# Īnanga spawning survey of Linwood Canal and Steamwharf Stream

Shane Orchard

Prepared for

Christchurch City Council
June 2018

Cover photograph:
Steamwharf Stream upstream of Ferry Road. Photo: S. Orchard

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**Document revision and status**

| Revision | Date | Status | Approved by | Issued by |
|---|---|---|---|---|
| v1 | 08/06/2018 | Draft for client review | S. Orchard | S. Orchard |
| vFinal | 18/06/2018 | Final | S. Orchard | S. Orchard |
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# EXECUTIVE SUMMARY


The purpose of this study was to gather information on īnanga spawning activity in Linwood Canal and Steamwharf Stream during the 2018 spawning season to support current and future restoration work in these waterways. The methodology consisted of salinity monitoring on spring high tides, surveys of riparian vegetation to detect spawning sites, and monitoring of artificial habitats provided by straw bales. In Linwood Canal, a single comprehensive spawning survey was completed during April to determine the distribution of spawning sites, spatial characteristics, and an estimation of egg numbers in the catchment following the early April spring high tides. In Steamwharf Stream, spawning surveys were completed over four consecutive months (Feb–May) that included monitoring of six straw bale installations.

In Linwood Canal the upstream limit of salt water intrusion was located at the Dyers Road culvert on most of the tides measured. The waterway has a strongly stratified salinity regime associated with a layer of relatively high salinity water at the bottom of the water column. This is generated by salt water ingress through the flap-gate structure at Humphrey's Drive with the southern pipe permitting in-flow of tidal water and the other three pipes apparently well sealed. A total of 16 spawning sites were found in the April spawning survey. These were distributed over a 340 m reach downstream of Dyers Road with the majority (12 sites) being located on the true right bank. Most sites on the true right were located on a bench that is a characteristic of the river bank in this reach. The total area of occupancy (AOO) of the spawning sites was 15.6 m$^2$ and egg production 162,000 eggs. These results show that Linwood Canal is a important waterway for īnanga spawning and must support an appreciable population of adult fish.

In Steamwharf Stream the salinity regime is also highly stratified. The upstream limit of salt water is typically located between Dyers Road and Alport Place on spring high tides. Fluctuations in the exact position were observed in response to different stream flows as well as tidal heights. There were no eggs found on the straw bales in any of the four months of monitoring. However, spawning sites were discovered in riparian vegetation in three of the four months, consisting of one site in March, two in April, and one in May. One of the two sites found in April has been used repeatedly in the past two years, as recorded in other studies. This same site was also the location of the eggs found in March and May in this study, although the AOO and number of eggs present were less on those months. The other site found in April was a location not previously recorded as a spawning site. The April (peak month) AOO was 0.71m$^2$ and egg production was 36, 700 eggs. The total egg production recorded over the four months was ~50,000 eggs. This is considerably less than was recorded in comparable studies completed in 2016 that included riparian vegetation surveys and the use of straw bale installations to bolster spawning habitat as was the case this year. These findings suggest that the population of adult īnanga was relatively small in 2018. This is consistent with observations made during field surveys in which adult fish were seldom seen.

Recommendations for Linwood Canal include:

- Protection of the spawning sites identified in this study, and restoration of an area of potential spawning habitat on the true left bank.
- Further monitoring to investigate temporal aspects of spawning activity and habitat use, and to provide additional information on whether the true left bank may support a greater area of spawning habitat than was recorded in this study.
- Monitoring the effectiveness of habitat protection measures over time.
- Careful attention to the ecological impacts of any proposed alteration to the flood gate structures on Humphrey's Drive.

Recommendations for Steamwharf Stream include:

- Continued monitoring of spawning activity to support the proposed riparian restoration project.
- Consideration of restoration options for juvenile & adult fish habitat for integration with other management activities in the catchment.
- Establishing a monitoring programme to provide information on characteristics of the adult fish population, including the potential movement of fish to and from the lower Heathcote/Ōpāwaho.

# 1. Introduction

## 1.1 Background

The purpose of this study was to gather information on īnanga spawning activity in Linwood Canal and Steamwharf Stream during the 2018 spawning season to support current and future restoration work in these waterways.

Christchurch City Council (CCC) is undertaking riparian restoration work at Steamwharf Stream involving the stabilisation and revegetation of stream banks that were affected by the Canterbury earthquakes, and have been slow to recover. Most of these areas are in close proximity to a gravel walking track that contributes to potential disturbance of the stream banks for vegetation recovery, as well as being source of sediment in rainfall events. These areas have been targeted for long term restoration in the current CCC project (Figure 1). The project will involve re-establishing riparian vegetation cover, preferably using native plant species that are suited to the area and can provide īnanga spawning habitat (B. Margetts, pers. comm.). The restoration planting design will be finalised and implemented after the 2018 īnanga spawning season. As an aspect of this project, straw bale installations are being used to provide temporary support for spawning in advance of the restoration work being completed.

**Figure 1**. Two views of the Steamwharf Stream restoration area showing initial stabilisation work on the riparian margins between the recreational track and the waterway, January 2018. Photos: S. Orchard.

Previous studies have identified īnanga (*Galaxias maculatus*) spawning sites throughout this stretch of the waterway. Pre-earthquake spawning in this area was first detected by Taylor (2004). However, the Canterbury earthquakes caused considerable damage that included lateral spread and liquefaction effects, and no spawning was found in a 2011 post-earthquake survey (Taylor & Blair 2011). More recent studies included a survey in 2015 that also failed to detect any spawning sites (Orchard & Hickford 2016). In 2016, straw bales were installed as a detection tool (Orchard et al. 2018b) as part of the Whaka Inaka - Causing Whitebait project (McMurtrie et al. 2016; Orchard et al. 2016). Spawning was detected on the straw bales and also in riparian vegetation that year. In the following year, no straw bales were in place but spawning was again detected in the riparian vegetation (Orchard 2017).

At Linwood Canal, there is no current riparian restoration project that targets īnanga spawning habitat. However, works are underway to improve the road network in the area, and these include ground stabilisation measures close to the waterway (Figure 2). These and other sites provide opportunities for ecological restoration activities in the near future. Previously, there has been only one record of īnanga spawning in this waterway. This was a small spawning site found in 1999 close to Dyers Road (Taylor 1999). In other respects, very little is known about the potential extent of spawning activity in the catchment or details of the fish population, especially in the post-earthquake context. However, adult īnanga were observed there in January 2018 (S. Orchard, B. Margetts, unpubl. data) indicating that migratory juveniles had successfully bypassed the outlet structure and may have done so previously.

