Smelt monitoring in the Ohau Channel and Lake Rotoiti (2017/2018)

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Executive summary

In 2008, a diversion wall was installed in Lake Rotoiti to channel the nutrient-laden water flowing out of Lake Rotorua around the edge of Lake Rotoiti and down the Kaituna River. This flow diversion was designed to reduce the nutrients entering Lake Rotoiti from Lake Rotorua thereby assisting in the restoration of water quality. Concerns were raised that this diversion wall could adversely affect the migrations of smelt and trout up the Ohau Channel, which connects Lake Rotoiti to Lake Rotorua. Hence, monitoring was carried out before and after the diversion wall was constructed to identify any significant adverse impacts of the wall on these fish. In this report, we present the results of the smelt monitoring for the 2017/2018 season, the tenth year since the diversion wall was constructed.

Overall, the results for 2017/2018 complement and add to those obtained in previous years and indicate that:

(a) The diversion wall does not prevent the movement of either adult or juvenile smelt into and up the Ohau Channel because migrations of both have continued after the wall was constructed. Common bully migrations also appear unaffected.

(b) Adult smelt migrate up the Ohau Channel in all months from September to June, but runs occur most frequently in spring (September to November). In contrast, juvenile smelt predominantly migrate up the Channel during summer and early autumn (December to April). This seasonal pattern of migration of adults and juveniles has occurred every year over the past decade.

(c) Before installation of the wall, the maximum size of a run detected by trapping was 34 smelt/minute (February 2006). This was exceeded in October 2013 (38 smelt/minute), March 2017 (48 smelt/minute). In the most recent sampling season the largest smelt run was 29 smelt/minute (February 2018), which is comparable to those observed before the construction of the diversion wall). Hence, there is no long-term trend in the monitoring data indicating a decline in the size of smelt runs.

Given the daily variation in runs detected by both trapping and observation over the past decade, it is apparent that runs do not occur every day, and that the daily occurrence of runs is sporadic with high temporal variability. Given such variability, detection of a change in the frequency of smelt runs up the Channel before and after the diversion wall would require near daily monitoring over five years both before and after the installation of the wall. This was not feasible, hence other approaches are required to detect changes in the daily frequency of smelt runs up the Ohau Channel.

Migratory species such as the common smelt have both physiological and environmental controls (e.g., endocrinological processes, water temperature, changes in flow) over the timing of their migrations. From a management perspective, the identification of the environmental cues can help to assess or predict how natural or anthropogenic changes (e.g., the diversion wall or climate change) may influence the size, timing and frequency of migrations. It would also allow for the estimation of population dynamics before the diversion wall was constructed, thus providing stronger historical (baseline) data to compare against. All data collected over the last 12 years was analysed to investigate any trends between changes in flow (mean daily flow, seven-day mean flow, 24-hour change in flow), water clarity and water temperature during sampling in the channel and the size of the smelt runs. Regressions indicated that the size of smelt migrations tended to increase with increasing mean daily flow and seven-day mean flow, while juvenile run size tended to decrease slightly with increasing temperatures, beyond 14°C. These findings infer a link between flow and temperature and the size of smelt runs, but more detailed research is needed to better understand the mechanisms involved. The ecological driver for the migrations (e.g., spawning, foraging) also remains unknown and presents an important area for future research. This information will provide a greater understanding of the size, timing and frequency of smelt runs allowing for more effective management of smelt populations in Lake Rotorua and Lake Rotoiti for the associated trout fishery.

1 Introduction

During the summers of 2003, 2004 and 2005, Lake Rotoiti was closed to contact recreation because of potentially toxic algal blooms caused by cyanophycean or blue-green algal cells. During summer, these blooms developed in the epilimnion of the lake and spread throughout its surface waters until the end of autumn. The blooms are believed to be related to the accumulation of nutrients (nitrogen and phosphorus) in Lake Rotoiti over the past century (i.e., eutrophication of the lake) and by seeding of cyanophycean species entering Lake Rotoiti from Lake Rotorua.

The relatively large concentrations of both nutrients and algae entering Lake Rotoiti from Lake Rotorua via the Ohau Channel were thought to be responsible for much of the deterioration in the water quality of Rotoiti. Hence, a diversion wall was installed at the outlet of the Ohau Channel to divert the nutrient-enriched water entering Lake Rotoiti down the Kaituna River (the lake's outlet). From July 2008, after the diversion wall was completed, this water was channelled along the lake edge such that it flowed down the Kaituna River. Over time, this diversion was expected to reduce the nutrient loading in Lake Rotoiti and hence its trophic status. It would also reduce the summer influx of phytoplanktonic cyanophycean from Rotorua that seeded and likely contributed to the toxic algal blooms in Lake Rotoiti.

An improvement in water quality in Lake Rotoiti was required primarily to reduce the frequency of toxic algal blooms, but it was also required to prevent deterioration in this lake's world-class rainbow trout fishery. A number of studies on the trout populations in the lakes of the central North Island plateau of New Zealand have established that trout growth rate and condition are generally lower in the eutrophic lakes compared with oligotrophic lakes (Fish 1964; Fish et al. 1968; Rowe 1984; Blair 2012). Furthermore, the decline in trout condition correlates closely with a reduction in trout predation on smelt, and this fits with observations of reduced smelt abundance in eutrophic lakes (Rowe 1984; Rowe & Taumoepeau 2004). Hence, the future status of trout in Lake Rotoiti was at risk because of the deterioration in the lake's water quality. Because of this risk, the Eastern Region Fish and Game Council supported measures proposed to reduce the decline in this lake's water quality. However, the Council was also concerned that the diversion wall may affect the migrations of smelt up the Ohau Channel from Lake Rotoiti and thereby affect the trout fishery in the Channel. Changes in the population dynamics of smelt in Lake Rotoiti, as a consequence of the diversion wall, were also a concern as this could reduce smelt abundance in the lake and hence trout growth rates. In addition, local iwi were concerned that the fishery for smelt in the Ohau Channel would be adversely affected.

Studies were therefore initiated by the Bay of Plenty Regional Council between 2005 and 2008 to provide more information on smelt migrations up the Channel prior to the installation of the wall. These studies were also designed to provide a pre-wall baseline for assessing any future impacts of the diversion wall on smelt runs up the Channel (Rowe et al. 2006, 2008). These initial studies were subsequently continued on an annual basis after the diversion wall was completed in July 2008 to provide further information on the smelt migrations up the Ohau Channel and to establish any effects of the wall on smelt in both the Channel and in Lake Rotoiti. The results of these studies are reported in Rowe et al. (2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016) and Shelley et al. (2017).

Results from the annual trapping of smelt runs in the Ohau Channel between 2006 and 2017 showed that runs of both juvenile and adult smelt occurred in most years after the wall was constructed. It was, therefore, concluded that the wall had not prevented the movement of either adult or juvenile smelt up the Ohau Channel (Rowe et al. 2015; Shelley et al. 2017).

This aside, concerns were expressed (by anglers) that the maximum size of smelt runs up the Ohau Channel was no longer as high as it was prior to the construction of the wall and that the annual frequency of runs had declined. Smelt runs recorded in October 2013 and March 2017 were higher than the highest run recorded prior to 2008, hence this supports the notion that there hasn't been a decline in the maximum number of smelt recorded running up the Channel since the diversion wall was installed.

The monitoring carried out to date has established that there is considerable variation in the daily duration and timing of smelt runs and hence in their frequency. This variation prevented the monitoring programme from establishing whether the frequency of smelt runs per season has exhibited temporal changes. Data indicates that near-daily monitoring would have been required over the four years prior to installation of the diversion wall to provide an adequate baseline for assessing temporal changes, which was not feasible. Other approaches to resolving this issue are possible (e.g., modelling) but this would require knowledge of the environmental factors controlling the onset of smelt runs up the Channel. In turn, this would require research to identify such factors and determine the feasibility of modelling.

In addition to smelt monitoring in the Ohau Channel, the abundance of larval smelt in Lake Rotoiti was monitored biannually to determine whether the smelt population in Lake Rotoiti changed greatly after the diversion wall was installed. The rationale for this monitoring was that a large decline in larval smelt in Lake Rotoiti over a period of three or more years would indicate a lake-wide decline in recruitment due to a reduction in the adult smelt population. In turn, the decline in adult smelt in the lake would be expected to reduce the growth of trout (as smelt are their main prey) as well as the size of smelt runs up the Ohau Channel. Conversely, an increase in larval smelt in Lake Rotoiti would indicate that water quality was improving because larval smelt abundance has been shown to be closely related to water clarity in the Rotorua lakes (Rowe & Taumoepeau 2004). Thus, monitoring of larval smelt in Lake Rotoiti has continued annually since completion of the diversion wall in 2008.

Smelt monitoring in the Ohau Channel and Lake Rotoiti is part of a broader programme of annual fish monitoring carried out under the auspices of the Bay of Plenty Regional Council who hold the resource consent for the diversion wall. In addition to the smelt monitoring, trout fishery monitoring in Lake Rotoiti and in the Ohau Channel is carried out annually by the Eastern Fish and Game Council. The University of Waikato undertakes an annual boat-based, electric-fishing survey of fish in the Ohau Channel, and Dr Ian Kusabs carries out monitoring of koura and kakahi in Lake Rotoiti.

