Response of īnanga spawning habitat to riparian vegetation management in the Avon & Heathcote catchments

Shane Orchard

Prepared for

Christchurch City Council
June 2017

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LIST OF ABBREVIATIONS

AOO	Area of occupancy
CCC	Christchurch City Council
DOC	Department of Conservation
ECan	Environment Canterbury
GIS	Geographic Information System
LINZ	Land Information New Zealand
MfE	Ministry for the Environment
NZCPS	New Zealand Coastal Policy Statement 2010
UC	University of Canterbury

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1. Introduction

1.1 Background

Christchurch City Council (CCC) has recently conducted a riparian management trial involving cessation of riverbank vegetation clearance in Christchurch City waterways. This report presents results from a survey of īnanga (*Galaxias maculatus*) spawning habitat completed in April 2017. The primary purpose was to assess the effectiveness of the CCC vegetation management trial for improving īnanga spawning habitat. While the trial has wider objectives around improved environmental outcomes, īnanga spawning habitat is directly affected by bank cutting and other forms of vegetation clearance. It is an excellent performance indicator for waterway management as well as being a specific management objective.

The Conservation Act 1987 includes protections relating to spawning fish. Disturbing or damaging the spawning ground of any freshwater fish is an offence under section 26ZJ. The conservation of riparian ecosystems and habitat is also addressed under a range of policies, strategies, and plans, at national (e. g. DOC & MfE, 2000), regional (e. g. ECan, 2005, 2013) and local levels (e. g. CCC, 2015; Jolly et al., 2013). National policy prepared under the Resource Management Act 1991 directly requires the protection of īnanga populations and habitat. In particular, all of the following are required under policy 11 of the New Zealand Coastal Policy Statement 2010 (NZCPS) addressing indigenous biological diversity in the coastal environment (DOC, 2010):

(a) avoid adverse effects of activities on:

> *(i) indigenous taxa that are listed as threatened or at risk in the New Zealand Threat Classification System lists;*
> *(ii) taxa that are listed by the International Union for Conservation of Nature and Natural Resources as threatened;*
> *(iii) indigenous ecosystems and vegetation types that are threatened in the coastal environment, or are naturally rare;*
> *(iv) habitats of indigenous species where the species are at the limit of their natural range, or are naturally rare;*
> *(v) areas containing nationally significant examples of indigenous community types; and*
> *(vi) areas set aside for full or partial protection of indigenous biological diversity under other legislation; and*

(b) avoid significant adverse effects and avoid, remedy or mitigate other adverse effects of activities on:

> *(i) areas of predominantly indigenous vegetation in the coastal environment;*
> *(ii) habitats in the coastal environment that are important during the vulnerable life stages of indigenous species;*
> *(iii) indigenous ecosystems and habitats that are only found in the coastal environment and are particularly vulnerable to modification, including estuaries, lagoons, coastal wetlands, dunelands, intertidal zones, rocky reef systems, eelgrass and saltmarsh;*
> *(iv) habitats of indigenous species in the coastal environment that are important for recreational, commercial, traditional or cultural purposes;*
> *(v) habitats, including areas and routes, important to migratory species; and*
> *(vi) ecological corridors, and areas important for linking or maintaining biological values identified under this policy.*

Īnanga is one of four whitebait species currently listed in the 'at risk' or 'endangered' categories of the New Zealand Threat Classification System (Goodman et al., 2014). This directly triggers the relatively stringent requirement to 'avoid adverse effects' under policy 11(a). Additionally, policy 11(b) sections (ii), (iii), (iv), (v), and (vi) and all highly relevant to īnanga spawning habitat. In achieving these requirements, the importance of īnanga for purposes under policy 11(b) (iv) is of particular interest since juvenile īnanga make up the bulk of the whitebait run (McDowall, 1965; McDowall & Eldon, 1980). This is a highly important cultural and recreational fishery for coastal communities throughout New Zealand (Kelly, 1988).

Consequently, īnanga conservation requires effective protection strategies that also enable a degree of sustainable use. Ensuring the protection of īnanga spawning sites is a practical conservation measure that assists with all of these aspects.

The degradation of riparian zones in lowland waterways is a particular issue for īnanga and other species that rely on riparian habitat for all or part of their life history. This has been a common occurrence in New Zealand history (DOC & MfE, 2000). The prevalence of high intensity land uses in the vicinity of lowland waterways also makes modern-day spawning habitat protection more difficult. Some of these land uses may be components of waterway management undertaken to address different issues. Others may be desired by various community interests in the same areas as spawning habitat. Particular threats include the channelisation of streams and rivers, modification of erosion and sedimentation rates, vegetation removal, and associated changes to the light, temperature and humidity environment. Although other factors may also be important, these changes have contributed to īnanga population decline (Mitchell, 1994; Hickford et al., 2010). Addressing these threats at īnanga spawning sites is a practical focus for management as well as being a policy requirement.

Determining the location of spawning sites is essential for effective management. However, this is not a straightforward task because the habitat requirements are strongly structured by salinity patterns and water levels, both of which are highly dynamic. At the catchment scale, the habitat is found in rivermouth environments close to the upper limit of saltwater intrusion (Burnet, 1965; Taylor, 2002). At the river reach scale the location is finely structured in the vertical dimension with eggs being laid very close to the spring tide high-water level (Richardson & Taylor, 2002; Hickford & Schiel 2011b). This strategy results in the spawning sites being situated high on riparian margins. For most of their development period the eggs are out of water and reliant on the condition of riparian vegetation for protection against desiccation and UV irradiation (Hickford & Schiel 2011a, 2014). They hatch in response to inundation after two to four weeks, usually coinciding with a subsequent spring tide (Benzie, 1968; Taylor, 2002). Due to these specific spatial requirements, īnanga spawning habitat is especially vulnerable to incompatible activities in riparian zones.

Following the Canterbury earthquakes extensive research was completed to investigate the potential for catchment scale habitat shift in Christchurch/Ōtāutahi waterways in response to salinity and relative water level change (Orchard & Hickford, 2016). Compared to the pre-quake pattern the results showed that spawning sites now occur in different locations. Major changes include the finding of many new spawning sites in both catchments and an overall expansion of area utilised in comparison to all previous records (Orchard, 2016). There are a range of management implications associated with this spatial shift, primarily relating to riparian management. In particular, there is a need to control threats at spawning sites to achieve the relevant policy objectives, and this demands attention to activities that take place in areas of spawning habitat, some which have changed.

1.2 Study scope

The CCC trial is an important first step towards developing appropriate management responses to address earthquake change. As is often the case with dynamic systems undergoing change, an adaptive approach is advantageous and can be facilitated by sequential rounds of management interventions and the monitoring of results. The present study contributes to this process and will help to identify the best course of action going forward.

The key components of the study are:

- survey of īnanga spawning habitat in the lower reaches of Christchurch City waterways
- detection and mapping of spawning sites
- occupancy and productivity measurements

The remainder of this report is set out as follows: Section 2 describes the field survey methodology. Section 3 presents the major findings and a comparison of the results with other post-quake data from studies in 2015 and 2016. Section 4 concludes the report with a brief discussion on management implications and recommendations.

2. Methods

2.1 Study area

The study area comprises upper estuarine areas in the Avon/Ōtākaro and Heathcote/Ōpāwaho catchments, both of which meet the sea at the Avon-Heathcote Estuary/Ihutai (Figure 1). The total reach length of the area surveyed was approximately 4 km in each catchment and included a section of Steamwharf Stream (Figure 1). The extent of the survey area is the same as used in 2016 for similar surveys in 2016.

