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Environmental cues for koi carp (*Cyprinus carpio*) spawning aggregations and bottleneck locations near Huntly, New Zealand

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By Jeremy Garrett-Walker

Environmental Research Institute
Te Pūtahi Rangahau Taiao
THE UNIVERSITY OF WAIKATO

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

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Reviewed by:

Approved for release by:

Dr Grant Tempero

Research Associate

Environmental Research Institute

University of Waikato

John Tyrrell

Research Developer

Environmental Research Institute

University of Waikato

EXECUTIVE SUMMARY

Koi carp (*Cyprinus carpio*) were monitored from August to December 2014 near Huntly, in the north Waikato, to document migratory and spawning behaviour. Monitoring involved a combination of daily water level and temperature logging, as well as semi-weekly observations of koi carp numbers and spawning activity. These data were used to examine the influence of water level and temperature on migration and spawning behaviour. No correlation between water level and koi carp migration was found; however, the monitoring period followed two years of drought in the region resulting in unusually low water levels for the time of year. In contrast, koi carp migration and spawning behaviour appeared to be related to water temperature, with spawning consistently observed after water temperatures were stable at 15^{o}C. This temperature spawning threshold is lower than previously observed for northern New Zealand, but is within the range identified in overseas literature. It is recommended that future studies investigate a greater range of seasonal and climatic variations, and address the potential for increased activity at night when fish may be more active.

ACKNOWLEDGEMENTS

We acknowledge the input and advice of Dr Bruno David, Waikato Regional Council, in developing methods and identifying monitoring locations. Thank you to Dr Grant Tempero and Bruno David for reviewing this document. This project is supported financially through the Lake Biodiversity Restoration program funded by the Ministry of Business, Innovation and Employment (Contract UOWX0505).

TABLE OF CONTENTS

EXECUTIVE SUMMARY ..... *ii*

ACKNOWLEDGEMENTS ..... *iii*

TABLE OF CONTENTS ..... *iv*

LIST OF FIGURES ..... *iv*

LIST OF TABLES ..... *v*

LIST OF APPENDICES ..... *v*

INTRODUCTION *1*

STUDY SITES *2*

METHODS *6*

RESULTS AND DISCUSSION *7*

W1 and W2 ..... **7**

W3 and P1 ..... **8**

W4 and S3 ..... **9**

S1 and TR1 ..... **10**

S2 ..... **11**

Conclusions and recommendations **12**

REFERENCES *13*

APPENDICES *14*

LIST OF FIGURES

Figure 1: Map of the Huntly region showing the locations of all sites used in this study. W = sites where walk counts were undertaken; S = sites where stationary counts were made; P = location of the pond where koi carp were counted; TR = location of temperature loggers deployed to capture reference temperature readings. For the location of temperature loggers, water level meters, and the barometric meter refer to Table 1. 2

Figure 2: Images of the one pond site (A) and the three stationary count locations (B= S1; C= S2; D= S3 – see Figure 1). 3

Figure 3: Images of the locations where koi carp were counted while walking up the drains. 4

Figure 4: Plot showing the water temperature (°C) and water depth (m) at site W1. The plot also shows the number of koi per 100 m seen on each monitoring occasion, and the presence or absence of spawning behaviour (1 = spawning, 0 = no spawning). The spot temperatures observed on each sampling occasion are included to show proximity to the corresponding daily mean temperature. 7

Figure 5: Plot showing the mean daily water temperature (°C), mean daily water depth (m), and koi carp per 100 m at W3. The corresponding spawning behaviour (2 = spawning, 0 = no spawning) at site P1 and water temperature (°C) at TR2 are included. 8

Figure 6: Plot showing the number of carp per 100 m at W4 and the number of carp per 30 minutes at S3. The mean daily water temperature (°C) and water depth (m) from the nearest water level logger are shown, as well as whether there was spawning behaviour observed in the upstream Lake Hakanoa (1 = spawning, 0 = no spawning). The water temperature at TR2 is included as a reference measure. 9

Figure 7: Plot showing the water temperature and water depth at site S1 as measured by the water level logger. The water mean daily water temperature at the reference site TR1 is included, along with the presence of koi carp spawning behaviour (2 = spawning, 0 = no spawning). 10

Figure 8: Plot showing water temperature at S2 as measured by the monitoring buoy in Lake Waahi. The water mean daily water temperature at the reference site TR2 is included, along with the presence of koi carp numbers per 30-minute count and spawning behaviour (1 = spawning, 0 = no spawning). 11

LIST OF TABLES

Table 1: Locations, the type of count undertaken and the type of data logger deployed at each site, and the length of walk where applicable. *denotes temperature logger was lost during the monitoring period. 5

LIST OF APPENDICES

Appendix 1: Summary data from W5 and W6, including the monitoring date, spot water temperature (°C), total koi carp observed on monitoring date. The total koi carp observed is also standardised to koi/100 m. 14

Appendix 2: Plot showing the mean daily water temperature (°C) measured form 15-minute logging intervals, the spot water temperature (°C) during observations, and the number of koi per 100 m at site W2. 15

INTRODUCTION

Koi carp, also known as common carp (*Cyprinus carpio*), have spread rapidly since their introduction into the lower Waikato River system in the late 1970s, and they now account for over half the total fish biomass in the Waikato River and nearby wetlands (Chapman, 1996; Hicks et al., 2008, 2010). Koi carp have been shown to undertake frequent migrations between the main Waikato River channel and connected waterbodies for spawning and feeding (Daniel et al., 2011; Gorski et al., 2014). Spawning events begin in September as water temperatures begin to increase and water levels are high following winter rainfall (Gorski et al., 2014; Hicks et al., 2010; Jones and Stuart, 2009). Tempero et al. (2006) observed koi spawning when the water temperature was 16.5^{o}C, while overseas studies have reported koi spawning in temperatures ranging from 15^{o}C (Australia; Stuart and Jones, 2002) to 28^{o}C (North America; McCrimmon, 1968).