A Technical Advisory Group (TAG) of independent experts was established in 2008 to consider and evaluate the results of this annual fish monitoring and to advise the Bay of Plenty Regional Council on any changes required, including actions considered necessary to address any decline in fish detected by the monitoring. In considering all the results available up to November 2015, the TAG recommended that the Bay of Plenty Regional Council continue smelt monitoring in the Ohau Channel and Lake Rotoiti until 2017 as the resource consent was being renewed at that time. At that point, the TAG decided to continue the full monitoring of smelt due to the value of the long-term dataset in assessing temporal changes in the fishery.

In this report, we present the results of smelt monitoring carried out in the Ohau Channel from September 2017 to June 2018 as well as the measurements of larval smelt density in Lake Rotoiti carried out in December 2017 and April 2018 (covering the smelt spawning season). These data are interpreted with respect to the baseline data obtained before the wall was constructed and the monitoring results obtained annually since then.

2 Methods

2.1 Monitoring of smelt runs and environmental conditions in the Ohau Channel

The locations of the sites used to monitor smelt movements in the Ohau Channel are shown in Figure 2-1. Only trap sites 1 and 2 were used after 2012 as the contribution of Sites 3 and 4 was generally minor (Rowe et al. 2011). Trap sites 1 and 2 have been monitored since 2006 so provide a longer record for comparing temporal changes.

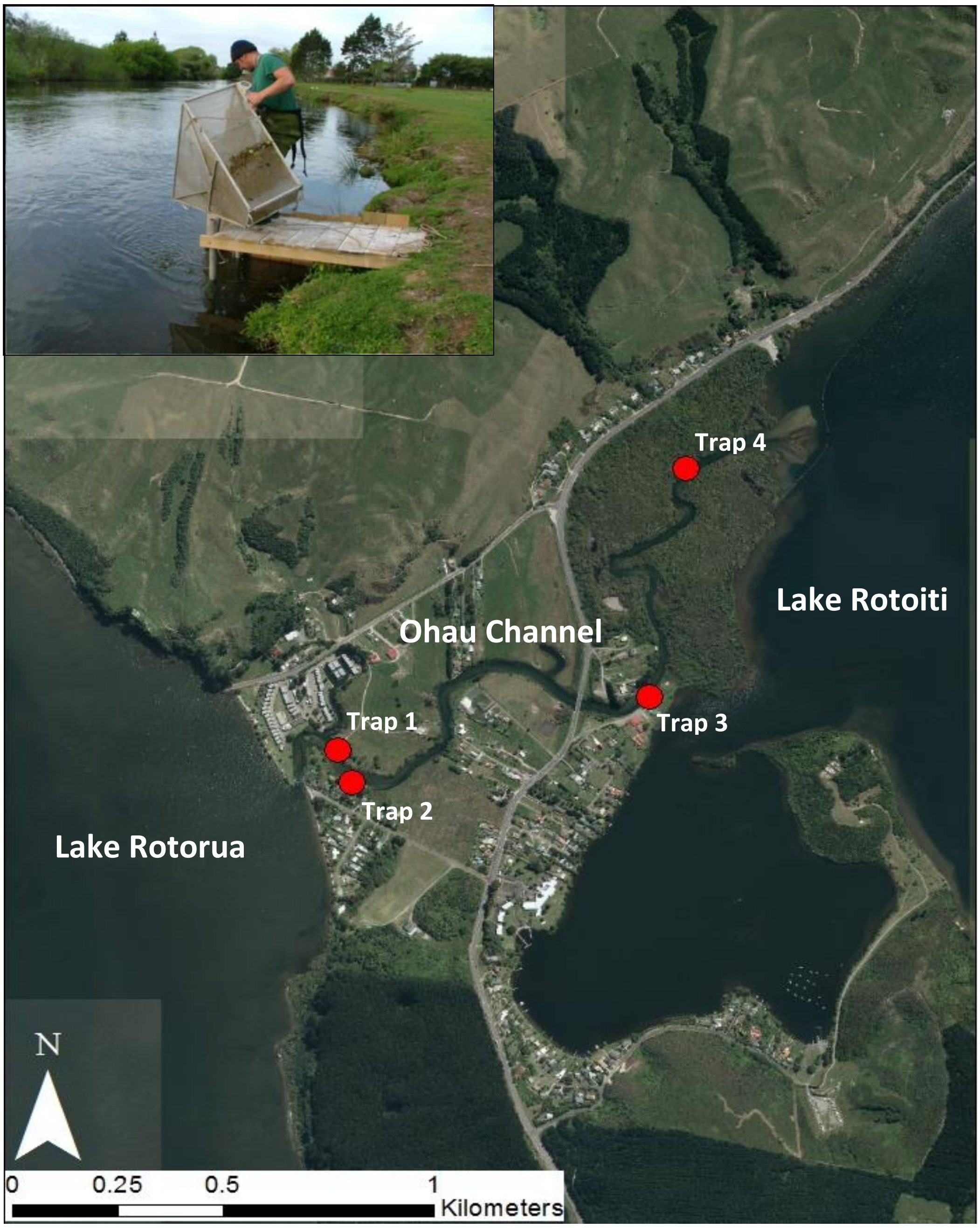

Figure 2-1: Location of sampling sites used for smelt trapping in the Ohau Channel. Only sites 1 and 2 have been utilised since 2012. Inset shows a smelt trap and the platform below which it is set.

Trapping was carried out at approximately 4 weekly intervals during the ten-month period from September 2017 to June 2018. Traps were placed close to the bank at each site, facing downstream in order to capture upstream migrant smelt. The traps were triangular with a 1 m wide by 0.5 m deep opening tapering to a 20 cm wide capture compartment (Figure 2-1 inset). Mesh size was 2 mm. Traps were usually set close to daybreak and the catch removed every 3-4 hours until late evening. The total number of smelt caught per trap per day and the total time for which the trap was fished per day were recorded. Depending on the number of fish present all, or a subsample, were used to determine the proportions of juveniles and adults in the catch. Both the length (under or over 45 mm total length) and coloration of smelt were used to distinguish juveniles from adults. The daily catch per unit of effort (CPUE) for smelt on each sampling date was calculated as the total daily catch for the two traps divided by the total trapping time in minutes.

Runs of smelt were defined through both long-term direct observation and the trapping data as either the movement of two schools of 50-60 smelt, or one school of 100-120 smelt per hour past a given point on the bank of the Ohau Channel, or a trap-based catch rate of over 2 smelt per minute (Rowe et al. 2012). On each sampling occasion, shag numbers (both on the banks and in trees lining the channel) were counted along the entire length of the Ohau Channel. Shags are predators of adult smelt and their abundance can provide an additional observational measure to detect the presence of prolonged high densities of adult (but not juvenile) smelt in the channel (Rowe et al. 2010, 2011). In addition to these data, water temperatures (Tidbit© data loggers), water clarity (black disc visibility), water velocities near the entrance to each trap, the flow of water through the Ohau Channel (data provided by Bay of Plenty Regional Council), and the by-catch of other fish species (i.e., common bullies, koaro, trout) were recorded.

2.2 Relationships between environmental variables and smelt run size

Smelt migrations up the Ohau Channel could potentially be influenced by environmental variables such as flow, water temperature and water clarity. Although Rowe et al. (2012) found no significant correlation between the occurrence of smelt runs and these variables, Shelley et al. (2017) found that the number of smelt in a run tended to increase with increasing mean daily flow, while the number of juveniles tended to decrease slightly with increasing temperatures beyond 14°C. Conversely, no significant correlation was observed between the size of smelt runs and water clarity. Here, we reinvestigate these relationships incorporating data from the 2017/18 sampling. Furthermore, we look at different aspects of the prevailing flow conditions leading up to and during sampling to see if they are better predictors of the number of smelt in the runs. Specifically, this included (1) the mean flow over the seven days prior to the completion of sampling on a given sampling day, and (2) the change in flow experienced over the 24-hour period prior to the completion of sampling on a given sampling day. For example, if sampling was conducted on 2018-01-20 and finished at 19:00:00, the seven-day period for that sampling event would be 2018-01-13 (19:00:00) to 2018-01-20 (19:00:00) and the 24-hour period would be 2018-01-19 (19:00:00) to 2018-01-20 (19:00:00). We selected these variables to investigate whether flow conditions over a more prolonged period than mean daily flow are stronger predictors of smelt run size, and whether the degree and direction of change in flow immediately preceding and during the run influences run size. To investigate any influence of our measured habitat variables on run size, Local (Loess) regressions of the mean daily flow, diurnal water temperature and water clarity against the catch rate (fish/minute) on sampling days were utilised. Although smelt migrate through the channel throughout the year, there are clear peaks in the timing of these runs for both adults (April-December) and juveniles (December-April) (Rowe . 2016). Therefore, we focussed our analysis on these respective periods. Interpretation of Loess regressions focusses on the fitted curve and the confidence intervals. If at any given point, the curve and its confidence intervals deviate entirely from another point along the curve (representing either an increase or a decrease) it is considered that the observed pattern between those points is significant. The narrower the confidence intervals are, the more confidence there is in the regression model fit and any observed relationship. The interpretation of the relative strength of those relationships is based on professional opinion.

2.3 Larval smelt density in Lake Rotoiti

Larval smelt in Lake Rotoiti have been sampled annually since 2007 to determine whether annual changes in larval abundance (reflecting smelt recruitment) could account for any large changes in adult smelt abundance in the lake and hence moving up the Ohau Channel.