Due to the extensive area of riparian vegetation that might support spawning in Linwood Canal, it was decided to focus the effort for this study on characterising the salinity regime and completing one comprehensive survey of riparian vegetation to detect spawning sites. The latter was completed after the early April spring high tide which was thought be a good candidate for the peak month of spawning activity based on previous studies in the Avon/Ōtākaro and Heathcote/Ōpāwaho catchments (Orchard et al. 2018a).

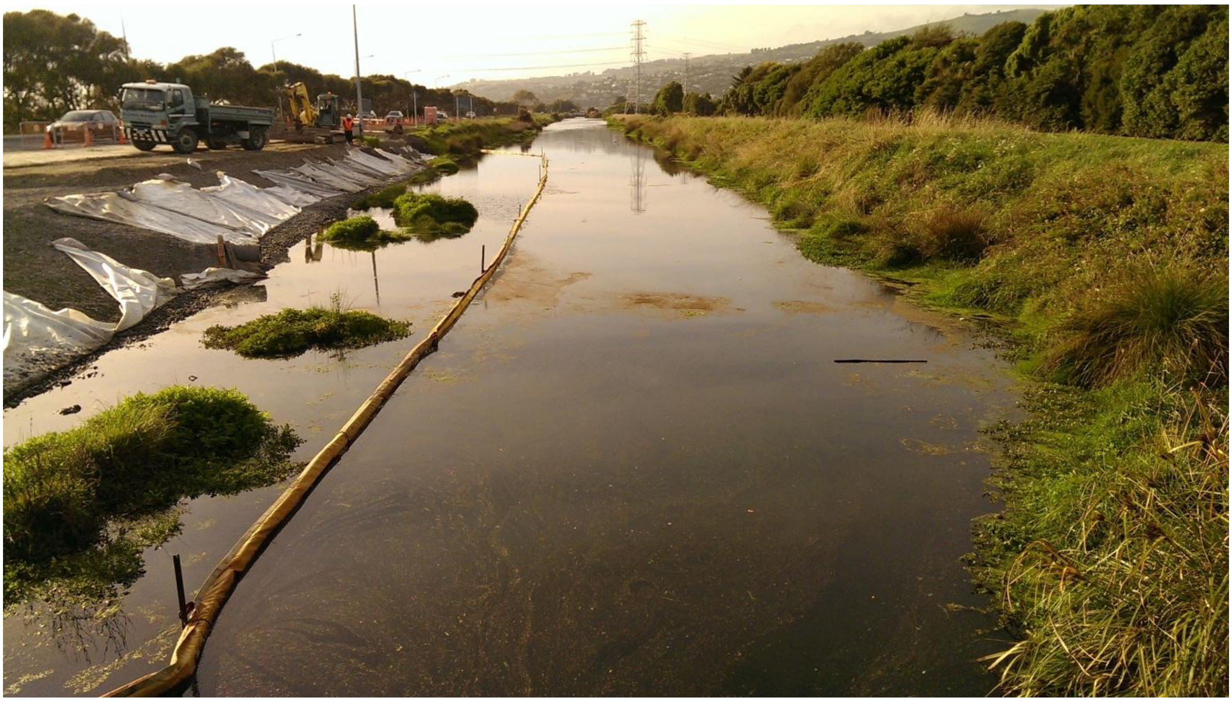

**Figure 2**. Linwood Canal looking downstream from Dyers Road showing current road works in the riparian zone. A silt curtain can be seen protecting the waterway from construction site run-off.

### 1.2 Objectives

Objectives for the Linwood Canal survey were:

- to determine whether this waterway is currently providing spawning habitat.
- to guide if, where, and how suitable riparian vegetation could be planted in the long term to provide favourable spawning habitat.

Objectives for the Steamwharf Stream survey were:

- to provide guidance on the placement of straw bales at Steamwharf Stream to provide temporary īnanga spawning habitat.
- to determine whether the straw bales or riparian vegetation are supporting spawning.
- to guide where, and how suitable vegetation should be planted in the coming months to provide favourable spawning habitat over the long-term.

### 1.3 Scope

*Linwood Canal*

The study consisted of:

- monitoring of salinity conditions during spring high tides, entailing one measurement per month for three months (February–April), to determine characteristics of salt water intrusion.
- a survey of riparian vegetation during April to determine the distribution of spawning sites, spatial characteristics, and an estimation of egg numbers at all sites found.

*Steamwharf Stream*

The study consisted of monthly monitoring over four months (February–May) to assess:

- the condition and position of bales on spawning high tides to inform adjustments as necessary.
- salinity conditions during spring high tides.
- īnanga egg numbers both within straw bales and riparian vegetation in the study area.

The remainder of this report is set out as follows: Section 2 describes the field survey methodology. Section 3 presents the major findings, Section 4 provides a brief discussion of management implications, and Section 5 concludes the report with brief recommendations.

## 2. Methods

### 2.1 Study area

The study area included Linwood Canal from the outlet structure on Humphrey's Drive to upstream of Dyers Road, and Steamwharf Stream from Ferry Road to the culvert at Alport Place (Figure 3).