Though water temperature appears a key environmental cue for spawning, McCrimmon (1968) suggested koi carp spawning is predominantly initiated by flow pulses which inundate waterbody margins shallower than 0.45 m. In support of this, spawning locations in northern New Zealand are typically shallow, vegetated margins of streams and lakes, where koi carp can aggregate, and in these locations densities can reach 4,000 kg/ha (Hicks et al., 2010).

The Waikato Regional Council is currently designing transportable carp traps which can be deployed in drains and channels to harvest koi carp during peak migration periods. The aim of this study was to identify (i) key koi migration channels and bottlenecks in the lower Waikato River catchment where koi could be trapped, and (ii) the temperature and flow thresholds associated with koi carp migration. However, there were few heavy rainfall events during the observation period, resulting in limited flood pulses and constraining the inferences that could be made regarding environmental cues for spawning.

STUDY SITES

Study sites were located near Huntly, in the north Waikato (Figure 1). Sites were selected for their accessibility and proximity to the main Waikato River channel. In total 11 sites were selected for monitoring; seven were suitable for channel walk counts, while three sites required stationary counts (Table 1). One pond was included in this study (P1) due to the high biomass of koi carp observed prior to the initiation of this study and its close proximity to other sites (Figure 2). Throughout the monitoring period water clarity at site S1 (Figure 2B) was consistently turbid and no counts of koi carp were possible; instead monitoring of this site consisted of walking upstream to the outflow of Lake Kimihia to note any spawning activity. Site S2 was at a rock weir (Figure 2C) and site S3 had a rock sill which provided excellent conditions for counting of koi carp as they negotiated the obstacles (Figure 2D).

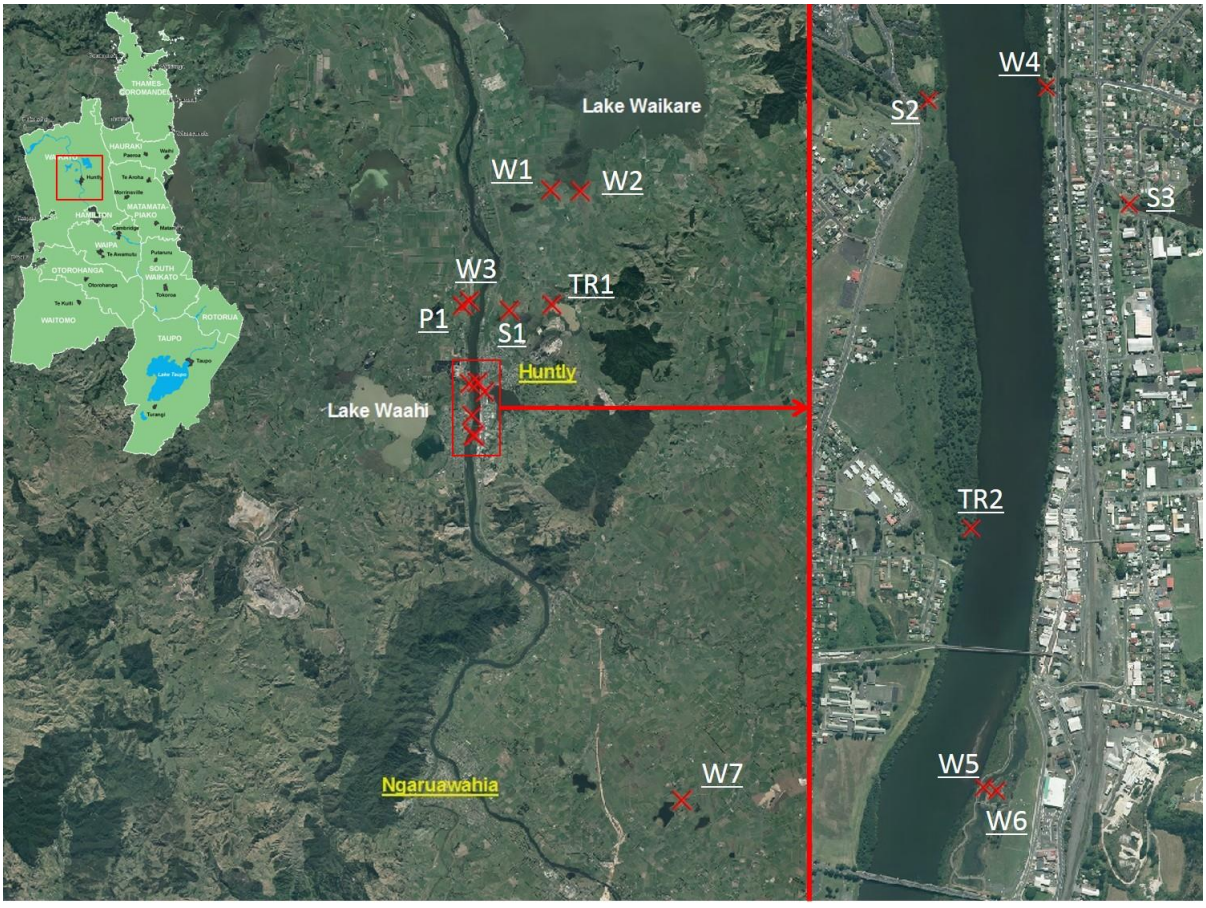

Figure 1: Map of the Huntly region showing the locations of all sites used in this study. W = sites where walk counts were undertaken; S = sites where stationary counts were made; P = location of the pond where koi carp were counted; TR = location of temperature loggers deployed to capture reference temperature readings. For the location of temperature loggers, water level meters, and the barometric meter refer to Table 1.