In the Rotorua lakes, smelt have an extended spawning period lasting from spring through to autumn, with the main peak in autumn (Jolly 1967, Rowe & Kusabs 2007, Blair 2012). After hatching, the transparent larvae become pelagic and remain in the water column at depths down to 50 m until they reach a length close to 25 mm (Blair 2012). At this stage, they become pigmented and move towards the lake surface where they form large schools in response to the increased risk of predation from trout and avian predators (Blair 2012). Larvae are present in the pelagic zone of the lakes predominantly in spring, summer and autumn (Blair 2012). Measurements of larval smelt abundance in Lake Rotoiti were carried out in both December (summer) and April (autumn) to capture the main spawning periods.

As per previous years, vertical drop netting using a closable Wisconsin plankton net (mouth area of 0.25 m^2, mesh size 250 µm) was used to sample larval smelt throughout the water column (surface to near the lake-bottom) of Lake Rotoiti in both December 2017 and April 2018. Sampling was carried out at 31 sites located throughout the lake. Larval fish sampled from the water column at each site were sorted into species (larval bullies vs. larval smelt), counted and their length measured to the nearest millimetre. Secchi disc depth was also measured because the overall number of smelt larvae in the Rotorua lakes has been found to co-vary with water clarity, which reflects lake trophic status (Rowe & Taumoepeau 2004). The lake-wide mean CPUE of larval smelt over both sampling events during the spawning season (December plus April data) was calculated for the 2017/18 summer season and plotted against secchi disc depth to indicate any change in smelt density, relative to overall changes in water clarity.

The data for the 2017/18 season were then compared to those from previous seasons to identify any marked change or long-term trends in (1) larval smelt density; and (2) the timing of spawning events (summer vs. autumn). Analysis of Variance (ANOVA) was used to assess differences between larval smelt density during summer recruitment (December sampling) and autumn recruitment (April sampling) during each sampling season.

3 Results

3.1 Comparison of environmental conditions to previous sampling seasons

Smelt monitoring in 2017/18 took place over a narrower range of flows than previous years (e.g., >35m^3 s^{-1} in May 2017) with fluctuations in line with seasonal variations in weather patterns (Figure 3-1). As expected, flows were generally the lowest between late Spring 2017 and early Autumn 2018, although an unseasonal high flow event occurred during February 2018. Overall, flow in the Ohau Channel on the monitoring days in 2017 and 2018 were typical of those recorded in previous years (Figure 3-2).

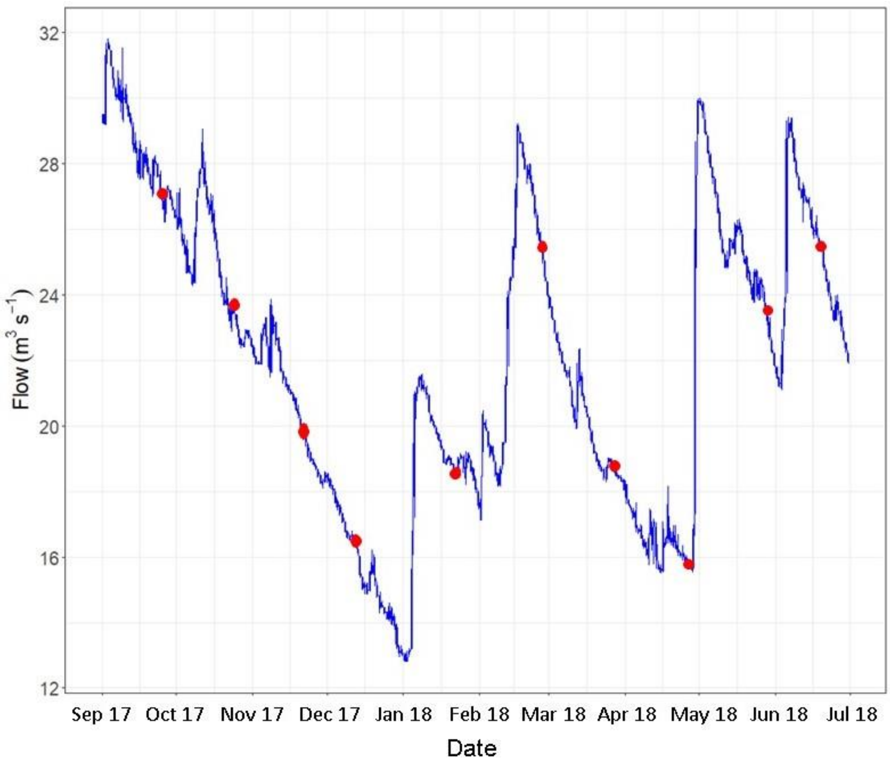

Figure 3-1: Hourly flow record in the Ohau Channel during the 2017/18 season and the days on which smelt monitoring was undertaken (red dots).

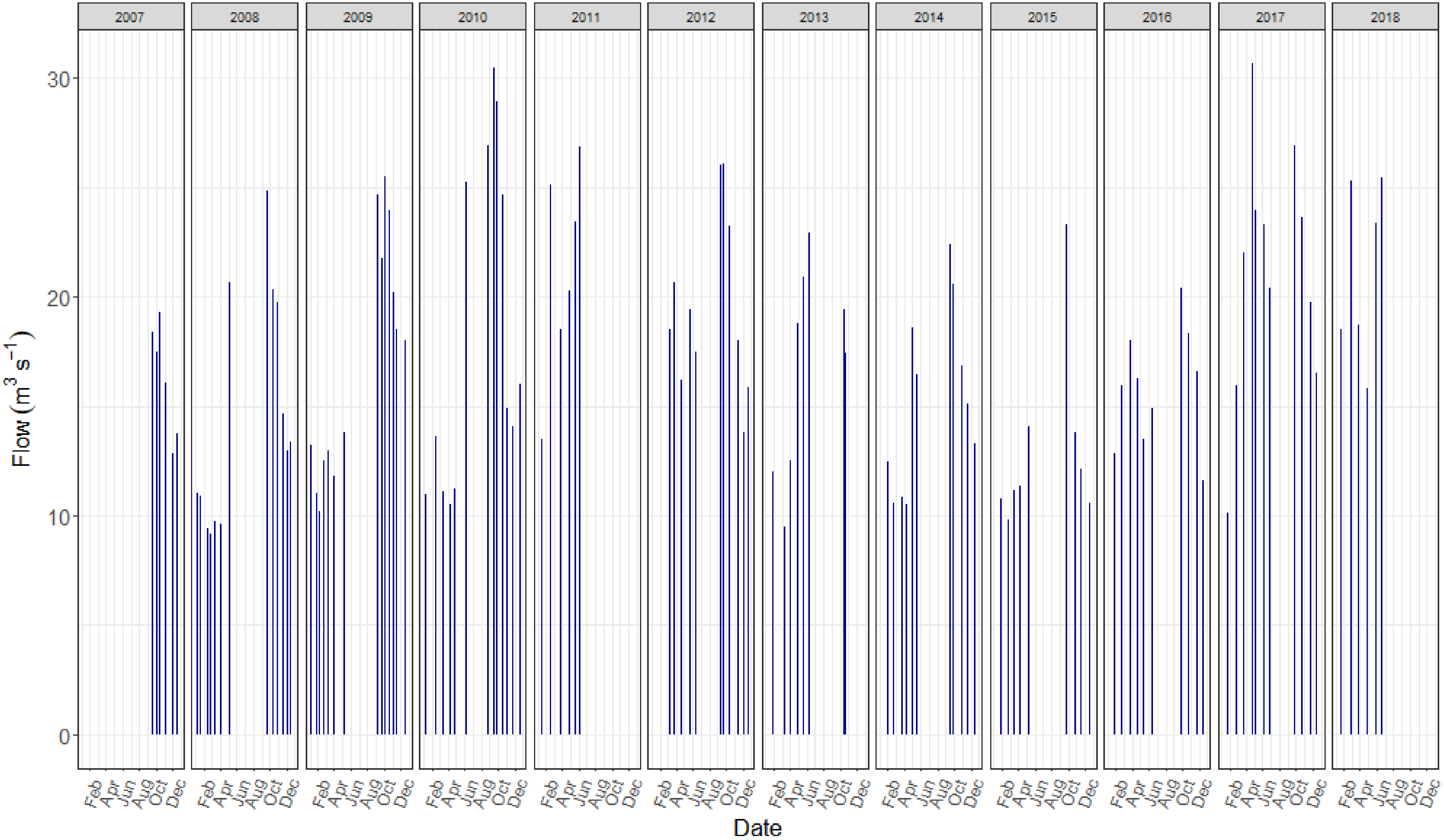

Figure 3-2: Flow in the Ohau Channel on the smelt monitoring days between 2007 and 2018.

Water clarity measurements taken in the Ohau Channel on the days when smelt were sampled during the September 2017 to June 2018 survey period were generally lower than those recorded between 2012 and 2014. However, they were comparable with all other years (Figure 3-3). These water clarity records are snapshots obtained at the time of sampling so do not reflect longer term trends in the clarity of lake water entering the Channel. Nevertheless, the greater water clarity noted between 2014 and 2018 is thought to reflect an improvement in water quality in Lake Rotorua after the construction of the diversion wall, considering an expected lag time between its construction and the biological response.

