Halswell and Heathcote Aquatic Values; selected aspects;

monitoring round # 4

Prepared for:
Christchurch City Council

AEL Report No. 90

Mark Taylor
Winsome Blair

Final Report

September 2012

Brown trout from the Heathcote River in the vicinity of Centennial Park

Aquatic Ecology Ltd.
PO Box 3254
Christchurch 8140
Telephone/ Facsimile (03) 366-4070
Email: info@ael.org.nz

Contents

1 Executive Summary

This document reports on the reassessment of selected freshwater fish habitats in the Heathcote and upper Halswell Rivers. It provides an update of a number of habitats previously assessed in the summers of 1989 and 2004 for the Heathcote River, and in 2004 for the upper Halswell River (Knights Stream, South-West Christchurch Stormwater Management Plan). Of note, the summer 2011 reassessments were all undertaken after the September 4 2010 earthquake and aftershocks, with most after the February 22, 2011 earthquake event.

One particular Heathcote River site (downstream of Tennyson Street) was assessed just before the February 22 earthquake, and re-assessed 7 weeks after that date. Two earlier baseline surveys had been conducted at that site. The assessment of this particular site, immediately before, and immediately after the February 2011 earthquake, illustrated a marked change in fish community following the earthquakes, with a significant increase in the number of shortfin eel elvers (i.e. eels less than 120 mm). The number of adult eels, both shortfin and longfins, were about the same at this site.

The reduction in bluegill bully abundance was echoed at each of the other known significant bluegill habitats, a fast-flowing reach downstream of Colombo Street, and in Cashmere Stream downstream of Hoon Hay Valley Road. We recommend that these sites be remediated by the extraction of sand and silt from the stream gravels, as bluegill bullies are considered to be highly vulnerable to bed sedimentation. Of interest was the identification of a single bluegill bully, in suitable habitat, upstream of Rose Street, adjacent to Centennial Park.

A resurvey of the upper Halswell catchment (Knights Stream) also revealed increased eel numbers, particularly longfin eels, an encouraging sign given the conservation status of this species, and that the river discharges into a nationally significant commercial eel fishery (Te Waihora, Lake Ellesmere). Fish biodiversity at the surveyed sites in Knights Stream had generally increased compared to the 2004 survey, although the loss of a significant koura breeding habitat near the corner of Sabys and Candys Roads, through seismic activity, was noted. It is recommended that this habitat be remediated, and if necessary, re-seeded with koura stock from other habitats in the middle Canterbury area.

Other than koura and bluegill bully, species richness was maintained across the monitoring sites. In particular longfin eels were found at a greater number of sites than previously.

A trout spawning survey was conducted in early August 2011, following on from the last survey in 2007, 2003, and what is thought to be inaugural survey, in 1996. Redd (trout egg congregations) numbers were little changed compared to 2007, but redd distribution had altered, with a thinner distribution along the spawning grounds adjacent to the Princess Margaret Hospital, and more redds along the reach following Hoon Hay Road. Of interest, was the record of a single trout redd in the vicinity of Warren Crescent, as trout spawning activity had not been observed upstream of Curletts Road since 1996. It was considered possible that spawning habitat suitability had decreased in Heathcote River mainstem, possibly due to bed siltation, with relatively increased preference for spawning gravels upstream of the Cashmere Stream. The presence of bluegill bullies in the upper reaches (Rose Street), may also be an artefact of upstream distribution shift due to increased sedimentation of the lower reaches, both from seismic activity and gradual sedimentation of gravel reaches.

2 Introduction

Since 2002, monitoring of aspects of freshwater fish ecology has been undertaken annually on the city rivers, and since 2007, with a strategy of surveying each of the three principal catchments (Avon River, Heathcote River, and Styx River) once every three years. In recent years, the upper Halswell River, including Knights Stream, became integrated into that monitoring programme, and given that the Heathcote and Halswell River catchments are adjacent to each other, it was considered logical to integrate the monitoring programmes on these two river catchments. Thus, this report provides an update of fish values within the Heathcote River and upper Halswell River sub-catchment, and compares and discusses the results to data from the same sites in previous years. Specifically, emphasis is placed on inanga spawning sites, trout spawning habitat, and resurveying selected sites based on the past studies in both the Heathcote and upper Halswell Systems (Eldon & Kelly 1992; Eldon *et al.* 1989; Eldon & Taylor 1990; EOS Ecology Limited *et al.* 2005). It is also important to note that the field programme bracketed a time of significant seismic activity in both catchments. This is likely to affect these comparisons, depending on the actual timing of the re-survey in respect to significant aftershocks.

3 Previous Studies

3.1 Heathcote River

General fish survey and monitoring work on the Heathcote River has been piece-meal and sporadic. Following the inaugural general fish study in the catchment (Eldon *et al.* 1989), fishing of the upper Heathcote catchment was also carried out in 2003/2004 as part of the South-West Christchurch Area Plan (EOS Ecology Limited *et al.* 2005), followed by a survey of the lower catchment in late summer and autumn 2004 (Taylor 2005). The 2004 study in the lower catchment was notable for identifying the bluegill bully in the catchment, despite not being identified in the 1989 study. This species now has conservation status ("declining" Allibone *et al.* 2010). Conversely, common smelt and yellow belly flounder were not identified during the later surveys, although present in 1989. In 2005, a "7 reaches" 'vision' document was prepared for the lower Heathcote River (Colombo Street downstream to Hansens Park) (Taylor & McMurtrie 2005), in respect to the then recently-adopted '6 visions' holistic management strategies for waterways. These visions are, in alphabetical order: culture, drainage, environment, heritage, landscape, and recreation (Christchurch City Council 2003). In 2007, a brief study was undertaken on the then recently constructed lower Heathcote ponds where a population of tench were identified (Taylor 2007), which was then subsequently drained and the population eradicated (Helen McCaughan, pers. comm.).

In parallel with the these studies, inanga spawning on the Heathcote River has been monitored for many years, commencing from the inaugural Heathcote survey (Eldon *et al.* 1989) to periodic checks since then (including the discovery of the Opawa site in 1994, and its redevelopment in the summer of 1995 (Taylor 1996b). The redeveloped Opawa habitat, reached a peak in utilisation for inanga spawning in 1996 (Taylor 1999), but became overtaken with weeds since then. In 2007, no inanga eggs were found at the re-developed Opawa Road site (Taylor & Chapman 2007), with a thick sward of reed canary grass smothering the original introduced grasses, and native vegetation.

In addition to inanga spawning, trout spawning has also received particular attention. The inaugural Heathcote River fish study reported a surprising total absence of trout in the catchment, despite intensive surveying during the summer months in 1989, although anecdotally trout were "jostling each other for space on the spawning gravels ... in the 1960s" (Eldon *et al.* 1989). However, confirmation of the presence of both brown trout, and trout spawning in the Heathcote River was obtained in 1996, which was the first GPS-based trout redd survey on the Heathcote River (Taylor 1996a). The next trout spawning survey was conducted in 2003, which reported a reduction in trout spawning habitat in the upper reaches, but that trout spawning extended further downstream, to near the eastern end of Martin Avenue (near Beckenham Park) (Taylor 2003). The third survey was conducted in 2007, and over the same reach as in 2003, but with the exception of the unproductive Cashmere Stream which almost completely lacks spawning gravels (Taylor & Chapman 2007). The 2007 survey confirmed the trend of declining trout spawning in the upper reaches, although numbers of trout redds counted in the mainstem - between the Cashmere Stream confluence and Colombo Street, had increased.

Following the June 2010 aftershocks, interest was expressed by Environment Canterbury and Christchurch City Council about the impact of seismic disturbance on trout spawning activity and trout spawning habitat, as trout spawn during the winter months. This led to a field investigation in the status of trout spawning activity in the Avon River, with water quality data also collected from the Heathcote River (Taylor *et al.* 2012). Some of these results are also re-presented here in the specific context of the Heathcote River

3.2 Halswell River

Relatively little ecological monitoring data is available for the upper Halswell River. A number of aquatic habitats in the CCC administrative area were evaluated as part of the South West Christchurch Area Plan (Christchurch City Council 2009; EOS Ecology Limited *et al.* 2005). An update of trout spawning potential, which now appears to be effectively nil in the Knights Stream catchment, was undertaken in the winter of 2007 (Taylor & Chapman 2007). A subset of the SWAP sites were reconsidered in a consideration of the Halswell West Development Area, including the koura breeding habitat after the September 2010 earthquake (Pattle Delamore Partners Ltd 2003).

4 Objectives

Initially the scope of the monitoring programme was covered under the CCC contract CN4600000834, which was the supply of services agreement for monitoring Waterways in the Halswell and Heathcote catchments which fall within the boundaries for Christchurch City. The core services to be supplied under this contract were outlined in Appendix A of the contract documentation:

1. Halswell River fish monitoring and re-sampling sites surveyed in 2004 for the South West (Christchurch) Area Plan.

2. Heathcote River trout spawning survey and an investigation into trout redd quality.

3. Fish survey of seven upper Heathcote and two lower Heathcote sites, previously surveyed in 1989, and 2005 respectively.

However, as suggested above, the scope of the programme was extended following the earthquake on February 22, 2011. This extension covered a trout spawning survey of the Avon River, to compare post-earthquake trout spawning activity to pre-earthquake activity, and the compilation of data relating to water quality within the trout egg nests, termed redds. This work has been reported separately to Environment Canterbury with a focus on the impacts on the Avon River (Taylor *et al.* 2012). By means of a control, water quality data was also obtained from redds in the Heathcote River, and an upland tributary of the Otukaikino River, which is just within the City's northern boundary.

5 Methods

There were two principal phases to the fieldwork. Firstly a late summer/autumn field programme in the Halswell and Heathcote Rivers, with the main field survey undertaken between 1st Feb – 14th April 2011. This was followed by a winter trout redd survey of the Heathcote River.

5.1 Summer Survey; sites and methods

The survey was undertaken during settled weather, with no significant period of high stream flows. However, the survey period did bracket a time of significant seismic unrest. The fieldwork commenced in the summer months after the M7.1 earthquake on September 4 2010, and extended before and after the M6.3 earthquake on February 22, 2011.

All of the 13 re-surveyed sites were re-assessed based on field surveys from 3 previous studies (Eldon *et al.* 1989; EOS Ecology Limited *et al.* 2005; Taylor 2005)(Table 1). For the 8 distinct sites in the Heathcote River catchment (Fig. 1), these previous sites were a combination of 6 survey sites from the inaugural 1989 Heathcote study (Eldon *et al.* 1989), 2 sites from a study of fish values in the middle reaches of the Heathcote River mainstem (Taylor 2005), and 2 sites in the upper catchment initially surveyed as part of the 2004 South West Christchurch Integrated Catchment Management Plan survey (SWAP)(EOS Ecology Limited *et al.* 2005). Two of the 8 sites had been previously fished twice as part of these 3 studies, with a 3rd site, in Cashmere Stream, having been surveyed several times since the SWAP study. Originally it was proposed to fish the Eldon (1989) Westmorland Site, but the waters were deep at that particularly site, and while the 1989 report states it was undertaken with a back-portable packset, the original card record clearly states it was fished with a powerful fishing machine powered by 4-stroke engine (NZFFDB 10358). This method is now deemed dangerous and was irreproducible in any instance. In the less-surveyed Halswell River catchment, a re-assessment of the 5 SWAP (2004) sites was undertaken (Fig. 2).

At all sites, every endeavour was made to fish the same reach as previously surveyed. This was relatively easy to do for the SWAP sites, and the Taylor (2005) study, due to reference to the accurate GPS fixes and the use of site photos. However, the site boundaries of the Eldon *et al.* (1989) sites were more difficult to geo-reference accurately, as the study pre-dated GPS technology, and no site photos were available. However, a site map is provided in the report, and NZMG co-ordinates were available off the New Zealand Freshwater Fish Database, along with some site descriptions.

Twelve of the 13 sites were shallow (mean depth < 0.5 m), and were initially surveyed using a MAF Fisheries portable packset fishing machine (in 1989), or its successor, the EFM Kainga 300 machine used in the later surveys (2004, 2005), and this study. Both machines are powered by a 12V battery supply, and probably having similar fishing efficiency.

For this study, a voltage setting of 200 V was employed, the minimum level required to achieve an effective electric field for capturing small fish with a current of 300-400 mA. Electric fishing serves only to briefly (approx. 3 seconds) render fish unconscious to facilitate their capture in nets for identification. Overall conditions for fish capture using electric fishing were adequate, owing to the suitable, but low water conductivity, high clarity, and swift water currents. The machine incorporates a timer, which allows the effective fishing time and effort to be recorded. All fish were anesthetised, identified, measured and released unharmed into their resident habitat.

The Quaifes Ponds were electric fished around the shallow margins, and netted in a similar way as the 2004 survey. A fleet of 4 baited fyke nets and 2 baited Gee Minnow traplines (a total of 10 traps) were set overnight in deep waters. The fyke nets possessing a single wing of 2.1 m in length, and a hoop size of 0.45 m. The stretched-mesh size of these nets was approximately 12 mm. Nets were set in the evening of 17 March, and raised the following day. The set time varied from approximately 15 hrs to 18 hrs. All fish were anesthetised, identified, measured and released unharmed into their resident habitat.

Table 1. The 13 re-surveyed sites fished during this study, and their original study.

This survey Site No.	Location	Survey dates, this survey in bold, with inaugral survey data unbold.	Original Site No.	Fishing method this study.
1	Tennyson St.	Jan 1989, April 2004, **2/2/2011, 14/4/11**	Site 139 Eldon *et al.* (1989)	Repeat-sweep electric fishing
2	Rose St.	Jan 1989, **2/2/11**	Site 114 Eldon *et al.* (1989)	Repeat-sweep electric fishing
3	Nash Rd	Jan 1989, **3/2/11**	Site 76 Eldon *et al.* (1989)	Repeat-sweep electric fishing
4	Worsley Rd	Jan 1989, **11/3/11**	Site 49 Eldon *et al.* (1989)	Single-sweep electric fishing*
5	Hoon Hay Valley Rd	4/2/2004**, 13/3/11**	Site 4 (EOS Ecology Limited *et al.* 2005)	Repeat-sweep electric fishing.
6	Upstream of Lincoln Road	Jan 1989, **9/3/11**	Site 96 Eldon *et al.* (1989)	Repeat-sweep electric fishing.
7	Downstream of Lincoln Road	Jan 1989, **9/3/11**	Site 97 Eldon *et al.* (1989)	Repeat-sweep electric fishing.
8	Downstream of Colombo St.	2/4/2004, **13/4/11**	Site 1 Taylor (2005)	Repeat-sweep electric fishing.
9	Quaifes Ponds	10/2/2004, **17/3/11**	Site 10a EOS Ecology Limited *et al.* (2005)	Electric fishing margins, fyke nets, and Gee Minnow traps.
10	Quaifes Drain	10/2/2004, **17/3/11**	Site 11 EOS Ecology Limited *et al.* (2005)	Single-sweep electric fishing.
11	Knights Stream	11/2/2004, **29/3/11**	Site 12, EOS Ecology Limited *et al.* (2005)	Single-sweep electric fishing.
12	Nottingham Stream	16/2/2004, **30/3/11**	Site 19, EOS Ecology Limited *et al.* (2005)	Single-sweep electric fishing.
13	Nottingham Stream	17/2/2004, **30/3/11**	Site 20, EOS Ecology Limited *et al.* (2005)	Single-sweep electric fishing.

* this site was regarded as too hazardous to repeat fish.

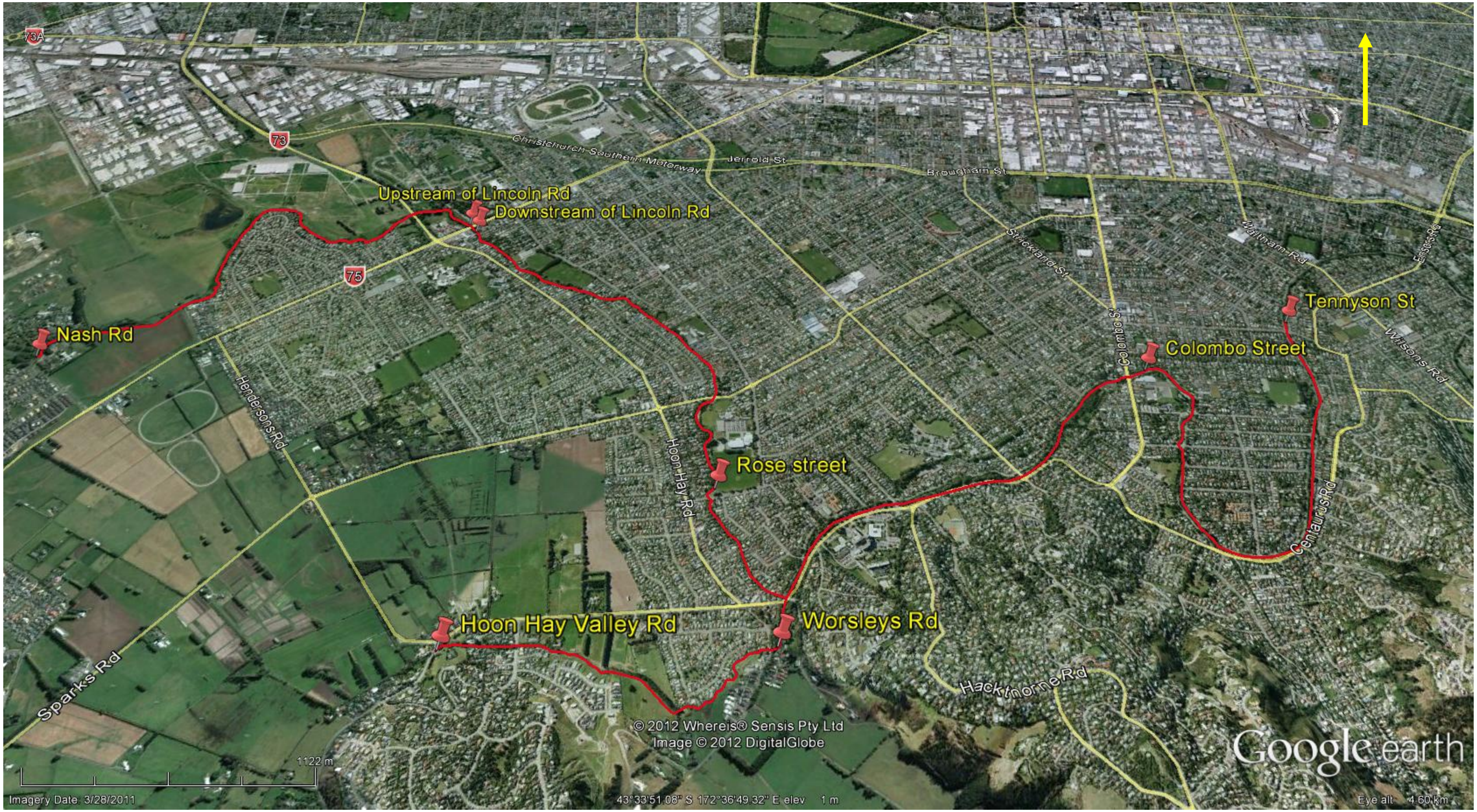

Figure 1. The eight monitored sites in the middle and upper reaches of the Heathcote River. Yellow arrow indicates north.