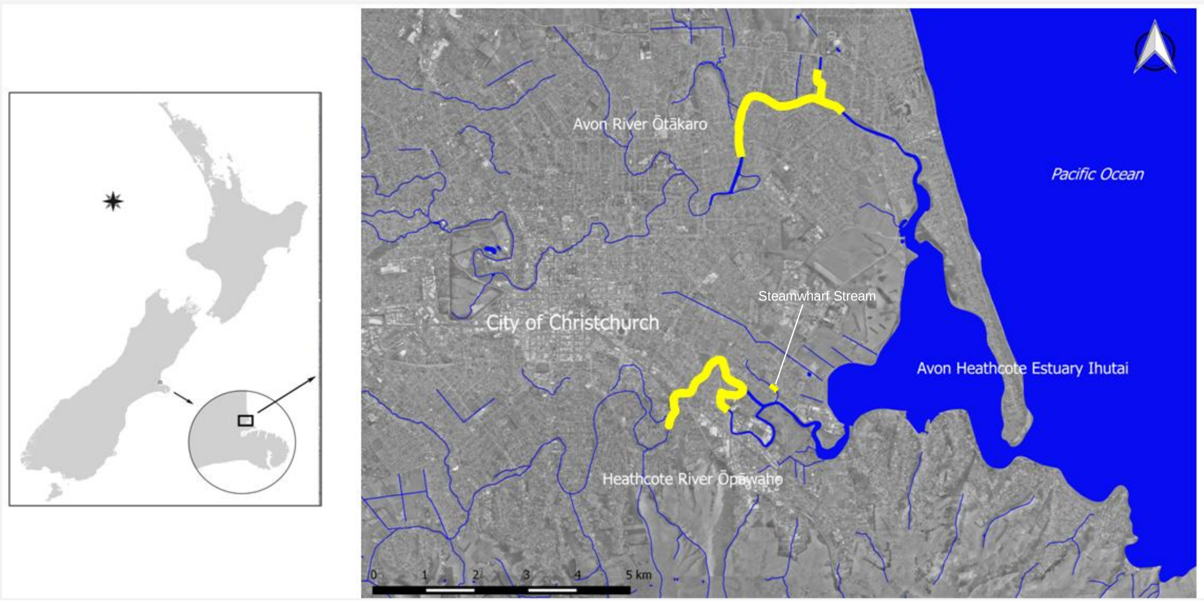


Figure 1. Location map showing reaches surveyed in the post-quake studies.

Historically, the study area was part of an extensive network of riparian floodplain wetlands supporting a rich mosaic of indigenous ecosystems (Tau et al., 1990). Currently, the riparian zone is truncated by a variety of adjacent land uses. Channelization occurs in many places associated with bank stabilisation treatments and other engineered structures including flood-gates. Significant ground level deformation and morphological changes to waterways occurred in the area during the 2010-2011 Canterbury earthquake sequence (Allen et al., 2014; Beaven et al., 2012; Quigley, 2016). The earthquake effects include a variety of implications for infrastructure maintenance, flood management, coastal inundation, and climate risk. Long term decisions are yet to be made regarding the future of a large proportion of the riparian zone in the study area. Of particular note, all of the study area within the Avon/Ōtākaro catchment lies within the planning area currently being addressed in the Ōtākaro / Avon River Corridor Regeneration Plan under the Greater Christchurch Regeneration Act 2016 (Regenerate Christchurch, 2017).

2.2 CCC vegetation management trial

Riparian land uses in the study area include residential, commercial, and industrial activities, together with green space associated with a network of parks and reserves. Beginning mid-October 2016 CCC commenced a trial approach for the management of riparian vegetation with a particular focus on the riverbanks. The primary activity that ceased was grass cutting along the banks, which had previous occurred via the use of mowers, line trimmers or scrub-cutters. Contractors continued with intermittent litter collection along the banks.

In relation to this study, bank cutting in the Avon River ceased throughout the entire known īnanga spawning reach. In the Heathcote River, cutting ceased from Radley Park upstream to Beckford Road (upstream of Hansens Park). No cutting has occurred in recent years downstream of Radley Park, and that remained unchanged for this trial. In addition, no cutting occurred in Steamwharf Stream from the Heathcote River confluence upstream to Alport Place.

Yellow flag iris (Iris pseudacorus) and reed canary grass (Phalaris arundinacea) are nuisance aquatic plants that occur in these rivers. Although CCC is looking into options for controlling these weeds in the near future, no targeted control work has been undertaken for several years in any of the waterways sampled.

2.3 Survey approach

The census survey approach as described in Orchard & Hickford (in prep.) was used, similar to that used in previous post-quake studies. Techniques used to establish the search area are based on salinity and vegetation attributes. The upstream extent of the search area was set at 500 m upstream of the 0.2 ppt saline intrusion peak recorded in the previous studies. This was interpreted as the upstream limit of sea water in both rivers because a 0.1 ppt measurement was consistently recorded for a long distance upstream of the apparent reach of the tide. The downstream extent was set at the transition to dominant saltmarsh vegetation which is considered to be unsuitable for spawning (Mitchell & Eldon, 1991).

For the purposes of surveying a single spawning event, the peak spawning month was identified using data from previous studies (Orchard & Hickford, 2016; Orchard et al., 2016a) to guide selection of the 2017 survey period. The new moon spring tide sequence in late March was targeted for which the dates of peak tidal sequence are close to the peak spawning dates recorded in the previous two years and between the two highest egg production months in both cases (Table 1). Surveys commenced five days after the peak tide in the spring tide sequence starting in the Heathcote/Ōpāwaho followed by the Avon/Ōtākaro (Table 1). Reaches surveyed later in the schedule were more sensitive to egg mortality effects due to the time elapsed since spawning. Results are more likely to underestimate the extent of spawning occurrences in these areas. To minimise these effects and improve comparability the survey schedule was similar to that used in the previous post-quake studies.

Table 1. Tidal cycle data and egg survey periods selected for the 2017 survey compared to the spawning tides with highest monthly egg production in the previous two years.

Year	Peak tidal cycle start	Peak tidal cycle end	Peak tidal height* (m)	Survey periods	
				Heathcote	Avon
This study					
2017	Mar 30	Mar 31	2.5	Apr 5 - 8	Apr 9 - 12
Peak spawning tides in previous years					
2016	Mar 10	Mar 13	2.6	Mar 18 - 22	Mar 23 - 27
2015	Mar 20	Mar 23	2.6	Mar 29 - Apr 3	Apr 4- 11

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

2.4 Vegetation and egg survey methods

Vegetation survey

Habitat condition was assessed in a subjective survey similar to the expert judgement approach of Hicks et al. (2010) but using set criteria to define areas of high, moderate and poor quality habitat (Table 2). All areas of moderate and high quality habitat were subsequently surveyed using a systematic method to detect egg occurrence (see below). The subjective survey was most critical at the beginning of the study since it set a precedent for identifying the areas to be searched for eggs. Subjectivity was improved by initially searching a large proportion of the study area systematically across a wide range of riparian vegetation types.

Table 2. Habitat quality classes.

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

Egg searches

A uniform search effort was applied to areas selected for systematic surveys. For each 5 m length of riverbank three egg searches were conducted at random locations. 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 depending on the bank slope. Where eggs were found the survey was extended at least 50 m either side of the last occurrence to confirm the full extent of spawning irrespective of whether adjacent areas had been earlier deemed unsuitable in the vegetation survey.

Area of occupancy (AOO)

All egg occurrences were associated with a given location that was identified as a spawning site. 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, the length along the riverbank measured, and GPS coordinates recorded for the centre point. The width of the egg band was measured at the centreline of each search transect within the extent of the site. A minimum of three width measurements were taken at all sites and mean width calculated. 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, 2017). 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. Atypical sites where the AOO was not a narrow band (e.g., in low bank gradient areas where a broad distribution can occur) were stratified where >1m wide to improve representativeness. A 1 m^2 grid was overlaid and a 10 x 10 cm quadrat sampled at the centre of the egg band at a random location within each grid. 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.

Egg survival rates

Two sites not affected by vegetation clearance were selected for comparison to data available from a site on Clarendon Terrace site in 2015 that had been cleared using line trimmers subsequent to spawning. The re-measurement was scheduled 14 days after the first measurement as used in 2015. Unfortunately the 2017 survey found no eggs at the same site. A different site was chosen in the Heathcote/Ōpāwaho further along Clarendon Terrace, and another in the Avon/Ōtākaro just upstream of Avondale Road on the true right. See Appendix 3 for site photos.

Comparison with previous post-quake surveys

GPS coordinates of site locations were compared by overlay analysis in QGIS v2.8.18 (QGIS Development Team, 2016). Original data were obtained from the University of Canterbury (UC) Resilient Shorelines programme for similar surveys completed in 2015 and 2016 including a set of estuarine offsets as used in previous studies. These are measurements of the estuarine channel length in relation to the Avon Heathcote Estuary/Ihutai outlet near Rapanui (Shag Rock) calculated from the centre of the main channel lines based on the LINZ 0.075 m urban aerial photos (2015-16) dataset[1]. Coordinates for 2017 spawning sites were transformed to NZTM 2000 and the estuarine offsets calculated. AOO data was binned into contiguous 100 m reach lengths spanning the study based on the offset of the centre-point coordinate of each site. Summary statistics were calculated for the 100 m bins for comparison to similar analyses available for 2015 and 2016.