Water temperatures in the Ohau Channel during the 2017/18 season were similar to the preceding seasons. The last four seasons are presented for comparison (Figure 3-4).

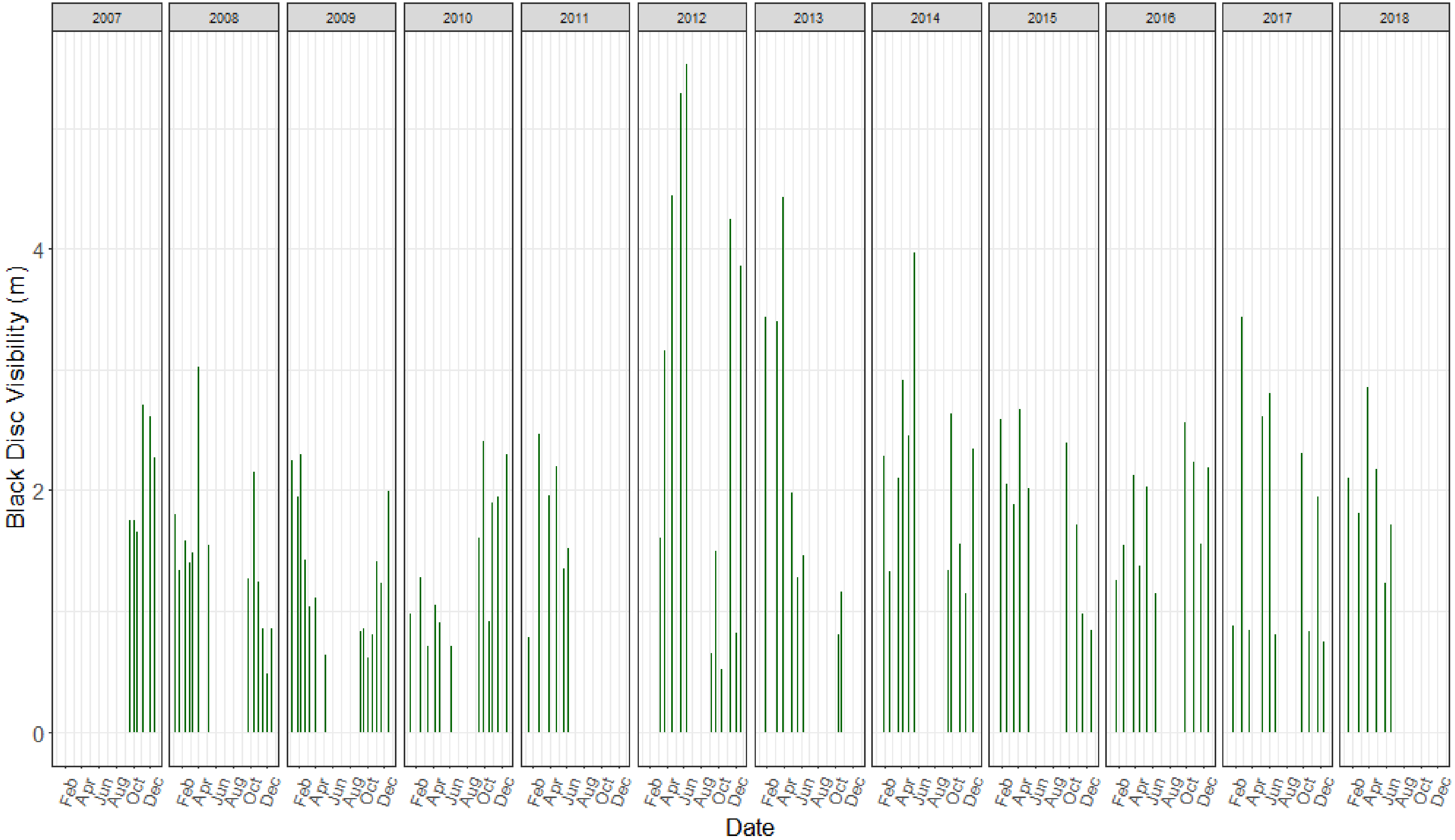

Figure 3-3: Water clarity (as measured by secchi disc depth) on the smelt monitoring days between 2007 and 2018.

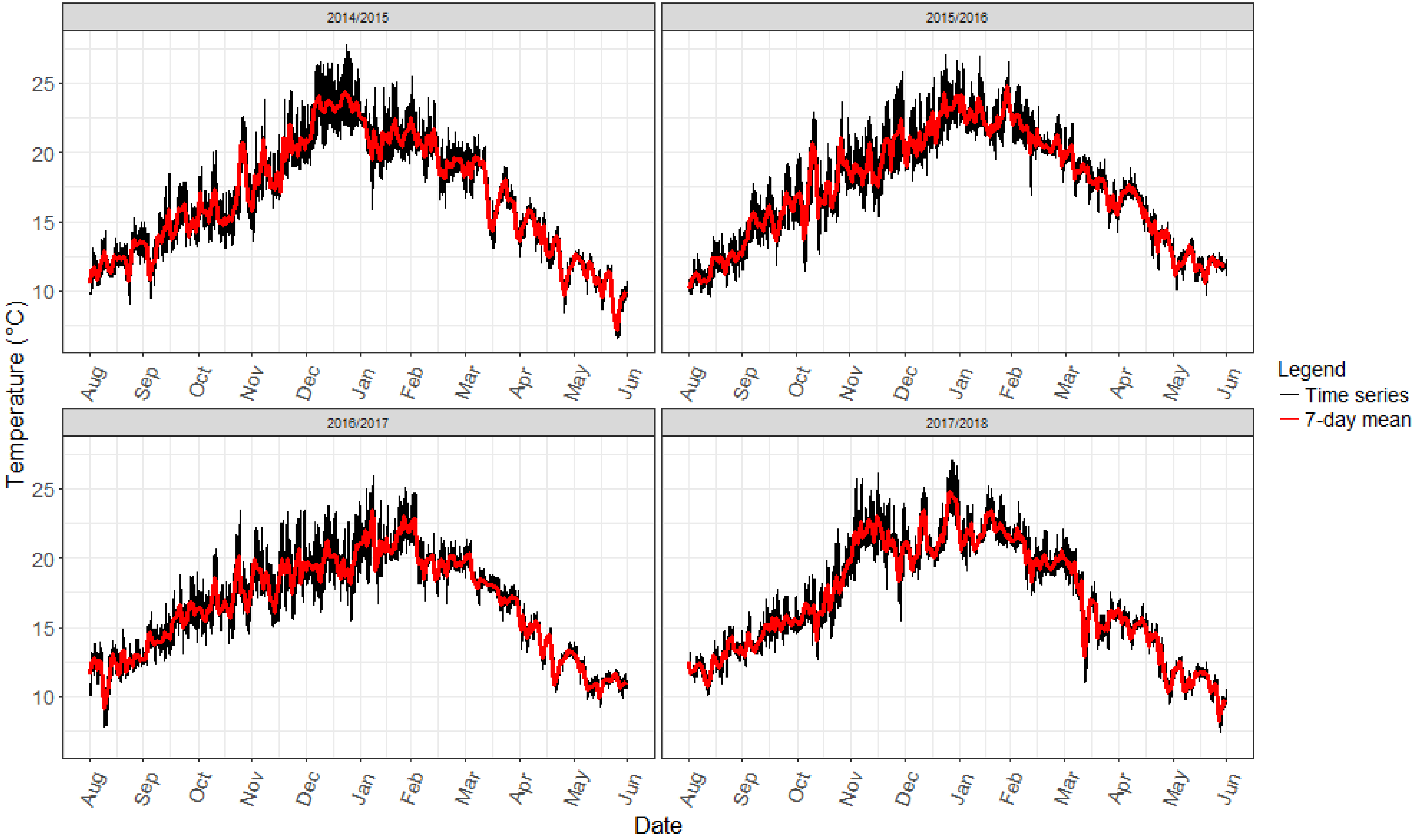

Figure 3-4: Water temperatures in the Ohau Channel across the sampling periods between 2014 to 2018.

3.2 Relationships between environmental variables and smelt run size

For both adult and juvenile smelt, there is an increasing trend in the number of fish migrating with increasing flow (at the time of sampling and mean flow over the last seven days), although juveniles were predominantly migrating at lower flows than adults (< 20 $m^3 s^{-1}$) (Figure 3-5). Overall (i.e., total catch) there was a steady and clear increasing trend in the number of smelt migrating with increasing flow. There was little difference between the relationship between the number of fish migrating and flow at the time of sampling or the mean flow over the last seven days. Observations from the 2017/18 field season generally reinforced these trends that suggest flow has an influence on run size, however, duration of the flow event does not appear critical. Overall, the change in flow over the 24-hour period prior to the completion of each sampling even did not appear to influence the number of fish migrating through the channel. While there appears to be an increase in juvenile fish migrating when flows recede between 0.2–0.7 m^3s^{-1}, compared to when flows showed little change or were increasing, few observations were made during rising flows and so the observation may be biased.

The number of adult smelt captured showed a slight decreasing trend with decreasing water clarity, although the number of observations at water clarity greater than three meters are relatively few, limiting any assumptions (Figure 3-6). The number of juvenile smelt did not appear affected by water clarity and overall, no relationship between the number of smelt captured and water clarity was observed. Observations from the 2017/18 field season were generally in line with those from previous years.