Figure 2: Images of the one pond site (A) and the three stationary count locations (B= S1; C= S2; D= S3 – see Figure 1).

Sites W1 and W7 (Figure 3) have fish barriers on them which prevent the migration of adult koi carp into the upstream lakes (Ohinewai and Kainui, respectively). Sites W5 and W6 are located in a constructed side channel in which significant koi carp biomass and suitable spawning habitat have been reported (Ginders 2011) (Figure 3). A floodgate between P1 and W3 is likely a barrier to movement of large fish during periods of low flow as it typically was ajar by only around 5 cm.

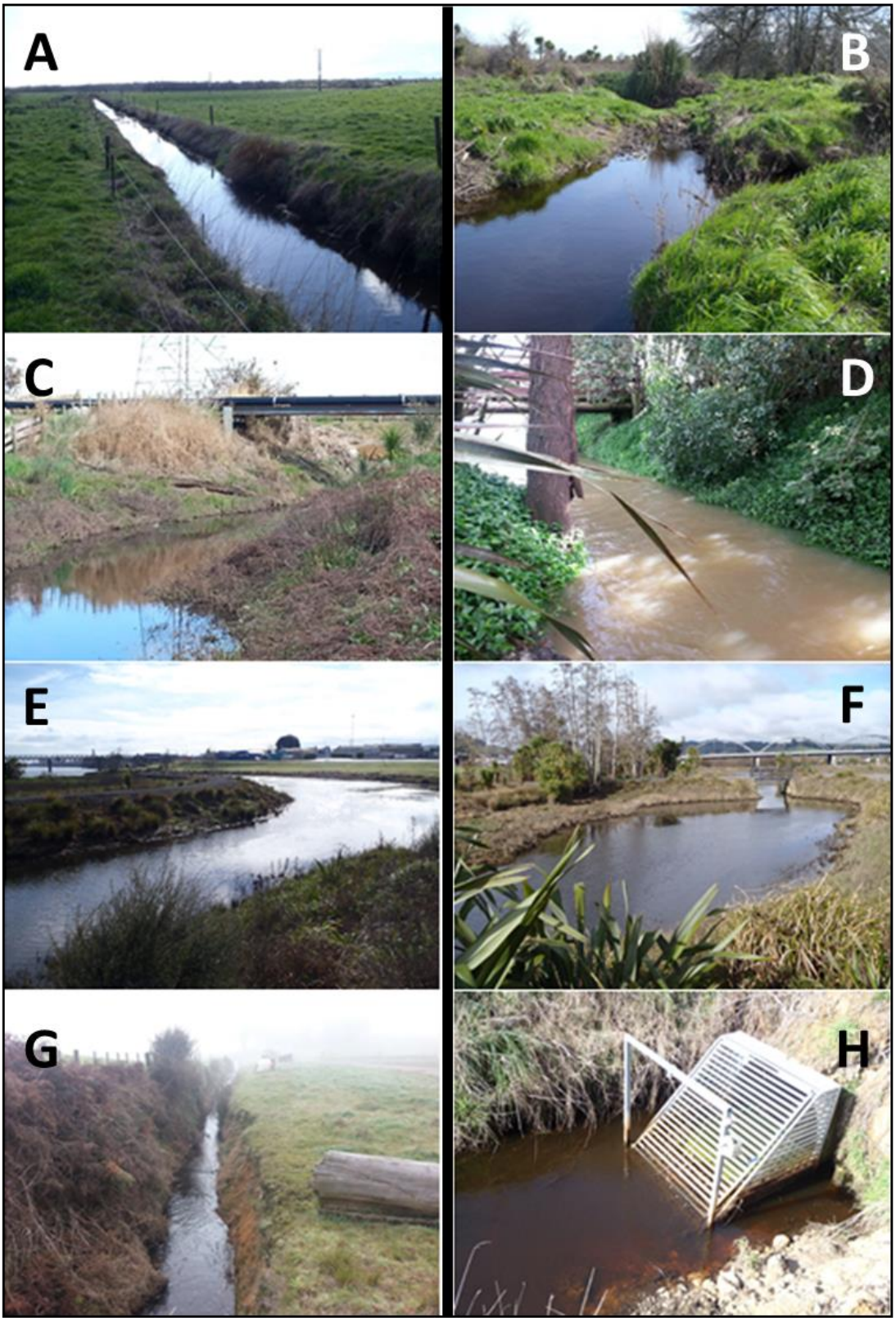

Figure 3: Images of the locations where koi carp were counted while walking up the drains. A = W1; B = W2; C = W3; D = W4; E = W5; F = W6; G = W7; H = the fish barrier present at W1.

Table 1: Locations, the type of count undertaken and the type of data logger deployed at each site, and the length of walk where applicable. *denotes temperature logger was lost during the monitoring period. N/A = not applicable.

Site	Count type	X coordinate	Y coordinate	Logger type	Length of walk (m)
W1	Walk	1793090	5848640	Water level/Barometric	183
W2	Walk	1794070	5848600	Temperature	108
W3	Walk	1790350	5844910	Water level	70
W4	Walk	1790650	5842150	Water level	31
W5	Walk	1790490	5840370	Temperature*	101
W6	Walk	1790520	5840370	N/A	79
W7	Walk	1797490	5828120	Water level	80
P1	Pond	1790130	5844720	Temperature	1,277
S1	Stationary	1791700	5844580	Water level	N/A
S2	Stationary	1790350	5842120	N/A	N/A
S3	Stationary	1790860	5841850	Water level	N/A
TR1	Temperature reference	1793130	5844780	Temperature	N/A
TR2	Temperature reference	1790450	5841030	Temperature	N/A

METHODS

Monitoring began on 11 August 2014 and continued through the koi carp spawning season until 10 December 2014, with counts conducted weekly where possible. For all counts, polarised sunglasses were worn to improve koi carp detectability. Evidence of spawning behaviour (typically activity in marginal vegetation) was noted.