[1] Available at http://data.linz.govt.nz/layer/3454

3. Results

3.1 Vegetation survey

Habitat quality and vegetation patterns are described in Table 3 and examples shown in Appendix 1. A comparison of habitat quality scores reflecting the dominant habitat condition across the study area is shown in Figure 2. In general this represents an improvement in the availability of high quality habitat versus typical conditions in 2016 (although this varied considerably between months as a consequence of when and where vegetation clearance was occurring).

Table 3. Summary of īnanga spawning habitat condition† in April 2017.

(a) Avon/Ōtākaro

Reach	Description
True left below Avondale Road bridge	Mostly high quality habitat downstream of the large willows in Amelia Rogers Reserve. Extensive spawning sites on the edge of the reserve inside the line of riparian plantings, some overlapping with mown areas.
Lake Kate Sheppard, true left bank	High quality habitat throughout. No overlaps with reserve mowing.
Corsers Stream, true left	Mostly high quality habitat, in places narrow between the stream bank and vehicle access track
True right below Avondale Road bridge	Regular patches of high quality habitat at the foot of the stop-bank interspersed with steep sections of moderate or poor quality habitat. Considerable vegetation recovery since 2016.
True left above Avondale Road bridge	Mostly high quality habitat upstream of the Horseshoe Lake/ Waikākāriki tidal gate in places close the reserve mowing line. Habitat condition generally deteriorates further upstream along Locksley Terrace with steeper bank profiles and sparse vegetation becoming more common there.
True right above Avondale Road bridge	Mostly high quality habitat from Avondale Bridget to Breezes Road deteriorating further upstream due to steeper bank profiles and sparse vegetation. Some sections of steep stony ground or poor or moderate quality associated with the temporary stop-bank.

(b) Heathcote/Ōpāwaho

True left below Woolston Cut tidal barrage	Large area of high quality habitat in the Connal Street recreation reserve on the inside of the prominent bend, tapering to smaller patches further downstream due to steep bank profiles becoming common.
True right below Woolston Cut tidal barrage	Mostly high quality habitat in Radley Park downstream of the concrete retaining wall, tapering to poor quality on the outside of the prominent bend due to a section of retaining wall and otherwise steep banks. Several patches of moderate and high quality habitat further downstream along Cumnor Terrace above Garland Road bridge.
Radley Street bridge – Woolston Cut tidal barrage	Mostly poor quality habitat on both banks. A few small patches of moderate or high quality habitat e.g. on true right just below Radley Street with potential to further restore.
True left above Radley Street bridge	Mostly moderate quality habitat along Richardson Terrace to Jacksons Creek, mostly poor quality above this due to near vertical bank profiles. Only small patches of high quality habitat in this reach with vegetation yet to thicken up in response to the no cut trial. Evidence of continued surface erosion throughout, especially in steeper sections.
True right above Radley Street bridge	Mostly high quality habitat along Clarendon Terrace except where extensive shade. Some sections of poor quality on retained or near-vertical banks below Opawa Road. Above Opawa Road upstream to near Grange Road vegetation has recovered considerably since 2016. Upstream of Grange Road quality deteriorates with generally steep bank profiles to the top end of Aynsley Terrace. Note that King George V Reserve is outside of the area surveyed in this study.
Steamwharf stream	Mixture of high, moderate and poor quality habitat on both banks between Alport Place and Dyers Road. Patches of high quality habitat are situated on narrow ledges between the stream and adjacent property boundaries (true right) or the walking track (true left). Bank profiles generally steepen upstream.

† poor, moderate & high quality habitat as defined in Table 2.

(a) Avon/Ōtākaro

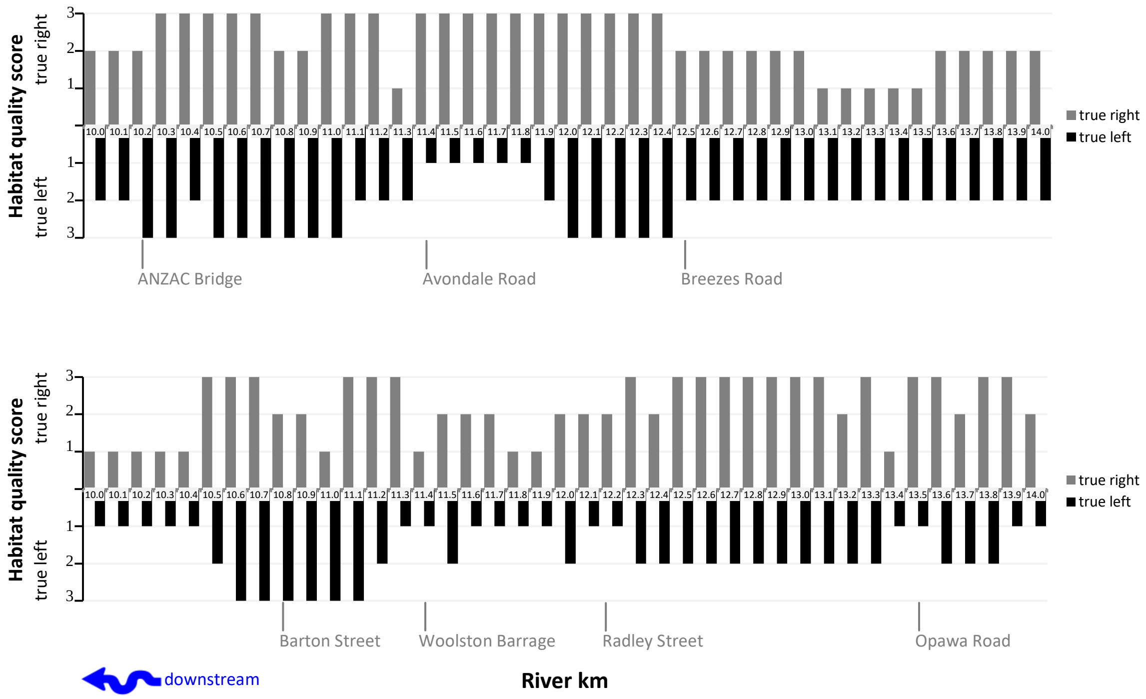


Figure 2. Habitat quality scores reflecting the dominant habitat condition for supporting īnanga spawning in contiguous 100 m reaches in April 2017. (a) Avon/Ōtākaro mainstem. (b) Heathcote/Ōpāwaho mainstem. The contribution of tributaries is not shown for simplicity. River km is the distance upstream from the Avon-Heathcote Estuary / Ihutai entrance following the major channel lines. Habitat quality score 1 = poor, 2 = moderate, 3 = high, as defined in Table 2.

3.2 Spawning sites

Overview of 2017 results

A total of 95 spawning sites were identified in the 2017 survey, 59 in the Avon/Ōtākaro and 26 Heathcote/Ōpāwaho (Figure 3). These totals include seven sites in Lake Kate Sheppard, four in Corsers Stream, and two in Steamwharf Stream. The spatial extent of spawning reach was very similar to that found in previous two years indicating that the post-quake habitat distribution is relatively stable (Figure 3). A selection of site photos is included in Appendix 1.

In the Avon/Ōtākaro the upstream limit was near Niven Street and the downstream limit near Anzac Road, similar to the previous two years. In the Heathcote the limits have expanded in both directions. This was due to the discovery of new sites along Aynsley Terrace upstream of Opawa Road and along Cumnor Terrace downstream of Radley Park. In both cases the vegetation condition has improved since 2016 in these areas in response to the CCC trial. There were also other previously unrecorded sites found across the study area, a total of 18 in the Avon/Ōtākaro and 14 in the Heathcote/Ōpāwaho. Several of these can be attributed to improved vegetation conditions. For example, five of the new Heathcote/Ōpāwaho sites were found on surfaces that were previously maintained as short grass or stubble. The two new sites recorded on Richardson Terrace were on benches that had recovered well in response to the trial. Downstream of Radley Park on the true right the vegetation condition has improved without direct assistance and spawning now occurs close to the Garlands Road bridge.