The number of adult smelt migrating each monitoring day showed a slight decreasing trend with increasing diurnal water temperatures, above 14°C (Figure 3-6). Observations from the 2017/18 field season reinforced this decreasing trend. However, the number of juvenile smelt captured showed no correlation with diurnal water temperature and overall (total catch) no relationship was observed.

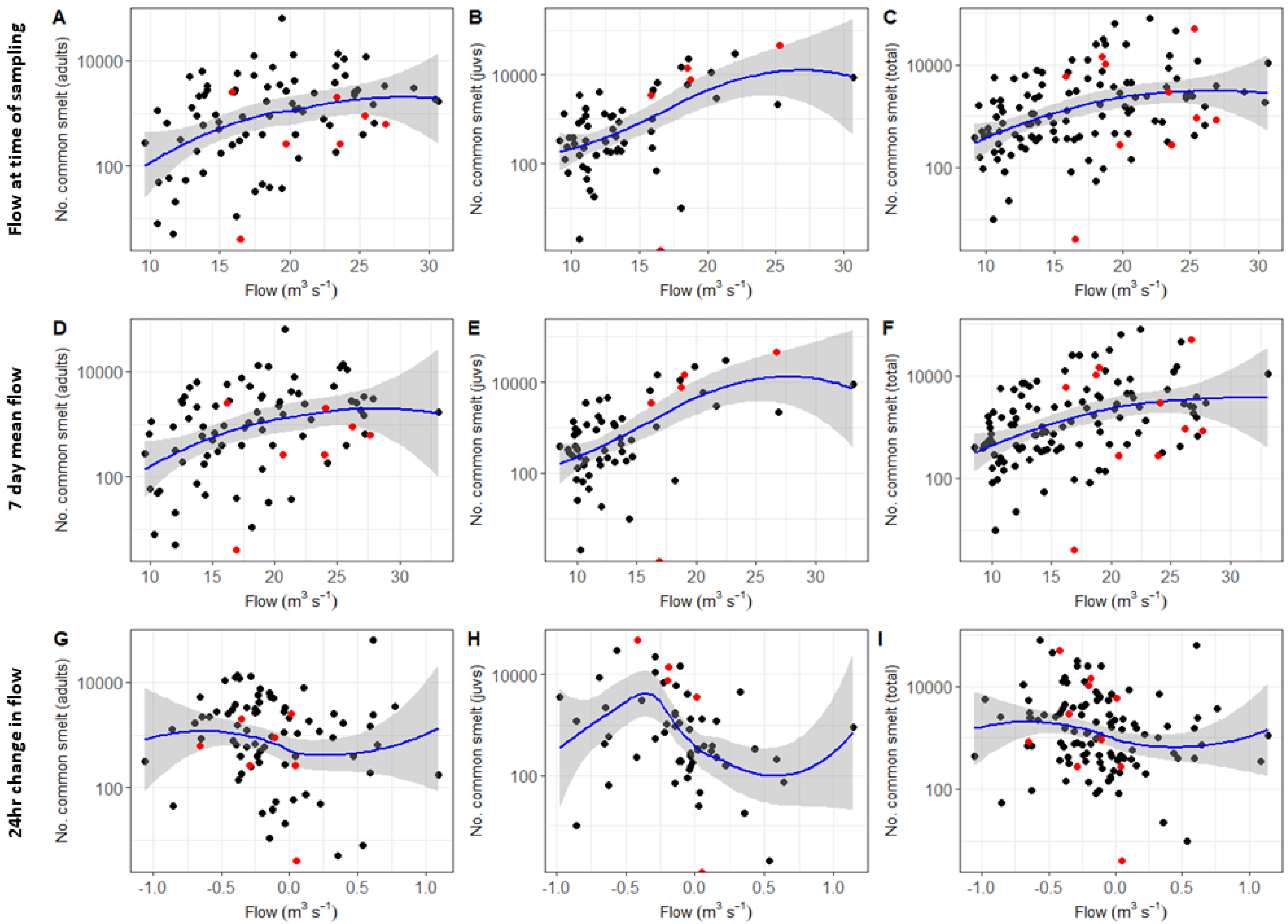

Figure 3-5: Local (Loess) Regressions of the number of common smelt adults, juveniles (juvs), and total catch as a function of flow at the time of sampling (A, B, C), 7-day mean flow leading up to each sampling event (D, E, F), and the 24 hour change in flow on the day of sampling (G, H, I). Data points collected during the 2017/18 sampling season are depicted as red dots. Confidence intervals are shaded grey. Adult data is from peak running season (April-December), juveniles (December-April). Total catch includes all sampling days.

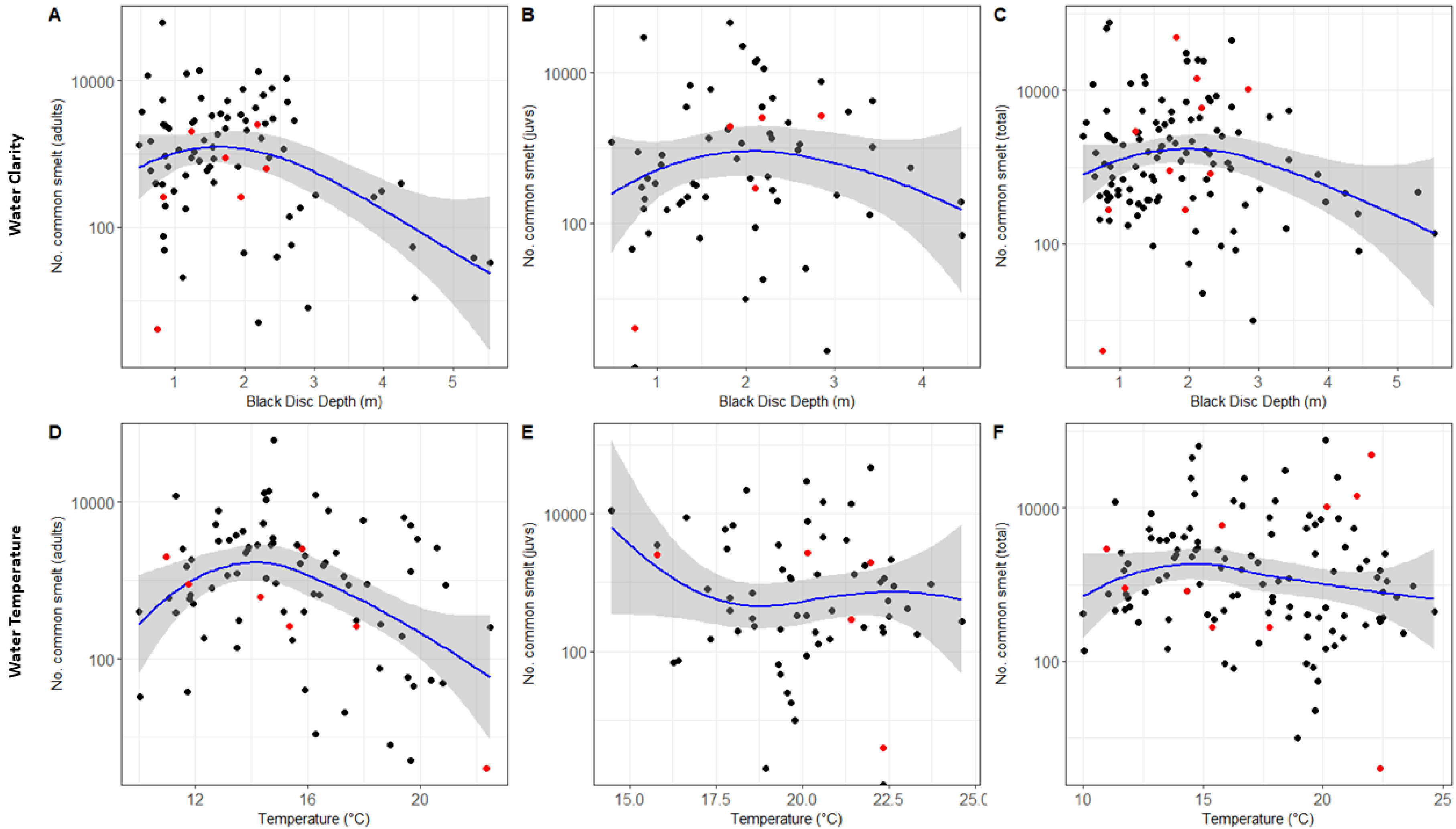

Figure 3-6: Local (Loess) Regressions of the number of common smelt adults, juveniles (juvs), and total catch as a function of water clarity (A, B, C) and diurnal water temperature (D, E, F). Data points collected during the 2017/18 sampling season are depicted as red dots. Confidence intervals are shaded grey. Adult data is from peak running season (April-December), juveniles (December-April). Total catch includes all sampling days.

While runs of adult smelt occur throughout the year, our findings over the last 12 years indicate that they predominantly run between mid-autumn (May) and late spring (November) (Figure 3-7). In comparison, juveniles largely migrate in the summer months (January, February, March). Essentially equal proportions of adults to juveniles run in April and December.