Water depth and temperature measurements

Before the counts began, Tidbit v2 Temperature loggers were placed at three sites (W2, W5, P1) as well as in the Waikato River (TR1) and Lake Kimihia (TR2) for reference, and five INW PT2X submersible pressure loggers were deployed to measure changes in water level and temperature (Table 1). An INW Aqui Star PT2X-BV Barometric and Vacuum Sensor was installed on the fish barrier at W1, and allowed for the conversion of water pressure to water level. All temperature and water pressure loggers were programmed to take measurements at 15-minute intervals throughout the monitoring period. No loggers were deployed near S2 as long-term water temperature data were available from the water quality monitoring buoy administered by the Waikato Regional Council located in Lake Waahi. The temperature logger at W5 was lost during the monitoring period, meaning that koi numbers and spawning events could not be analysed for temperature cues. For this reason sites W5 and W6 are not included in the final results (summary data from these sites can be found in Appendix 1).

Drain walk counts

The seven drains used in this study varied in length, depth and width. Counts involved slowly walking from downstream to upstream alongside the drain whilst counting all visible koi which were prevented from moving further upstream by barriers (e.g., floodgates, exclusion screen). The total number of koi carp counted during the walk was then converted to a standard measure of number of koi carp per 100 m.

Stationary counts

Stationary counts consisted of counting the number of koi swimming across an identified feature in the water during a 30 minute period. Koi carp were counted as they swam up a rock weir in the Lake Waahi outlet (S2) and a small rock sill in the Lake Hakanoa outlet (S3). Koi were never counted as they passed through a culvert on the Lake Kimihia outlet channel as the water was always too turbid, however all other measurements were taken during the monitoring period. Koi carp spawning behaviour was noted by walking upstream of S1; koi could be seen aggregating in spawning groups in shallow, vegetated margins of the channel and koi eggs were often visible on macrophytes.

Pond count

Koi carp were visually quantified by walking the perimeter of the pond and counting the number seen. Limitations to these counts include the likelihood of counting the same fish more than once, and the reduction in visibility throughout the monitoring period as macrophyte cover increased. The increase in macrophyte cover in the pond led to the koi carp counts ceasing on the 13th October.

RESULTS AND DISCUSSION

W1 and W2

Koi carp were observed on 13 of the 14 monitoring occasions at W1, more frequently than any other walk site (Figure 4). In total, 177 koi carp were observed at W1 and four at W2. Koi carp appeared to be spawning on four occasions at W1, but no such behaviour was observed at W2 (Appendix 2). An increase in mean water depth on 22 September 2014 preceded two occasions of observed spawning behaviour. Koi carp were also observed spawning as water depth increased from the lowest recorded water depth on 4 October 2014. The fourth observed spawning occasion was not related to a change in water depth, but did occur as mean water temperature rose by around 4°C. The first three spawning events occurred after the temperature had stabilised at 15°C for approximately two weeks. Due to the low number of koi observed at W2 no linkages between koi numbers and water temperature were found.