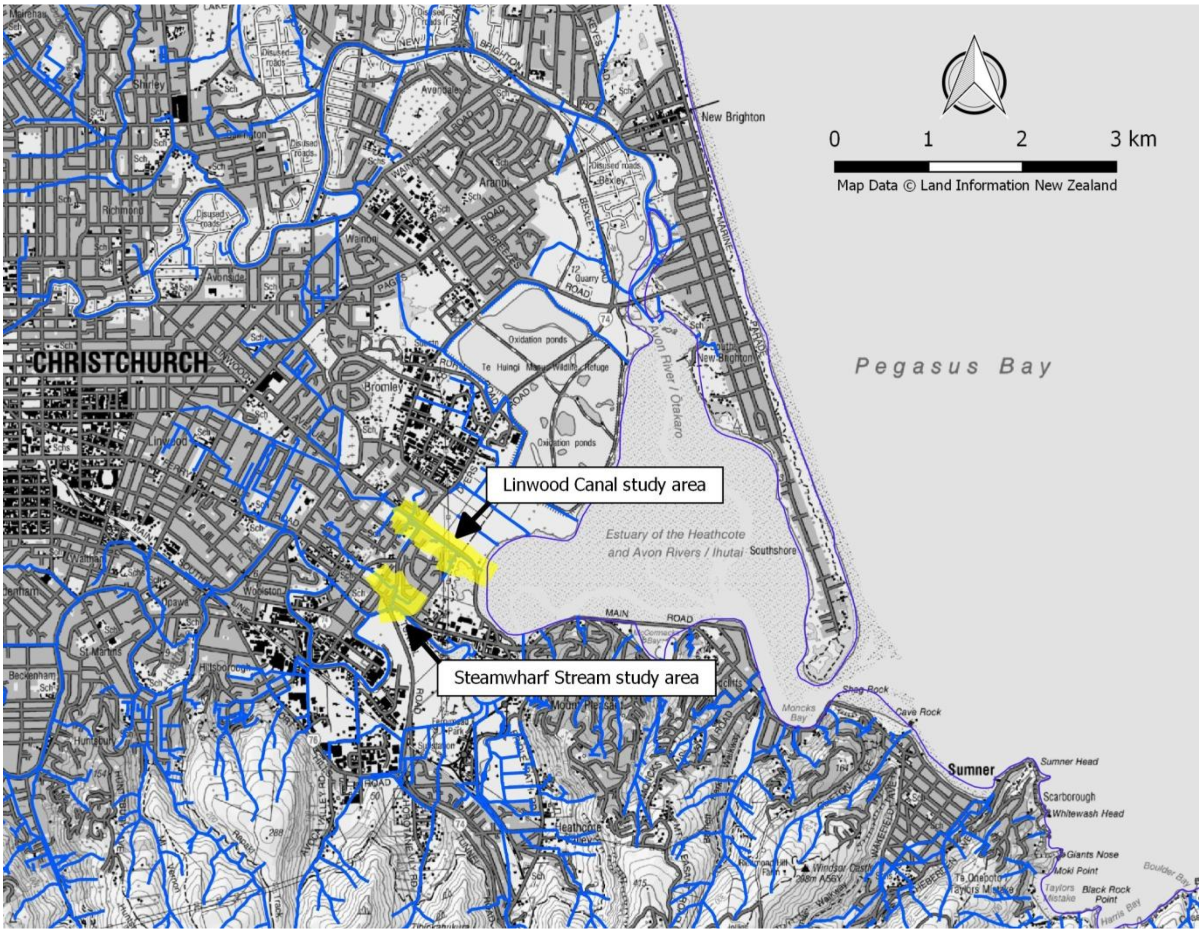


**Figure 3**. Overview map showing location of the study areas at Linwood Canal and Steamwharf Stream.

## 2.2 Salinity surveys

Salinity monitoring sites were established at regular intervals across the study area in both waterways (Figure 4). At each site, salinity was measured on spring high tides using a YSI Model 30 salinity meter following Orchard & Hickford (2018). Two measurements were taken at each monitoring site; the first at the bottom, and the second 10 cm from the top of the water column. Each survey was timed to follow the incoming tide upstream with the objective of taking the furthest upstream measurement at time of peak high water in that location. In both waterways this is associated with a turn-around point in flow direction under most conditions (i.e. typical discharge rates). Because of its proximity to the main estuary, the time of peak high water at Linwood Canal occurs 1-2 hours earlier than at Steamwharf Stream.


**Figure 4**. Location of salinity monitoring points in Linwood Canal and Steamwharf Stream.

## 2.3 Spawning site surveys

*Egg searches*

Intensive surveys of riparian vegetation were completed in each of four months (February –May) at Steamwharf Stream and in April at Linwood Canal (Table 1). A census survey approach following Orchard & Hickford (2018) was used with the objective of locating all spawning sites in the catchment. The search area was first assessed in a subjective survey of the riparian vegetation using set criteria to define areas of high, moderate and poor quality habitat (Table 2). All areas of moderate and high quality habitat were then searched systematically for eggs. This involved conducting three searches at random locations for every 5 m length of river bank in these areas. Each search involved inspecting the stems and root mats of the plants along a transect line spanning and perpendicular to the high water mark. Typically, a 0.5 m wide swathe of vegetation 1-2 m long was inspected on each transect depending on the bank slope and degree of difficulty locating the high water mark. Where eggs were found the survey was extended at least 50 m either side of the last occurrence to confirm the full extent of the spawning site.

**Table 1.** Tidal cycle data and egg survey periods for the 2018 survey.

| Survey Month | Peak tidal cycle start | Peak tidal cycle end | Peak tidal height* (m) | Survey periods | |
|---|---|---|---|---|---|
| | | | | Linwood Canal | Steamwharf Stream |
| February | Feb 1 | Feb 2 | 2.7 | - | Feb 8 |
| March | Mar 1 | Mar 3 | 2.6 | - | Mar 8 |
| April | Mar 30 | Apr 1 | 2.5 | April 8 – 10 | Apr 7 |
| May | Apr 25 | Apr 30 | 2.4 | - | May 7 |

* predicted tide levels above Chart Datum at Port of Lyttelton (Lat. 43° 36' S Long. 172° 43' E) (Source: LINZ).

**Table 2**. Habitat quality classes.

| Class | Quality of habitat for supporting spawning | Expected egg mortality rate | Criteria |
|---|---|---|---|
| **1** | Poor | High | Vegetation cover <100%<br>or<br>Stem density <0.2cm$^{-2}$ |
| **2** | Moderate | Moderate | Vegetation cover 100%<br>Stem density >0.2cm$^{-2}$<br>Aerial root mat depth <0.5cm |
| **3** | High | Low | Vegetation cover 100%<br>Stem density >0.2cm$^{-2}$<br>Aerial root mat depth >0.5cm |

**Classification schema**

A. Vegetation cover <100% Class 1
   Vegetation cover >100% Class 2 or 3
B. Stem density <0.2cm$^{-2}$ Class 1
   Stem density >0.2cm$^{-2}$ Class 2 or 3
C. Aerial root mat depth <0.5cm Class 2
   Aerial root mat depth >0.5cm Class 3

*Area of occupancy (AOO)*

All egg occurrences were associated with a given location that was identified as a spawning site (Orchard & Hickford 2018). Individual sites were defined as continuous or semi-continuous patches of eggs with dimensions defined by the pattern of occupancy. For all egg occurrences the upstream and downstream extents of the patch were established, and the length along the riverbank measured. GPS coordinates were recorded using hand-held units in the field and corrected in QGIS v2.18 (QGIS Development Team 2017) against ground-truthed landmarks to obtain an estimated accuracy of ± 1 m.