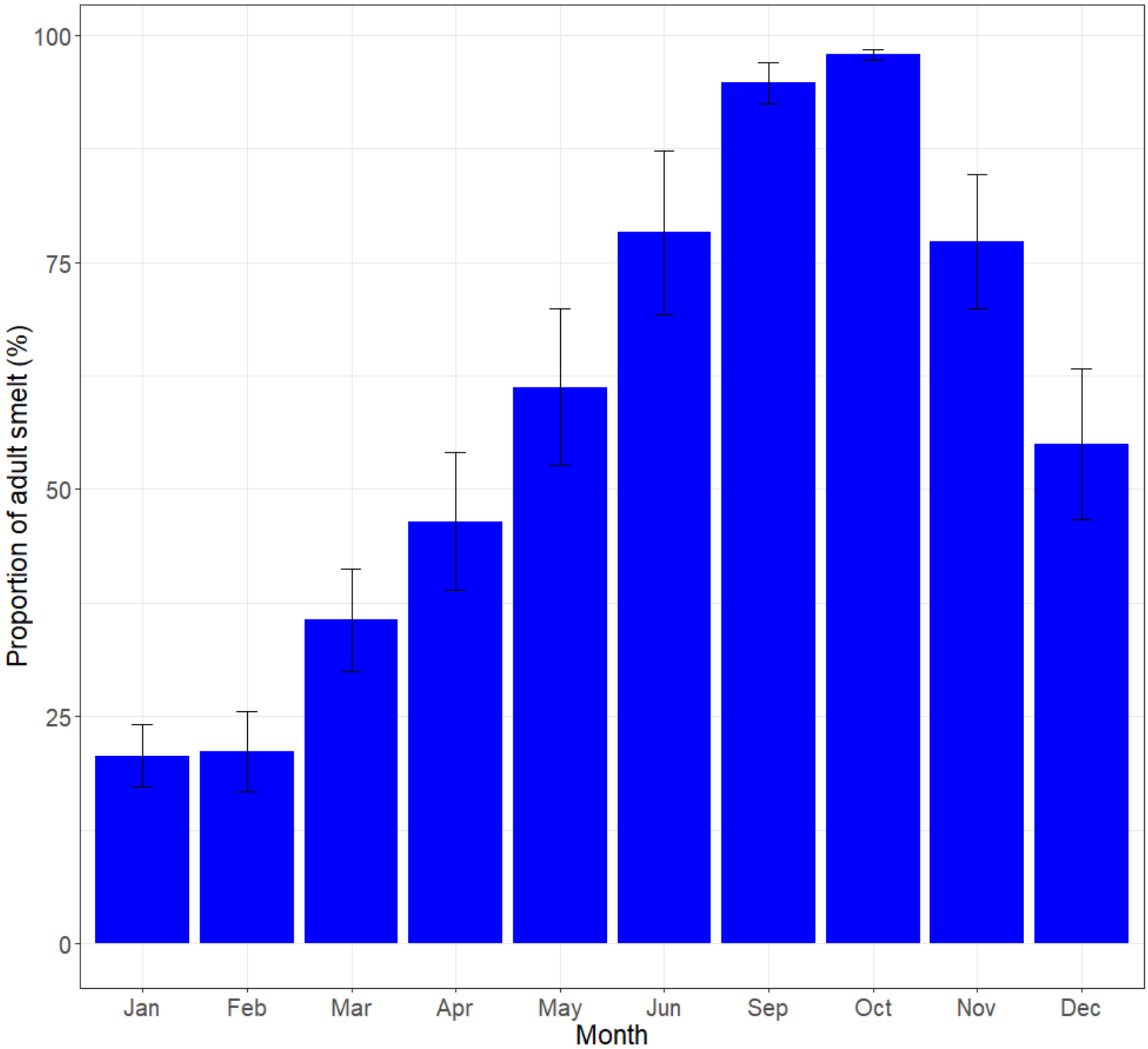

Figure 3-7: Mean percent composition of the smelt catch for each month over the period 2005-2018. Error bars represent ± standard error.

Six runs were observed during 2017/18 sampling; two adult dominated runs on the 24th October 2017 (2.7 smelt/min, 94% adults) and 28th May 2018 (2.2 smelt/min, 70% adults), three juvenile dominated runs on the 22nd January 2018 (8.6 smelt/min, 98% juveniles), 26th February 2018 (28.7 smelt/min, 96% juveniles) and 27th March 2018 (6.6 smelt/min, 74% juveniles), and one run on the 26th April 2018 that was made up of relatively equal proportions of juveniles and adults (4.4 smelt/min, 58% juveniles, 42% adults) (Figure 3-8). The smelt runs were within the range of variability observed in previous years.

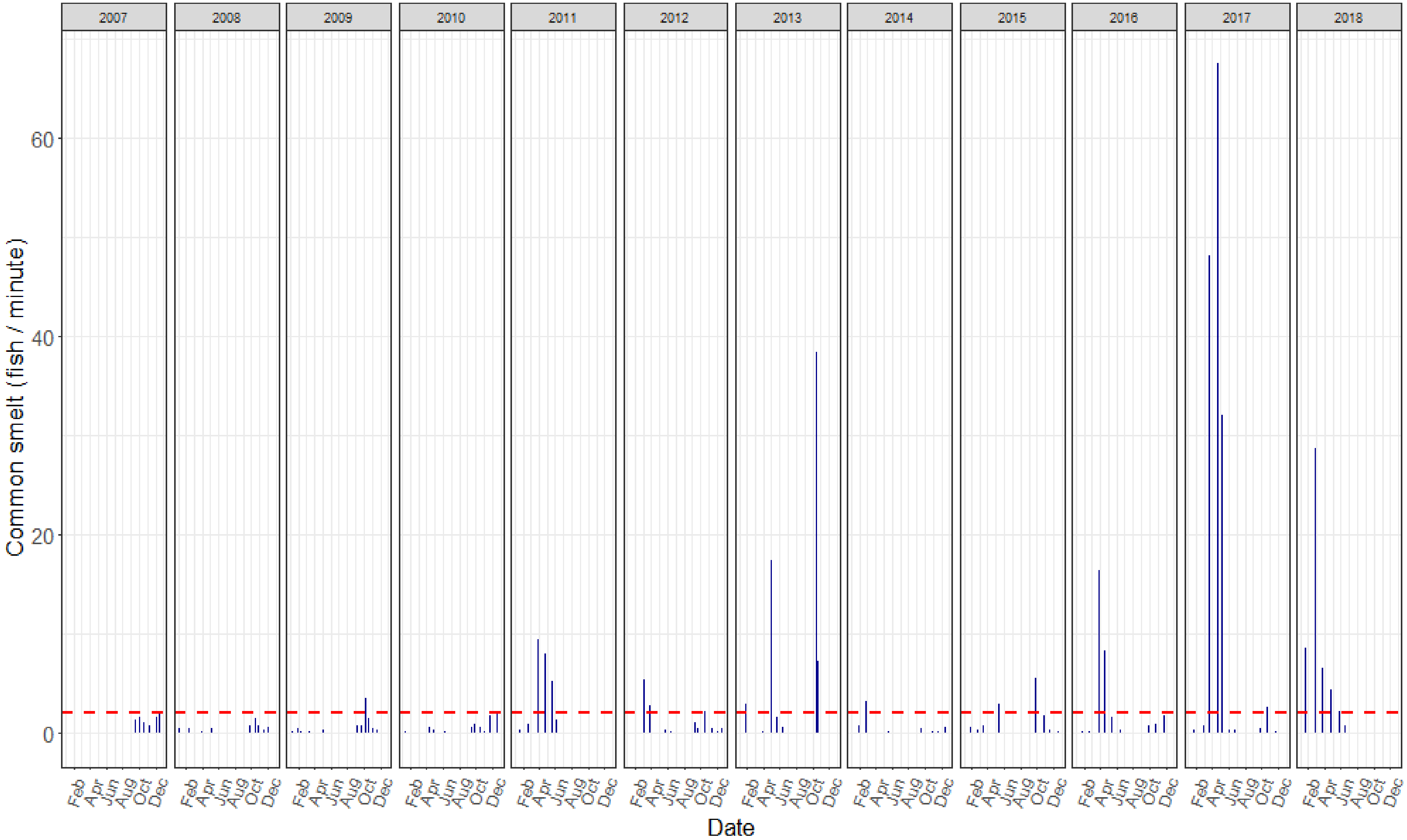

Figure 3-8: Smelt catch rates recorded in the Ohau Channel between 2007 and 2018 showing days when runs of smelt were recorded. The diversion wall was completed in July 2008. The CPUE threshold of 2 smelt/minute defines a run of smelt (red-dashed line).

Rowe et al. (2013) noted a gradual but statistically significant decline in the catch rates of common bullies over the seven-year period between 2007 and 2013. Because this decline occurred steadily each year after 2008 when the diversion wall was installed, it could reflect a decline in common bullies moving upstream in the Ohau Chanel. However, the mean catch rate for bullies has been greater than the 2012/13 sampling season in all subsequent sampling seasons. Furthermore, the catches in the last three sampling seasons were within the range recorded in 2007, prior to the installation of the diversion wall. Overall, the results suggest that the diversion wall has not caused any long-term decline in the upstream movement or abundance of common bullies in the Ohau Channel.