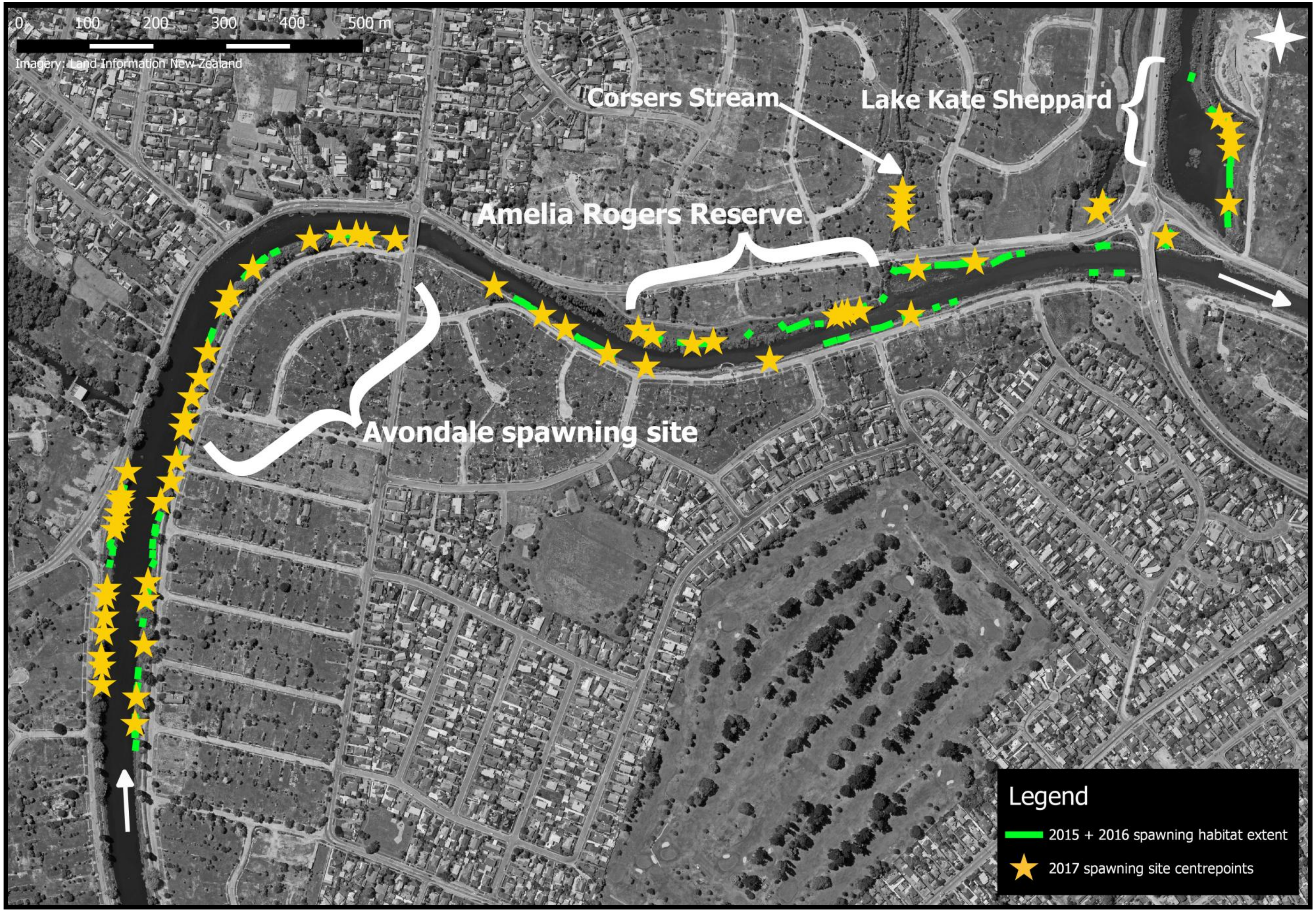


Figure 3a. Avon/Ōtākaro spawning sites identified April 2017 (yellow stars) overlaid on combined 2015 & 2016 data showing the maximum extent of spawning sites measured on any month (n= 7) (green lines).