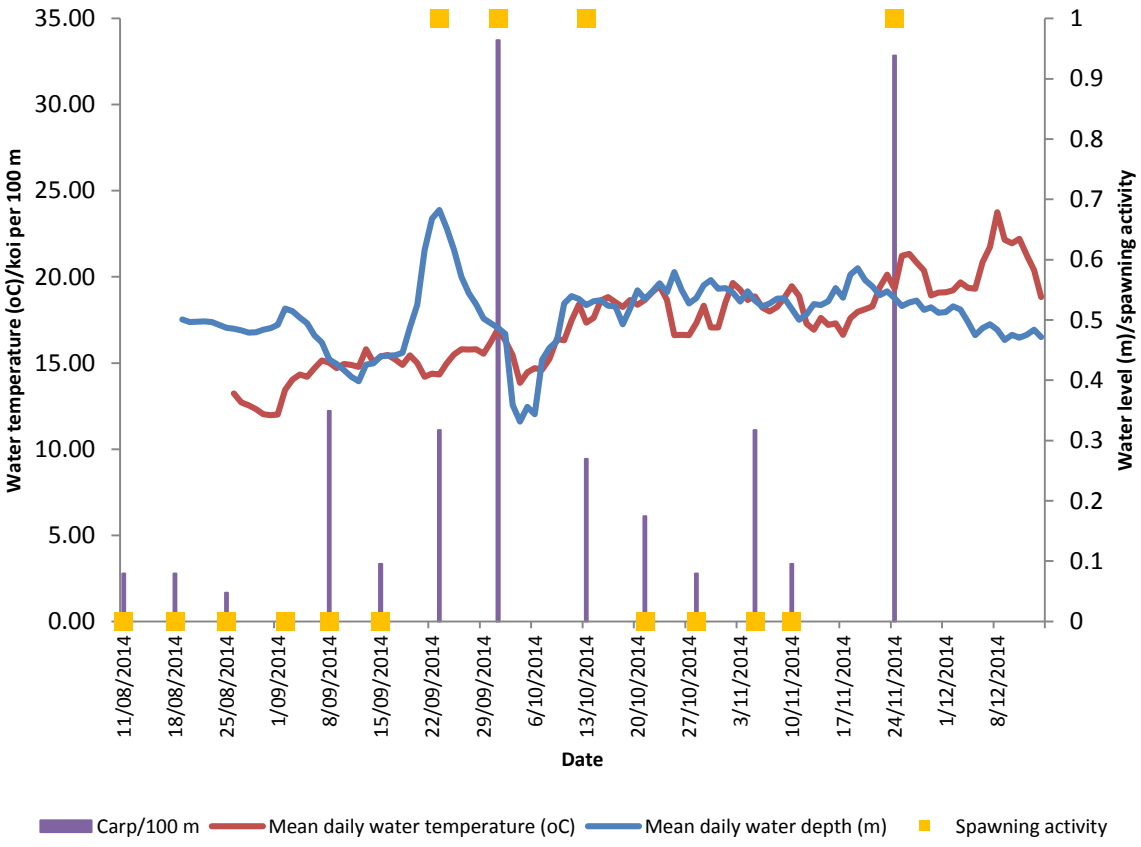

Figure 4: Plot showing the water temperature (°C) and water depth (m) at site W1. The plot also shows the number of koi per 100 m seen on each monitoring occasion, and the presence or absence of spawning behaviour (1 = spawning, 0 = no spawning). The spot temperatures observed on each sampling occasion are included to show proximity to the corresponding daily mean temperature.

W3 and P1

Koi carp were observed in the W3 channel on five occasions, with densities of less than 2 per 100 m (Figure 5). The first three occasions that koi carp were observed coincided with spawning activity in the P1 pond which is upstream of W3. The final three spawning events observed at site P1 occurred after water temperature exceeded 15°C for approximately two weeks. The first spawning event occurred as the water temperature rose from around 12°C to 15°C. Spawning behaviour ceased after the 23 September which coincided with a 0.2 m rise in water depth.

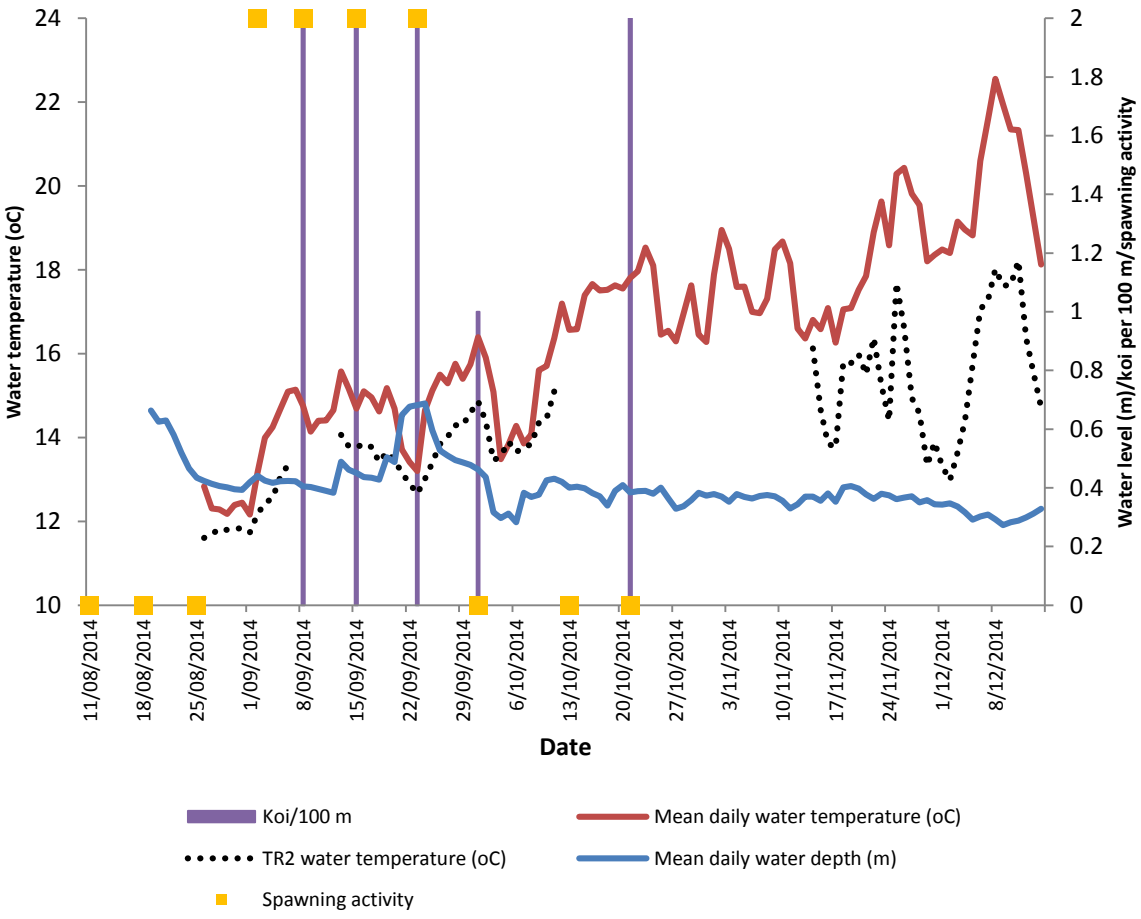

Figure 5: Plot showing the mean daily water temperature (°C), mean daily water depth (m), and koi carp per 100 m at W3. The corresponding spawning behaviour (2 = spawning, 0 = no spawning) at site P1 and water temperature (°C) at TR2 are included.

W4 and S3

Koi were observed in W4 and S3 on one occasion, however, no koi were observed spawning (Figure 6). Water temperature and depth fluctuated throughout the monitoring period, resulting in no apparent relationship with spawning behaviour. On the two occasions that koi were observed exhibiting spawning behaviour in Lake Hakanoa, the water temperature was between 17°C and 20°C. Water depth (m) was 0.17 m the week prior to spawning behaviour being observed, and depth fluctuated throughout the spawning period, reaching 0.3 m on two occasions.