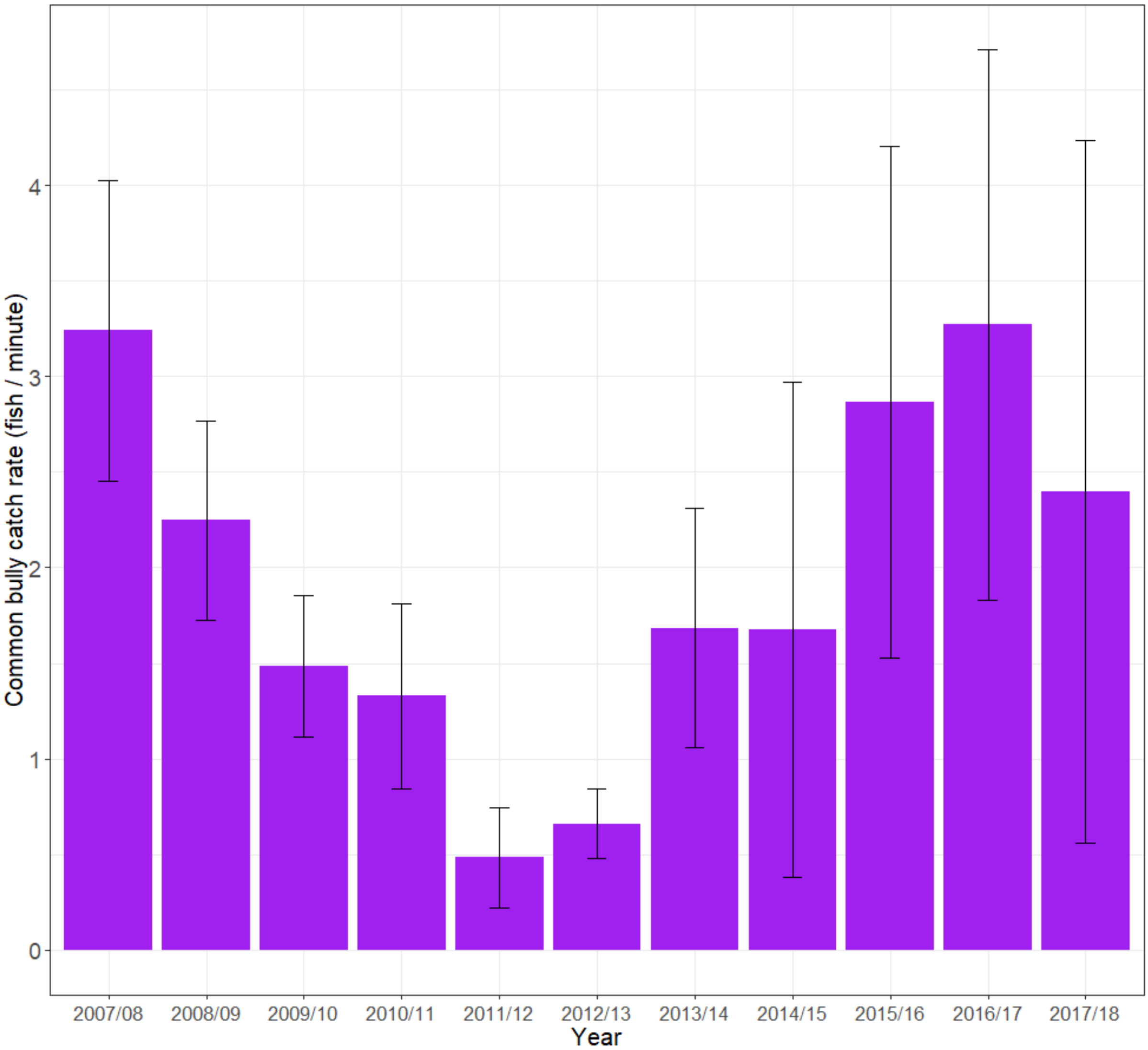

Figure 3-9: Catch rates for common bully in the Ohau Channel between 2007 and 2018. The diversion wall was completed in July 2008. Error bars represent ± standard error.

3.3 Larval smelt densities in Lake Rotoiti

The catch rate of larval smelt in Lake Rotoiti was 0.45 larvae/net in December 2017 and 0.93 in April 2018 (Table 3-1). For both months combined, the mean catch rate was 0.69 larvae/net. The density of larval smelt was significantly higher in April 2018 compared with December 2017. Larval smelt density is typically lower in April than in December (Table 3-1). The results suggest that spring spawning was not successful in 2017. The combined spring and summer catch rate for the 2017/18 season was relatively low (0.69 ± 0.12) and like that observed in the 2016/17 season (0.56 ± 1.06). The average larval density during these two seasons was like that recorded before the completion of the diversion wall and immediately after (0.79 and 0.71 in 2007/08 and 2008/09, respectively).

Table 3-1: Mean catch rates of smelt larvae in Lake Rotoiti in December and April of each summer since 2005/06. Shaded cells indicate when a statistically significant (ANOVA, P < 0.05) and higher mean density for December (spring spawning and recruitment) compared with April (summer spawning and recruitment).

Summer	Net hauls per survey	Mean catch rate (No. net^{-1} ± SE) per survey		
		December	April	Combined
2005/2006	15	0.60 ± 0.74	0.47 ± 0.52	0.53 ± 0.63
2007/2008	31	0.65 ± 1.28	0.94 ± 1.15	0.79 ± 1.22
2008/2009	31	1.00 ± 1.34	0.42 ± 0.76	0.71 ± 1.12
2009/2010	31	2.52 ± 1.39	1.68 ± 1.49	2.10 ± 1.49
2010/2011	31	0.81 ± 1.22	0.97 ± 1.14	0.89 ± 1.17
2011/2012	31	4.07 ± 0.48	2.58 ± 0.39	3.32 ± 0.32
2012/2013	31	10.50 ± 1.60	0.45 ± 0.14	5.47 ± 1.02
2013/2014	31	1.26 ± 0.19	2.45 ± 0.49	1.86 ± 0.27
2014/2015	31	3.29 ± 0.55	1.07 ± 0.23	2.18 ± 0.33
2015/2016	31	3.90 ± 0.67	0.19 ± 0.09	2.05 ± 0.41
2016/2017	31	0.68 ± 0.95	0.45 ± 1.00	0.56 ± 1.06
2017/2018	31	0.45 ± 0.15	0.93 ± 0.17	0.69 ± 0.12

As there is a relationship between larval smelt abundance and water clarity across the Rotorua Lakes (Rowe & Taumoepeau 2004, Figure 3-10) larval smelt density in Lake Rotoiti can be expected to increase as its water clarity (as measured by secchi disc depth) increases, and vice-versa. Larval smelt densities measured over the past decade in Lake Rotoiti show that although there is a wide inter-annual variation, the general pattern is one of increase when water clarity is high and decrease when it is low. In line with these findings, the greater water clarity (Secchi disc depth ≥ 6m) observed between 2012/13 and 2015/16 sampling seasons corresponded with a higher mean larval density. The lower water clarity (Secchi disc depth ≤5.6m) observed before the diversion wall was completed (2005/06 and 2006/07), in the four seasons immediately after completion (2008/09, 2009/10 and 2010/11, 2011/12), and more recently (2016/17 and 2017/18) corresponded with lower larval densities especially when water clarity readings fell below 5.2m. In the two most recent sampling seasons (2016/17 and 2017/18), water clarity (Secchi disc depths 5.5m and 5m respectfully) and larval density (0.56 and 0.69 No. larvae net^{-1}) were notably low and were similar to observations before and soon after the diversion wall was constructed.

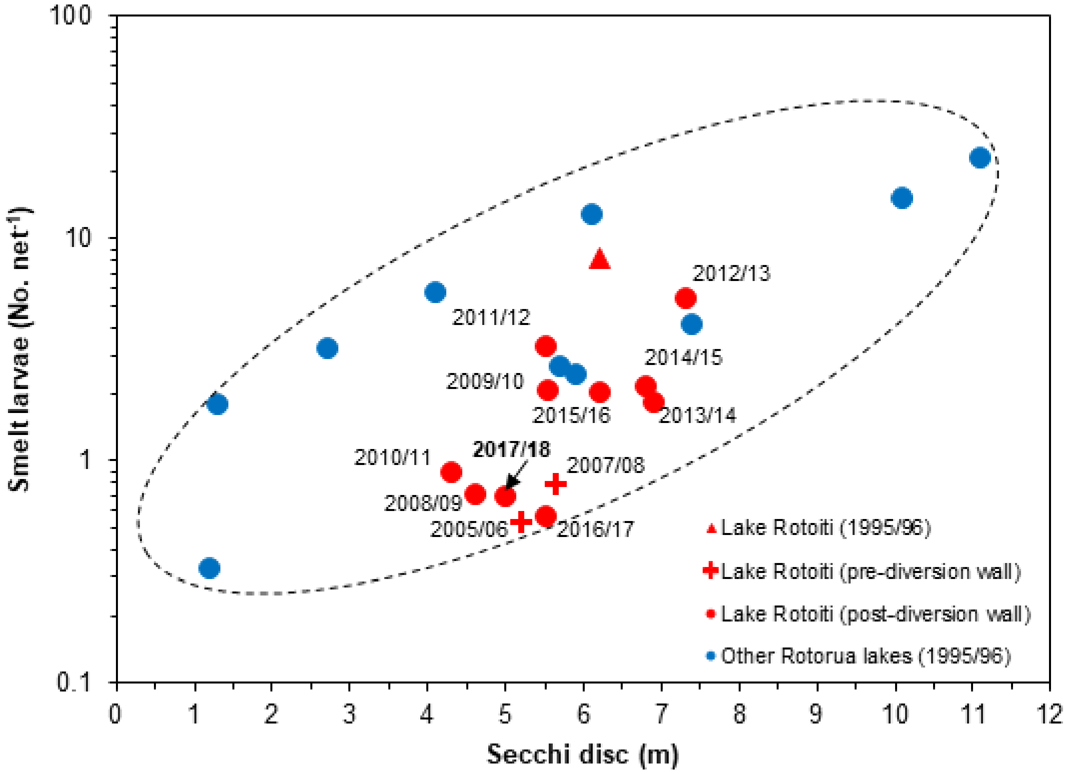

Figure 3-10: Abundance of smelt larvae (log scale) in Lake Rotoiti as a function of mean secchi disc depth. Secchi disc depth in the Rotorua lakes is a measure of water clarity and is influenced mainly by plankton abundance and hence lake trophic status. It is well correlated with larval smelt density (see dashed ellipse). The most recent sampling season is in bold font. Note that 1995/96 data is from before the diversion wall, but also before water quality had declined to the critical levels that prompted this project.