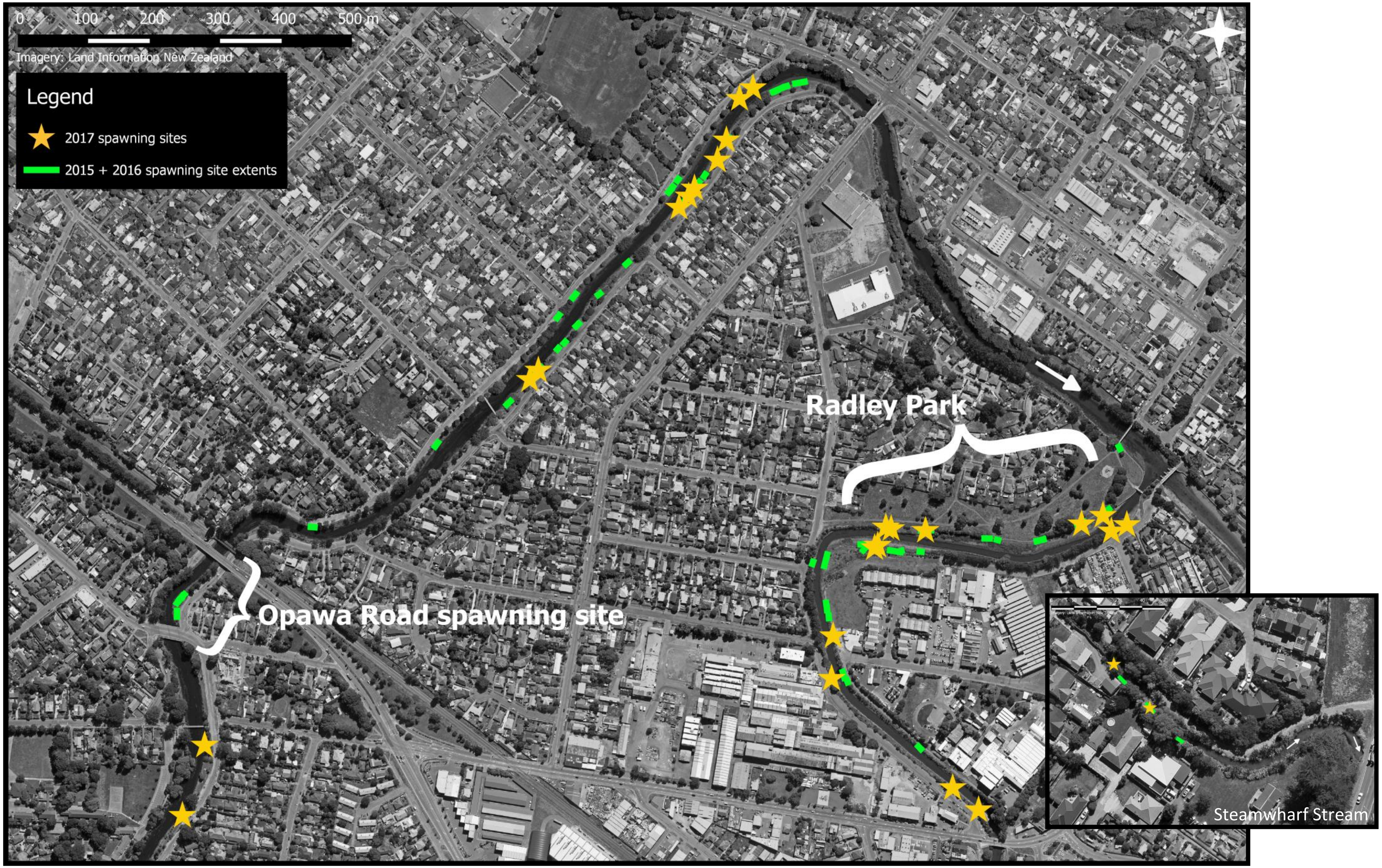


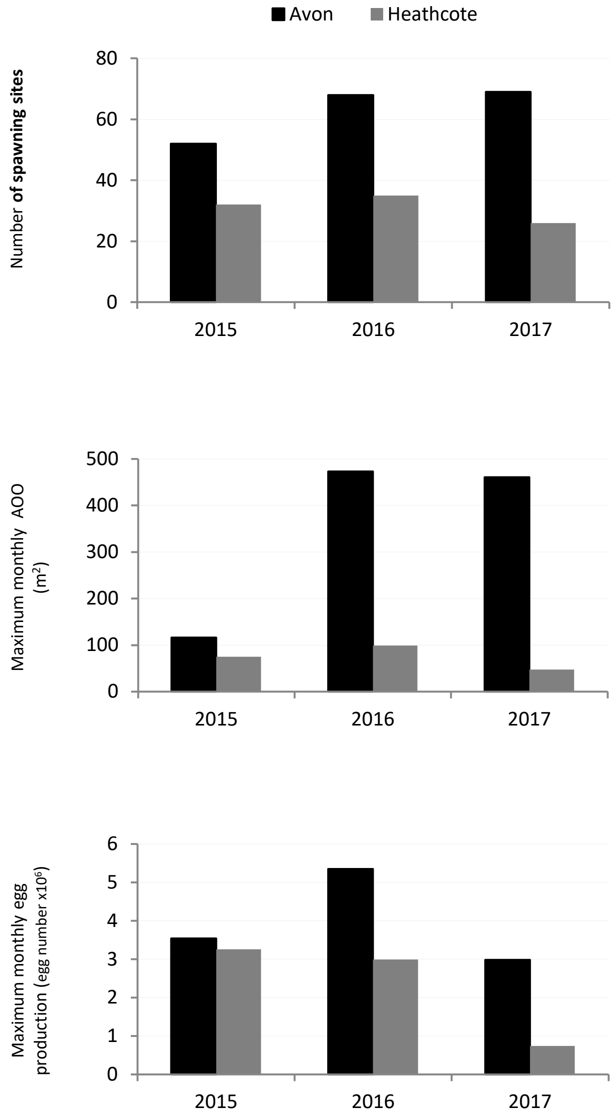
Figure 3b. Heathcote/Ōpāwaho spawning sites identified April 2017 (yellow stars) overlaid on combined 2015 & 2016 data showing the maximum extent of spawning sites measured on any month (n= 7) (green lines). The inset shows Steamwharf Stream.

In the Avon/Ōtākaro four sites were found in Corsers Stream, all above the tide gate. This is the first time spawning has been recorded here. These sites were found outside of the original survey area for this study and there may be other sites upstream in this tributary. The area searched in this study only covered the lower part of the stream on the true left. Many of the other new sites occurred in previous gaps in the known post-quake distribution, in some cases showing an obvious response to improved riparian vegetation. An example from upstream of Avondale Road bridge on the true right is shown in Figure 4. This site occurred in an area that was previously mown to the water's edge. Although the mowing line was relaxed only a short distance it was sufficient to accommodate the position of the high water mark on the spawning tide.

Figure 4. Īnanga spawning at a site that was regularly mown prior to the CCC trial.

Another area where new or expanded sites were found is downstream of Avondale Road bridge on the true right where the vegetation has recovered well in response to the trial. Eight new sites were also recorded upstream of the Horseshoe Lake/Waikākāriki confluence. These are in locations that were not typically mown in maintenance work previously though are close to the edge of the mown area. There was also a considerable area of high quality habitat in both rivers that was not utilised for spawning. This included previously used sites located at a similar elevation on the bank face in comparison to the sites that were used.

A comparison of summary statistics is shown in Figure 5. The number of sites found was similar to the total number of sites identified in the two previous years (Figure 5a). The area occupied by these sites was surprisingly large in the Avon/Ōtākaro and close to the total maximum AOO recorded across all sites identified in the 2016 surveys (Figure 5b). Despite this egg production was down on previous years when compared to the maximum recorded at each site per year (Figure 5c) or the peak monthly productivity recorded per year (see below for further details).



(a) Total number of spawning sites recorded per year.

(b) Summed totals for the maximum AOO recorded at each site per year. This value reflects the area of habitat utilised at least once during the study period.

(c) Maximum monthly egg production recorded in surveys over three years. The 2015 and 2016 values are presented for comparison with the single month figure recorded in 2017.

Figure 5. Comparison of results from spawning site surveys conducted over three years. 2015, n=4 (Feb - May spawning), 2016, n=3 (Feb - Apr spawning), 2017, n=1 (March spawning).

Area of occupancy (AOO)

In the Avon/Ōtākaro the total AOO was 460.8 m². This figure includes 419.3 m² in the mainstem, 36.3 m² in Lake Kate Sheppard, 0.8 m² in Anzac Creek, and 4.4 m² in Corsers Stream. In the Heathcote/Ōpāwaho the total AOO was 47.5 m² with 45.3 m² in the mainstem and 2.2 m² in Steamwharf Stream. Several large sites were found at locations not previously recorded. Examples include new sites in Amelia Rogers Reserve in the Avon/Ōtākaro, and a large site in Radley Park in the Heathcote/Ōpāwaho. Figure 6 shows a comparison of the maximum AOO recorded over three years using all available data binned into contiguous 100 m reaches in each catchment. Each bin reflects the combined data for sites occurring on either bank.

In the Avon/Ōtākaro the notable differences from previous years' are at river km 10.9 – 11.0 reflecting the large sites discovered in Amelia Rogers Reserve. Upstream of river km 11.4 the comparison shows differences reflecting shifting patterns of usage between sites on both sides of the river. On the true right upstream of Avondale Road many of these sites are often a semi-continuous band of eggs along the riverbank as was the case in 2017. On the true left the 2017 results show relatively high levels of occupancy for sites upstream of the Horseshoe Lake/Waikākāriki confluence. In the Heathcote/Ōpāwaho the notable differences from previous years' is at river km 11.0. This was associated with the only large site recorded in this survey. In previous years there have been other large sites in this vicinity, and they may occur on either side of the river.

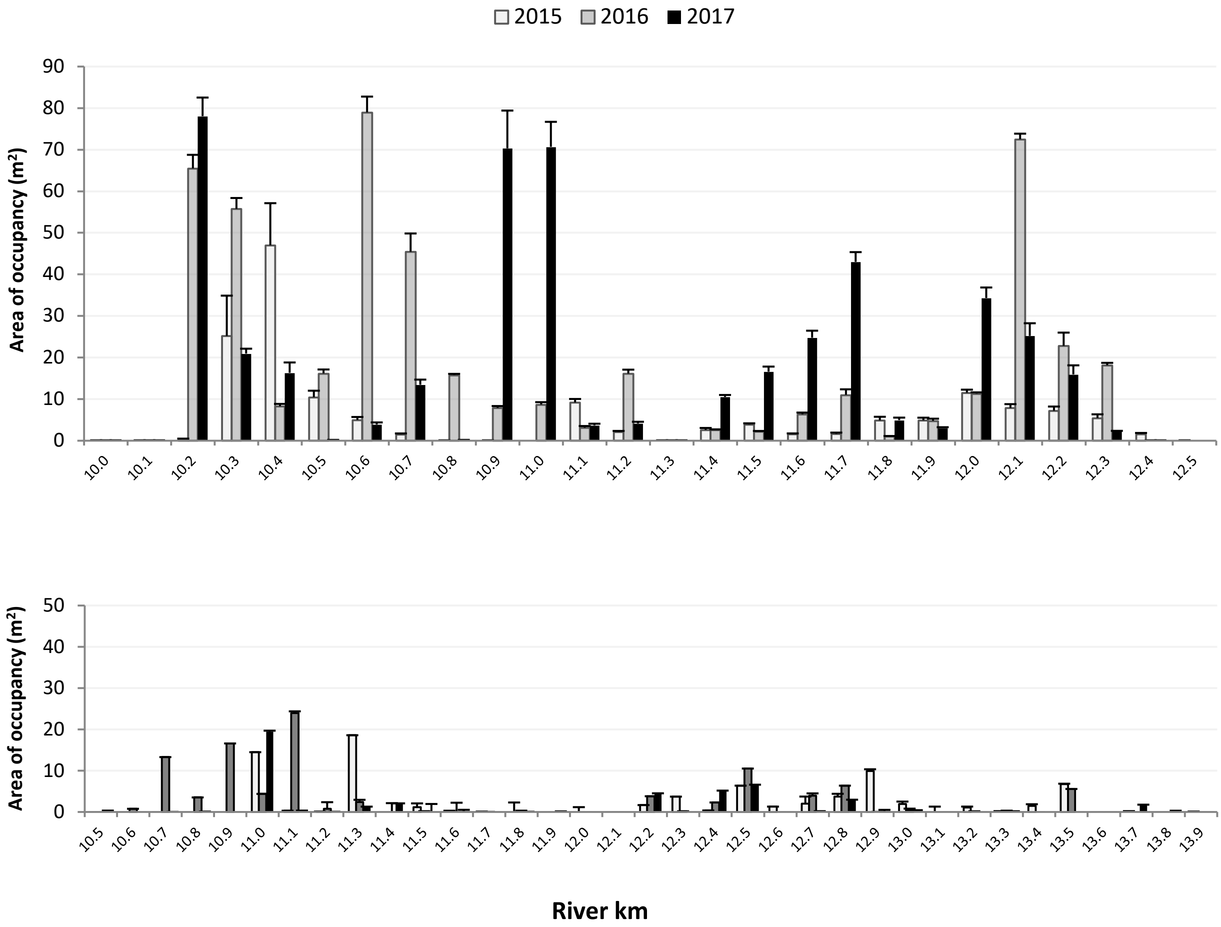


Figure 6. Area of occupancy (AOO) of spawning sites in contiguous 100 m reaches in April 2017 compared to the maximum AOO recorded in the same reaches in 2015 (n= 4 surveys) and 2016 (n= 3 surveys). (a) Avon/Ōtākaro. (b) Heathcote/Ōpāwaho. Note different scales on the x axis. Avon/Ōtākaro values are inclusive of tributaries. For the Heathcote/Ōpāwaho, Steamwharf Stream values are not shown for simplicity. These sites are lower in the catchment at 8.3 – 8.4 river km on the x axis scale.