For each spawning site, the width of the egg band was measured at each search transect that fell within the extent of the site. Additional transects were inspected where needed to provide a minimum of three measurements at all sites. Zero counts were recorded when they occurred such as where the egg distribution was not a continuous band. AOO was calculated as length x mean width.

*Spawning site productivity*

Productivity was assessed by direct eggs counts using a sub-sampling method (Orchard & Hickford 2016; Orchard & Hickford 2018). At each transect, as above, a 10 x 10 cm quadrat was placed in the centre of the egg band and all eggs within the quadrat counted. Egg numbers in quadrats with high egg densities (> 200 / quadrat), were estimated by further sub-sampling using five randomly located 2 x 2 cm quadrats and the average egg density of these sub-units used to calculate an egg density for the larger 10 x 10 cm quadrat. The mean egg density was calculated from all 10 x 10 cm quadrats sampled within the site. Productivity was calculated as mean egg density x AOO.

### 2.4 Straw bale monitoring

Straw bales were installed by City Care Ltd at six locations in Steamwharf Stream on 29 January 2018. At each location a set of three straw bales was positioned with the long side perpendicular to the stream bank and a 5 cm gap between adjacent bales following Hickford & Schiel (2013), except that pea straw bales were used instead of wheat straw due to availability. Each bale set was placed to straddle the high tide waterline on the spring high tides of each month, and secured in place using a wire loop between two steel warratahs. At all locations the ground surface had previously been stabilised with GeoCoir 400 g/m$^2$ coconut fibre sheets which also provided a potentially suitable surface for spawning in the gap between the bales. A field inspection was completed on the spring high tides each month to check on the condition of the bales and ascertain the waterline position. This resulted in adjustments to bale positions in first month (February) to ensure correct placement relative to the waterline. Due to some concerns with deterioration of the pea straw (which is less robust than wheat straw), and since no spawning had been recorded on the bales in monitoring prior to then, all installations were replaced with fresh bales in April. All installations were monitoring for eggs over four months (February–May). Monthly monitoring consisted of inspecting all surface of each bale and also the GeoCoir surface within a 1 m radius of each installation to check for a halo effect that is sometime observed, as detailed in Orchard et al. (2018b).

## 3. Results

### 3.1 Linwood Canal

*3.1.1 Salinity surveys*

Despite being a shallow waterway, field measurements showed that the salinity regime is highly stratified in Linwood Canal (Figure 5). This is associated with a relatively high salinity layer at the bottom of the water column with lower salinity water near the surface (Figure 6). Repeat measurements at different times showed that the tidal waters move slowly upstream on incoming tides and may also sit in locally deeper areas between tides creating a complex salinity environment.

Inspection of the outlet structure at Humphrey's Drive showing that salt water ingress occurs through the flap-gate on the southern pipe with the other three pipes apparently well sealed (Figure 7). A weir prevents ingress of tidal water to the small freshwater lake near the Charlesworth footbridge on small tides, but retains saline waters following larger tides. Salinity recorded in this lake was as high as 7.4 ppt (on February 2nd). In the main channel of Linwood Canal, a sill created by the floor of the large box culvert at Dyers Road appears to prevent the intrusion of salt water further upstream on all but the largest tides. Salinity above 0.1 ppt (which is the background value in the waterway) was recorded only once in the survey period upstream of Dyers Road (0.2 ppt on February 2nd).


**Figure 5**. Typical spring high tide salinity ranges in Linwood Canal, as recorded on 2 March 2018. Two measurements are shown at each monitoring site; at the bottom of the water column (bottom marker), and 10 cm below the water surface (top marker). All measurements are the maximum salinity value recorded during the field survey at different times on the incoming tide.

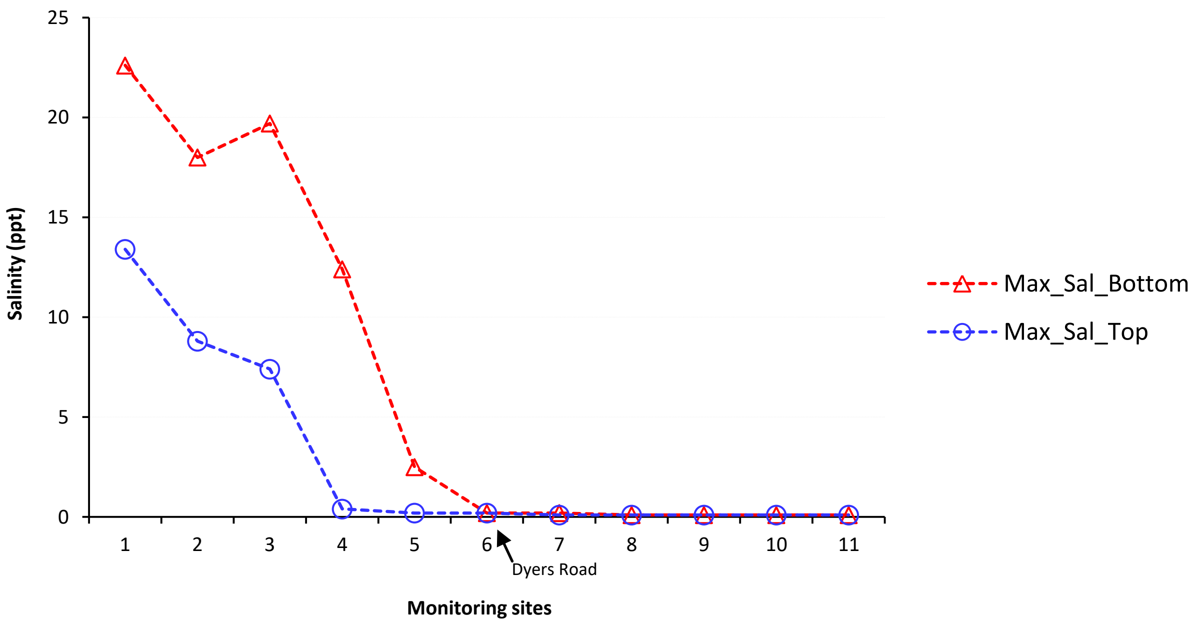


**Figure 6**. Plot of maximum salinities at the bottom and 10 cm from the top of the water column, as recorded on the spring high tide of 2 March 2018 in Linwood Canal. Upstream is to the right of the plot.