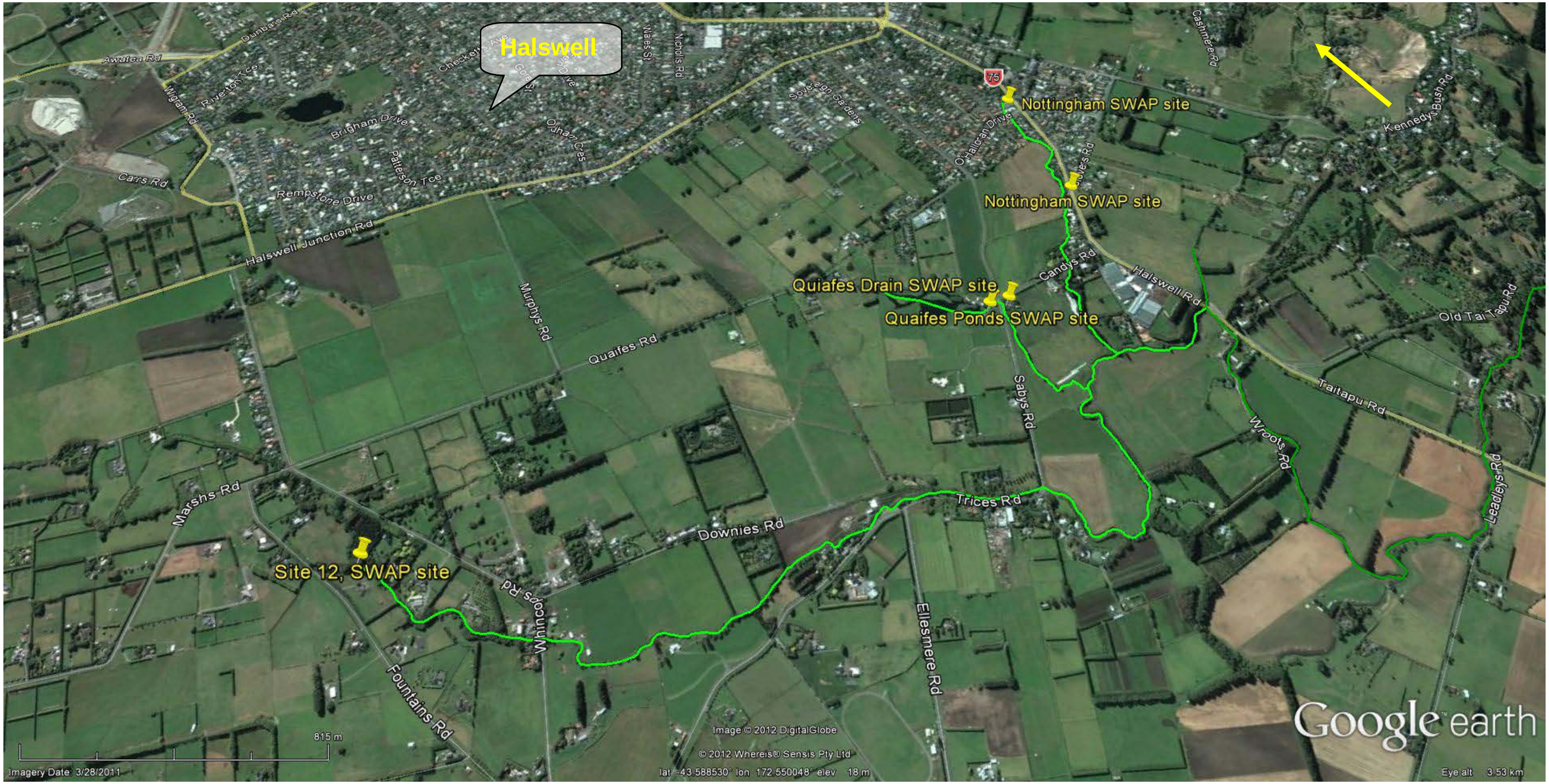

Figure 2. The five sites in Knights Stream, within the Halswell River catchment, that were previously surveyed during the SWAP survey. Yellow arrow indicates north.

5.1.1 Summer site habitat assessment

A number of habitat parameters were estimated for each fished site. These included mean flow depth, wetted width, and maximum depth within the surveyed channel length. Substrate embeddedness, substrate composition, riparian bank composition, and fish cover were also assessed. Substrate embeddedness is the degree (expressed as a percentage) to which the large substrate particles are buried into the fine substrate material (i.e. sand or silt). Thus, cobbles about a third buried into surrounding silt is considered to be 30% embedded, while a silty stream bed is considered to be 100% embedded (App. I). The overall substrate composition (expressed as a percentage of stream bed area) was visually estimated using modified Wentworth substrate particle sizes. The wetted habitat area of each site was approximated by using the mean width (based on three or more transects depending of variation) multiplied by the length of the fished channel.

The riparian composition is the percentage landuse (i.e. grass, scrub, native etc) of each of the two riparian margins (50% each bank), and extending out to 15 m from the water's edge. Fish cover is the amount of refugia provided by aquatic macrophytes, instream debris, overhang bank vegetation, undercut banks, or overhead shade (i.e. directly above the stream bed). These cover components are estimated separately along three equidistantly spaced sectors along each reach, and measured or assessed as a percentage of the stream bed. The % area of the bed with adequate substrate cover (i.e. particles > 60 mm) is also assessed, but considered in respect to the level of substrate embeddedness. These cover components are calculated and summed to provide an estimate of total available fish cover, or cover points. Some of these critical measurements used to assess fish cover are depicted graphically in App. I.

5.2 Winter trout spawning surveys

The second phase of work took place through mid-winter, when a trout redd survey was conducted in the Heathcote River catchment. A survey of the upper Halswell River was not attempted. Earlier surveys (Taylor & Chapman 2007) had indicated that historic spawning reaches in the upper Halswell River had since become irreversibly silted for some years.

5.2.1 Trout spawning studies; survey range and methods

Trout Spawning Surveys

This report therefore represents the 4th trout spawning survey of the Heathcote River, and was undertaken over what is now a standardised reach, from the Waltham Road bridge upstream to Templetons Road, and at the same time of year (August), as previous surveys (Table 2). However, the 2007 survey was at the end of that month, due to water clarity issue, largely due to discharge from Cashmere Stream, which reduces the clarity in the mainstem to an inadequate level downstream of its confluence.

The 2011 redd survey occurred during stable weather with the river at winter baseflow, but after significant seismic activity from September 2010 to June 2011, with strong aftershocks on and after the 13th June (M6.3, 6 km deep). Cashmere Stream is omitted from surveys, it has been checked previously and, at least in recent decades, no spawning gravel remains in this tributary, other than a 10 m patch downstream of the Hoon Hay Valley Bridge, although trout are present. Similarly, no spawning gravel, or trout redds have been recorded downstream of the Waltham/Wilson Road bridge, nor in the headwaters, upstream of Templetons Road.

Similar to previous surveys, fieldworkers donned Polaroid sunglasses, and surveyed upstream when the river was clear, with redds logged onto a GPS receiver unit. Field notes were made on the size of the redd, and the subjective age of the redd, that is whether the redd appeared freshly constructed, mature, or old. Redd age was subjectively assessed based on the relative amount of periphyton on the excavated gravels compared to the surrounding undisturbed bed. The location, number and approximate length of observed trout were also recorded.

Table 2. Past trout spawning surveys of the Heathcote River, and this survey (pink-shaded).

Year, survey dates	Extent of survey
1996 19/8, 20/8,26/8, 28/8	Cashmere Road to Nash Road, mainstem only (Taylor 1996a)
2003 8-10/8	Mainstem: Wilson Road bridge to Templetons Road. Cashmere Stream: upstream from Cashmere Stream to confluence to Hoon Hay Valley (Taylor 2003)
2007 31/8, 3/9	Mainstem: Wilson Road bridge to Templetons Road. No survey on Cashmere Stream (Taylor & Chapman 2007)
2011 3-6/8	Mainstem: Wilson Road bridge to Templetons Road. No survey on Cashmere Stream.

On the Heathcote River, and the study control river (the Otukaikino River), preliminary surveys were undertaken early in the trout spawning survey (i.e. June/early July) to locate fresh redds, or redds under construction.

Earlier trout spawning surveys of the Halswell River had revealed that there is little trout spawning activity in the catchment within the Christchurch City Councils administrative area. In particular, spawning gravels within earlier reported trout spawning reaches (Piper 1980) of Knights Stream, are now heavily sedimented and unused by spawning trout (Taylor & Chapman 2007). However, it is quite possible that trout spawning gravels exist in spring-fed tributaries of Dawsons Creek, to the south of the Christchurch City Council boundary (NCFG, pers. comm.).

IGDO and nitrate bioassays

These were conducted in a similar way as previous studies over the last few years, with intragravel dissolved oxygen levels (IGDO) being extracted from trout redds over the egg development period (3-4 weeks). Field surveys were initially undertaken to identify ‘fresh’ redds upstream of the Colombo Street bridge, targeting redds which were fully excavated, and just after when the attendant hen (female) trout had finished excavating. Several field trips were required to locate and monitor five fresh redds (Fig. 3), with field trips involving a combination of obtaining IGDO data from existing monitored redds, and monitoring hen trout activity on partially excavated redd constructions.

On each redd, three IGDO probes were inserted equidistantly along the midline of the gravel tailspill in each of five monitored redds. Every few days, 2 replicate water samples (30 mls) were aspirated by syringe from each of the three probes, and the dissolved oxygen (DO) measured and recorded using a calibrated commercial grade DO meter.

Water samples for nitrate analysis were obtained from each of the probes when redds were approximately mid-age (i.e. c. 2 weeks old) and from the stream bed adjacent to the monitored redds. The water samples was analysed for nitrate at the Environment Canterbury laboratory at Kyle Street.

Figure 3. The 5 monitored trout redds on the Heathcote River upstream of Barrington Street. Four redds were located adjacent to Cashmere High School, with a fifth redd upstream of the Cashmere Stream confluence.

5.3 Analytical methods and approach

The Nitrate data was analysed using the parametric ANOVA procedure in SYSTAT 12™.

The analysis of the intragravel dissolved oxygen (IGDO) data was more complex, with two different software packages used to compare and cross-validate the statistical output. Initial statistical analyses were employed using mixed-effects modelling and repeated-measures ANOVA in R™ (v. 2.11.1, `lme` and `aov` commands) and the `MIXED` procedure in SPSS™ (IBM SPSS Statistics v.19).

The response variable IGDO was tested with a mixed-effects model using a restricted maximum likelihood method (REML). River and age of redd (days) was specified as fixed effects whilst redd and time since probe was inserted (days) were specified as a random effect ((Pinheiro & Bates 2000; Zuur *et al.* 2009).

The model took the following form:

$$IGDO_{ij} = \alpha + \beta_1 \times River_{ij} + \beta_2 \times Age_{ij} + \beta_3 \times River_{ij} \times Age_{ij} + a_i + \varepsilon_{ij}$$
$$a_i \sim N(0, d^2_{Redd,Probe\ Insertion})$$

To compare post-hoc differences in IGDO between rivers, a Tukeys Honestly Significant Difference (HSD) test was performed in R. To compare post-hoc differences in the slope of the parametric linear regression curves modelling the relationship of IGDO to age of redd for each river, a procedure was performed in R based on a procedure described by Wonnacott and Wonnacott (1990). This involves the use of a mute variable D that had a binary value according to the group to which a given point belonged (e.g. River 1 : D=0; River 2: D=1). The following equation was computed, and multiple comparisons tested:

$$IGDO_{ij} = \alpha + \beta_1 \times River_i \times Age_i + D \times \beta_2 \times River_j \times Age_j + \varepsilon_{ij}$$

6 Results

6.1 Temporal changes in habitat and fish community in the Heathcote River

Three sites were re-surveyed prior to the February 22nd seismic event and its aftershock, although still subject to the September 2010 event. These were Tennyson Street, Rose Street, and Nash Road. The Tennyson Street site was repeat-fished again after the February earthquake, to provide a comparative indication of seismic effects at that site.

6.1.1 Tennyson Street Reach

Physical habitat

The physical habitat at Tennyson Street has changed over time (Fig. 4). In 1989, the reach was described as ‘tidal’ (NZFFDB card 10356), and mean widths and maximum depths were significantly greater than in successive surveys. The reason for its ‘tidal’ nature in January 1989, was that the then recently commissioned ‘Woolston Cut Diversion’ was in operation during normal flows which effectively shortened the distance to the sea, increasing the impact of tidal ingress.

In later surveys, depths were much reduced, with a minor, but measureable, component of surficial sediment in April 2011. This sediment is apparent from the ‘before and after’ photos in Figs. 5a-c, both along the true right (eastern) bank, and elsewhere on the bed. Sand and silt was also deposited amongst the riparian grasses to a level approximately 1 m above the observed water level in April 2011. In one part of the reach, a distinct hollow had formed in the bed, (causing a higher maximum depth), whereas, near the upstream site boundary section of uncompacted stream gravels had uplifted (Fig. 5d).

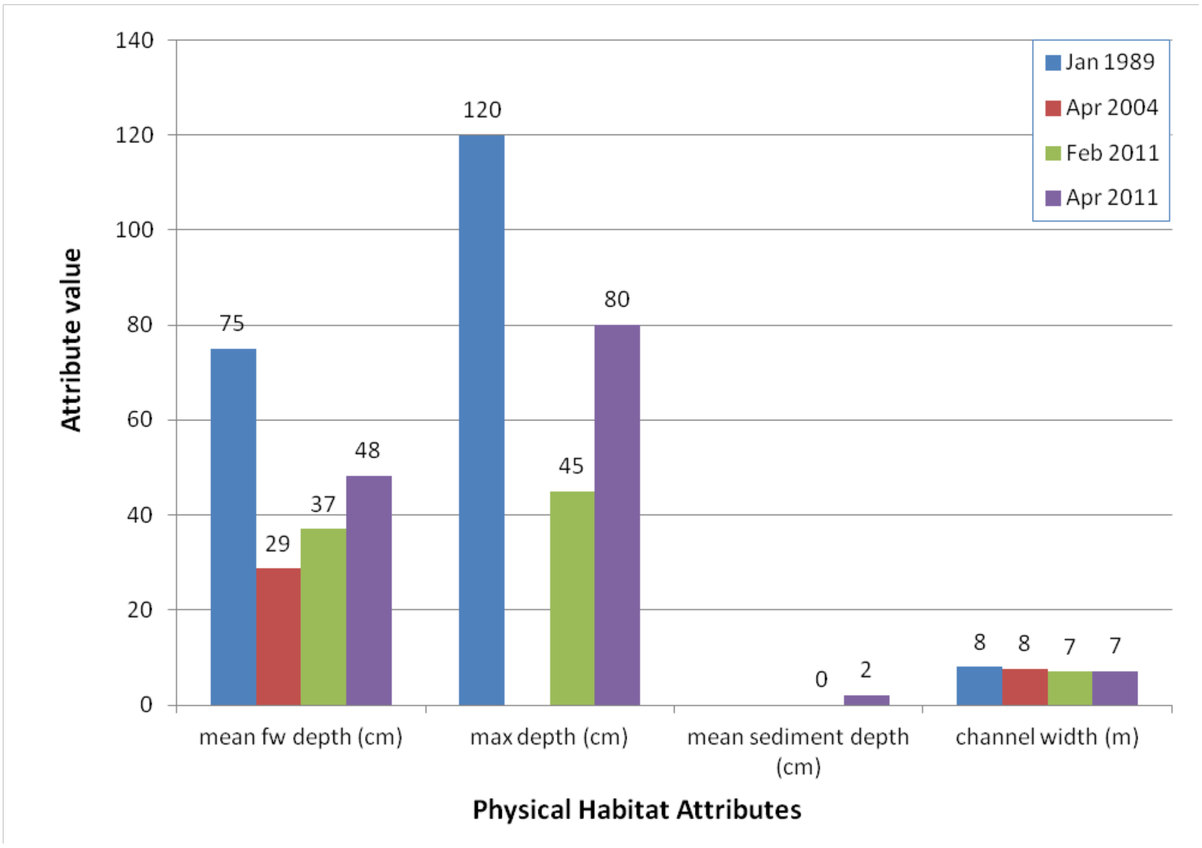

Figure 4. Temporal changes in mean depth, maximum depth, mean sediment depth, and channel width at a re-surveyed reach near Tennyson Street.

Figure 5a. The Tennyson Street reach in 10 February 2011, prior to the Feb 22 earthquake

Figure 5b. The Tennyson Street reach in April 2011. The true right bank (arrowed) has slumped significantly

Figure 5c. Significant slumping along the true right bank (arrowed). Earthquake-mediated sediment is apparent along the bank.

Figure 5d. An uplifted gravel bed section at the upstream margin of the site. This habitat contained a multitude of shortfin elvers.

Fish community

The fast-flowing reach downstream of Tennyson Street has been fished systematically on at least four occasions, with the abundance of the numerically dominant species illustrated below (Fig. 6). The fish community in January 1989 also was composed of a marine flounder (yellow-belly flounder 1 specimen), and the giant bully (3 specimens), and 3 common smelt. None of these species have been recorded from this site since 1989.

The catch from the 1989 survey differs from the later surveys partly because the fishing effort at that time was composed of a significant netting effort composed of 12 nets (1 large V-wing fyke net, 3 single–ended large fyke nets, 6 mini-fyke nets), combined with two sweeps with a "pack-set" electric fishing machine.

In April 2004, the fauna differs markedly from that in 1989, in that common bully, and upland bullies were present in the later study. A low number of bluegill bullies were also reported at this site, when they were clearly not present in 1989. The shift from a lower-river semi-estuarine fauna to freshwater fish fauna is very probably due to the decommissioning of the Woolston Cut after the inaugural survey.

Prior to the February earthquake, but after the September 2010 earthquake, bluegill bully abundance was higher than in 2004, as were numbers of elvers (almost all shortfin eels < 120 mm T.L.). After the February 2011 earthquake, over the same reach, and using identical methods, shortfin eels numbers had nearly doubled compared to that prior to the earthquake, and the number of upland bullies had increased. However, the number of bluegill bullies was heavily reduced. Common bully numbers had decreased slightly between 2004 to 2011 period, but were much more abundant than in 1989. This pattern is consistent with a shift from a lower-river saline-influenced fish fauna (due to the operation of the Woolston Diversion) to one with perennial freshwater, when the Diversion was decommissioned for normal river flows. Of note was the capture of a very large migrant longfin eel, exhibiting the distinctive mottled underbelly which characterises this life-stage (Fig. 7).

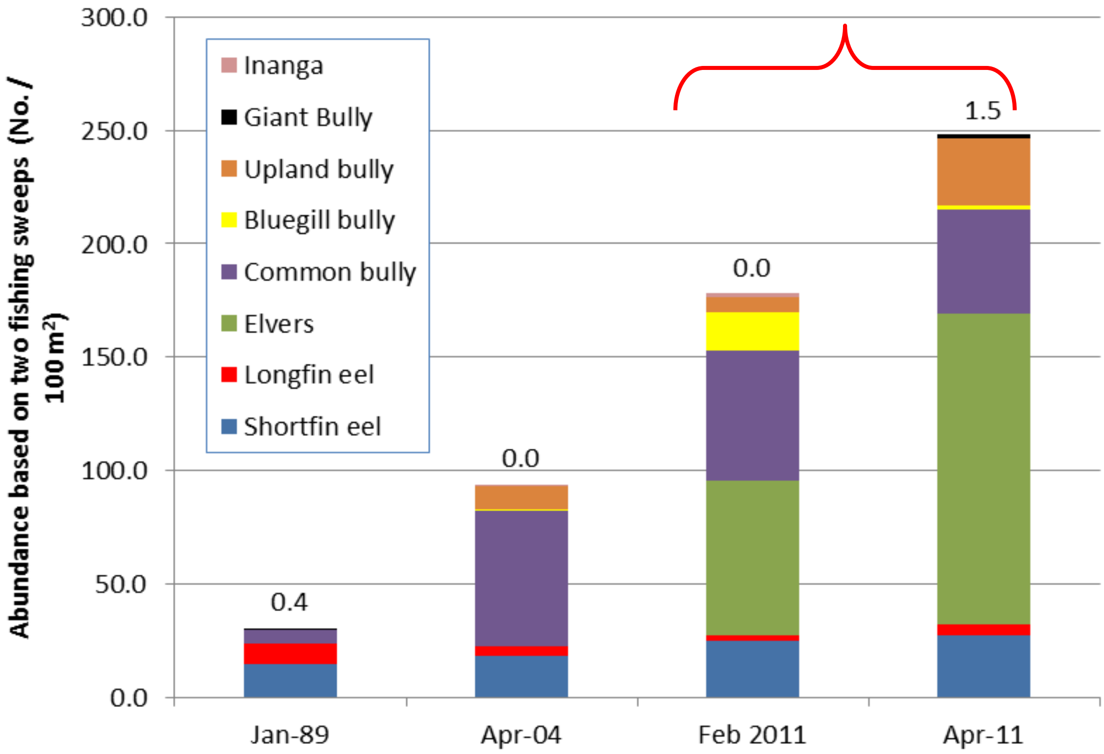

Figure 6. The change in fish abundance of common species over time at the Tennyson Street site. The bracketed data represents samples immediately before and after the 11th February earthquake. All of the elvers were identified as shortfin eels and were defined as having a length of less than 120 mm. The numerals represent the catch per unit area, of giant bullies, which are otherwise indicated by the thin black lines in this figure.

Figure 7. A very large (1250 mm T.L.) migrant female longfin eel captured from the Tennyson Street site shortly before the February 2011 earthquake. We failed to relocate this fish in April.