Egg production

In the Avon/Ōtākaro the total egg production was just under 3 million eggs. The breakdown by sub-catchment was: mainstem 2.6 x 10^6, Lake Kate Sheppard 0.37 x 10^6, Corsers Stream 0.01 x 10^6, and Anzac Creek 0.003 x10^6 eggs. Total production in the Heathcote/Ōpāwaho was 0.74 x10^6 eggs. The breakdown by sub-catchment was 0.72 x10^6 eggs in the mainstem and 18249 in Steamwharf Stream. Figures 7 and 8 show the spatial distribution of production for all sites recorded in this study together with maps showing the pattern of production in 2015 and 2016.

Figure 7. Egg production in the Avon/Ōtākaro. (a) Egg production recorded at each site in this study. (b) Total egg production at spawning sites recorded in 2015 and 2016.

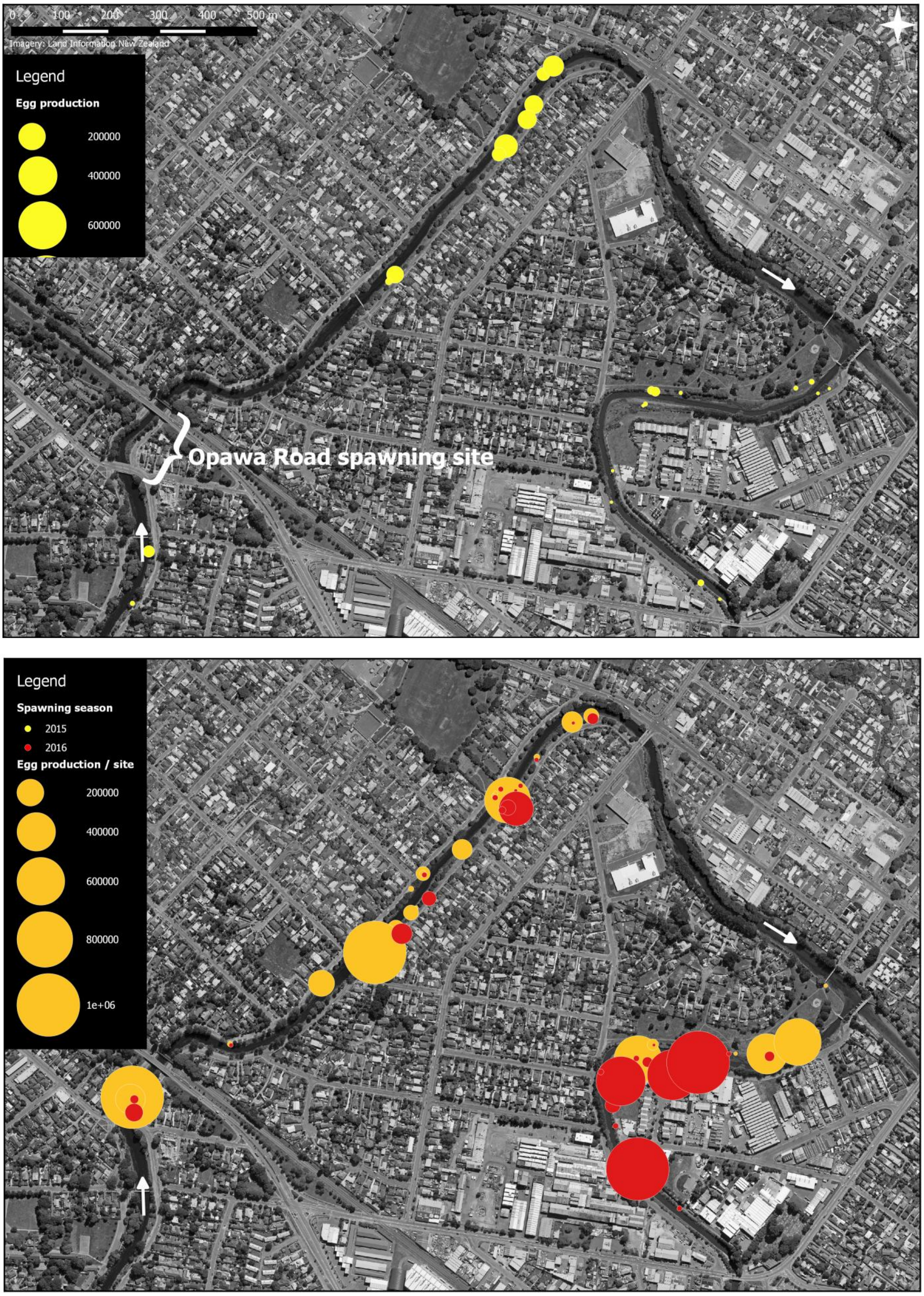


Figure 8. Egg production in the Heathcote/Ōpāwaho. (a) Egg production recorded at each site in this study. (b) Total egg production at spawning sites recorded in 2015 and 2016.

Egg survival rates

The vegetation remained in good condition over the study period at both of two sites selected for re-measurement. At the Avondale Road site (26080 eggs) the survival rate was 84.2%±7.2(SE). This was a patchy site with high densities in clumps of favourable vegetation. At the Clarendon Terrace site (88178 eggs) the survival rate was 67.3%±0.02(SE). This was a less patchy site with relatively high densities throughout. For comparison, a survival rate of 1.6% was recorded at a site re-measured in 2016 following the clearance of vegetation on the bank face using line trimmers (Orchard & Hickford, 2016). See Appendix 3 for site photos. These results are also comparable with survival rates reported in previous studies (e.g. Hickford & Schiel, 2011b).

Comparison of summary statistics with previous years

Although the different months and number of surveys completed in each year makes production comparisons more difficult of īnanga spawning metrics from surveys over three years is shown in Table 4. Over the whole study area the 2017 total production recorded in 2017 was 3.7 million eggs. This compares with totals of 11.9 million in 2015 from four surveys and 18.8 million in 2016 from three surveys (Table 4). A comparison of production between months is shown in Table 5.

Table 4. Comparison of īnanga spawning metrics from census surveys completed over three years.

Catchment		**Year**		
		2015	2016	2017
	surveys completed (n)	4	3	1
Avon	**Number of spawning sites**			
	Avon mainstem	47	59	58
	Lake Kate Sheppard & Anzac Creek	5	9	7
	Corsers Stream	0	0	4
	Total	52	68	69
	AOO			
	maximum (m^2)	116.5	472.9	460.8
	Production			
	total of all surveys (eggs x 10^6)	6.94	13.79	2.98
	Number of spawning sites			
Heathcote				
	Heathcote mainstem	32	32	24
	Steamwharf Stream	0	3	2
	Total	32	35	26
	AOO			
	maximum (m^2)	75.4	99.1	47.5
	Production			
	total of all surveys (eggs x 10^6)	4.93	5.03	0.74

Table 5. Comparison of monthly egg production. The month refers to the spring tide sequence on which spawning occurred. The peak production month (in bold) was March in 2015 and 2016 for both rivers.

