evidence that eels could act as a biocontrol for catfish

Evaluation of Waikato shallow lakes with mark-recapture biomass estimates showed evidence of coexistence of eels and catfish in lakes Mangahia, Kaituna, Ohinewai, Rotopiko (Hicks et al. 2015) and Lake Milicich (Hicks et al. 2017). The number of longfin eels is relatively low in these lakes, but there is large number of shortfin eels, some of which approach the size of longfin eels and approximately equal numbers of catfish. Eels clearly do not provide effective control of catfish in these lakes.

Conclusions

Lakes Rotoiti and Rotorua together have a current wild brown trout abundance of at least 2,000-3,000 adults that has not prevented the spread of brown bullhead between 2016 and 2018. Catfish breeding can overwhelm the ability of predators to control them.

The abundance of brown trout could be increased by stocking but they are likely to have minimal interaction with catfish because of their very different preferred temperatures. Warm water temperatures in summer in the littoral habitats that catfish typically inhabit would likely be avoided by brown trout. Brown trout could, however, be a risk to taonga species such as kōura and and kōaro.

Catfish have a window of vulnerability for predation that probably lasts for as little as six months after spawning. After this, their antipredator defences (stout spines) and size (>100 mm) probably means that they cannot be eaten by piscivorous fish. This remains to be tested definitively.

Longfin eels have similar temperature preferences to catfish, so should be able to occupy the same habitat, leading to the potential for predation of catfish by eels. However, the diet of longfin eels is similar to shortfin eels, which are abundant in Waikato lakes where they do not effectively control catfish abundance.

Eels stocked into the Waikato hydro lakes appear to have extirpated or vastly reduced the abundance of kōura, suggesting that the risk of kōura predation outweighs the potential benefit of catfish control.

Warm summers, which are especially conducive to catfish spawning, are likely to occur more frequently with climate change, increasing the success of catfish reproduction and reducing the likelihood of biocontrol of juvenile catfish by brown trout.

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