**Figure 7**. Linwood Canal outlet structure at the Avon Heathcote Estuary Ihutai on Humphrey's Drive. (a) View of the four flap-gates in operation on a high tide. (b) Tidal ingress into Linwood Canal through the southern culvert on an incoming tide.

*3.1.2 Spawning site surveys*

A total of 16 spawning sites were found in the Linwood Canal survey completed in April (Figure 8). These were distributed over a 340 m reach downstream of Dyers Road with the majority (12 sites) being located on the true right bank. Most sites on the true right were located on a bench that is a characteristic of the river bank in this reach (Figure 9a). The vegetation species supported spawning on the true right were mainly clumps of tall fescue (*Schedonorus arundinaceus*) and dense swards of creeping bent (*Agrostis stolonifera*). However another species present is Caldwell's sedge (*Bolboschoenus caldwelli*). It appears to provide an important scaffolding function, especially in association with creeping bent. The four spawning sites on the true left were all relatively small and located at the toe of the main bank. The vegetation here consisted of a mixed grass and herb community that is relatively short in stature compared to the true right (Figure 9b). This difference results from regular weed-eating down to the waterline that does not occur on true right (J. Carlton, pers. comm.).

The total area of occupancy (AOO) of spawning sites was 15.6 m$^2$. Spawning sites on the true right bank accounted for 95% of the AOO (Figure 10). The largest site was 20 m in length with an AOO of 7.1 m$^2$. Total egg production across all sites was 162,000 eggs with spawning sites on the true right contributing 99% of the total. The largest site (TR7) contributed 52%. Figure 11 shows the spatial distribution of egg production across the different sites.


**Figure 8**. Location and extent of īnanga spawning sites identified in Linwood Canal, April 2018.

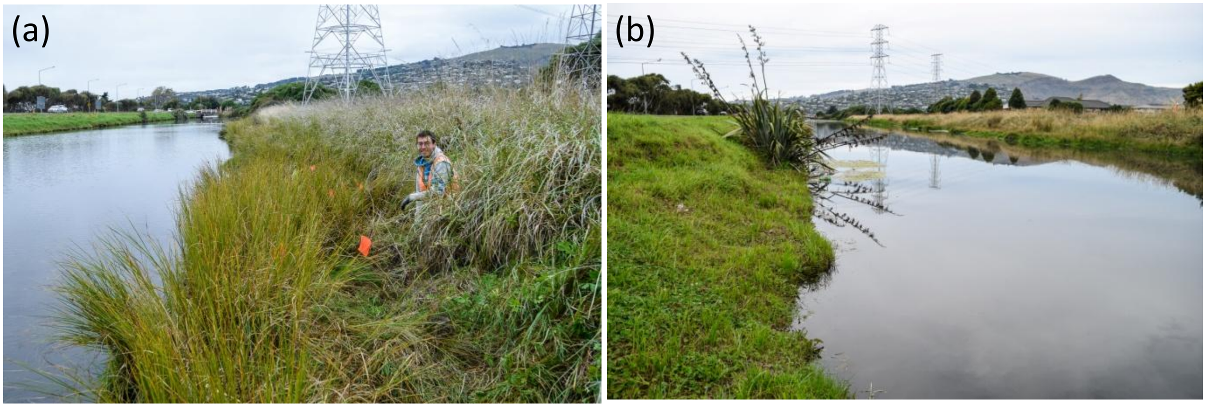


**Figure 9**. Examples of īnanga spawning habitat in Linwood Canal.(a) A bench at the toe of a steeper slope on the true right bank was found to support several spawning sites. (b) Typical spawning habitat at the high tide waterline on the true left where regular weed-eating occurs. Although spawning sites were identified on this bank egg mortality rates are likely to be high.

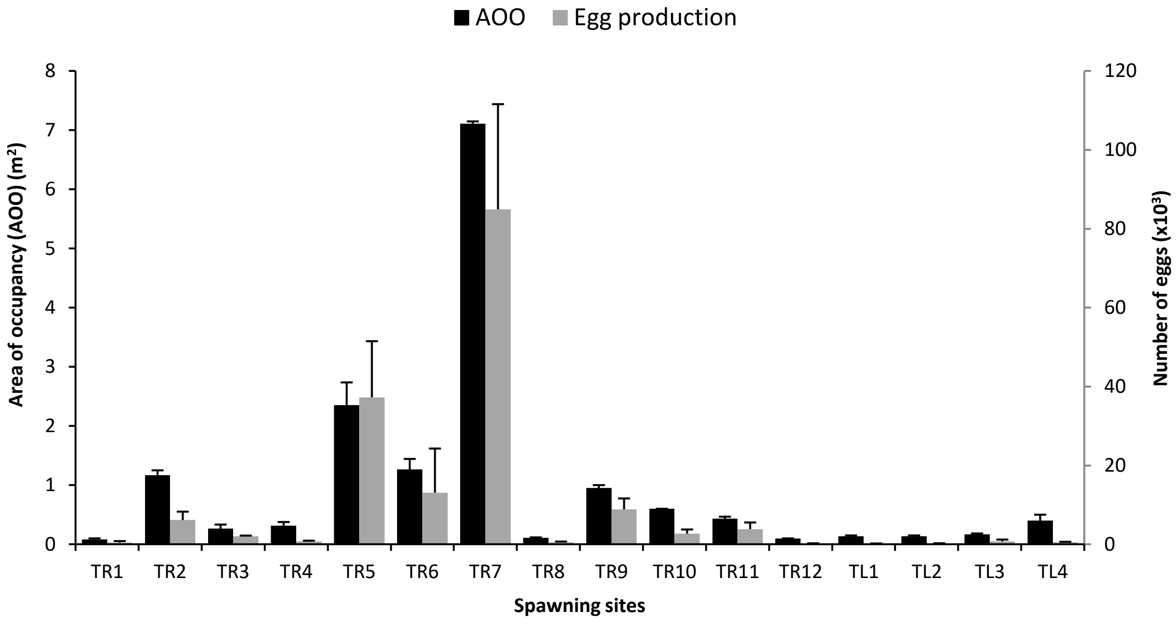


**Figure 10**. Area of occupancy (AOO) and egg production of īnanga spawning sites in Linwood Canal on 9 April 2018. Error bars are standard error of the mean


**Figure 11**. Spatial distribution of egg production in Linwood Canal as recorded on 9 April 2018.

## 3.2 Steamwharf Stream

### *3.2.1 Salinity surveys*

The salinity range in Steamwharf Stream is typically less than at Linwood Canal (Figure 12) consistent with the effects of mixing in the mainstem of the Heathcote/Ōpāwaho (Orchard & Measures 2017). However, as with Linwood Canal it is also highly stratified (Figure 13). The upstream limit of salt water typically occurs close to Dyers Road on spring high tides. Fluctuations in the exact position were observed in response to different stream flows as well as tidal heights.