6.1.2 Colombo Street

This site is a long winding fast-flowing shallow reach (i.e. riffle or shallow run) immediately downstream of the Colombo Street bridge, and situated about 3 km upstream of the Tennyson Street site. This site has always been upstream of the tidal influence, even when the Woolston Cut was in operation. It was evident that the baseflow depth of this section was shallower before the earthquake (mean depth 21 cm, April 2004) compared to that after the earthquake (mean depth 54.7 cm, April 2011) (Figs. 8a, b). In 2004, the substrate was largely un-embedded, compared to the sand-embedded nature of the substrate after the earthquake (Figs. 8c – 8d), (Figs. 8e- 8f). After the earthquake, two giant bullies were recorded from this site, and they were also recorded in 1989 (3 specimens).

2nd April 2005

Figure 8a. Looking upstream from downstream margin of site in 2nd April 2004.

Figure 8c. Clean substrate, 2nd April 2004.

13th April 2011

Figure 8b. Colombo Street reach, looking upstream (13th April 2011).

Figure 8d. Silted habitat, 13th April 2011.

Figure 8e. Clean substrate, 2nd April 2004

Figure 8f. Silted margins, 13th April 2011.

Similar to the Tennyson Street reach 3 km downstream, there was a marked decrease in bluegill bully abundance between 2004 and April (post-earthquake) 2011, and an increase in the number of shortfin eels (Fig. 9). There was a reduction in the number of longfin eels, but due to the low numbers of this species, this reduction may not be significant. There was also a reduction in common bully abundance, over time, between 2004 and 2011, of approximately the same proportion as observed at Tennyson Street. One surprise was the presence of a single large freshwater crayfish or koura, with a body length of 110mm (Fig. 10). Koura were not recorded at this location in 2004, despite a section of bank being electric fished. However, little weight can be placed on the presence or absence of just one individual.

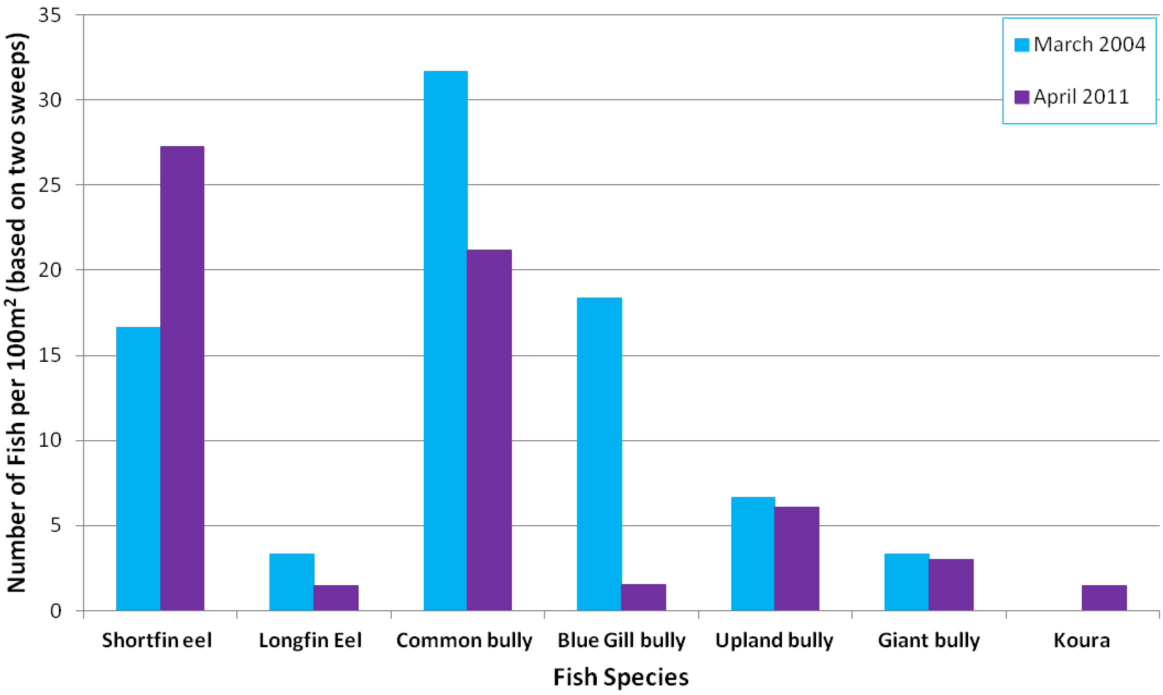

Figure 9. Temporal changes in freshwater fish composition in the riffle downstream of the Colombo Street bridge.

Figure 10. A large freshwater crayfish from the Heathcote River, captured in April 2011, downstream of Colombo Street.

6.1.3 Centennial Park

This site is directly upstream from the Rose Street bridge, and is composed of a shallow riffle-type flow, or fast run, depending on river stage. This site was assessed on three occasions, in 1989 (2 passes, Eldon *et al.* 1989), in 2004 during the SWAP survey (1 pass in EOS Ecology Limited *et al.* 2005), and during this recent survey just prior to the February earthquake (2 passes in 10th February, 2011). In 2011, there was a marked increase in bank vegetation cover since the 2004 assessment, but a reduction in tree canopy shade due to the removal of large willows on the park side of the river (Figs 11a, b, c). Instream macrophyte cover varied over the three surveys, probably as a function of survey timing with the council maintenance programme. Based on available data, the site had changed little in terms of overall structure between 1989 and the time before the major February 22nd earthquake, although the mean and maximum depth has increased over time, with little change in wetted width (Fig. 12).

To provide comparable figures (and assuming escapement levels remain about the same), the first pass fishing CPUE is provided below (Fig. 13). Of note, was the identification of bluegill bully (a single specimen), which have not been identified from this site previously. The numbers of common bullies and eels (especially shortfin elvers) had increased. Also in 2011, two adult trout were identified from this section, possibly due to the increasing depth, and bank cover at this site (F.L. = 415 mm, 290 mm). No follow-up survey has been conducted at this site following the February 22nd earthquake.

Figure 11a. Centennial Park site, 2nd February 2004

Figure 11b. Centennial Park site, 10th February 2011. The yellow sign demarcates the upstream boundary of the fished section.

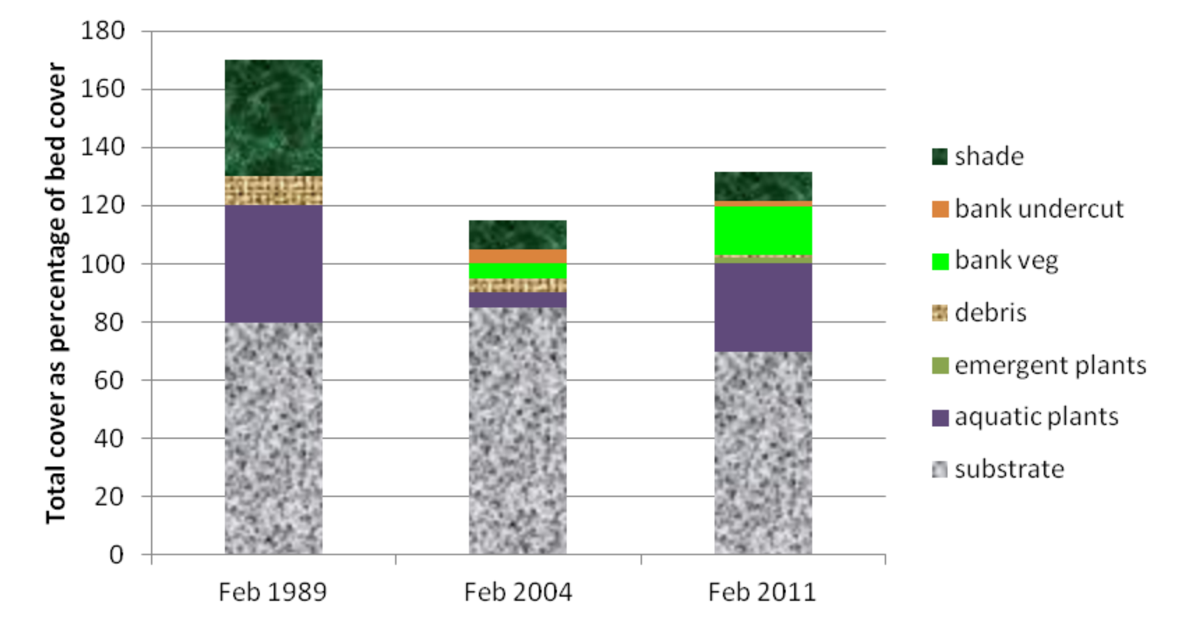

Figure 11c. Reduction in tree shade, and increase in bank vegetation over time at the Centennial Park site.

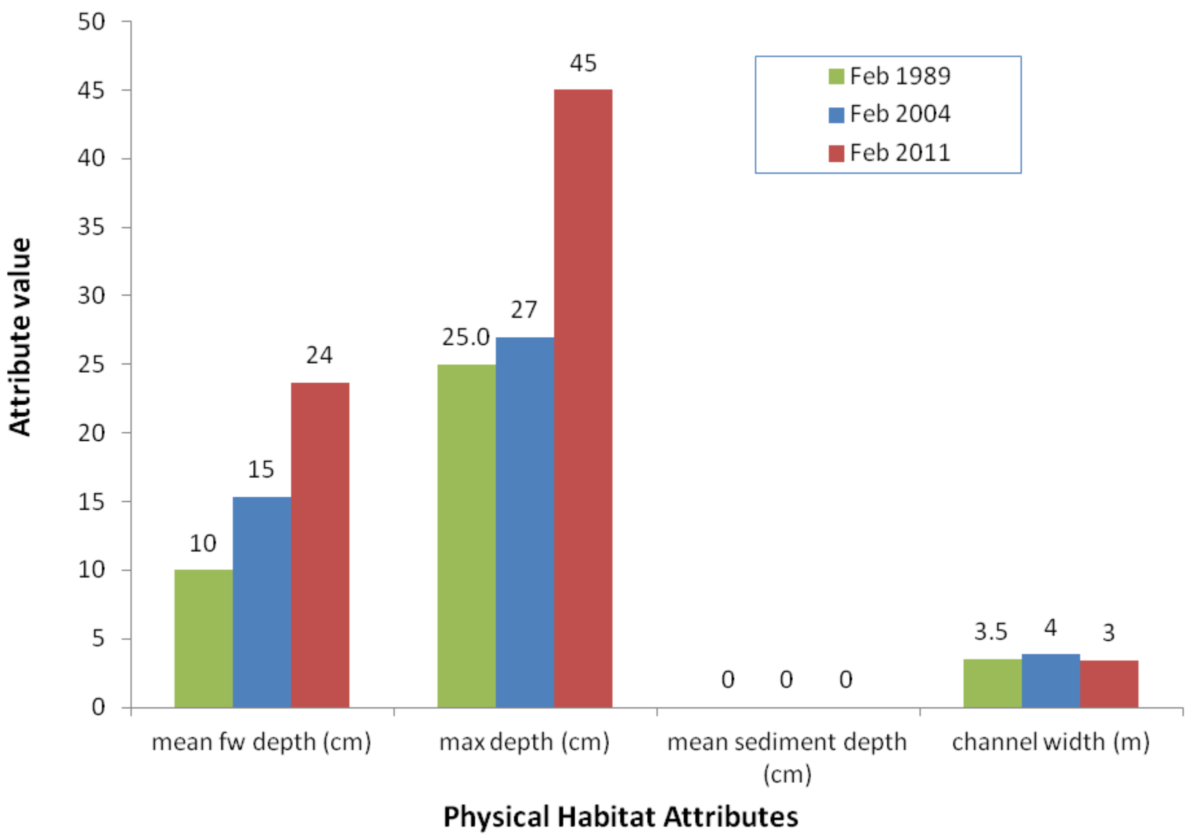

Figure 12. Basic physical habitat attributes of the Centennial Park habitat through Centennial Park. Numerals represent actual attribute values. The magnitude of the attribute value is provided at the top of each column.

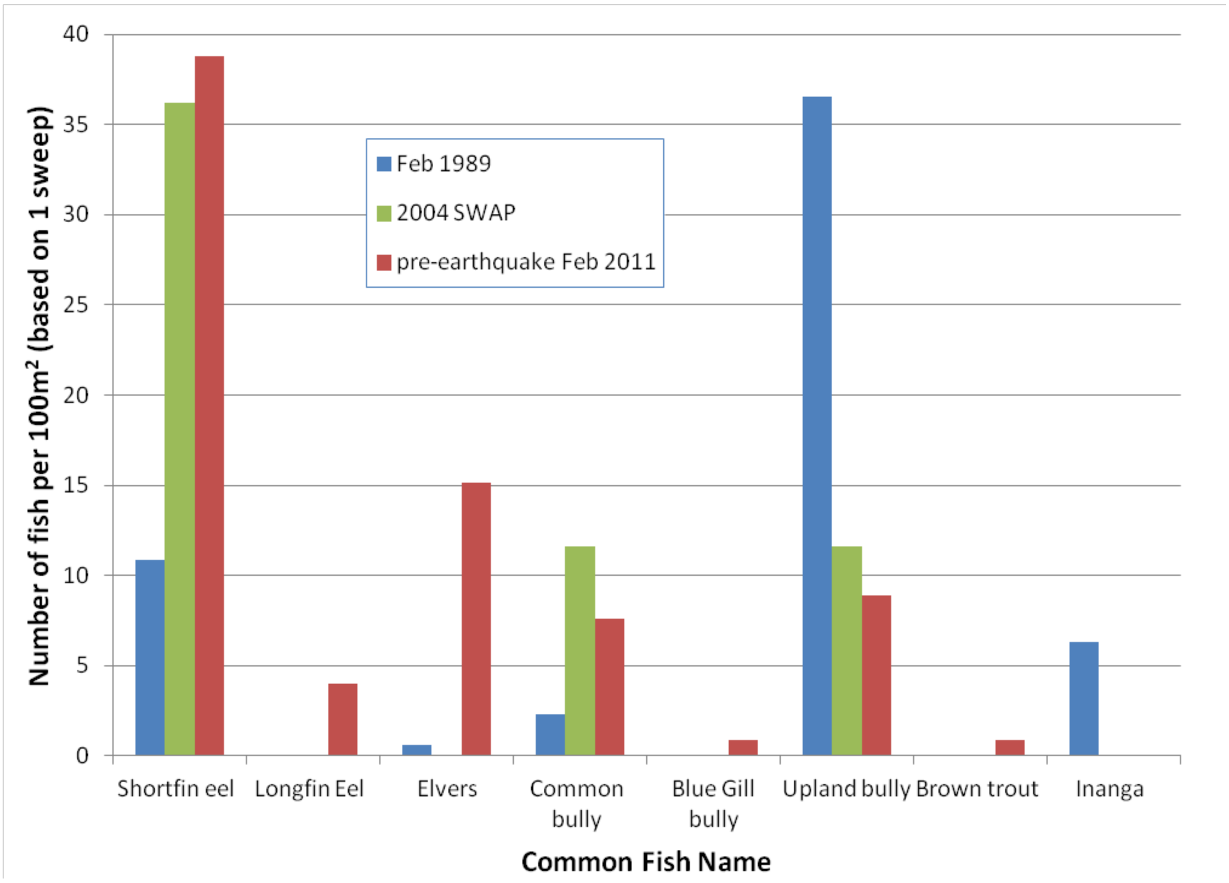

Figure 13. Changes in the fish community structure in the Heathcote River over three fishing surveys.

6.1.4 Lincoln Road

The reach downstream of Lincoln Road, has been fished on two occasions, in January 1989, when the water was warm (17 ^{o}C), and flow regarded as very low, and on 7 March 2011, not long after the major earthquake. The described location for the 1989 record is rather vague, but the description suggests a reach downstream of Halswell Road, which coincides with our Site 7 (Fig. 14), but under reduced flow conditions. The basic physical habitat attributes are provided in Fig. 15, with most of the available fish cover in the form of substrate (95 cover points), overhanging vegetation (6.7 cover points), and tree canopy shade (100 cover points). However, the 1989 habitat cover attributes were not quantified (just ticked on the data form), precluding meaningful comparison with the 2011 cover attributes.

The fish catch per unit effort is provided in Fig. 16, which demonstrated a significant increase in fish numbers (and almost certainly biomass) over the survey reach compared to the drought conditions in 1989. A longfin eel, not identified from this site in 1989, and many shortfin elvers were also recorded.

Figure 14. Looking downstream at the Heathcote River reach downstream of Halswell/Lincoln Road.

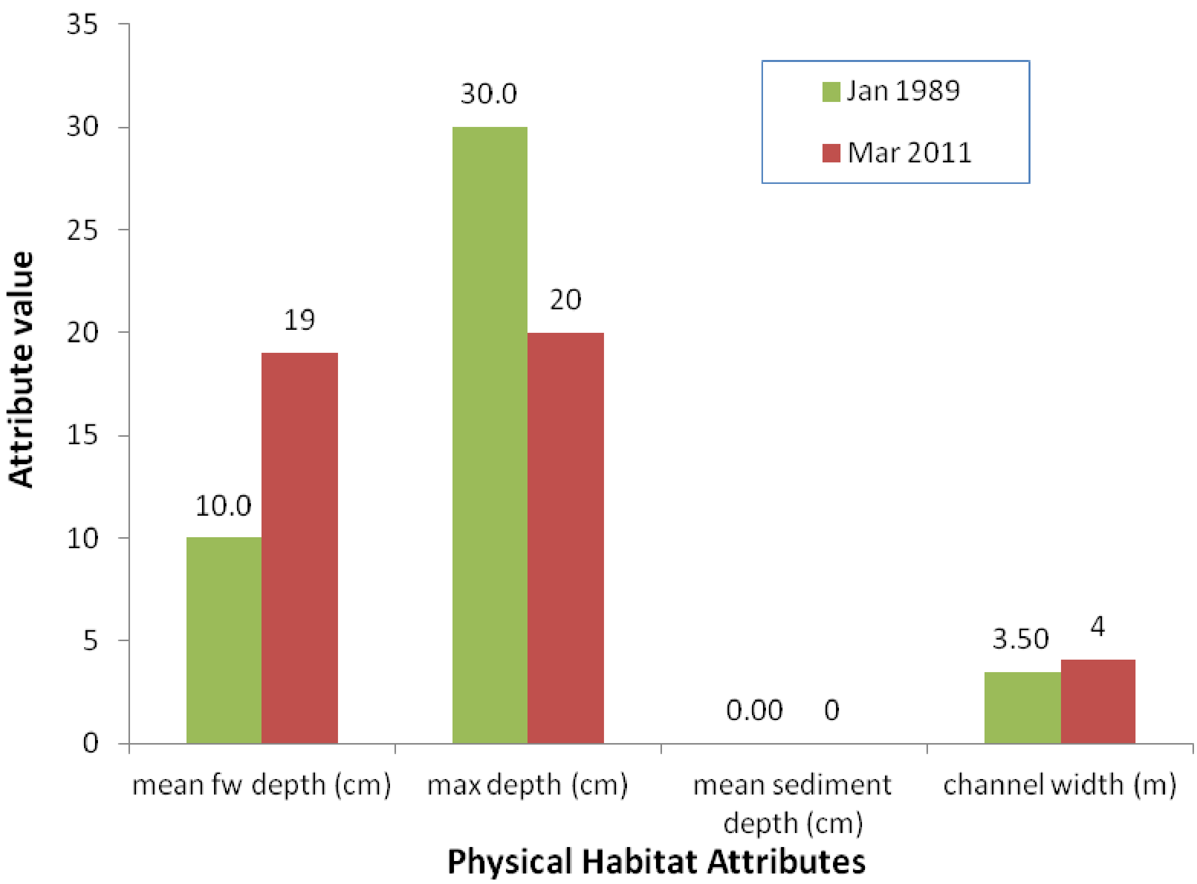

Figure 15. Basic physical habitat attributes of the Heathcote River habitat downstream of Halswell Road.