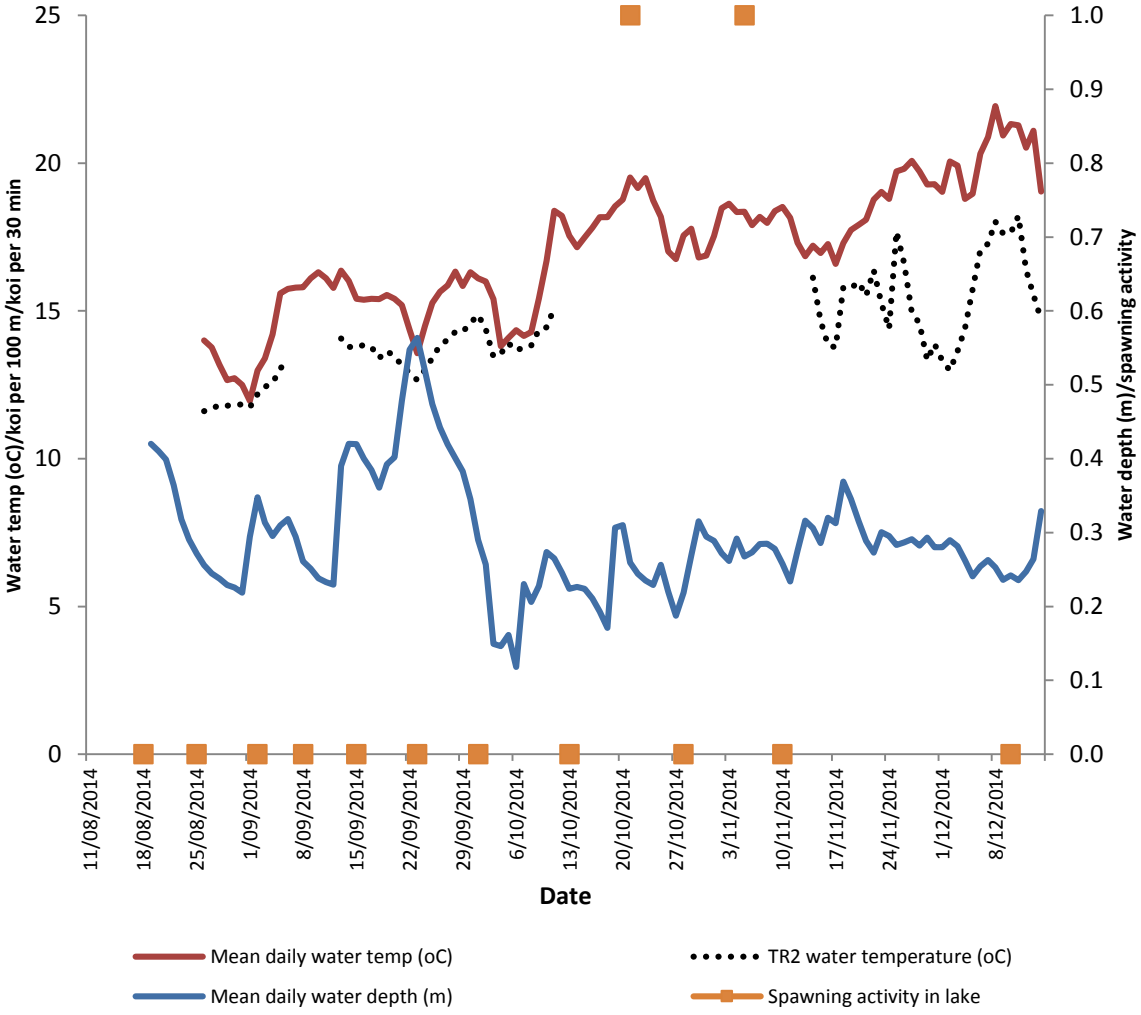

Figure 6: Plot showing the number of carp per 100 m at W4 and the number of carp per 30 minutes at S3. The mean daily water temperature (°C) and water depth (m) from the nearest water level logger are shown, as well as whether there was spawning behaviour observed in the upstream Lake Hakanoa (1 = spawning, 0 = no spawning). The water temperature at TR2 is included as a reference measure.

S1 and TR1

Koi were observed spawning in the channel between S1 and TR1, and in the lake margins near TR1 on three occasions (Figure 7). On the first spawning occasion, water temperature was just below 14°C and followed a brief period where water temperature exceeded 15°C. Koi eggs were found in high numbers on upturned macrophytes near TR1, suggesting koi had been spawning for a few days prior to this visit. The water temperature for the remaining two spawning occasions was approximately 15°C where the S1 logger was located. The water temperature at TR1 was similar to S1 when koi were seen exhibiting spawning behaviour on the second occasion, however, TR1 water temperature was 2°C warmer than S1 on the third spawning occasion. There appeared to be no relationship between water depth at S1 and spawning behaviour.