Catchment		Year		
		2015	2016	2017
Avon	Feb	661992	4109256	-
	Mar	**3539785**	**5345385**	2982177
	Apr	2104518	4333249	-
	May	637269	-	-
	Total	6943564	13787890	2982177
Heathcote				
	Feb	603014	1610165	-
	Mar	**3256717**	**2991339**	741670
	Apr	1062650	427482	-
	May	3120	-	-
	Total	4925501	5028986	741670

4. Discussion

Vegetation recovery

A range of effects have resulted from the CCC vegetation trial in relation to īnanga spawning habitat. These include the identification of new spawning sites in both catchments in comparison to all previous records. At these sites the trial has demonstrated the potential to restore degraded habitat through vegetation management techniques. The findings are also consistent with recommendations in Orchard (2016) regarding the identification of spawning habitat for protection in statutory plans. These results further suggest that the entire reach between upstream and downstream limits of the known spawning should be regarded as spawning habitat in the mainstem, and in tributaries such as Steamwharf Stream that support spawning. Within these areas there are only relatively short sections of riverbank that have not supported post-quake spawning at least once or could be not be restored. The largest of these within the study area is downstream of Radley Street bridge where steep bank profiles and extensive shading has contributed to the establishment of riverbank vegetation that is currently unsuitable for spawning.

Another notable result was the identification of new post-quake limits of spawning in the Heathcote/Ōpāwaho mainstem. The upstream limit has extended nearly 300 m versus all 2015 and 2016 surveys that included the installation of straw bales as a detection tool in the same area in both years (Orchard et al., 2016b; McMurtrie et al., 2016). This appears to be a direct response to the CCC vegetation trial and may reflect the influence of a more continuous margin of suitable habitat for attracting shoaling adult fish versus isolated artificial habitats (e.g. straw bales) in otherwise inhospitable locations i.e. devoid of bank-side cover. It was also notable that no eggs were found at the Opawa Road spawning site despite it being searched on two separate dates a week apart as a confirmation measure. Spawning was recorded there in all of the 2015 and 2016 surveys. Overall, these results highlight important aspects of spatio-temporal variability. There is a need for survey approaches that can adequately account for these in identifying īnanga spawning habitat for protection (Orchard & Hickford, in prep.).

Alongside the above positive impacts, the trial was only partially successful in some respects. The main aspects in which further improvements could be made relate to:

- areas where the mowing footprint continues to overlap or is very close to the footprint of known spawning sites.
- areas in which the vegetation remains sparse despite the recent protection from clearance. An example is along Richardson Terrace where surface erosion remains evident despite the canopy of long grass, and stem densities at ground level are typically low. This is consistent with other

studies showing that development of a plant community structure favourable for spawning may take several seasons post-disturbance (Hickford & Schiel, 2014).

- some small areas where vegetation clearance using line trimmers on the bank face appears to have continued on the true right of the Avon/Ōtākaro above Alloway Street and true left of the Heathcote/Ōpāwaho along Richardson Terrace. In these locations better delineation of the area requiring protection may be useful.

In the Avon/Ōtākaro habitat conditions have recovered noticeably on the true right below Avondale Road in response to cessation of flood management clearance. The spawning sites in this reach are often found at the foot of the stop-bank on stony substrates that are prone to drying out when the vegetation is sparse. The opposite bank in Amelia Rogers Reserve is one of the few areas without engineered embankments within the study area. It supports an extensive area of high quality spawning habitat resulting from suitable vegetation combined with a gentle bank slope. However this is one location where the mowing line continues to encroach on spawning habitat. In the 2017 survey the mowing line coincided with the upper limit of several spawning sites indicating that the spawning event may have occurred after mowing. In 2016 the spawning sites were situated in the area that continues to be mown (Figure 9).

(a) (b)

Figure 9. Spawning sites in Amelia Rogers Reserve. (a) 2016 photo showing the footprint of a March spawning site that was mown after spawning had occurred, resulting in destruction of the habitat and close to 100% egg mortality. (b) 2017 photo showing a nearby spawning site that was used in both 2016 and 2017. The footprint of the 2017 site is shown by the location of the flags on the edge of the mown area, and approximate position of the 2016 site (which was considerably larger) is shown by the dotted line.

In several other locations inundation on spring high tides typically overtops the obvious (visual) line of the riverbank. In general, the CCC trial has been implemented by relaxing the mowing line a little versus its typical location in 2016. However, in areas with gentle bank gradients small changes in inundation levels can translate to substantial horizontal shifts of the high tide water mark. These same areas may support extensive spawning sites. In most cases it would be difficult for mowing contractors to detect the upper limit of the inundation area (and therefore the location of spawning sites) without guidance and/or local knowledge. These results suggest that further guidance is required to develop a practical approach for reserves maintenance that is effective in avoiding disturbance to known sites. The above situations also illustrate an important aspect of resilience, since some variance in the location of sites can be expected in the future (e.g. on slightly bigger tides or in response to longer term change).It is likely that a combination of detailed maps and field orientation and/or the use of delineation measures on the riverbank would be effective in providing support to contractors for identifying spawning habitat. Once an appropriate mowing line is established, regular maintenance is likely to be straightforward complemented by monitoring to detect ongoing change. Often the areas concerned are relatively wet and a wetland plant community is likely to re-establish.

In the Heathcote/Ōpāwaho habitat conditions have recovered noticeably on the true right from Grange Street to Radley Street. On the true left along Richardson Terrace only patches of high quality habitat have developed, as noted above, with most of the vegetation remaining sparse at ground level. Most of this stretch is dominated by reed canary grass (*Phalaris arundinacea*). On the true left the bank profiles are often steep and this in combination with the southerly aspect may be hampering the establishment of other plant species due to increased shading in comparison to the true right. There is also evidence of continued surface erosion in some places. Below Radley Street the habitat condition is similar to that observed in 2016. There were no specific changes made to riparian vegetation management in those areas under the CCC trial (G. Burrell, pers. comm.). In Steamwharf Stream further restoration work is needed in some areas that could support spawning but are currently erosion prone with sparsely vegetation. The spawning sites being used are narrow ledges on relatively unstable banks in confined locations between high intensity land uses and the stream channel. These sites may be vulnerable to disturbance and proactive protection measures would be beneficial.

Challenges for pest plant control

During the trial period no pest plant control programmes were conducted within the study area (in areas of īnanga spawning habitat). However, this is a particular challenge due to the spatial overlap between spawning habitat and the distribution of weed species. In the Heathcote/Ōpāwaho, reed canary grass is the primary concern along with *Glyceria maxima* in the lower reaches. Spawning has been recorded on both species in post-quake studies (Orchard & Hickford, 2016). However the discovery of high levels of egg production in habitats dominated by reed canary grass is the most problematic aspect. These sites account for the majority of all egg production in the catchment. Furthermore this pattern has been consistent in all of the post-quake surveys and has included the identification of several highly productive sites in pure stands of reed canary grass. In the Avon/Ōtākaro the situation is quite different with yellow flag iris (*Iris pseudacorus*) being the main invasive species of concern. The distribution of this species partially overlaps the spatial distribution of spawning sites and in terms of the inter-tidal range is similar to *G. maxima*. For these species control activities also have the potential to destroy spawning habitat depending on the control methods chosen. Control strategies that are effective in protect spawning habitat are required. Potential avenues include staged approaches, careful timing of control activities, and interactions between these options and the choice of eradication methodologies. There is also the need for a long term view that considers the future trajectory of the ecosystems involved and ideally encourages transition to a self-maintaining state that meets biodiversity and other objectives.

Area of occupancy and habitat utilisation

Although the single month of data from 2017 precludes trend analysis, the maximum AOO recorded for individual spawning sites provides a useful comparison point. In the Heathcote/Ōpāwaho, the total AOO recorded in this study was around half of the maximum area occupied at least once in 2016 (Table 4). This suggests that the area being utilised was comparable to previous years although the sites were spread out over a slightly longer length of riverbank. As was the case in the Avon/Ōtākaro, a considerable area of high quality habitat was not utilised suggesting that spawning was not limited by habitat availability on this particular spawning tide.

In the Avon/Ōtākaro the AOO was surprisingly high (460 m^3), almost matching the sum of maximum AOO's at all sites recorded in 2016 (Table 4). Relatively speaking this finding is important since it shows very high occupancy in the catchment for the second year running. For comparison, the next largest spawning area recorded in the National Īnanga Spawning Database is 215 m^3 in the Otaika catchment in Northland, and the Avon/Ōtākaro has historically supported around 50 m^2 based on an extensive history of surveys (Taylor, 2002). This is consistent with a substantial earthquake induced shift that has effectively created habitat. However an important factor is the size of the adult fish population. Due to a lack of baseline data it is not possible to ascertain whether this has also increased since the earthquakes. If so, it would suggest that the extent and/or condition of adult habitat might also have improved. In any event, both adult/rearing habitat and spawning habitat are important areas for management and require protection under policy.