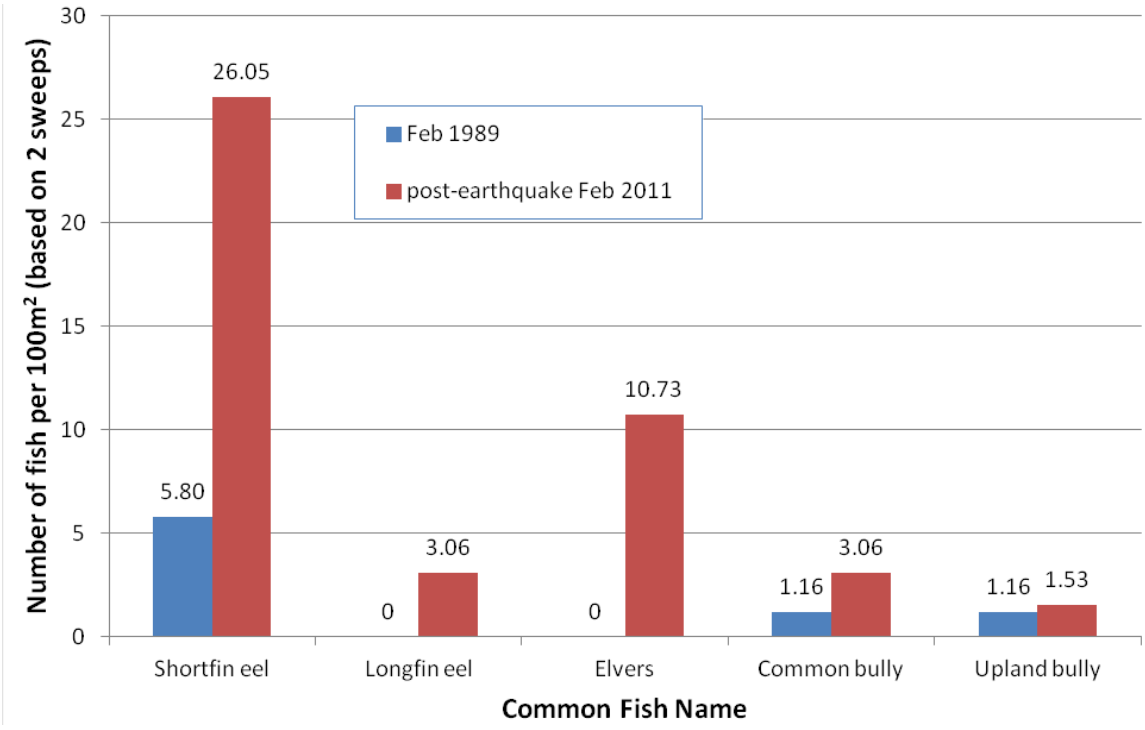

Figure 16. The fish catch based on 2 electric-fishing sweeps on a habitat downstream of Halswell Road.

6.1.5 Heathcote River upstream of Halswell Road

This reach was a mixture of riffle and run-type flow with a recent planting of luxuriant *Carex* for a portion of the true left bank (Fig. 17a, b). The habitat was a mixture of riffle and run-type flow, with substrate compositions of gravel and silt respectively. Overall, the mean sediment depth was 3 cm (Fig. 18), with silt covering about 40% of the bed. The 1989 physical data is provided on NZFFDB record 10352 (Site 96 *in* Eldon *et al.* (1989)). It is clear that 90% of the bed was mud in 1989, but there is no information on the depth of the soft substrate. The apparent width reduction over time, may not be 'real', as the 1989 width is based on a fished length and area, which may only be approximate.

The reach was electric-fished twice on 9th March 2011, similar to 1989, and it was relatively much more productive in terms of numbers of shortfin eels (including juveniles), and upland bullies were also more common. Four common bullies were present in March 2011, but absent in 1989, although an inanga, and a juvenile goldfish was present in 1989, but not recorded from the present survey (Fig. 19). No photographs were present for the 1989 site, but no fish cover was indicated, compared to 105 cover points in 2011, including 26 points for substrate, and 76 for shade.

Figure 17a. Looking downstream at the stopnet upstream of Lincoln Road. Spreydon School is on the true right bank.

Figure 17b. Looking upstream towards the upstream end of the fished section (yellow sign).

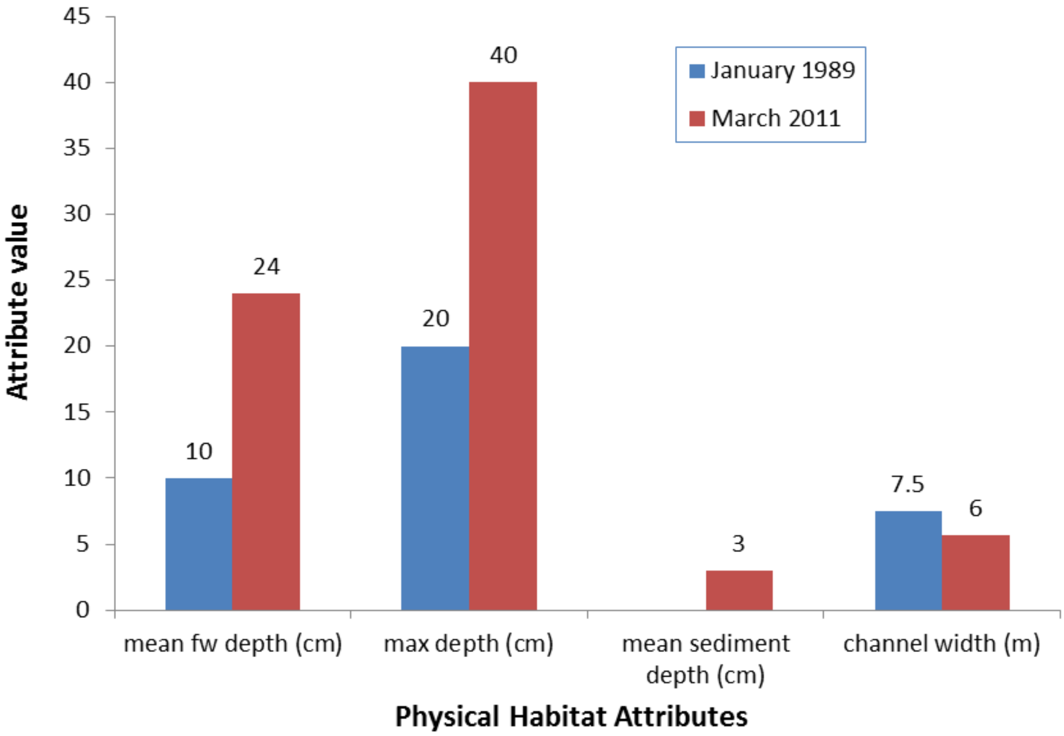

Figure 18. Basic habitat attributes of the Spreydon School site, upstream of Lincoln Road. Sediment depth was not recorded in 1989.

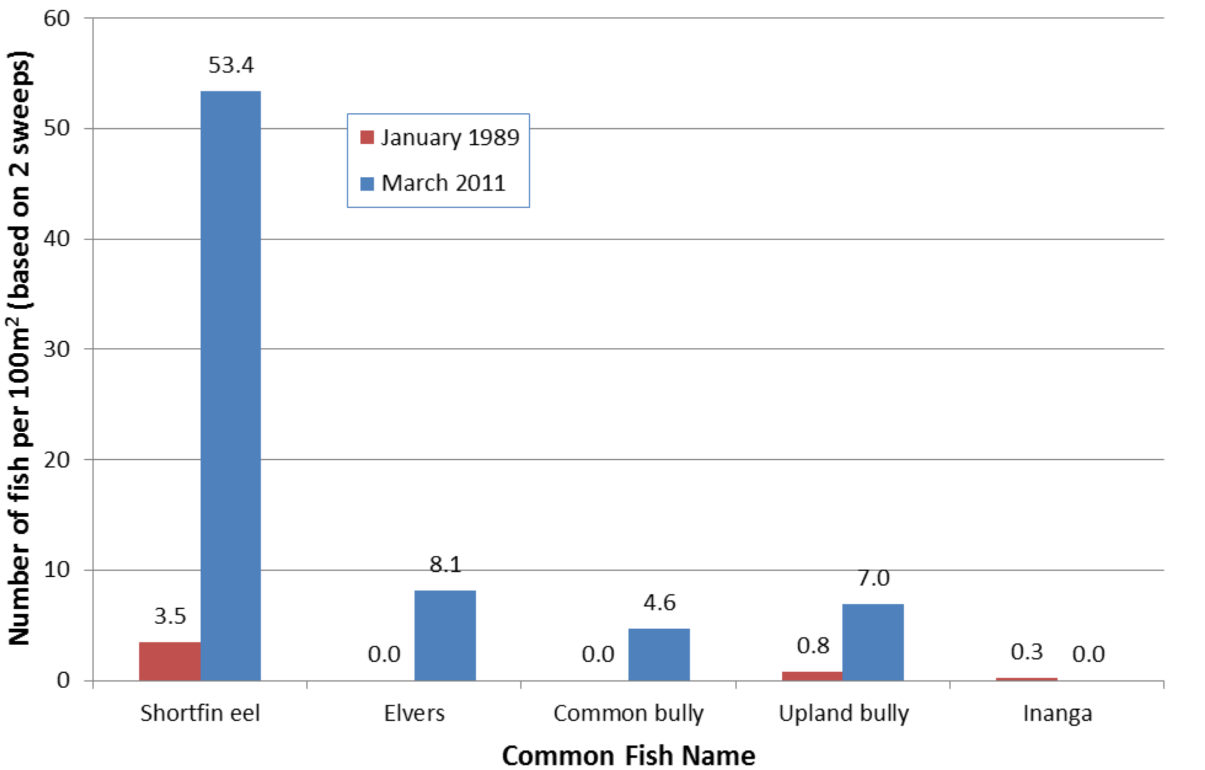

Figure 19. The fish catch based on 2 electric-fishing sweeps on a habitat upstream of Halswell Road.

6.1.6 Nash Road

Nash Road, in the Heathcote River headwaters was first surveyed in January 1989 (one sweep of the electric fishing machine) and resurveyed on 17 February 2011 (2 sweeps with an electric fishing machine). The 2011 habitat was atypically (according to landowner) well-watered at the time of survey, and flowed as a very slow run (1 cm/s, 0.23 m on local staff gauge) with a mean width of 2m (Fig. 20).

Typically the river bed is dry and cracked at that time of year. In 1989, the channel was composed of three distinct pools, and provided only standing very warm water (32 ^{o}C). The NZFFDB record relating to this site (10353) does not provide a defined channel width. Unfortunately recent photographs of this site are missing, due to the destruction of a work computer during the earthquake a few days after the survey. However, the 2011 catch was similar to that of 1989, consisting of just shortfin eels, and elvers, but our catch rate was higher, with a catch rate of 35 shortfin eels and elvers / 100 m^2 (based on one fishing sweep) compared to 23.7 fish/100 m^2 in 1989 from the three pools, where the fish were concentrated. This rise in catch rate would reflect the healthier perennial environment in 2011 compared to the warm standing water habitat existing in January 1989.

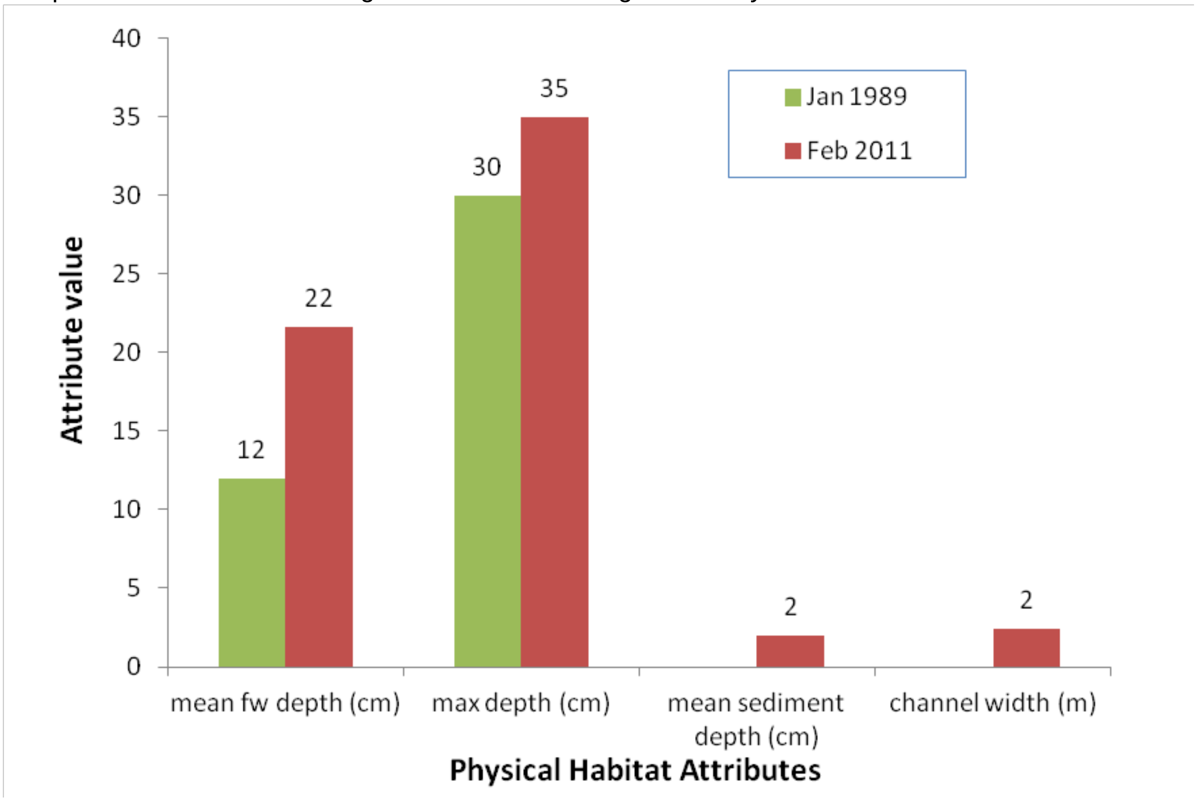

Figure 20. Basic habitat parameters from the normally ephemeral Nash Road site. Sediment depth was not recorded during the 1989 survey, and channel width was not applicable as the habitat was ponded.

6.1.7 Worsleys Road

Worsleys Road is in the heavily wooded section of the lower Cashmere Road. The bed of Cashmere Stream was heavily sedimented, and comprised a sluggish run (Figs. 21a, b). The basic nature of the habitat would appear to have little changed since 1989, although was slightly deeper in March 2011 (Fig. 22)

This site was aligned as closely as possible to Site 76 (Eldon *et al.* 1989), and this large habitat was electric fished on 11 March 2011, within a few weeks of the February earthquake. A number of species were recorded in 2011, which were not identified in 1989. These included a single koura, two observed trout (350, 450 mm), two longfin eels, and a flounder, probably a black flounder (Fig. 23). No giant bullies were found at this site in 2011, despite 7 being recorded in 1989.

Figure 21a. The shaded silty bed of lower Cashmere Stream at Worselys Road. The ladder facilitates access to the river bed.

Figure 21b. Setting the stopnet across the lower Cashmere Stream.

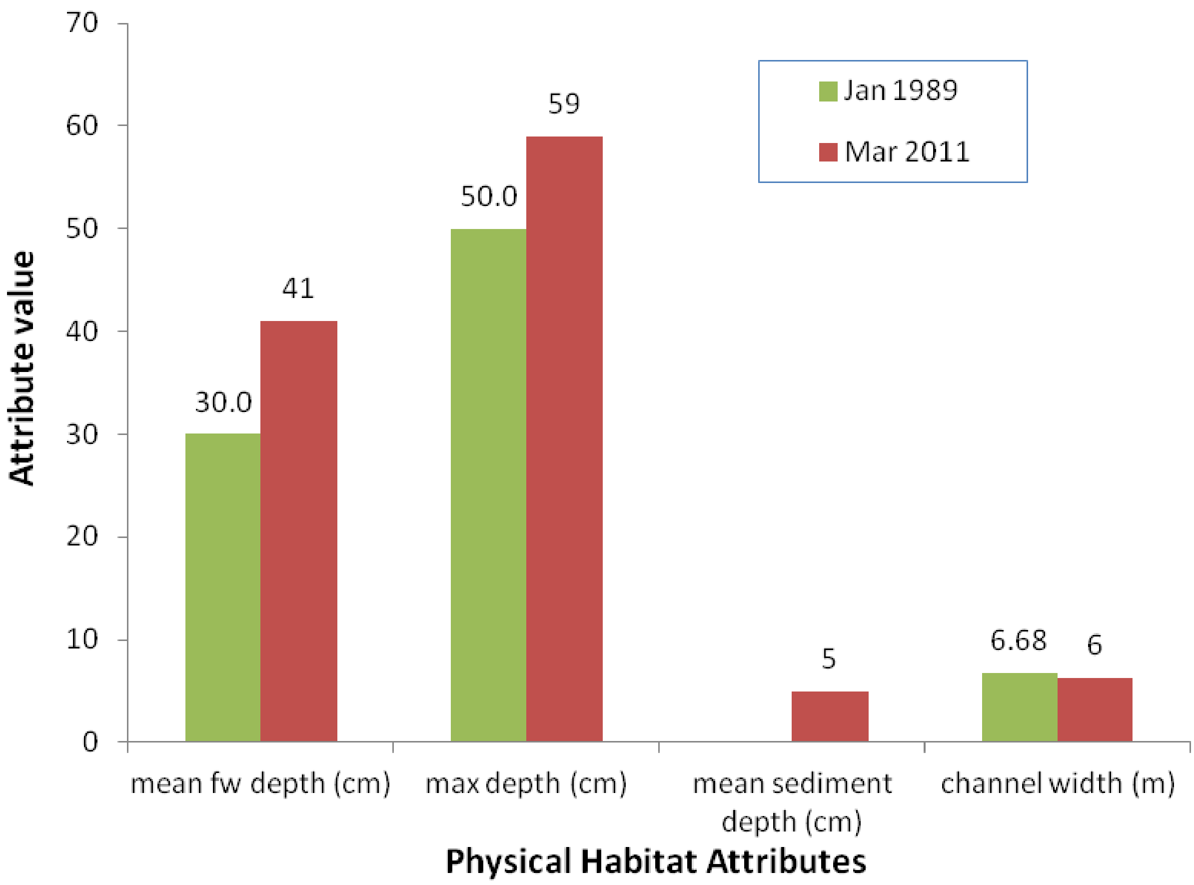

Figure 22. Basic habitat parameters for the Worsley Road reserve site. Sediment depth was not recorded during the inaugural 1989 survey.

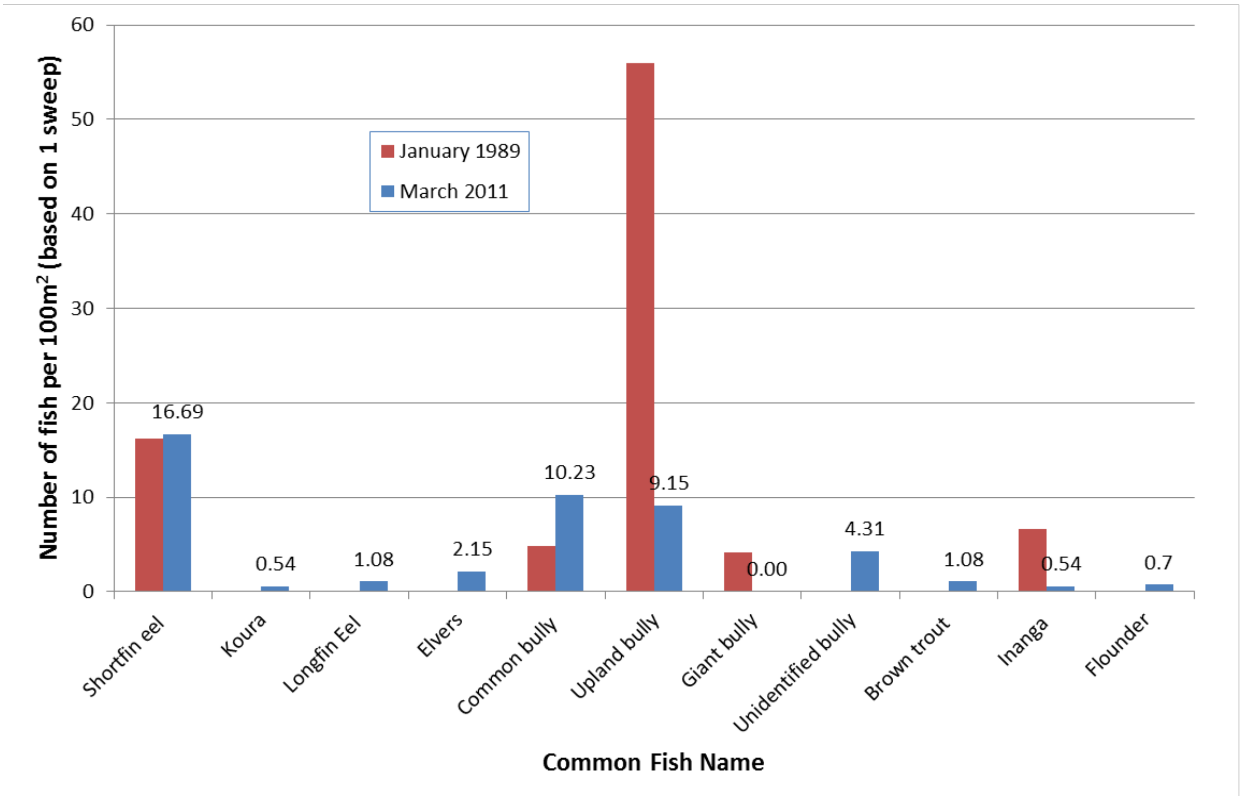

Figure 23. Catch per unit area from the first fishing sweep. Catch for March 2011 is also provided in digits. The 1989 1st sweep catch was dominated by upland bullies, but species diversity was greater in 2011. Elvers, usually shortfin eels, were those less than 120 mm in length.