4 Discussion and conclusions

4.1 Does the diversion wall impact on smelt and bully migrations?

Results from 2017/18 support previous monitoring in that the diversion wall does not adversely impact smelt migrations up the Ohau Channel. Although there is limited comparative data from before the construction of the wall, available data also indicates that the size and duration of the smelt migrations has not changed since the diversion wall was installed. Runs of both adult and juvenile smelt have continued to occur after construction, with catch rates frequently exceeding pre-diversion wall numbers, 2017/18 being no exception. Similarly, the migration of bullies appears unaffected, and the potential decline raised by Rowe et al. (2012) is likely to represent natural variability.

Other aspects of the smelt migration, such as the frequency of the runs (i.e., the number of days when a run occurs per annum) cannot be determined from the data obtained under this monitoring program design. Such information would allow the assessment of any decline in run frequency, which would provide more detail on how the diversion wall may be affecting smelt populations. In addition, the monthly monitoring program coupled with the high temporal variability in the size and occurrence of smelt runs means that the data collected are not a true reflection of population abundance.

4.2 Smelt densities in Lake Rotoiti

Sampling before the installation of the diversion wall, and in the seasons immediately afterwards, before the effects of the wall on water quality and clarity in Lake Rotoiti could be seen, suggested that the density of larval smelt in the lake was variable but often low. As water clarity in the lake improved between late 2012 and early 2016, the density of smelt larvae increased with peak densities occurring in 2012/13. Larval smelt densities were higher than pre-diversion wall years, every year during the 2012 to 2016 period. However, in the two most recent sampling seasons (2016/17 and 2017/18), water clarity and larval density declined notably, and each were recorded similar to pre-diversion wall levels. It was hypothesised in Shelley et al. (2017) that the poor water clarity and low larval smelt density observed in the 2016/17 season was due to increased runoff from extreme rainfall events related to Cyclone Cook that preceded the Summer (December) and Autumn (April) sampling. However, it is unlikely that these events would still be having an influence. Further, there was no unusual weather conditions prior to sampling in 2017/18.

There are many possible explanations for the decline in smelt larvae observed since 2016. One possibility could be that the decline is linked to increased nutrient levels, indicated by lower water clarity. Changes in nutrient levels can alter the species composition and abundance of zooplankton communities, which could negatively affect the feeding dynamics of the smelt larvae (Lazzaro 1987). However, the water clarity readings are based on only two spot measurements and may not represent the predominant conditions experienced both spatially and temporally in Lake Rotoiti over the last two years. Also, little information exists on the feeding dynamics of smelt. Alternatively, resource consent conditions reduced lake level fluctuations in 2012, and there may be a time lag in observing ecological responses to that regime change (David Rowe, pers. comm.). The seasonal variation in lake level has reduced from around 0.5m to less than 0.1m. This is expected to have major implications for littoral zone habitats where smelt spawn (Blair 2012). Water level fluctuations play an important role in the lake's physical processes, particularly sedimentation, which can in turn impact upon biological communities (Leira & Cantonati 2008). In lacustrine habitats, water level fluctuations act to suspend fine silts, not allowing them to settle in the shallow littoral margins. Conversely, siltation increases in these areas when the water level is near constant. Increases in silt cover allow for macrophytes, which require silty substrates to establish roots, to proliferate in shallower areas further covering the bare, sandy substrates that smelt lay their eggs upon (Baker & Bartels 2011; Leira & Cantonati 2008). If there has been an increase in plant growth and silt deposition in the shallow margins of the lake since the reduction of water level variations, smelt spawning habitat would be reduced and consequently, larval density would be expected to have declined. A further possibility is that higher trout numbers and subsequent smelt predation could have reduced the adult spawning stock leading to fewer recruits. However, no accurate information on trout and smelt numbers is currently collected to test this hypothesis. Finally, the reduction in larval smelt densities correlates with a known increase in abundance of the invasive catfish (*Ameiurus nebulosus*) in Lake Rotoiti and they could be directly or indirectly affecting smelt populations (e.g., predation upon smelt eggs). However, presently, catfish densities appear highest in the western bays of Lake Rotoiti (Shane Grayling, BoPRC, pers. comm.) and smelt spawning is thought to occur predominantly in the eastern parts of the lake (Blair 2012). Therefore, catfish may not currently be affecting smelt populations, but this possibility should be considered if catfish abundance continues to increase. It is also important to note that in the sampling seasons where larval densities were lowest, the largest impacts were observed in December (post-spring), while densities in April (post-summer) often remained at levels typical of those observed in the broader monitoring program (e.g., 2017/18 sampling). Therefore, there may be a temporal dynamic to the impact, where the peak spring spawning period is affected, greatly reducing overall the larval smelt population.

Currently, there is not enough data to determine the cause of the reduced larval smelt densities, and the hypotheses outlined above are speculative. Further years of sampling will reveal whether these results reflect a short-term response to an acute impact or a trend arising from a chronic one. Regardless, given that these observations are eight years on from construction of the diversion wall and smelt densities have generally been higher since it's construction, the results are unlikely to be related to the diversion wall. To better understand smelt population dynamics in Lake Rotoiti further research is required. We suggest four key areas that would likely provide the greatest insights: (1) the influence of fluctuating nutrient levels on zooplankton communities and corresponding changes in smelt feeding dynamics; (2) the impact of reduced lake level variation on smelt spawning habitat and spawning success; (3) the relationship between trout and smelt abundance in the lake; and (4) investigate the impacts of increased catfish densities on the ecology of smelt.

4.3 What environmental factors are influencing smelt runs?

Migratory species have evolved innate senses that detect changes in the environment (e.g., increased flow) and trigger migratory movements (Liedvogel et al. 2011). From a management perspective, the identification of these drivers is important as it allows for the assessment or prediction of how natural or anthropogenic changes (e.g., the diversion wall) may influence these migratory cues and the size, timing and frequency of migrations.

With the addition of recent monitoring data, investigations into the influence of average daily flow, seven-day mean flow and 24-hour change in flow preceding the completion of sampling, average diurnal water temperature, and water clarity on the size of smelt migrations identified trends relating to flow and water temperature. The size of smelt runs showed a moderate, but clear increasing trend with increased mean daily flow and seven-day mean flow that held true for both juvenile and adult fish. Furthermore, a slight decreasing trend between adult smelt numbers and diurnal water temperature were observed. Conditions experienced within the Ohau Channel largely reflect the conditions in Lake Rotorua, which is the source waterbody. While some smelt may live in the channel, it predominantly represents temporary habitat for fish that are migrating between the lakes. For instance, during the peak migration season over 10,000 fish were observed moving up the Ohau Channel on a given sampling day. For those transitory smelt, changes in flow and temperature may indicate that lake conditions have changed in their favour, thus instigating more fish to migrate.

The analysis discussed here has identified trends between increasing flows and temperature, and the size of smelt runs. Further research is needed to conclusively establish these relationships and to better understand the mechanisms involved. Further research efforts should also focus on other elements of the temperature and flow regime (e.g., rate of change, direction of change) and investigate other environmental cues not included in this study. The ecological driver for the migrations (e.g., spawning, foraging habitat) also remains unknown and presents an important area for future research. Together, this information will provide a greater understanding of the size, timing and frequency of smelt runs allowing for more effective management of smelt populations in Lake Rotorua and Lake Rotoiti to benefit the associated trout fishery.

4.4 Ohau Channel weir, smelt migration, and the trout fishery

Observations made over the entire project, suggest that that the weir at the top of the Ohau Channel may impede the movement of smelt from the Ohau Channel into Lake Rotorua during high flows (Rowe et al. 2016). It is thought that water velocities at the edge of the weir exceed the swimming capabilities of smelt under such conditions. This is the likely cause for the accumulation of smelt below the weir which consequently attracts trout, shags and gulls. The increase in trout creates a valued fishery at this site, based on high catch rates. Therefore, the fishery is thought to be reliant on; (1) the smelt running, and (2) high flows/water velocities. At present, detailed knowledge of the flow conditions required in the Channel to impede smelt movements over the weir is lacking. While the weir is expected to contribute positively to the trout fishery when flows over it are high and a smelt run occurs, it can also be expected to impede the migration of smelt into Lake Rotorua under the same conditions. Further research is needed to quantitatively assess the observations of the impact of the weir on smelt migration. Such information will help to better manage smelt populations and the trout fishery.

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