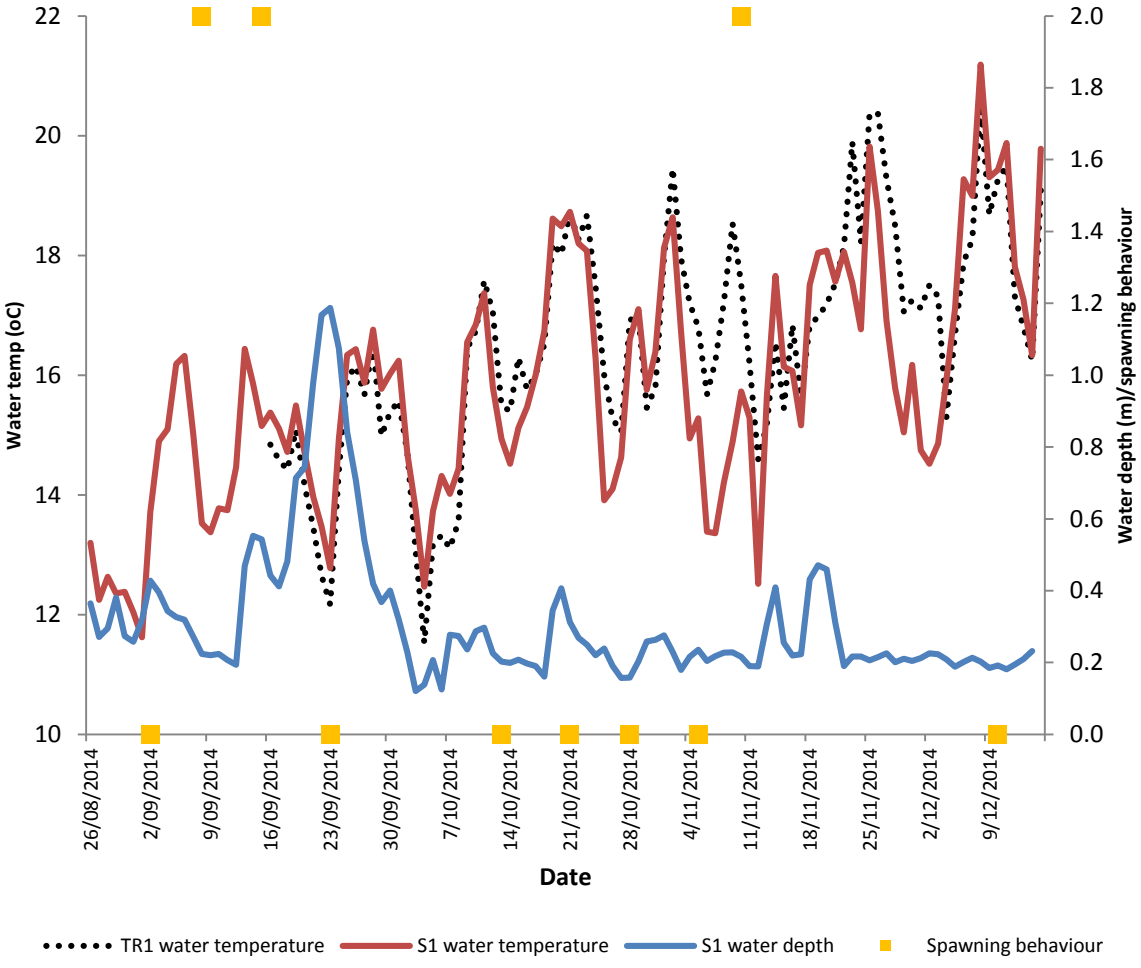

Figure 7: Plot showing the water temperature and water depth at site S1 as measured by the water level logger. The water mean daily water temperature at the reference site TR1 is included, along with the presence of koi carp spawning behaviour (2 = spawning, 0 = no spawning).

S2

Koi were observed at site S2 on 12 occasions, but spawning behaviour was only observed once (Figure 8). Koi carp were observed to congregate in groups upstream of the rock weir in shallow, vegetated margins. The water temperature had been stable at 15°C for approximately three weeks before spawning was observed. Water temperature declined to 13.5°C on 4 October before rising to 18°C; subsequently, no further spawning behaviour was observed during the remainder of the monitoring period. Greatest numbers of koi carp were observed swimming up the rock weir immediately after periods of warming water temperature. The water temperature measured at TR2 was consistently lower than at S2, suggesting the koi are migrating from cooler to warmer waters.