6.1.8 Hoon Hay Valley Road

This site represents the fastest flowing reach in Cashmere Stream (Fig. 24), and one of the last known remaining reaches in Cashmere Stream where some exposed gravels are retained. This site is approximately 175 m upstream of the Eldon's 1989 Westmorland Site near Brookford Place.

This particular fast-flowing reach has been well monitored for ecological values for several years in the past (2004-2008). Firstly in respect to an accidental sediment discharge into the waterway during the development of Aidanfield subdivision, and then for monitoring ecological values, including the Aidanfield subdivision stormwater discharge, in the catchment (James & Taylor 2009; McMurtrie & Taylor 2006).

The basic channel dimensions suggest a steady increase in channel width, and, at the time of the March 2011 survey, a distinct increase in maximum and mean water depth (Fig. 25). Fish cover changed substantially due to shading from a new footbridge over the site after the 2004 monitoring year (Fig. 26a). A small, but variable quantity of plant detritus on the stream bed usually provided valuable fish cover, but this was absent in 2011, although some emergent vegetation was present. Substrate embeddedness (i.e. the extent that cobbles and stones are embedded into fines) was much higher than previously recorded (65% cf. average 20% pre-earthquake) Fig. 26b.

Fish species richness, fish abundance, and koura abundance, were well down in March 2011 compared to previous years (Figs. 27, 28). Notably, only one small koura (60 mm body length) was obtained from the site at this time. This is despite fishing time for each of 2 passes being approximately double in March 2011 compared to previous years. Notably no bluegill bullies were identified in the catch, the first time in six years that this site has been fished by this agency.

Figure 24. Looking upstream at the shallow fished section of Cashmere Stream. Little detritus was in the fished section, although a small amount can be see upstream of the fished section (i.e. beyond the yellow sign).

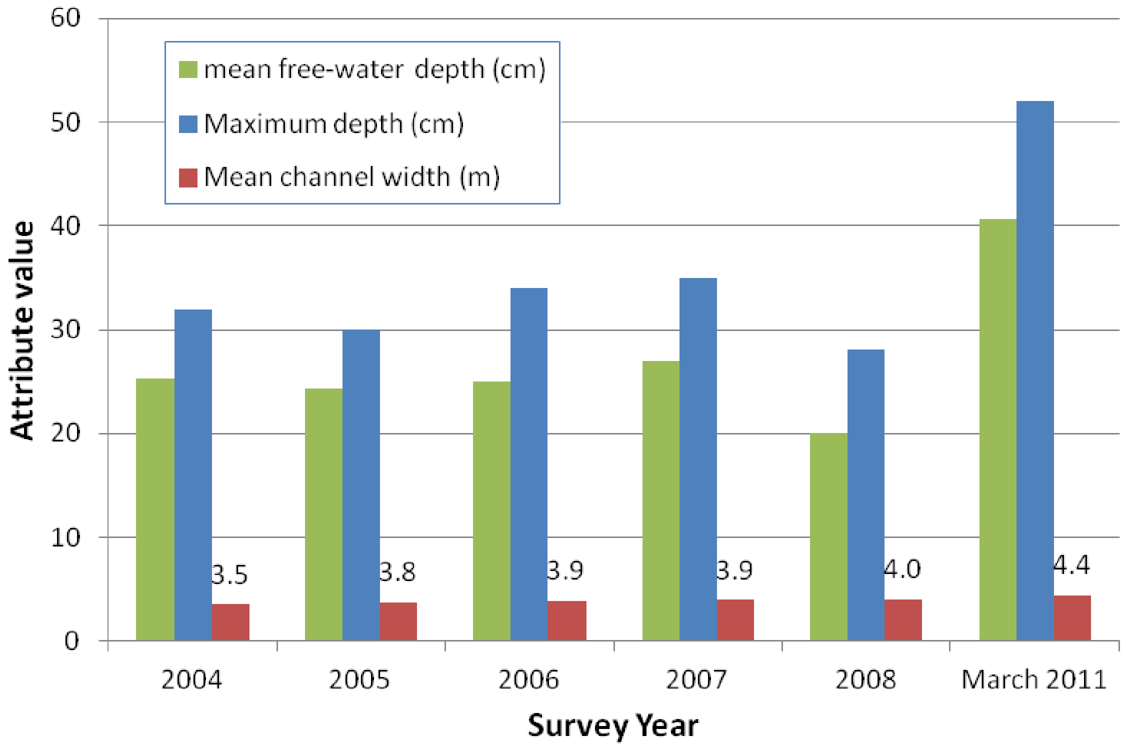

Figure 25. Basic habitat parameters for the Hoon Hay Valley Road site over a six year monitoring period. Channel widths are printed above the columns for clarity.

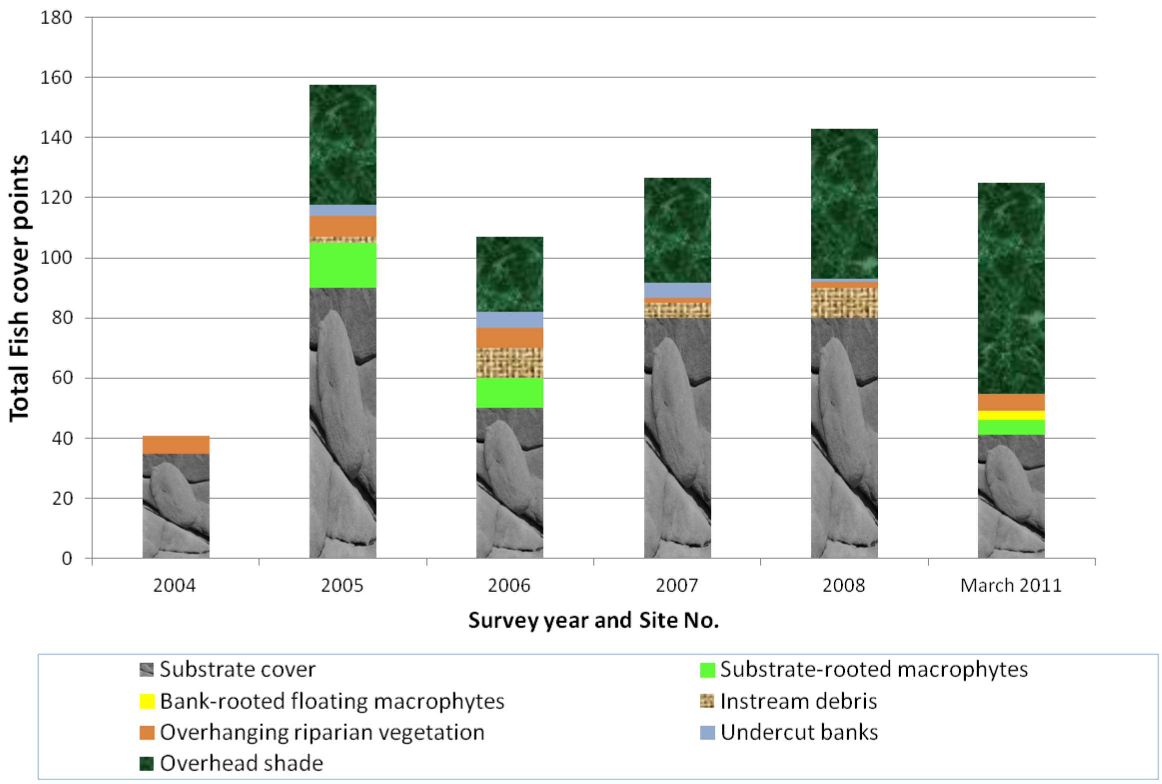

Figure 26a. Fish cover (refuge) changes over six habitat assessments (2004-2011).

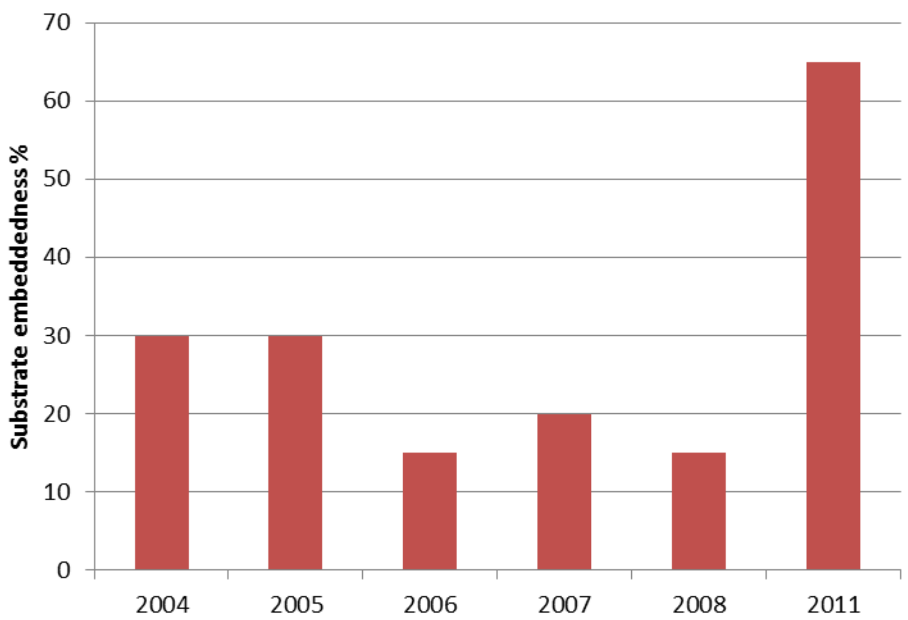

Figure 26b. The increase in substrate embeddedness following the February 2011 earthquake.

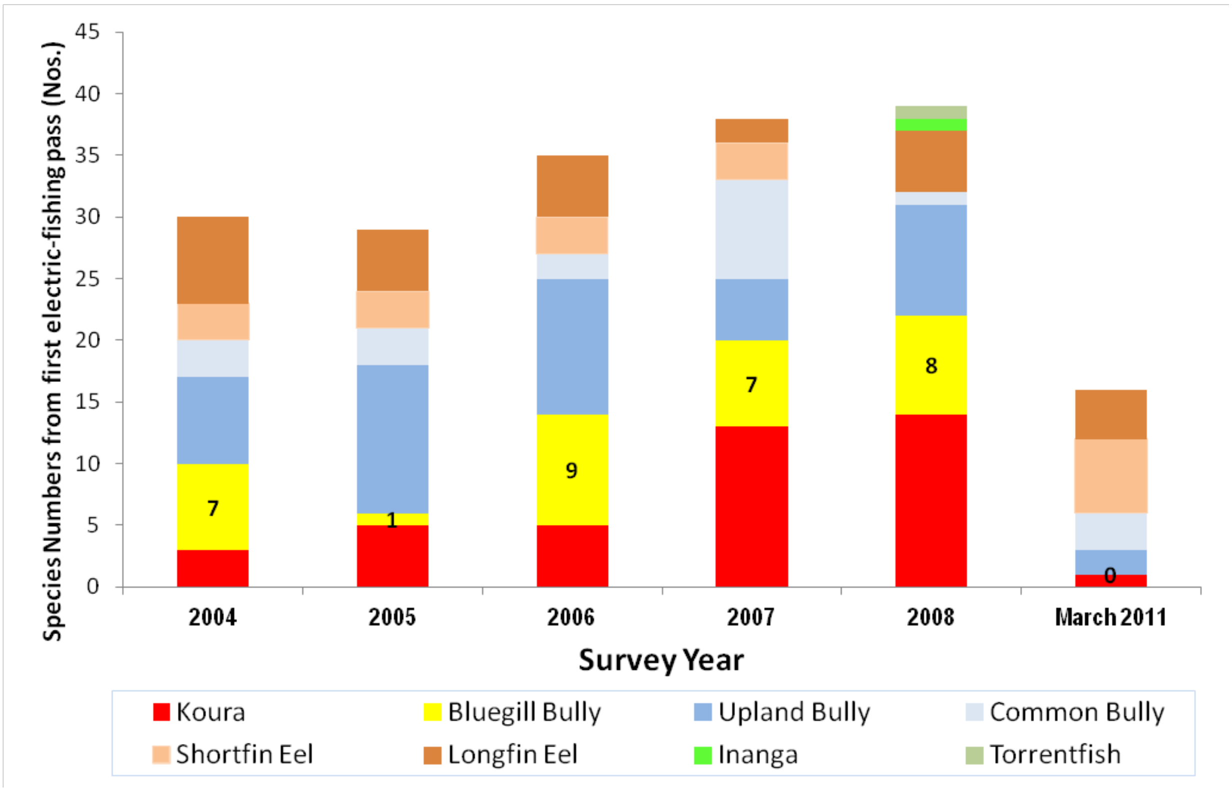

Figure 27. 'First-pass' electric fishing numbers of fish and koura from 2004 to 2011 for the standard fishing area at this site. The numerals relate to bluegill bully abundance.

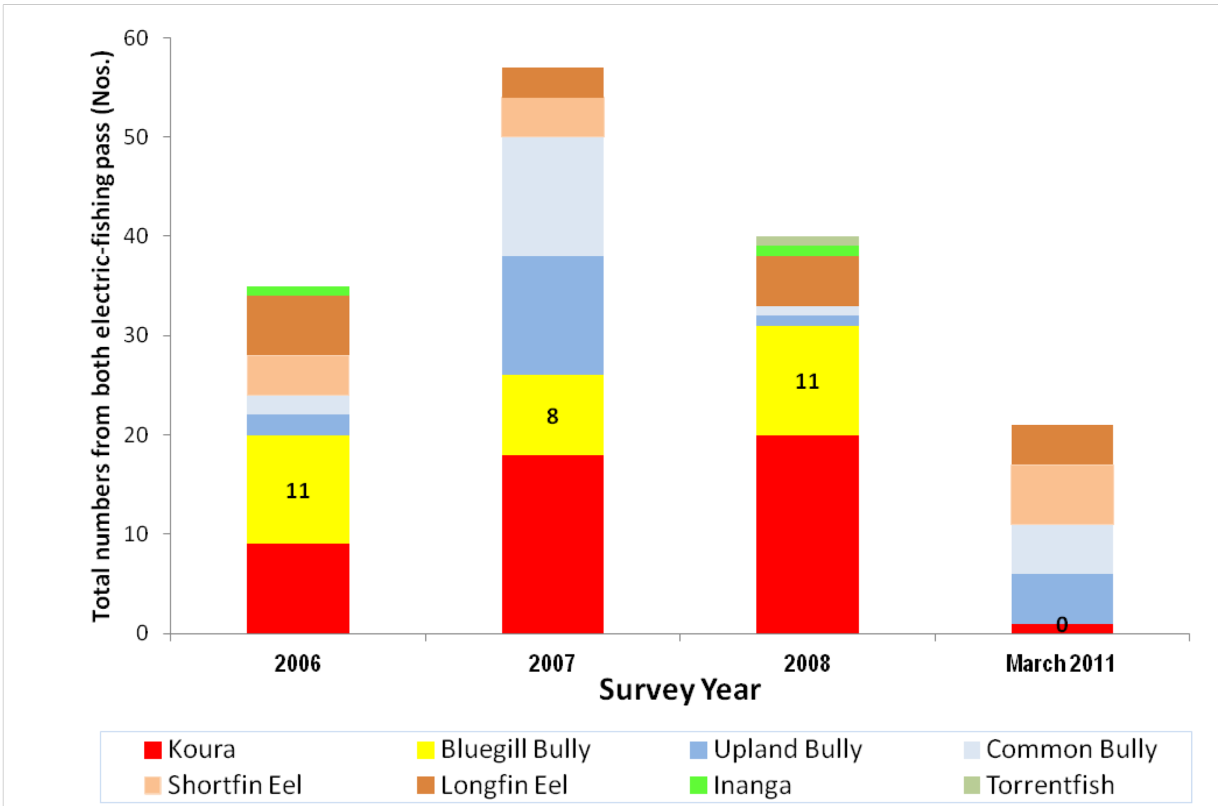

Figure28 . Fish and koura abundance based on two electric fishing passes over the standard fishing area at this site. Bluegill bully numbers are printed on the respective column categories.

6.2 Temporal changes in habitat and fish community in the Halswell River

6.2.1 Quaifes Ponds

The 'Qaiffes Ponds' are a two large ponds constructed on the lower reach of Quaifes Drain (Fig. 29). A proportion of the flow of the spring-fed Quaffes Drain is diverted through two ponds before being rediverted back into the lower reaches of the drain, whereby it flows into Knights Stream and the Halswell River.

Figure 29. The upper Quaifes Pond, looking north (17/3/11). It is approximately 110 m long by 78 m wide.

In March 2011, the margins of the larger upper pond (Fig. 29) was fished with fyke nets and Gee Minnow traps, with fishing effort complemented by electric fishing around the margins and outlets. This fishing effort and resultant catch is summarised with that of the 2004 SWAP survey in Table 3.

Table 3. Netting and trapping results from three netting surveys.

Survey	Fishing Effort	Inanga	Koura	Longfin Eel	Shortfin Eel	Upland Bully	Perch	Gold-fish
10 Feb 2004	Upper Pond 3 fykes, 1 GM			1	4			
10 Feb 2004	Lower Pond 2 Fykes, 1 GM	1		1	1		6	
10 Feb 2004	E fishing margins (5 min, 200 V)					3		
16-17 March 2011	Upper Pond 4 Fykes, 2 GM	0	0	18*	18	2	13	1
16-17 March 2011	Lower Pond margins E fishing (13 min, 200 V)	0	0	1	5	4	1 (obs. Large school)	
16-17 March 2011	Lower Pond outlet E fishing(6 min, 200 V)	0	0	0	0	10	0	

- There were particularly large specimens in this pond (max. length = 1182 mm T.L.)

It is evident that the CPUE of eels and perch has increased appreciably within the ponds, and schools of juvenile perch were observed in the margins of the upper pond. However, high numbers of upland bullies were present in the stony channel between the two ponds (Fig. 30), and a single wild goldfish was caught, and it is likely more are present in these habitats (Fig. 31). No inanga were seen during our site visit.

Figure 30. The clean stony channel between the two channel provides a spawning and rearing habitat for upland bullies.

Figure 31. A wild goldfish (F.L. 80 mm) from the Quaifes Ponds (17/3/11), as indicated by bronze, rather than gold, colouration.

6.2.2 Quaifes Drain (koura breeding habitat)

During the SWAP survey (EOS Ecology Limited *et al.* 2005), a particular reach of Quaifes Drain, comprising a shallow run with steep-sided banks, was identified as providing a breeding and rearing habitat for freshwater crayfish (koura). However, the site was severely damaged following the 4 September earthquake, with significant lateral spread on the true right bank (Figs. 32 c,d). There were deep cracks across the road opposite the drain, and the telegraph poles on the true right bank were well off vertical.

Figure 32a. Quaifes Drain koura habitat (10/2/2004), looking upstream.

Figure 32b. Intact koura burrows (arrowed)(10/2/2004).

Figure 32c. The same site 8 September 2010, this photo left bank was subject to significant lateral spread from the 4 September 2010 earthquake.

Figure 32d. 8/9/10, slumping on the true right bank, probably due to siesmic activity on the 4th September 2010.

The physical habitat had changed dramatically, with the substrate overlaid with more soft-sediment, greater water depth, and slightly narrower wetted width (Fig. 33). Repeat fishing of the koura breeding reach yielded no crayfish, with a tenfold increase in the number of shortfin eels. Longfin eels were now present, but absent from the previous SWAP survey. A single brown trout (c. 250 mm) was observed, but not caught in the fished section.