Since adult fish can be observed in the lower river year-round there may be substantial adult habitat in the same general area that supports spawning habitat. All of the side tributaries are likely to be important in this part of the catchment along with connections to riparian wetlands. An integrated catchment management approach addressing the condition of riparian margins throughout the corridor would likely be beneficial to provide for the different life cycle stages of īnanga and help reduce high mortality bottlenecks. Important management aspects include waterway connectivity and the characterisation of fish passage barriers. Assuming that earthquake ground movements may have improved these aspects of catchment ecology, it would be important to ensure that the gains are secured in the design of future infrastructure and earthquake recovery activities. For example, earthquake-damaged tide gates have potentially enhanced fish passage. Any tide gate repair or re-design work should aim to maintain or enhance fish passage and other aspects of ecological connectivity. These include different aspects of the 'fish passage' concept that are important to īnanga life history. Aspects requiring specific attention in the form of ecological design including access of adult fish to suitable spawning locations and tidal connectivity to provide the inundation cycle needed for hatching and egress of larvae from the catchment.

The finding of spawning sites in Corsers Stream upstream of the tidal gate is itself significant and indicates that hydrological connectivity to Travis Wetland may be important. Although the productivity of these sites was modest there may be potential for further enhancement of habitat in the side tributaries. Establishing the spatial structure of the adult īnanga population across the Ihutai catchment may also be important. Questions that are directly relevant to spawning site (and adult habitat) management include whether sub-populations are relatively stable since if this was the case there may be specific spawning requirements in different sub-catchments (for example in Travis Wetland and Lake Kate Sheppard). These aspects could be influenced by effects on fish passage. It is also important to know whether there is significant exchange of breeding stock between the two main rivers. Answering these questions requires a focus on habitat utilisation that can be supported by spatial ecology studies to quantify the areas currently used and responses to management interventions.

Due to the magnitude of the change that has been detected in comparison to historical data, the factors responsible for creating New Zealand's largest known spawning site also deserve more attention. Establishing baseline data on habitat structure and monitoring future trends are important needs to inform the design of planning methods and tools such as mapping. The apparent excess of habitat is a positive aspect of the CCC trial and suggests that there may be some room to move when accommodating other land uses and infrastructure developments. However it is important to identify the variability in location and extent of spawning habitat on different tides and between seasons. Without repeat-month data it is impossible to know which spawning tide may be the peak event of the season with the highest habitat requirement. It is also important to consider scenarios for the impact of future change such as the effects of sea level rise on the present-day distribution of habitat.

Production

When compared to the AOO results the egg production figures are more modest. Production in both catchments was less than the peak month recorded in the each of the past two years (Table 5). In comparison to the AOO pattern this reflects differences in average egg densities. In this case, the between-year production comparison paints a much different picture and could indicate that the adult population is in decline relative to 2016. However, the true situation cannot be ascertained without repeat-month data to confirm whether the late March spawning event reported here was the peak spawning event of the season and other aspects important to the overall trend. This illustrates the utility of the available data as a post-quake baseline, but also the importance of comparable measurements in the future to inform management and identify trends. Egg production in the Heathcote/Ōpāwaho was surprisingly low in consideration of the earlier studies and despite an abundance of high quality spawning habitat supported by the CCC trial. Further work is required to establish whether there any substantial changes are underway that could have implications for īnanga conservation.

Limitations

Several important limitations must be recognised when interpreting the results of this study, many of which are discussed above. The single month of data from the 2017 spawning season make direct comparisons with earlier data more difficult. However, these data have been relied upon as the baseline conditions for consideration of effects attributable to the CCC trial. Throughout this report the most meaningful comparisons have been selected in an effort to shed some light on the responses of īnanga to the vegetation management trial. Ideally similar datasets would be available from before and after the management intervention to inform an assessment of effects. In addition, confounding variables such as egg mortality effects between the date of spawning and the date of survey must be kept in mind. The potential for stochastic effects to have influenced any of survey results reported here is impossible to ascertain and is an important limitation for interpretation.

5. Conclusions

The CCC vegetation trial has produced demonstrable benefits in terms of increasing the availability of high quality spawning habitat. This was reflected by relatively high AOOs being recorded for a single spawning event, the discovery of new sites, and expansion of the reach known to support post-quake spawning in the Heathcote/Ōpāwaho.

The egg production results suggest a possible adult population decline and require follow-up to determine the actual trend using the other post-quake studies as a baseline. A minimum of three months' data is required to interpret seasonal trends and to facilitate between-year comparisons.

On a positive note, this study has confirmed that the Christchurch City waterways are home to New Zealand's largest known area of īnanga spawning habitat. This in itself is an important find and cause for celebration. It is important that the factors leading to its creation are better understood. This will help secure the gains for īnanga conservation and set a useful example for waterway management in dynamic natural environments.

6. Recommendations

The key recommendations for management arising from this study are:

- Habitat protection requirements should be applied to a contiguous reach of riparian margin between the known upstream and downstream limits of spawning on a sub-catchment basis. Within these areas there are only small sections that do not currently support spawning or could be not restored.
- The development of more specific guidance materials is recommended to support contractors involved in waterway and riparian reserves management. The focus of policy requirements is on avoiding activities that involve damage and disturbance (e.g. mowing) of spawning habitat.
- More permanent self maintaining plant communities could be established as a long term approach to riparian management. However, plantings and other restoration activities need to be specifically designed to avoid impacts on īnanga spawning habitat.
- With correct placement, riparian plantings could be used to help delineate spawning habitat, thereby assisting its protection and simultaneously improving other biodiversity values and aesthetics associated with the stigma of 'unkempt margins'.
- Pest plant control programmes need to be specifically designed to avoid adverse effects on īnanga spawning habitat and are particularly challenging in the Christchurch City waterways. The development of appropriate strategies is urgently required to support work on invasive species control.

- Ongoing monitoring is required to establish the effectiveness of management going forward. This will demonstrate whether relevant policy objectives have been achieved and provide practical support for impact assessments and other tools to inform decision-making.
- A minimum of three months' data and preferably more is required to interpret season trends in spatial data and other indicators of success and facilitate comparisons between years.
- An integrated catchment-wide approach to riparian management is recommended. This is important for the different stages in the īnanga life cycle and will assist in managing the effects of different land-use options and building resilience to future events.

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Appendix 1. Examples of spawning sites in the Avon / Ōtākaro catchment. (a) sites along Locksley Terrace on the true left bank.
Note: yellow flags are used to mark the upstream and downstream limits of the spawning site in all photos.




Appendix 1. Examples of spawning sites in the Avon / Ōtākaro catchment. (b) sites above the Horseshoe Lake/Waikākāriki confluence along New Brighton Road on the true left bank.

Appendix 1. Examples of spawning sites in the Avon / Ōtākaro catchment. (c) sites upstream of the Avondale Road bridge on the true right bank.

Appendix 1. Examples of spawning sites in the Avon / Ōtākaro catchment. (d) sites upstream of the Avondale Road bridge on the true right bank along Hulverstone Drive.

Appendix 1. Examples of spawning sites in the Avon / Ōtākaro catchment. (e) sites downstream of the Avondale Road bridge on the true left bank in Amelia Rogers Reserve.

Appendix 1. Examples of spawning sites in the Avon / Ōtākaro catchment. (f) sites on the true left bank of Corsers Stream above the tide gate.

Appendix 1. Examples of spawning sites in the Avon / Ōtākaro catchment. (g) sites in Lake Kate Sheppard (top), in the wetland near the Anzac Road bridge (bottom right), and in Anzac Creek near the New Brighton Road culvert (bottom left).

Appendix 2. Examples of spawning sites in the Heathcote / Ōpāwaho catchment. (a) clockwise from top left; furthest upstream site on Aynsley Terrace, spawning along the edge of the reserve near the Aynsley Terrace footbridge, two views of a site on Clarendon Terrace, on the true right bank.

Appendix 2. Examples of spawning sites in the Heathcote / Ōpāwaho catchment. (b) spawning sites in the Radley Park area, on the true right bank.

Appendix 2. Examples of spawning sites in the Heathcote / Ōpāwaho catchment. (c) Spawning sites in the Connal Street area, on the true left bank (top), two sites in Steamwharf stream (bottom).

Appendix 3. Sites re-measured to obtain egg survival rates. (a) Clarendon Terrace (Heathcote/Ōpāwaho, 88178 eggs). (b) Avondale Road (Avon/Ōtākaro, 26080 eggs). (c) & (d) 2015 site on Clarendon Terrace with 118000 eggs for which the mortality was 98.4% following the clearance of vegetation on the banks (right).