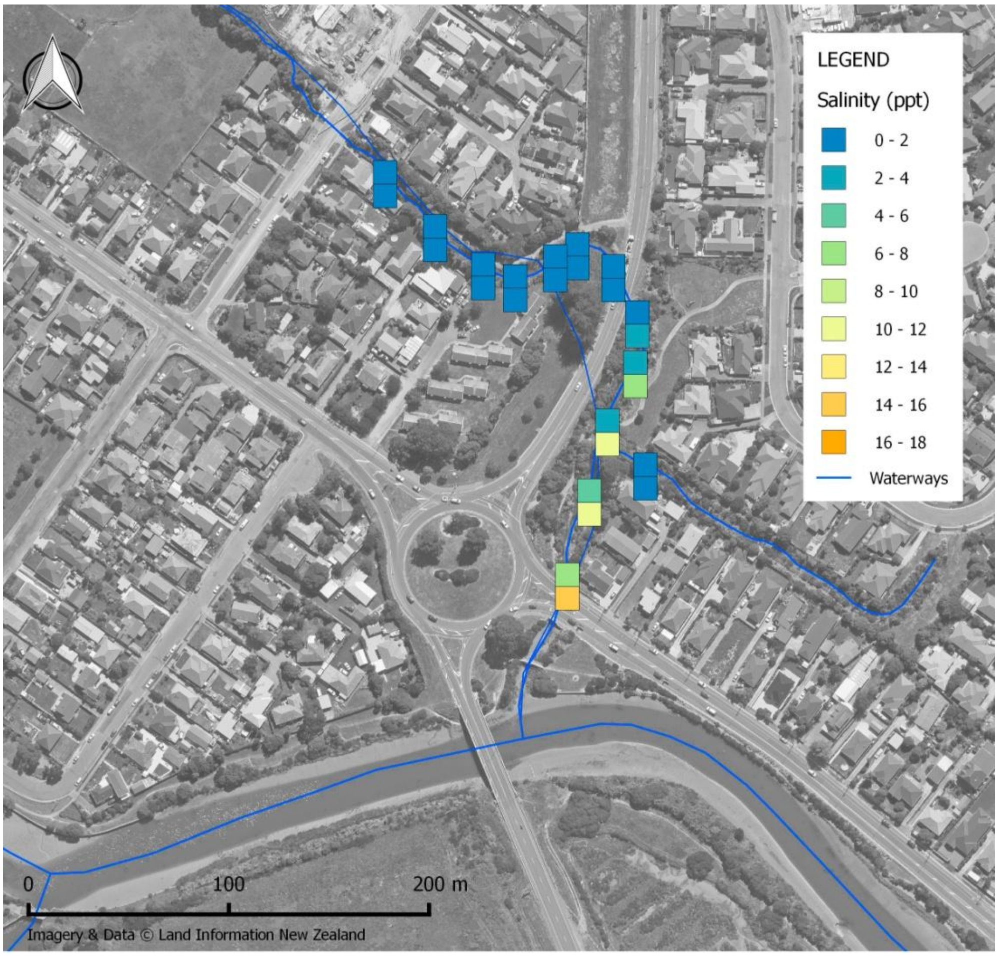


**Figure 12**. Typical spring high tide salinity ranges in Steamwharf Stream on the spring high tide of 2 March 2018. Two measurements are shown at each monitoring site: at the bottom of the water column (bottom marker), and 10 cm below the water surface (top marker). All measurements are the maximum salinity value recorded during the field survey at different times on the incoming tide.

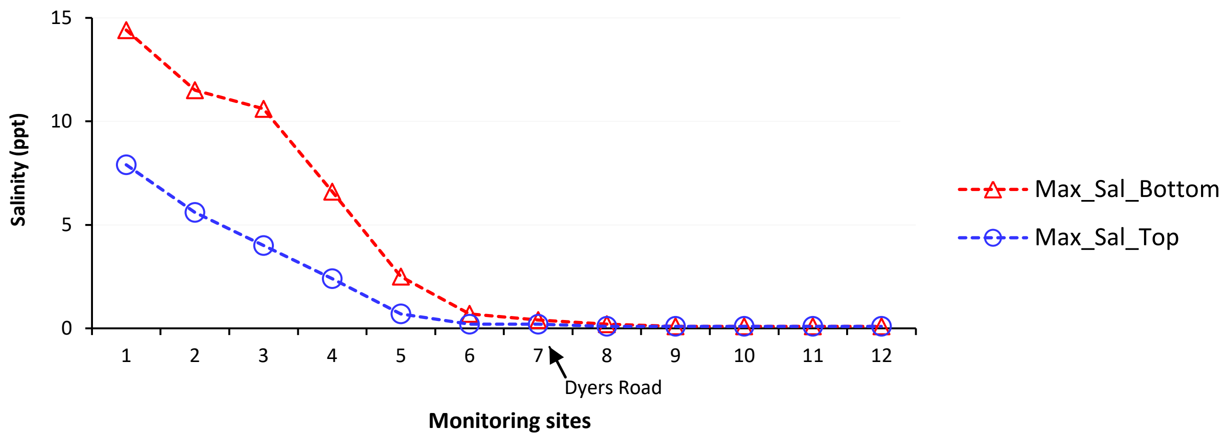


**Figure 13**. Plot of maximum salinities at the bottom and 10 cm from the top of the water column, as recorded on the spring high tide of 2 March 2018 in Steamwharf Stream. Upstream is to the right of the plot.