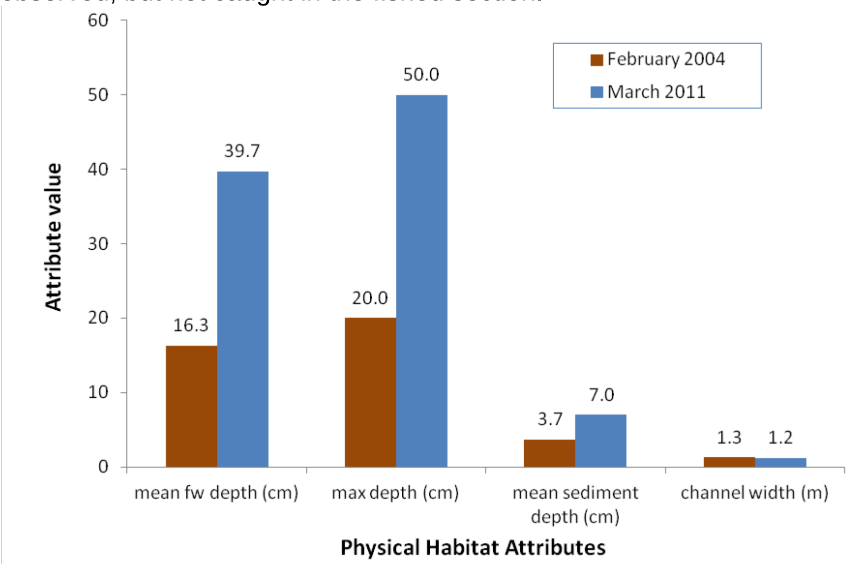

Figure 33. Basic habitat parameters for the koura breeding habitat on Quaifes Drain near corner of Sabys and Candys Road.

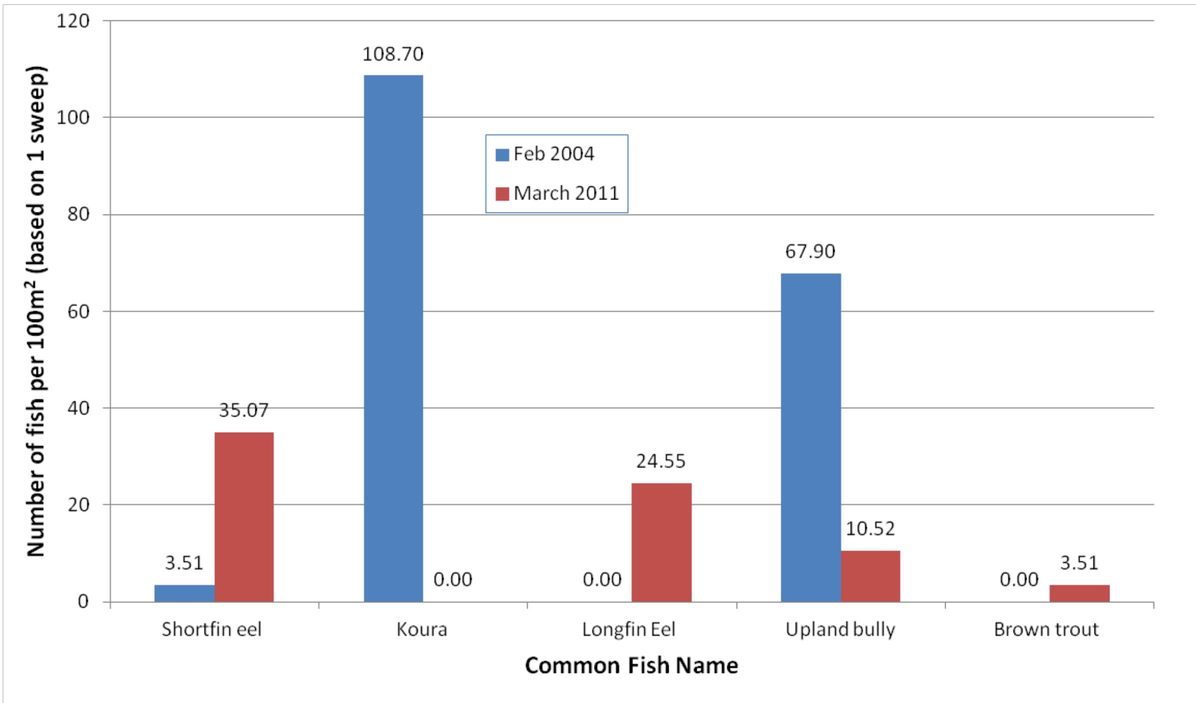

Figure 34. Change in fish and koura population density at the koura breeding habitat on Quaifes Drain near corner of Sabys and Candys Road.

6.2.3 Knights Stream

The headwaters of Knights Stream are fed by a spring downstream of Marshs Road, but also receives a controlled inflow from the Marshs Road drain, which has a direct controlled-flow link to the Paparua Irrigation Scheme at SH73 (Agriculture N.Z. Ltd 1997). Local landowners report of greater inflows from the scheme in the past, when small trout were conspicuous in the headwaters.

In the vicinity of this site, the waterway adopted a meandering gentle run (Fig. 35a, b). Since the 2004 survey, the true left bank has been planted in *Carex* and tree ferns, and the native vegetation on the right bank has matured. At the time of survey, large willow trees were being removed downstream of the section. The upper Knights stream was carrying significantly more flow than in February 2004, although the channel width remained the same (Fig. 3.6). Soft-sediment depth has also increased.

Figure 35a. 11/2/2004, looking upstream from the site's downstream boundary.

Figure 35b. 29/3/2011. Looking upstream from the site's downstream boundary. The waratahs indicate the downstream stopnet location.

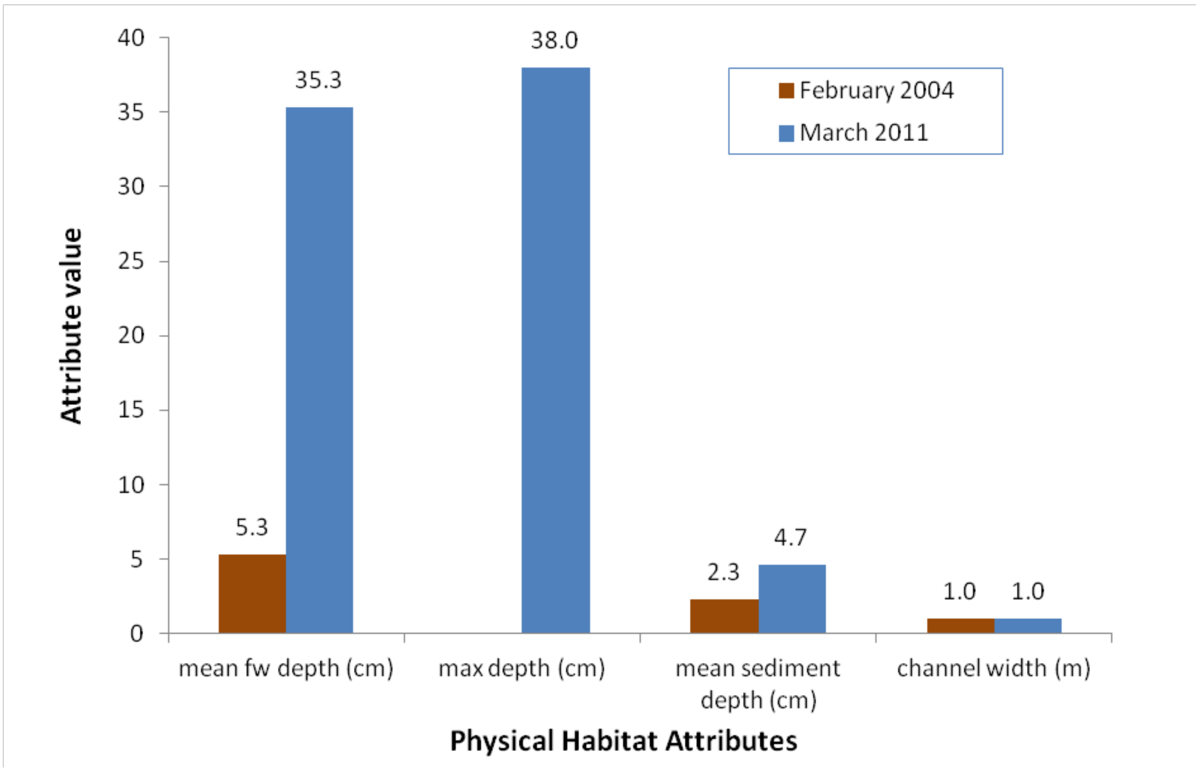

Figure 36. Basic habitat attributes of the Knights Stream site.

In terms of catch, the numbers of upland bully remained similar to the previous 2004 survey, but diversity had increased with shortfin eels and longfin eels also present (Fig. 37). One large longfin eel, of approximately 900 mm in length was observed just downstream of the section.

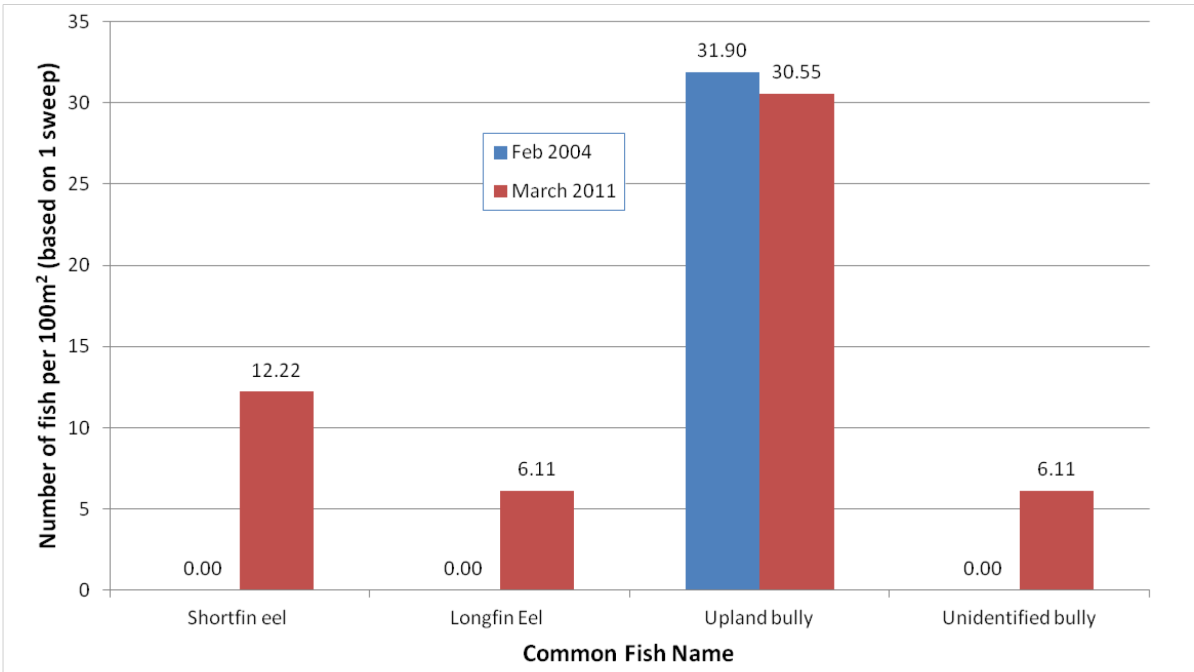

Figure 37. Increased biodiversity at the Knights Stream site compared to 2004.

6.2.4 Nottingham Stream, upper

Nottingham Stream rises from the centre of the suburb of Halswell, and relates Site 20 in the SWAP surveys (EOS Ecology Limited *et al.* 2005). It is approximately 2.7 km from its source near Oaklands, although most of the channel through Halswell was dry in the summer of 2004 (17 February).

Figure 38a. 30 March 2011**.** Looking downstream at the shaded channel of Nottingham Stream. Most of the channel was boxed through private property

Figure 38b. 30 March 2011. The stopnet at the bottom of the fished section.

Figure 39c. 17/2/2004. The fished section of Site 20, on Nottingham Stream. A gravel substrate, quite embedded into sand

Hydraulically, the stream flows as a shallow run, over a gravel substrate somewhat embedded in sand, both in 2004 and in 30 March 2011. The flow depth was somewhat greater in 2011, but otherwise was very similar to the environment observed in 2004. No sediment depth data was recorded in 2004. However, since 2004, and possibly due to the earthquakes, some of the dry stone cladding had collapsed, and the banks were in the process of being re-clad in wood, which explains the change in wetted width.

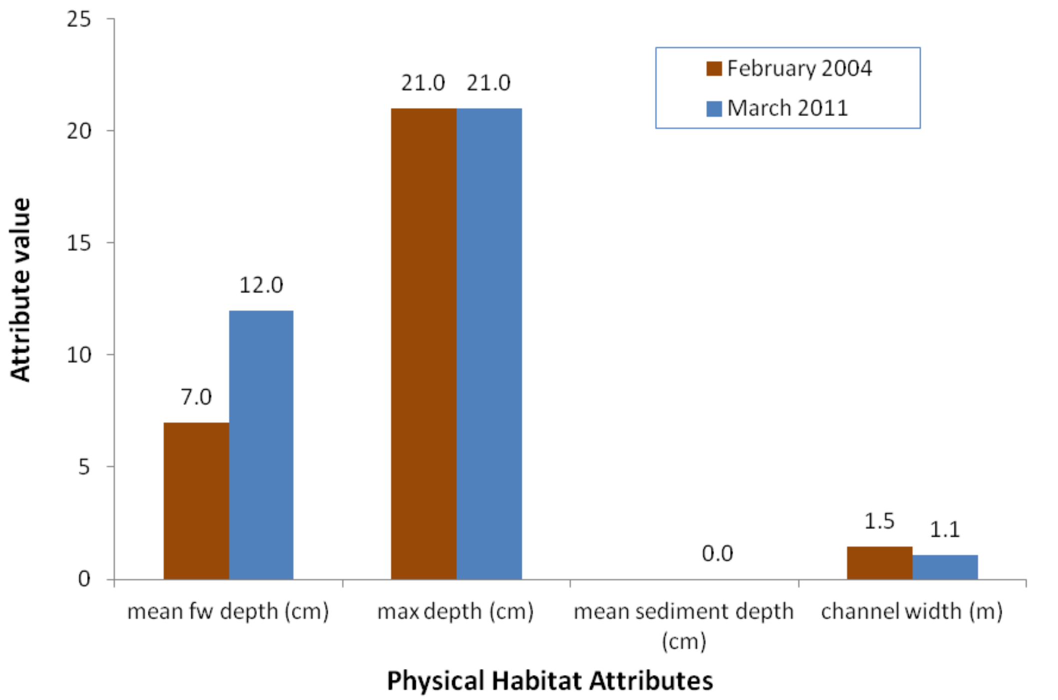

Figure 39. Basic habitat attributes of the upper Nottingham Stream site (SWAP Site 20).

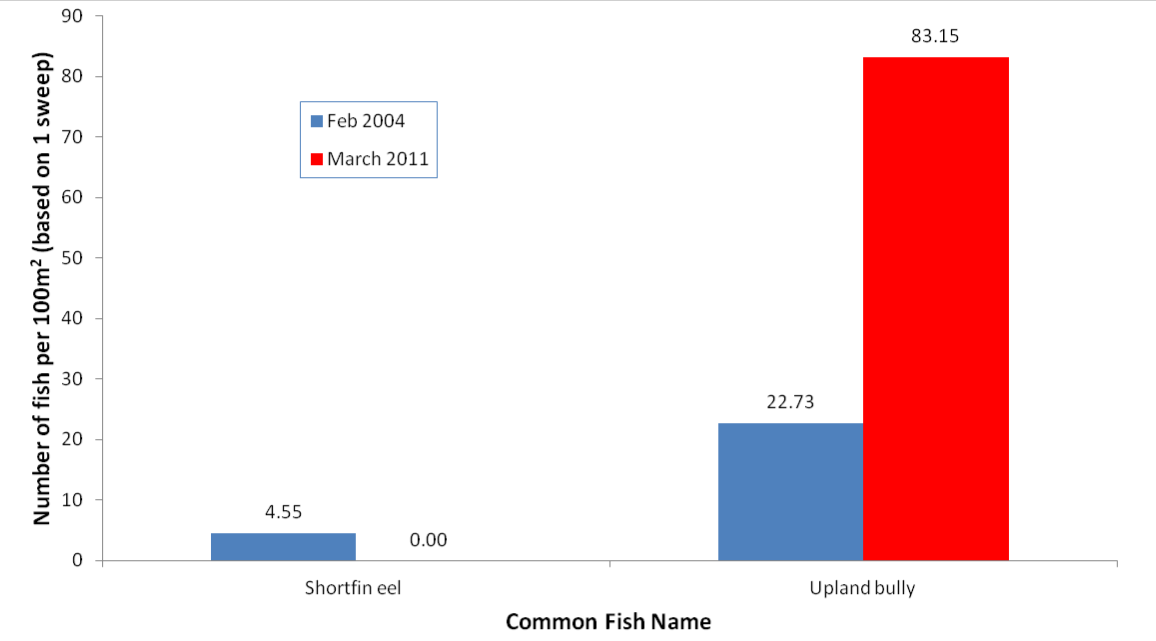

Figure 40. Fish abundance in the upper Nottingham Stream (SWAP Site 20), 2004, 2011.

6.2.5 Nottingham Stream, lower (SWAP site, Site 19)

This reach is referred to as Site 19 in the SWAP surveys (EOS Ecology Limited *et al.* 2005). This particular reach of Nottingham Stream is conveniently accessible from Halswell Road at this location. At the time of the recent survey (30/3/11), and possibly at most times, the channel was heavily overgrown with *Carex*, flax, some water-emergent water cress, and water celery (Figs. 41a, b). Aquatic plants included curly pondweed, and charophytes. In 2011, the waterway flowed as a slightly meandering run over a totally embedded silted bed with an appreciable silt depth (Fig. 41). However, in 2004, the channel was more open (Fig. 41b) substrate cobbles and gravels were slightly exposed, and the exposed cobbles and gravel was about 60% embedded.

Figure 41a. SWAP site, Site 19, 30 March 2001. Looking upstream along Nottingham Stream, which was heavily overgrown with instream and riparian vegetation.

Figure 41b. SWAP site, Site 19, 16 February 2004 looking upstream. The channel was less overgrown than in 2011.

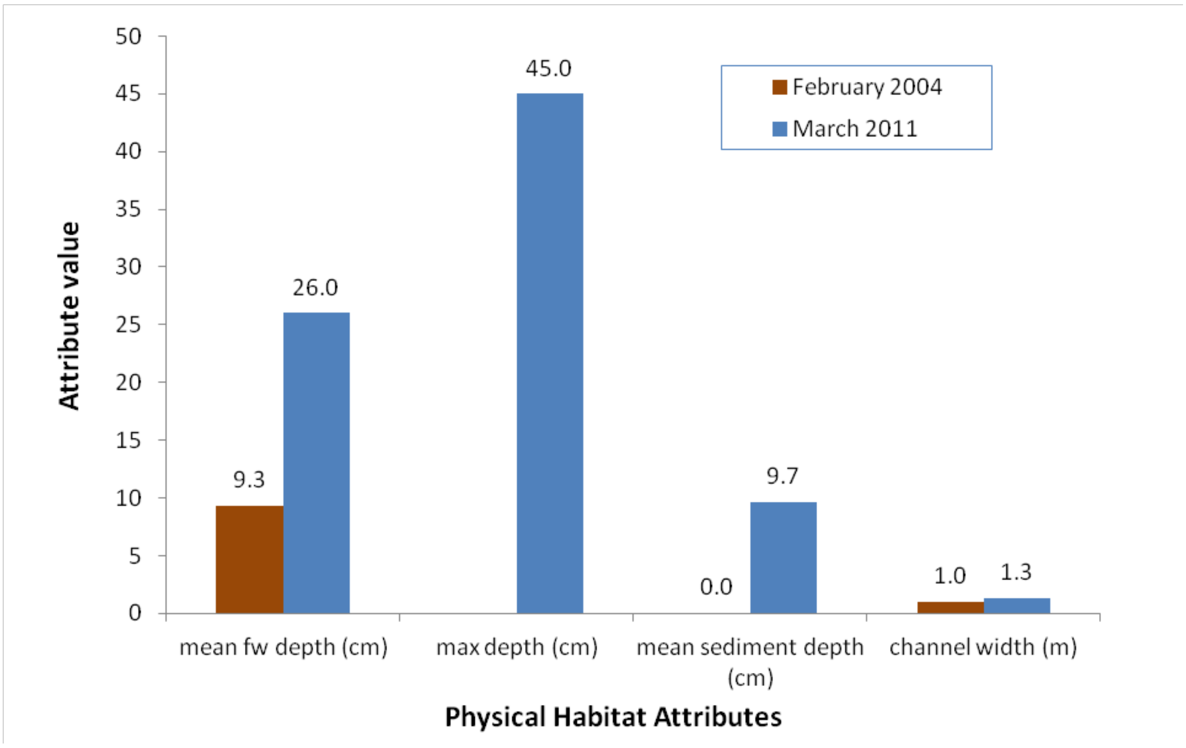

Figure 42. Change in physical habitat attributes between 2004 and 2011. Sediment depth has increased appreciably since 2004.