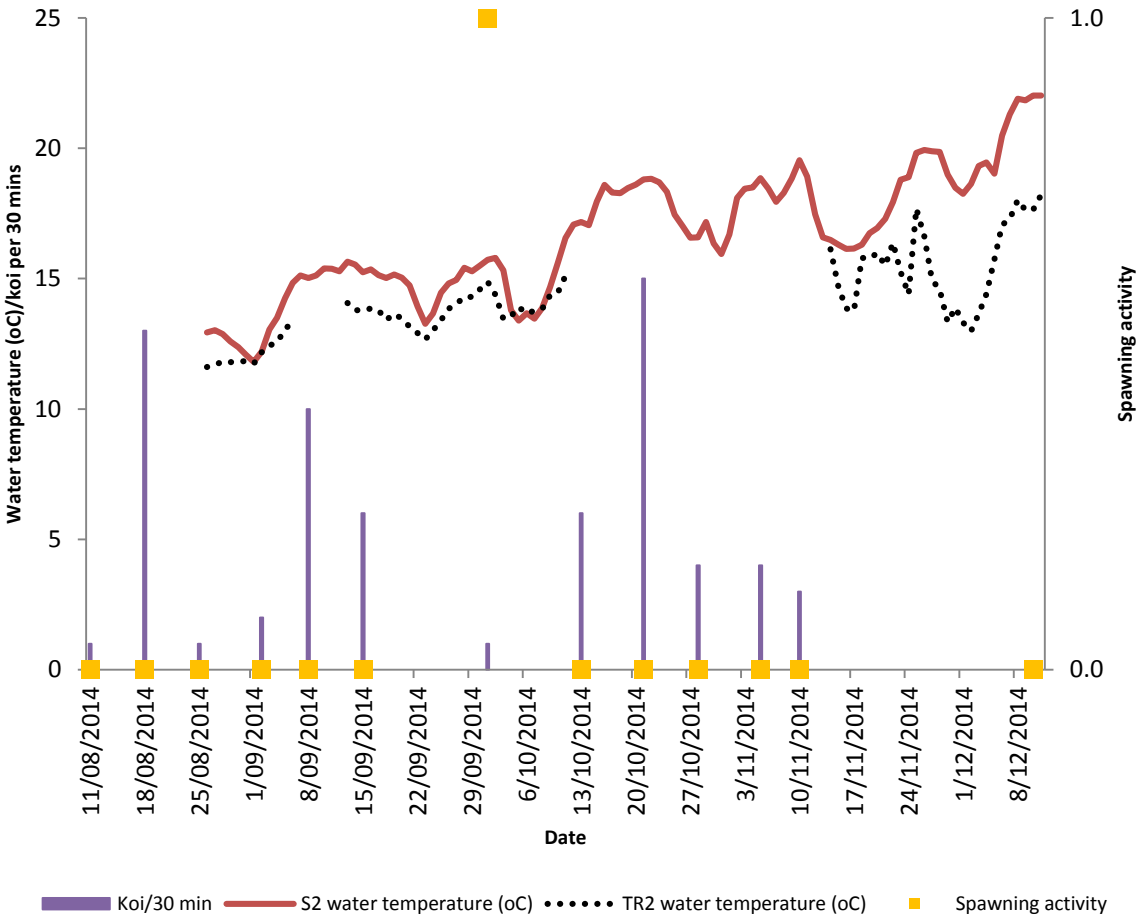

Figure 8: Plot showing water temperature at S2 as measured by the monitoring buoy in Lake Waahi. The water mean daily water temperature at the reference site TR2 is included, along with the presence of koi carp numbers per 30-minute count and spawning behaviour (1 = spawning, 0 = no spawning).

Conclusions and recommendations

In the present study of bottleneck and aggregation sites, spawning was usually observed when water temperatures had been stable at around 15°C, although in some instances temperatures prior to spawning varied up to 16°C. The 15°C temperature was similar to that observed by Stuart and Jones (2002) for koi spawning in Victoria, Australia, and lower than the 16.5°C noted by Tempero et al. (2006) for koi spawning in the Waikato River in 2003. No spawning behavior was observed when water temperature was within the 18 to 28°C range proposed by McCrimmon (1968). Tempero et al. (2006) concluded that, in accordance with the water temperature cues identified for koi carp spawning overseas (McCrimmon, 1968; Stuart and Jones, 2002), fish could feasibly spawn in northern New Zealand from September through to April, although subsequent observations have also indicated spawning can also occur in August (G. Tempero, unpubl. data); future studies would therefore benefit from ongoing monitoring throughout late winter and summer.

No linkages between water flow and spawning behavior were found from this study. However, this study was conducted during a spring following two years of summer droughts when water tables were significantly depleted. Similar work should be conducted over multiple spawning seasons to encompass annual variations in rainfall and flood events. Waikato Regional Council carp monitoring at Lake Waikare suggests koi carp migration activity is highest during the night. Therefore, it would be beneficial to incorporate spot-light monitoring as part of future research.

Use of koi carp counters and water level, temperature, and rainfall loggers would be beneficial in future studies to better understand the timing of mass koi carp migration events. This would also allow for location-specific environmental cues to be determined. Also, if the koi carp counter could be monitored remotely, it would allow an observer to visit sites in response to migration events and confirm the presence, or absence, of associated nearby spawning behaviour.

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APPENDICES

Appendix 1: Summary data from W5 and W6, including the monitoring date, spot water temperature (°C), total koi carp observed on monitoring date. The total koi carp observed is also standardised to koi/100 m.

Site code	Method	Date	Water temperature (°C)	Total koi	Koi/100 m	Spawning activity
W5	Channel walk	11/08/2014	11.1	0	0.00	No
W5	Channel walk	18/08/2014	12.1	0	0.00	No
W5	Channel walk	25/08/2014	12	1	0.99	No
W5	Channel walk	2/09/2014	13.9	2	1.98	No
W5	Channel walk	8/09/2014	15.4	4	3.96	Yes
W5	Channel walk	15/09/2014	15.3	0	0.00	No
W5	Channel walk	23/09/2014	12.8	0	0.00	No
W5	Channel walk	1/10/2014	16.9	0	0.00	No
W5	Channel walk	13/10/2014	16.4	33	32.67	Yes
W5	Channel walk	21/10/2014	18	4	3.96	No
W5	Channel walk	28/10/2014	16	0	0.00	No
W5	Channel walk	5/11/2014	16.8	9	8.91	Yes
W5	Channel walk	10/11/2014	19.6	3	2.97	No
W5	Channel walk	24/11/2014	18	4	3.96	No
W5	Channel walk	10/12/2014	19.9	0	0.00	No
W6	Channel walk	11/08/2014	11.2	0	0.00	No
W6	Channel walk	18/08/2014	11.8	0	0.00	No
W6	Channel walk	25/08/2014	12	1	1.27	No
W6	Channel walk	2/09/2014	13.9	0	0.00	No
W6	Channel walk	8/09/2014	15.3	0	0.00	No
W6	Channel walk	15/09/2014	15.4	1	1.27	No
W6	Channel walk	23/09/2014	12.9	0	0.00	No
W6	Channel walk	1/10/2014	17.5	0	0.00	No
W6	Channel walk	13/10/2014	17.2	14	17.72	Yes
W6	Channel walk	21/10/2014	17.8	0	0.00	No
W6	Channel walk	28/10/2014	15.5	0	0.00	No
W6	Channel walk	5/11/2014	16.8	1	1.27	Yes
W6	Channel walk	10/11/2014	17.5	0	0.00	No
W6	Channel walk	24/11/2014	17.3	0	0.00	No
W6	Channel walk	10/12/2014	20	2	2.53	No

Appendix 2: Plot showing the mean daily water temperature (ºC) measured form 15-minute logging intervals, the spot water temperature (ºC) during observations, and the number of koi per 100 m at site W2.