### *3.2.2 Spawning site surveys and straw bale monitoring*

No eggs were found on the straw bales in any of the four months of monitoring. However, spawning sites were discovered in the riparian vegetation surveys on three of the four months. One spawning site was found in March, two in April, and one in May. There was no spawning found anywhere in the catchment in February. One of the two sites found in April has been used repeatedly in other years 9as reported in other studies), and the other was a location not previously recorded as a spawning site [see Orchard (2017)]. Figure 14 shows the location of these sites with the previously used site being the further upstream site of the two. This same site was also the location of the eggs found in March and May.


**Figure 14**. Location and extent of īnanga spawning sites identified in Steamwharf Stream over four months (February–May) in 2018. Downstream is to the right.

April was the month of peak spawning activity in terms of the number of spawning sites (two), total AOO (0.71m$^2$) and total number of eggs (~38, 300). The upstream site was the major contributor with an AOO of 0.44m$^2$ and 36, 700 eggs in this month. This site was dominated by buttercup (*Ranunculus* spp.) and had changed little from previous years. The downstream site was smaller (AOO of 0.27m$^2$) and contributed 1, 600 eggs. This site was partly shaded by toetoe (*Cortaderia richardii*) with most of the eggs laid in creeping bent (*Agrostis stolonifera*). See Appendix 2 for site photographs.

Figure 15 summarises the AOO and egg production trends as recorded over the four month survey period.

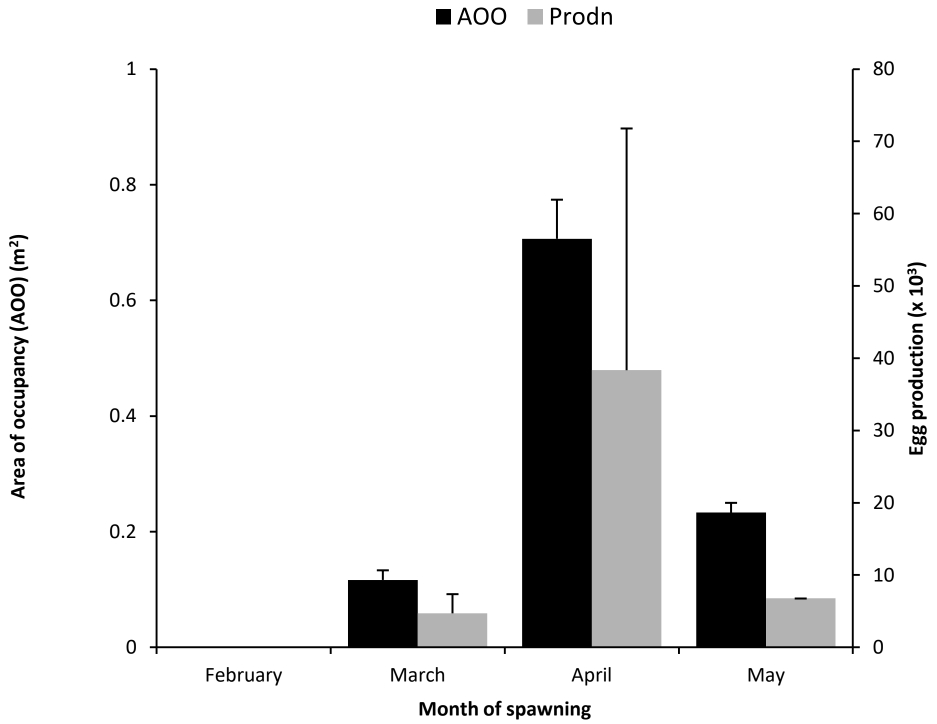


**Figure 15**. Area of occupancy (AOO) and egg production of īnanga spawning sites in Steamwharf Stream over four months (February– May) in 2018. Error bars are standard error of the mean.

## 4. Discussion

### 4.1 Īnanga spawning in Linwood Canal

The discovery of 16 spawning sites in Linwood Canal was a notable finding and confirms that this waterway must support an appreciable population of adult īnanga. The total AOO of these sites (15.6 m$^2$) is comparable to the pre-quake AOO (~20 m$^2$) that was typically recorded in surveys of the Heathcote/Ōpāwaho mainstem (Taylor 2002). Since the 2018 survey provided only a one month 'snap-shot' of spawning activity, the full extent of spawning habitat is likely to be greater than that recorded here. To address this, future surveys over a minimum of three months are recommended to provide a better picture of the habitat distribution and seasonal patterns in occupancy and egg production. In addition, further attention is needed on the true left bank where weed-eating of riparian vegetation down to the waterline had occurred during the 2018 spawning season. Only small spawning sites were found in the patchy vegetation that remained. With vegetation recovery more extensive areas of spawning are likely to be found on this bank.

Ensuring that the spawning habitat in Linwood Canal is effectively protected is an important next step. This will be assisted by appropriate recognition of the areas involved in resource management plans (Orchard

2016). It is also important that the known spawning sites are monitored to evaluate the effectiveness of the protection methods used (Orchard et al. 2018a). In this case, the locations involved appear to be relatively straightforward to protect since there are wide riparian margins between the waterway and adjacent land uses. On the true right bank the spawning habitat is located on a bench at the foot of a steeper slope. The steeper slope helps isolate the bench from foot traffic and other disturbances, and the vegetation is well established. On the true left bank, protection from weed-eating is required as noted above. The bank profile in the area of potential habitat is relatively steep and only the toe of the bank is likely to be in the elevation range that becomes inundated on spring high tides and would therefore provide habitat. Maintenance treatments such as mowing or weed-eating are unlikely to pose a problem higher on the bank face though it would be important to provide contractors with a means of identifying the correct position of the area to be protected. Alternatively, strategically placed riparian plantings could be introduced as a long term maintenance solution to provide a buffer between the spawning habitat and the grassed area that is regularly mown adjacent to Linwood Avenue.

### 4.2 Īnanga spawning in Steamwharf Stream

The Steamwharf Stream study found considerably less spawning than was recorded in comparable studies in 2016. These included riparian vegetation surveys and the use of straw bale installations to bolster spawning habitat as part of the Whaka Inaka – Causing Whitebait project (McMurtrie et al. 2016; Orchard et al. 2016). The total egg production recorded in 2016 was nearly 300, 000 eggs (University of Canterbury & Whaka Inaka Partners, unpubl. data). In comparison, the 2018 total (~ 50, 000 eggs) strongly suggests that there were less adult īnanga present this year. In contrast to the 2016 studies, the straw bale installations were not utilised on any of the months within the survey period this year. However, they did ensure that the availability of good quality habitat was not a limiting factor.