Because of the plant ingress since 2004, fishing efficiency was considered to be low, due to high escapement. However, biodiversity was higher in 2011, with longfin eels and common bullies present, despite not being recorded in 2004. Upland bullies and shortfin eels, recorded in 2004, were also present in 2011 (Fig. 43).

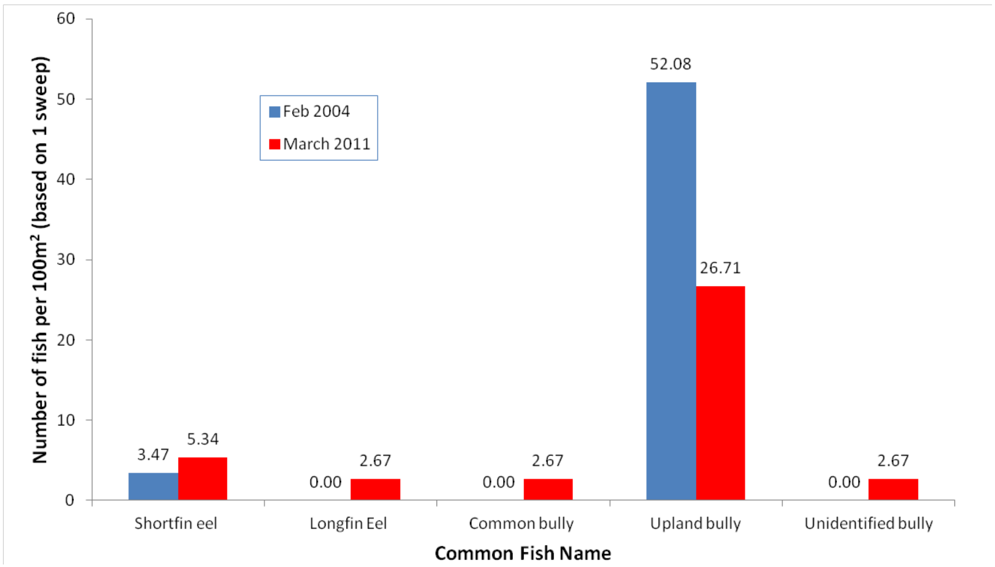

Figure 43. Fish abundance in the lower Nottingham Stream, 2004 - 2011

6.3 Fish populations

Fish populations, and species communities were generally well maintained, with the exception of the bluegill bully and koura (Fig. 44a, b). Longfin eels, in particular, were found in many more sites than prior to the earthquake.

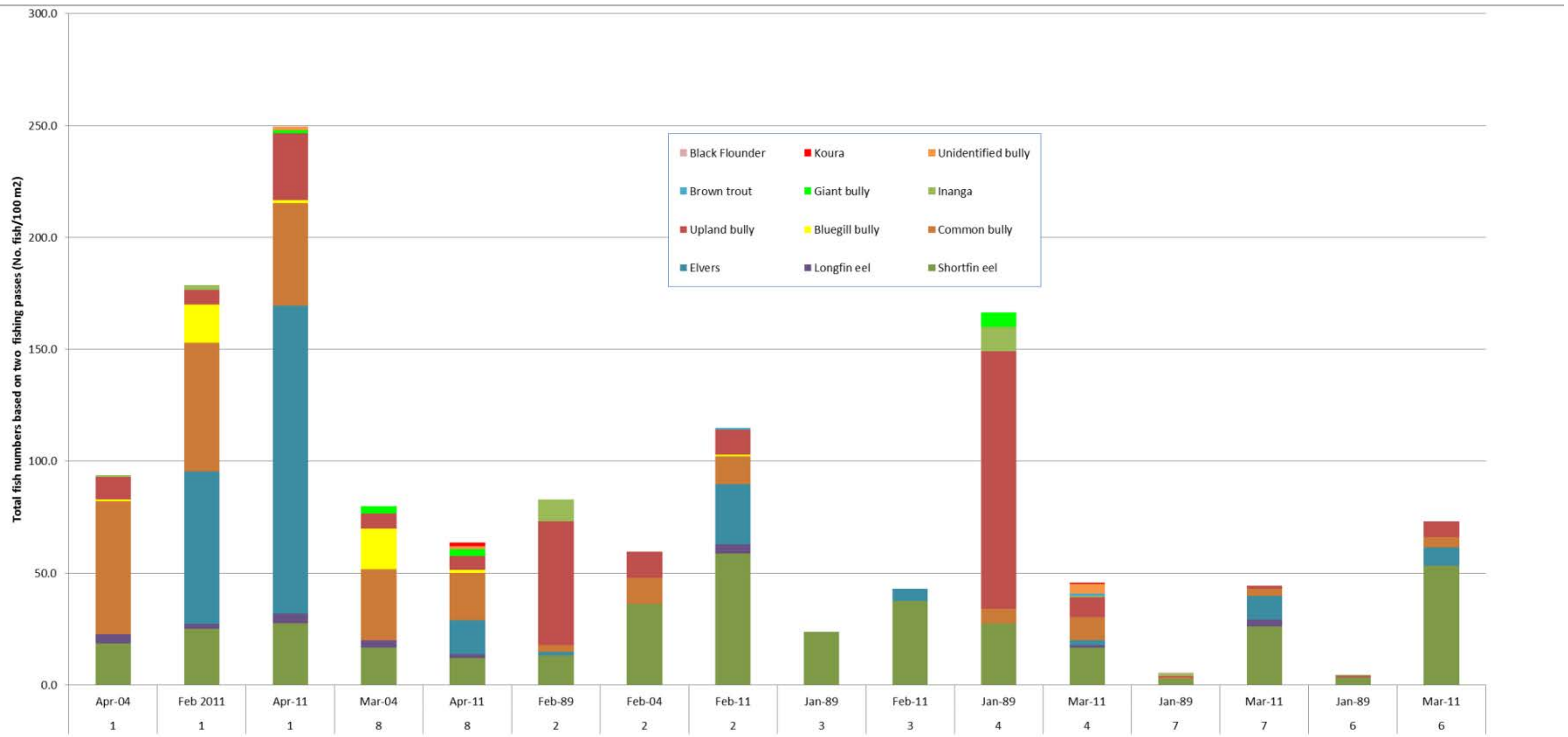

Figure 44a. Catch from electric fished habitats in the Heathcote River, based on two electric fishing passes.

Site numbers in Fig. 44a.

Site No	Locality	Site No.	Locality	Site No.	Locality	Site No.	Locality
1	Tennyson St	3	Nash Road	6	Upstream of Lincoln Rd	8	Colombo St
2	Rose St	4	Worsleys Road (Cashmere Stream)	7	Downstream of Lincoln Rd		

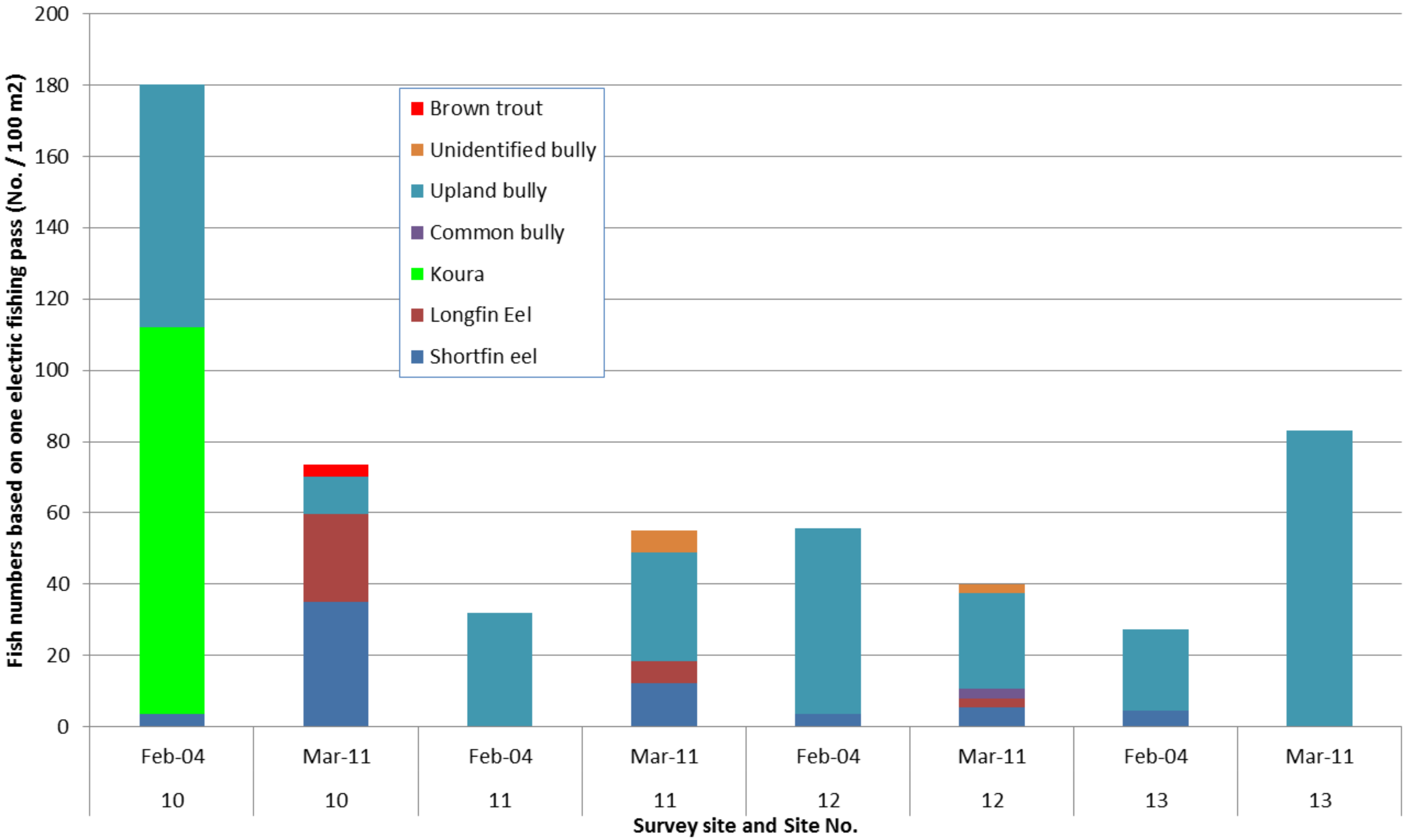

Figure 44b. Catch from electric fished habitats in the Halswell River, based on one electric fishing pass.

Site numbers in Fig. 44b.

Site No	Locality	Site No.	Locality
10	Quaifes Drain	12	Nottingham Stream, lower
11	Knights Stream	13	Nottingham Stream, upper

6.4 Trout Spawning Survey and redd water quality

The distribution of brown trout redds recorded in August 2011 is presented below, with overlays from the previous surveys in 2003 and 2007 (Fig. 45). The GPS survey in 1996 was incomplete, due to water clarity issues (Taylor 1996a), and does not appear in Fig. 44. In any case, in 1996, all GPS data was subject to spurious random error (i.e. "S.A." c. ± 100m) introduced by the U.S. Defence Department, which reduced the usefulness of that dataset for graphical comparison.

However, redd count data for all four recent redd surveys, incl. 1996, is presented in Fig. 46, illustrating changes in redd distribution over a 15-year time interval. Since 1996, numbers of trout redds have about halved in the surveyed reach upstream of the Cashmere Stream confluence, although 2010 redd numbers in the upper catchment were improved on the low numbers recorded in 2007.

In contrast to the 2007 survey, the 2010 redd distribution was characterised by somewhat reduced number of redds downstream of Colombo Street, but with a largely compensating increase in the number of redds upstream of Colombo Street. The total number of redds has remained much the same over the 2003 to 2010 period, from 22 (2003), 24 (2007), and 22 (2010). Over the same time period, the number of partially excavated redds recorded were 6(2003), 12 (2007), and 14 (2010). The 1996 trout redd survey did not included the reach downstream of Cashmere Stream.

Thus, overall the number of full and partially excavated redds in 2010 was about the same as in 2007, but with a slight (but statistically insignificant) upstream shift in distribution (Kruskal-Wallis). It was noteworthy that for the first time since 1993, a trout redd was identified upstream of Curletts Road, although this in itself is of no statistical significance.

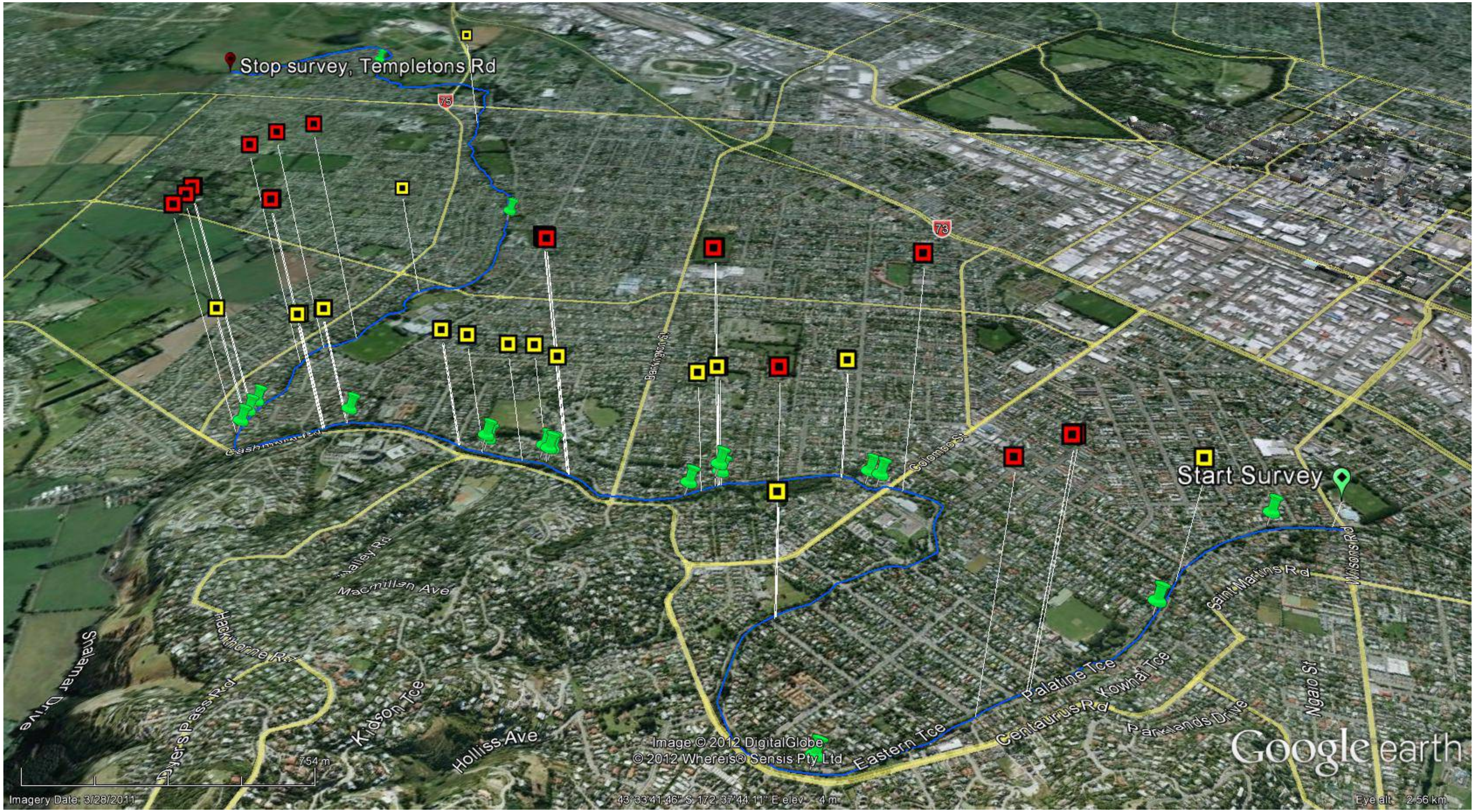

Figure 45. Distribution of brown trout redds from three surveys in the Heathcote River mainstem. Red squares = 2003 survey, yellow squares = 2007 survey, green pins = 2010 survey.

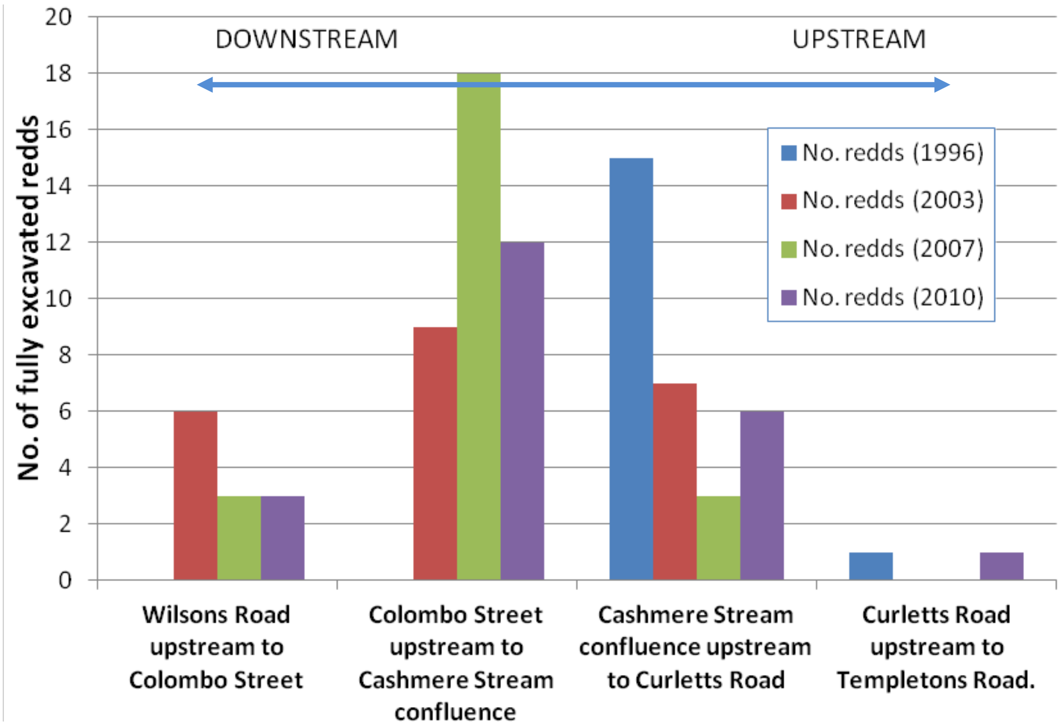

Figure 46. Numbers of complete trout redds over the four historically recent trout spawning surveys.

6.5 Water quality within trout redds

Water quality data was obtained from a number of trout redds in the Heathcote River, and this was previously reported in an earlier report to Environment Canterbury (Taylor *et al.* 2012). Summary tables of nitrate and IGDO (intragravel dissolved oxygen) levels are reproduced below (Tables 4, 5). Nitrate levels in the Heathcote and Avon Rivers were significantly higher than in the Otukaikino River (i.e. North Boundary Stream tributary). The Heathcote River nitrate levels were higher than those in the Avon River, but not significantly so at the 95% level (Fig 47).

Table 4. Nitrate statistics from trout redds and the substrate from 3 Christchurch rivers (date=11/8/11).

River	n	Median (N mg/L)	Mean (N mg/L)	SEM (N mg/L)	Minimum (N mg/L)	Maximum (N mg/L)
Wairarapa -in redd	15	1.0	0.8	0.10	0.1	1.3
Wairarapa streambed	1	0.9	0.9	-	0.9	0.9
Wairarapa Stream-surface water*	1	1.0	1.0	-		
Avon – Mona Vale – in redd pre-earthquake*	1	1.2	1.2	-		
Heathcote – in redd downstream of Cashmere Stream	12	1.2	1.1	0.14	0.5	1.8
Heathcote – in redd upstream of Cashmere Stream	3	1.8	2.0	0.25	1.7	2.5
Heathcote- streambed	1	0.1	0.1**	-	0.1	0.1
Heathcote surface water – Rose St***	1	2.9	2.9			
Otukaikino-in redd	15	0.2	0.2	0.024	0.1	0.4
Otukaikino-streambed	1	0.3	0.3	-	0.3	0.3

* From Avon River IGDO study, July 2010 (Taylor & Burdon 2010)
** This data value may be in error.
*** CCC data for August

Nitrate levels in the Heathcote mainstem were high (i.e. 2.9 mg/L at Rose St, CCC data), but reduce downstream of the Cashmere Stream confluence, presumably due to dilution from the significant flow input from Cashmere Stream. At the monitored redd downstream of Cashmere Stream, the nitrate levels were at about the same level as in the Avon River.