The conclusion of low adult fish numbers is also consistent with walk-through surveys of the reach between Ferry Road and Alport Place that were conducted on each of the four months of monitoring, and in which adult īnanga were seldom seen. In comparison, fish were commonly seen in 2015/2016, especially between Ferry Road and Dyers Road (Figure 16). Comparatively low spawning activity was also found in 2017, although the survey period was only a single month in that study. Spawning was found at two sites that produced a total of ~18, 000 eggs, and other areas of high quality habitat were not utilised (Orchard 2017).

**Figure 16**. Juvenile īnanga in Steamwharf Stream in December 2015 in the reach between Ferry Road and Dyers Road. Photo: S. Orchard.

These results suggest that attention to the quality of rearing habitat for juvenile īnanga may be beneficial in Streamwharf Stream. In general, habitat quality can be improved by ensuring that adequate cover is provided, for example by overhanging vegetation, in-stream debris, or macrophyte beds (Richardson & Taylor 2002). During the 2018 survey period, large scale clearance of emergent vegetation in the channel was observed between Ferry Road and Dyers Road (Figure 17). Reducing these activities when fish are present is one potential strategy for ecological restoration. Another possibility might involve forms of ecological engineering such as the introduction of large in-stream debris, which is rarely found at present. Investigating the opportunities to integrate these potential enhancements with flood management work is recommended.

In conjunction with the above, monitoring the stream for adult fish may also be a useful strategy. There are at least three potential influences on spawning activity for which information is currently lacking. The first is the degree to which recruitment varies in the stream year to year which relates to the number of juvenile whitebait entering stream. The second is their survival rate which can be expected to be influenced by the quality of rearing habitat, and potential other stressors such as pollution. Lastly, although adult fish are generally thought to mature in the waterway to which they migrated as juveniles (McDowall 1968), there is the possibility of some exchange between adult populations. In this case, a current unknown is whether adult fish may move from Steamwharf Stream to the lower Heathcote/Ōpāwaho or vice versa. A previous study by Hill (2013) found that some adult fish migration may occur between tributaries of the same river or estuarine system.

**Figure 17**.Clearance of emergent vegetation in the channel observed on 7 April 2018 in Steamwharf Stream. Photo: S. Orchard.

### 4.3 Study limitations

*Salinity surveys*

The salinity profiling methodology aims to establish the furthest upstream extent of salt water intrusion. As a result the salinity measurements taken downstream do not represent the peak salinity value at that point on that particular tide. This would require near-simultaneous measurements throughout the waterway to capture the peak salinity at each monitoring point. The salinity profile obtained should be interpreted with this in mind. Although it provides a general indication of salinity characteristics near the salt water limit there is the potential for considerably higher salinities to have occurred (versus those measured) at the downstream end of the study area.

The positioning of each monitoring site is also important in relation to the thalweg (deepest part of the channel). In both waterways the channel profile was relatively easy to ascertain due to clear water conditions and/or shallow depths. However, even small differences in the positioning of the measurement point have the potential to influence the measurements obtained, especially in highly stratified waterways such as Linwood Canal.

*Spawning site surveys*

Important limitations of the methodology include egg detection issues that may arise from mortality between the date of spawning and the date of survey (Hickford & Schiel 2011; Orchard et al. 2018b). These effects can have a bearing on the number of sites detected, the AOO observed, and the estimation of egg production. In this study, both waterways were observed to have stretches where the habitat had been degraded as a result of disturbances during the study period. However, despite the potential for egg detection issues to have affected results if spawning had occurred in those areas, there were also considerable areas of unused high quality habitat nearby. In Steamwharf Stream this included the straw bale installations which were provided for the purpose of ensuring that high quality spawning habitat was available. These aspects improve confidence for interpreting the survey results in terms of their ability to provide a measure of the full extent of spawning habitat in each of the waterways. For the Linwood Canal study, however, the single month surveyed is unreliable as an indication of the overall level spawning activity in the catchment. Important seasonal trends such as the months of peak activity, total area of spawning habitat used, and total egg production, would require surveys over consecutive months (similar to those completed for Steamwharf Stream). These data are also needed to facilitate comparisons between years since one-off measurements are susceptible to variations in the timing of peak activity in relation to the survey date. If unaddressed, this produces a confounding factor for the interpretation of apparent trends (Orchard & Hickford 2018).

## 5. Recommendations

Linwood Canal:

- Take steps to protect the spawning sites identified in this study.
- Restore the area of potential spawning habitat on the true left bank.
- Complete further monitoring to investigate temporal aspects of spawning activity and habitat use, and to provide additional information on whether the true left bank may support a greater area of spawning habitat than was recorded in this study.
- Monitor the effectiveness of habitat protection measures over time.
- Give careful attention to the ecological impacts of any proposed alteration to the flood gate structures on Humphrey's Drive.

Steamwharf Stream:

- Continue monitoring of spawning activity to support the proposed riparian restoration project.
- Consider options for the restoration of juvenile & adult fish habitat for integration with other management activities in the catchment.

- Consider establishing a monitoring programme to provide information on characteristics of the adult fish population, the potential for the movement of fish to and from the lower Heathcote/Ōpāwaho, and consequences for the level of spawning activity observed in Steamwharf Stream.

## 6. Acknowledgements

Thanks to Dr. Belinda Margetts, CCC, for coordinating this study. Thanks to Christian Wild and David Louw for field assistance, and to Dr. Mike Hickford at the Marine Ecology Research Group, University of Canterbury, for technical support. Comparative data on īnanga spawning in Steamwharf Stream were sourced from the Whaka Inaka - Causing Whitebait project and studies conducted by the University of Canterbury.

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**Appendix 1. Examples of īnanga spawning sites in Linwood Canal.**

A. Sites on the true right bank. Clockwise from top left – TR2, TR5, TR10, TR11.

**Appendix 1. Examples of īnanga spawning sites in Linwood Canal.**

B. Sites on the true left bank. Left – TL1, right - TL2.

**Appendix 2. Examples of īnanga spawning sites in Steamwharf Stream.**

A. April 2018 spawning sites. (a) & (b) two views of the furthest downstream of the two spawning sites identified in the 2018 surveys. (c) & (d) two views of the furthest upstream site. This site accounted for most of the spawning recorded in 2018 and has been used in previous years (Orchard 2017).