Table 5. Summary statistics for IGDO data for middle-aged redds between 10 and 20 days after redd construction. Heathcote River values are indicated in red.

	Otukaikino	Wairarapa	Heathcote
N (number of readings from 5 redds in each stream)	**39**	**23**	**35**
Minimum	**5.0**	**3.57**	**3.9**
Maximum	**13.2**	**10.7**	**9.0**
Median	**10.4**	**9.64**	**6.37**
Mean	**10.0**	**8.80**	**6.47**
SEM	**0.29**	**0.45**	**0.29**

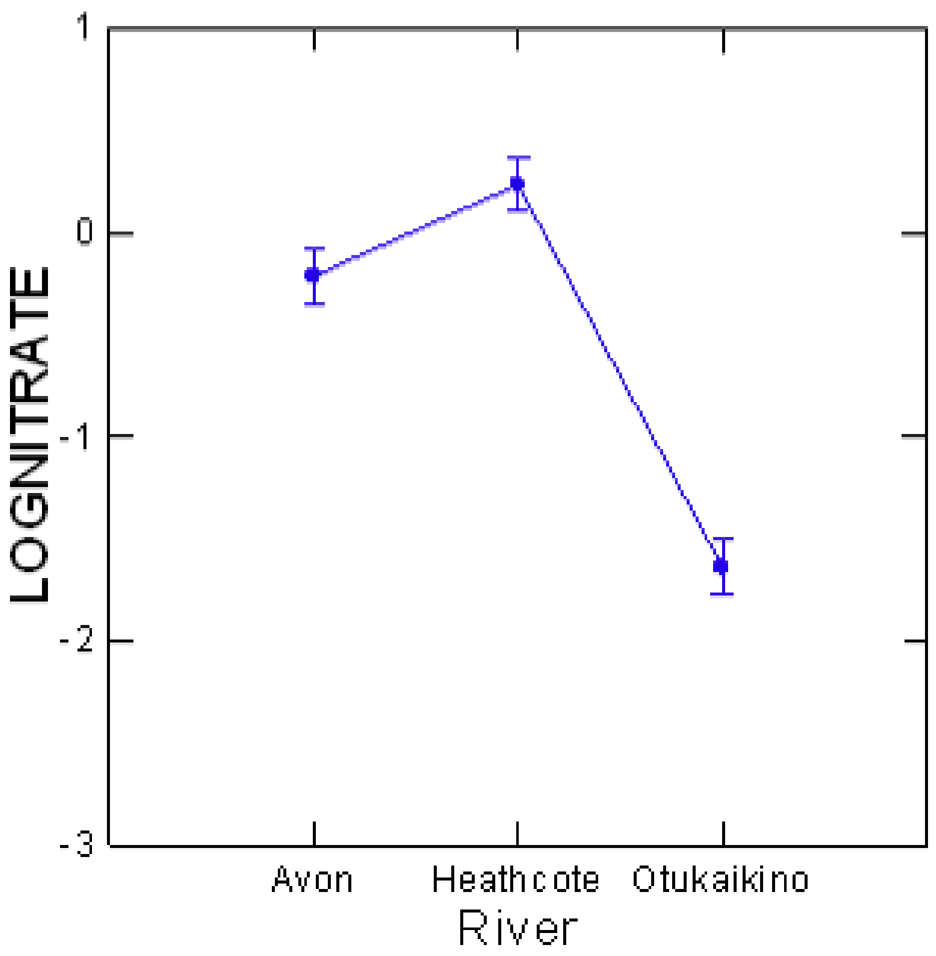

Figure 47. ANOVA Factor influence plot of least-squares means of log-transformed Nitrate levels against location (River) (SYSTAT 12 output).

Of the three monitored rivers, the Heathcote River had significantly lower IGDO (i.e. intra-gravel dissolved oxygen)(Type III mixed effects model, $p=0.001$), but there was no significant difference in IGDO between the Wairarapa and Otukaikino redds (Tukey HSD post-hoc test, $p>0.5$)(Table xi). However, IGDO did not significantly decrease over time in the Heathcote River during the egg incubation period, but were consistently low over the egg incubation period.

7 Discussion

7.1 Temporal changes in fish populations at monitored bluegill bully habitats in the Heathcote River

The use of fyke nets in 1989, in addition to electric fishing, frustrated a rigorous comparison of fish proportions. However, it is clear that the fish fauna was quite different to surveys conducted after the decommissioning of the Woolston Diversion. The Woolston Diversion is a man-made canal which diverts floodwaters out to sea. Before 1993, the Diversion was in continuous operation, effectively shortening the distance between the sea and upstream habitats, with salt extending almost 2 km further upstream than previously (Roper-Lindsay 1994). This caused a number of reported problems, of which one was river bank collapse and the death of bankside trees due to salt intrusion (Watts 2010). The 24/7 use of the Woolston Diversion was decommissioned in 1993, and its use for floodwater relief is now restricted to flood events.

Before the decommissioning of the Diversion's continuous use, it was reported that the distribution of the burrowing mud crab *Helice crassa* extended its range well upstream. In fact, the burrowing habit of this crustacean exacerbated saline intrusion into the banks, facilitating tree death and bank collapse. It is therefore possible that the distribution of fish at Tennyson Street in 1989 was also affected. In this context, the absence of yellow-belly flounder (a true marine flounder), and giant bully (which may have links to estuaries), in later surveys is likely be because of the greater distance from the estuarine environment. Conversely, the presence of upland bullies and bluegill bullies in surveys since the decommissioning is also consistent with a less 'down-river' fish distribution.

What is also interesting are the numbers of juvenile eels (elvers) which were present in the Tennyson Street reach after the September earthquake in early February, and then after the February earthquake in April 2011. It may be speculative to suggest that juvenile eel immigration into the system may have been induced by seismic activity, but there is some justification for that viewpoint. It is known that sewage discharges into the Heathcote and Avon Rivers which followed the February earthquakes, caused a modest decline in DO and Ammonia, but were not considered to be significantly adverse to the aquatic environment, as measured 28th April to 2nd May (Rutherford & Hudson 2011). A DO minimum occurred near the Railway Bridge near Opawa Road of about 4 mg/L, although, there is no data on the probably environmentally adverse levels in the days immediately following the February 22nd earthquake, and there were data reliability issues regarding the data on the first day of recording. A useful observation was made by a landowner on the Heathcote River immediately after the earthquake, when she observed eels climbing out the water (pers. comm.). Eels abandoning waters is a well-known behaviour for eels under adverse environmental conditions, caused by, at least in part, by hypoxic conditions. It is likely that if the physiologically robust eels are compromised by water quality, many other fish (especially smelt and trout) would be worse affected.

However, beyond the immediate acute effects after the earthquake, a degree of ammonia contamination and lowered oxygen saturation is unlikely to have adversely affected eels as other fish species. Both the shortfin and longfin eels exhibit high tolerance to ammonia (LC50 (96hr) shortfin elver c 2.35 mg/l, LC50 (96hr) longfin 1.8 mg/l) (Richardson 1997). Eels have very good olfaction, and it is not unreasonable to consider that the discharge of raw wastewater may attract foraging resident eels, which are attracted by a range of organic molecules (Hara 1994). Organic matter (decomposing meat, rotten eggs, blood etc) is often added to rivers to attract eels in New Zealand rivers (McDowall 1990).

The city's outflow of ammonia-contaminated waters during the spring summer period coincides with the glass eel and whitebait run (Jellyman 1977; McDowall & Eldon 1980). In laboratory trials, adult inanga were actually strongly attracted to ammonia-contaminated waters (Richardson *et al.* 2001), and the LC_{50} for juvenile inanga (FL 46 mm, prob. post whitebait) is high (1.13 mg/l, 96h) compared to other freshwater fish (Richardson 1997), and the levels recorded from river waters (max 0.6 mg/l). Thus, ammonia alone is unlikely to provide a deterrent for this species. It is interesting to speculate whether dilute ammonia, or some element in the sewage discharge, enhanced the glass-eel run into the city rivers, as glass-eels, are known to home by olfaction, and the Japanese eel (*Anguilla japonica*) is known to behaviourally respond to a mixture of amino acids (Hara 1994). However no information has been found on the olfaction and behaviour of New Zealand eels. A similar rise in juvenile shortfin eels was observed in the Avon River, and this change is probably for a similar reason (Eldon 1979).

Increases in shortfin eel numbers was also observed at the fished reach in Centennial Park, upstream of Rose Street. This site was fished the day before the significant February earthquake, but after the September 2010 seismic event, and aftershock sequence. This site had a similar shortfin eel numbers as in 2004, but a modest rise in numbers of elvers. The observed changes in the bully community at this site could well reflect changes in the nature of the reach; a higher amount of overhanging bank vegetation in 2004 and 2011, compared to 1989, would favour common bullies, which are associated with bank cover. Of interest as this site was the identification of a single bluegill bully. The identification of the one specimen is not ecologically significant in itself, but it may mean that should the level of substrate embeddedness be reduced at this site, then it may be attractive for this species.

The reduction in bluegill bully numbers at the Tennyson Street site (see Fig. 6) may be due to the increase in sediment depth at this site, from negligible before the earthquake, to an overall mean sediment depth of 2 cm. This trend in bluegill bully reduction was echoed in bluegill numbers at downstream of Colombo Street, and Hoon Hay Valley Road. It is suspected that bluegill bullies are sensitive to substrate sedimentation, and the decrease in number could be due to the settled fines reducing the spaces under the cobbles in which they feed and spawn. The bluegill bully is invariably found in fast-flowing waters with clean substrate, and are morphologically (and probably behaviourally) adapted for feeding on the invertebrates on undersides of rocks, as demonstrated by the undershot jaw (McDowall 1990). This same under-rock habitat is also considered likely to serve as a spawning substrate for these small fish, similar to other bullies (McDowall 1990).

The sharp reduction in bluegill bullies in the long riffle/run downstream of Colombo Street riffle co-occurred with a higher proportion of sand and silt recorded after the earthquakes than in 2004, but while the earthquakes were suspected, over this time period, other upstream sources of sediment are likely to provide an adverse impact. The Hoon Hay Valley Road site, on Cashmere Stream, has been monitored for some years, and habitat attributes in respect to suitability for fish communities has been well recorded. This site has suffered from several perturbations since monitoring began, including bridging, and, at least initially, overly-zealous bank vegetation trimming. However, following the February earthquake, the fact that we didn't record any bluegill bullies here, and just one koura, is of some concern, and this faunal depletion may well be due to seismic activity, as it was associated with increases in embeddedness and fine sediment. It is recommended that this site be remediated by the removal of silt

In summary, we consider that remediation of these three reaches downstream of Tennyson Street, Colombo Street, and Hoon Hay Valley Road is warranted to protect the specialised bluegill bully, which now has a conservation status of "declining" (Allibone *et al.* 2010).

A modest reduction of bluegill bully numbers was also noted in the recent Avon study, although the evidence was considered not strong enough to warrant remediation, but of further monitoring (Eldon 1979). We recorded a more significant compelling decline in bluegill bully numbers in the Heathcote River catchment, and given that sedimentation of gravels is ecologically adverse to a range of ecological values, and that their particular habitats are not extensive, we believe remediation is a reasonable option. Based on our observations of the habitats affected, the interstitial sand does not 'flush' during freshes since the earthquakes, and the adverse changes can be regarded as permanent without intervention. Recent trials with imported equipment suggest that liquefaction sand and silt can be removed from stony beds effectively, but the ecological perturbation of the removal process is still being assessed.

7.2 Synopsis of temporal changes at other monitored sites

Below is a discussion on the fish ecology of some of the monitored habitats, which are not previously addressed above in respect to bluegill bully habitats.

7.2.1 Heathcote River Lincoln Road habitats

Downstream of Lincoln Road, post-earthquake, rises in the number of shortfin eels were recorded, but there was little apparent perturbation to the stony habitat, based on available material from 1989. Upstream of Halswell Road, the silty bed is similar to the silt-laden bed suggested in the 1989 dataset, but the large increase in the number of shortfin eels and the appearance of elvers is consistent with the trend associated with the earthquake. Fish cover was not quantified in 1989, but the relatively recent *Carex* planting on the true left bank may explain the increase in the number of bullies at this site (upland and common bullies) given that the silt bed offers little fish refuge, with the exception of burrowing habitat for shortfin eels.

7.2.2 Nash Road (Heathcote River headwaters)

It was clear that, the upper Heathcote River was carrying much more flow in March 2011 than during the summer of 1989, with continuous flow and greater mean depths, and this feature alone may explain the higher eel biomass at the Nash Road site. The lack of an increase in fish species diversity does suggest that from 1989 to March 2011, there is no evidence of an increase in aquatic habitat permanence. The local landowner also stated that the habitat is normally dry in late summer.

7.2.3 Worsley Road (Cashmere Stream)

The Worsleys Road, based on available data, had changed little since the inaugural 1989 survey, although no bank vegetation cover was available at the time (NZFFDB record 10357). The increase in bank vegetation may explain the increase in common bully numbers, but the absence of any giant bullies, where 11 where recorded in January 1989, is noteworthy. However, at the Tennyson Street site, we identified two giant bullies following the earthquake, even though they have not been recorded from this site before, so there is no evidence that giant bully numbers generally have suffered from the seismic activity.

7.2.4 Quaifes Drain Koura Habitat

It was clear from our results and habitat assessment that this koura habitat has been damaged by the earthquake, probably due to the attendant lateral spread and bank slumping collapsing the burrows. This damage was apparent after the September earthquake, and the re-visit in March 2011 confirmed the ecological impact of this event, and the February 11 aftershock.

If the slumped banks have stabilised, it may be possible to reintroduce koura at this site, and make artificial refugia in the bank by driving in PVC tubes (c. 30 mm dia). This should be undertaken with the removal of soft sediment as the presence of soft sediment facilitates the colonisation of potentially predatory shortfin eels. If the banks are deemed currently unstable, the existing native vegetation will have to be removed, then the banks stabilised and replanted.

7.2.5 Quaifes Ponds

These ponds continue to provide a breeding and rearing habitat for Perch, and the lower Halswell Perch fishery probably recruits juveniles from this habitat. Goldfish have been recorded from the Halswell River many times before, and the ponds in Oaklands suburb. Therefore, their presence in the ponds is not a surprise. Goldfish are omnivorous, thus while competing with native fish for insect food items, they will not actively predate on native fish. In contrast, perch are piscivorous, and will feed on bullies and inanga, and small eels, given the opportunity. Equally, the very large eels present in the ponds are likely to feed on small perch. There is probably little that can be done in controlling perch or goldfish in this habitat, given that they are well-distributed in the catchment, and it could be argued that there is little need to. The Halswell River supports a recreational perch fishery well-regarded amongst the coarse fish angling community, and the ponds form a component of this resource. The ponds also form an excellent rearing ground for large eels, probably because of the high numbers of small prey fish on which they forage.

7.3 Temporal changes in trout spawning activity and water quality in the Heathcote River.

It was of interest that, following the Canterbury earthquakes there was no clear overall decline in trout spawning activity compared to pre-earthquake activity, as monitored in 2007. The slight, but insignificant, upstream shift in distribution following the earthquakes is of interest, but it is unclear if this trend reflects relatively better and improving spawning conditions in the upper reaches, compared to that downstream of Cashmere Stream. It is tempting to suggest that earthquake fines may have clogged spawning gravels downstream of Cashmere Stream causing this reduction in use, but the 2003 redd distribution and tallies indicate a no better utilisation than the 2010 survey following the earthquakes. However, a loss of a trout spawning reach, between Martin and Malcolm Avenues is apparent since 2003, but the absence of trout spawning activity in that reach pre-dated the earthquakes. Thus, there is some evidence of a lower utilisation of the reach downstream of Colombo Street, but this trend predates the earthquakes, and the numbers of trout redds are few, and it is impossible to attach significant to these low numbers.

Remarkably trout were not identified in the Heathcote River during the inaugural 1989 fish survey, but this report cites an anecdotal account of trout “jostling each for space on the spawning gravels of the Heathcote River in the 1960s” (Eldon *et al.* 1989). However, the location of these spawning grounds is unknown, but it quite likely to extend over a similar general reach of river as recorded here. In our opinion, there are little water gradient inflections (changes in water slope) or suitable substrate downstream of Wilsons Road which would induce trout to spawn.

The numbers of partially excavated redds tends to be increasing over time, although it is difficult to interpret the significance of partially excavated constructions. Sometimes a fresh partially-excavated redd represent one still under construction, or it may represent an attempt to build a redd, and the hen fish (i.e. the excavating female trout) has deemed the location as unsuitable, and excavated a full redd somewhere else. In our experience, we often find partially excavated redds, or simply localised disturbances in the river gravels, near fully excavated redds. So we regard partially excavated redds as ‘trials’, before the hen fish finds a better location, and excavates a full redd nearby.

Therefore, we considered it meaningful to only map the distribution of completely formed redds, as these constructions are most likely to contain eggs, and are more likely to represent reaches of ecological significance. The increase in the number of partially excavated redds over the four surveys may simply represent that our survey this year was somewhat earlier, by a week or two, than previous years. Many partially excavated redds were located between Colombo and Barrington Streets, a reach where many fully excavated reach were found.

7.4 Water quality in trout redds

While there is good knowledge of trout redd distribution, there is no previously known redd water quality data for the Heathcote River. What is clear is that IGDO levels are significantly lower than in that found in the Otukaikino River which has apparently less organic-bound sediment. Combined with somewhat elevated nitrate levels, due to high geological source (Kingett Mitchell Limited 2005), it is unknown what the synergistic impact these known stressors impose on successful trout fry production. Based on North American studies using caged eggs and artificial redds, brown trout egg survival was compromised below 8 mg/L (Maret *et al.* 1993), therefore there is sufficient grounds to suggest trout survival could be reduced in the Heathcote River. This remains a topic of research interest.

8 Recommendations

AEL recommends the following:

- Remediation of bluegill bully habitats, particularly substrate remediation, in the Heathcote River (Colombo Street, Tennyson Street, Centennial Park, this coming summer, and possibly other rivers in the Christchurch area.
- Remediation of the koura breeding habitat on Quaifes Drain, near the corner of Sabys and Candys Road. This may involve bank stabilisation, silt removal, and the reintroduction of koura and refugia.

9 Acknowledgements

We thank Malcolm Main, Ross Taylor, and Lynda Barneveld for assistance in the field under sometimes stressful conditions. We also appreciate the patience of CCC staff in providing us a generous extension in preparing this report.

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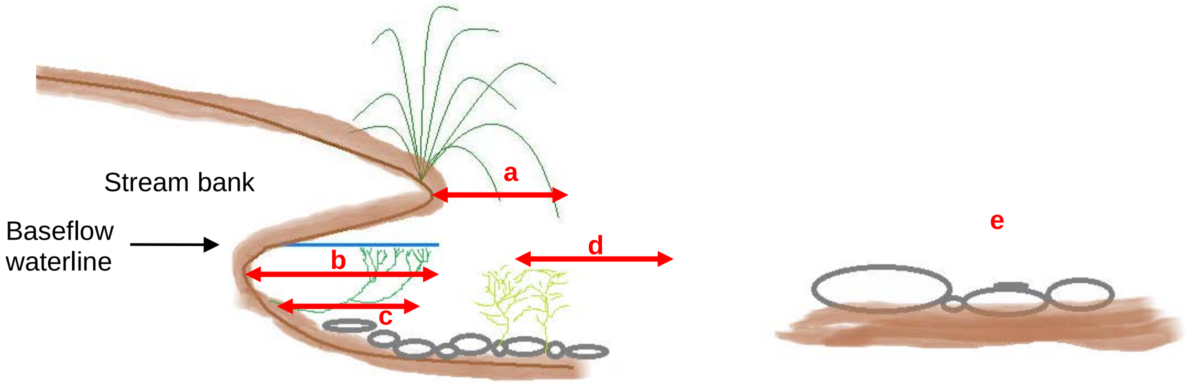
11 Appendix I. Schematic of fish cover components



Bank profile schematic depicting field measurements of (a) = vegetation overhang distance, (b) = bank overhang distance, (c) = width of bank-rooted marginal emergent vegetation, d = area of bed-rooted aquatic macrophytes (d). Expansion of bed profile depicts the coarse substrate nearly half buried in surrounding fines. This equates to an embeddedness of approximately 30%.