The Styx

Pūrākaunui

Mark Taylor

A E L
Aquatic Ecology Limited

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Styx Report: 2005/2
AEL32

Trout Spawning in the Styx River

An Update

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Contents

Executive Summary

A trout spawning survey of the Styx River catchment was undertaken during early August 2005, and the results compared to previous surveys. Despite complications in comparing results with earlier work due to timing of earlier surveys, the results indicated an increase in trout redds numbers and a greater distribution of redds compared to the last surveys in 1999 and 2000. This is attributed to improvements in riparian management and habitat quality within important trout spawning grounds. No trout redds were reported from Kaputone Stream, consistent with past surveys.

In the year 2000, preliminary measurements of IGDO (intragravel dissolved oxygen) from trout redds were obtained and compared to readings obtained from redds in the Avon River and Silverstream. IGDO readings from the lower Styx River spawning grounds (i.e. immediately upstream of the Styx Mill Road), were significantly lower than ecologically desirable.

A number of other environmental issues still need to be addressed in the catchment; in respect to riparian management and pollution control. Recommendations are made on these issues.

Spawning trout in Smacks Creek

1 Background and objectives

In the past, the Styx River has provided a valued small-trout fishery to the local community. Based on a survey of anglers, one of the reasons why it was valued was its easy access from the city, which allowed commuters to fish before and after work (Teirney *et al.* 1987).

However, the same survey revealed that anglers perceived water quality to be low. Historically the Styx River, especially the Kaputone Stream, received wastewater from a range of industries, and riparian management through agricultural land was often poor or non-existent. The first comprehensive fish study on the Styx River depicted a waterway of contrasts; with both reaches of good trout habitat, and reaches with degraded polluted habitat (Eldon & Taylor 1990).

Brown trout deposit their eggs amongst gravels in fast-flowing reaches of streams during winter and early spring. Each female trout (or hen fish) deposits her eggs in a series of small excavations (called pockets) in the gravel. After fertilisation by an attendant male fish (or jack), the eggs are buried by gravel dislodged immediately upstream (McDowall 1990). The distinctive gravel formation resulting from this activity is called a redd (Fig. 1).

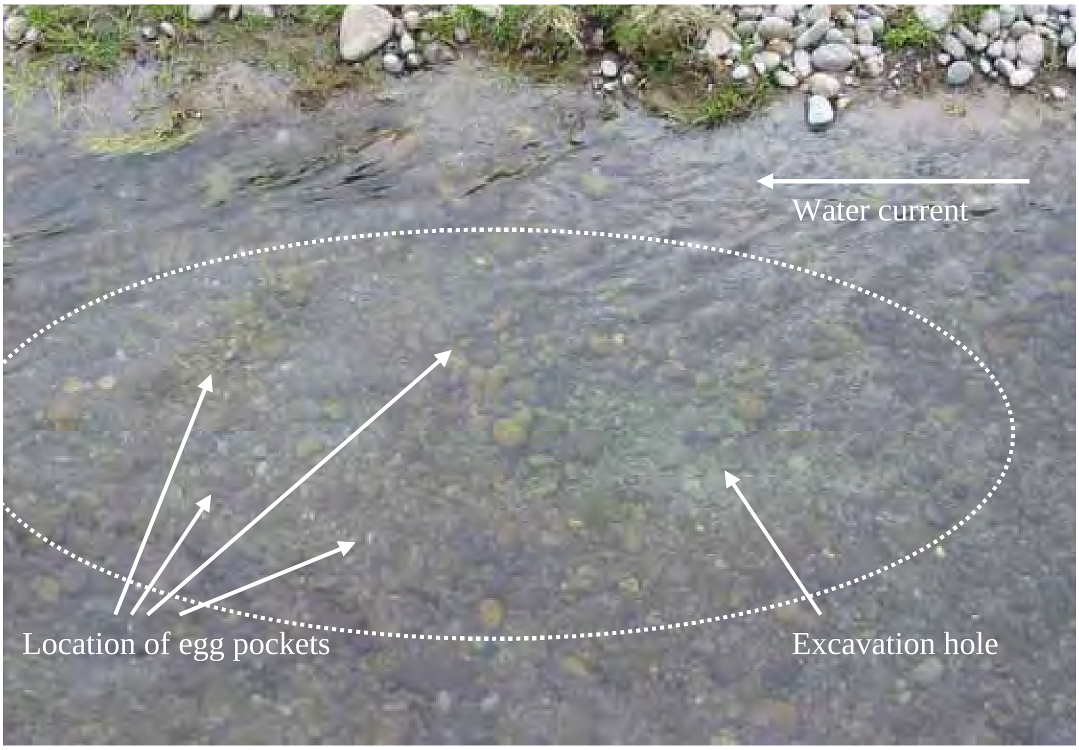


Figure 1. A small trout redd. The cobbles from the upstream end have been excavated and swept downstream to cover the eggs.

At least three trout spawning surveys have been previously conducted on the Styx River. The first recorded survey was conducted in the winter of 1989, as part of a Ministry of Agriculture and Fisheries (MAF) investigation into fish values in the catchment (Eldon & Taylor 1990). Then, in 1999, the Fish and Game Council was approached by CCC to conduct a trout spawning survey of the Styx River (Ross 1999). This survey extended on the mainstem from "just below' the bridge on the Main North Road, upstream to near Sawyers Arms Road. A survey on Smacks Creek appeared to have been limited to the reach within Willowbank Wildlife Reserve, and the Kaputone Stream was not surveyed.

A third survey was conducted in the winter of 2000 by the National Institute of Water and Atmospheric Research (NIWA). The NIWA investigation also undertook preliminary tests on the dissolved oxygen levels within the trout redd gravels, termed the IGDO (intra-gravel dissolved oxygen). At the time funding was only available for field work and data collation; this work was not written up and tabled to CCC.

Since 2000, there have been some changes in the catchment which could potentially affect trout spawning. The residential development of the formerly rural middle and upper catchment has accelerated to the point that the impacts of some residential developments (through stormwater discharges, and changes in sub-catchment flow regime) could potentially impact on trout spawning reaches. Other reaches which were subject to stock access in 2000 have since been fenced from stock, or the stock removed. The Styx Mill conservation reserve has also been developed further since 2000, with the maturation of the riparian vegetation, which could also provide refuge for spawning trout.

Given this background, this study was proposed with the following three objectives:

1. Present the findings of the 2000 trout spawning survey.

2. Undertake a trout spawning survey in the winter of 2005; and compare the results of these and other surveys, including that from 2000.

3. Provide recommendations to enhance or protect trout spawning habitat in the Styx River catchment.

2 Catchment description

The Styx River is a small coastal river with a catchment area of approximately 55 km^2. In addition to groundwater inflows from aquifers fed by the Waimakariri River, the catchment receives runoff from the suburbs of Belfast, Northcote, Casebrook, and Redwood. In the lower reaches, the river drains rural and semi-rural land of Marshlands, Chaneys, Kainga and Brooklands.

In the past, the river rose within Nunweek Park south of Harewood Road, but more recently permanent water is only found north of Sawyers Arms Road (Fig. 2), after it receives inflow from several significant springs. The mainstem flows for approximately 21 km, with its two major tributaries (also spring fed) having lengths of 2 km (Smacks Creek) and 11 km (Kaputone Stream). The surveyed reaches of these tributaries are discussed in more detail in the results section. A number of smaller tributaries enter the lower reaches.

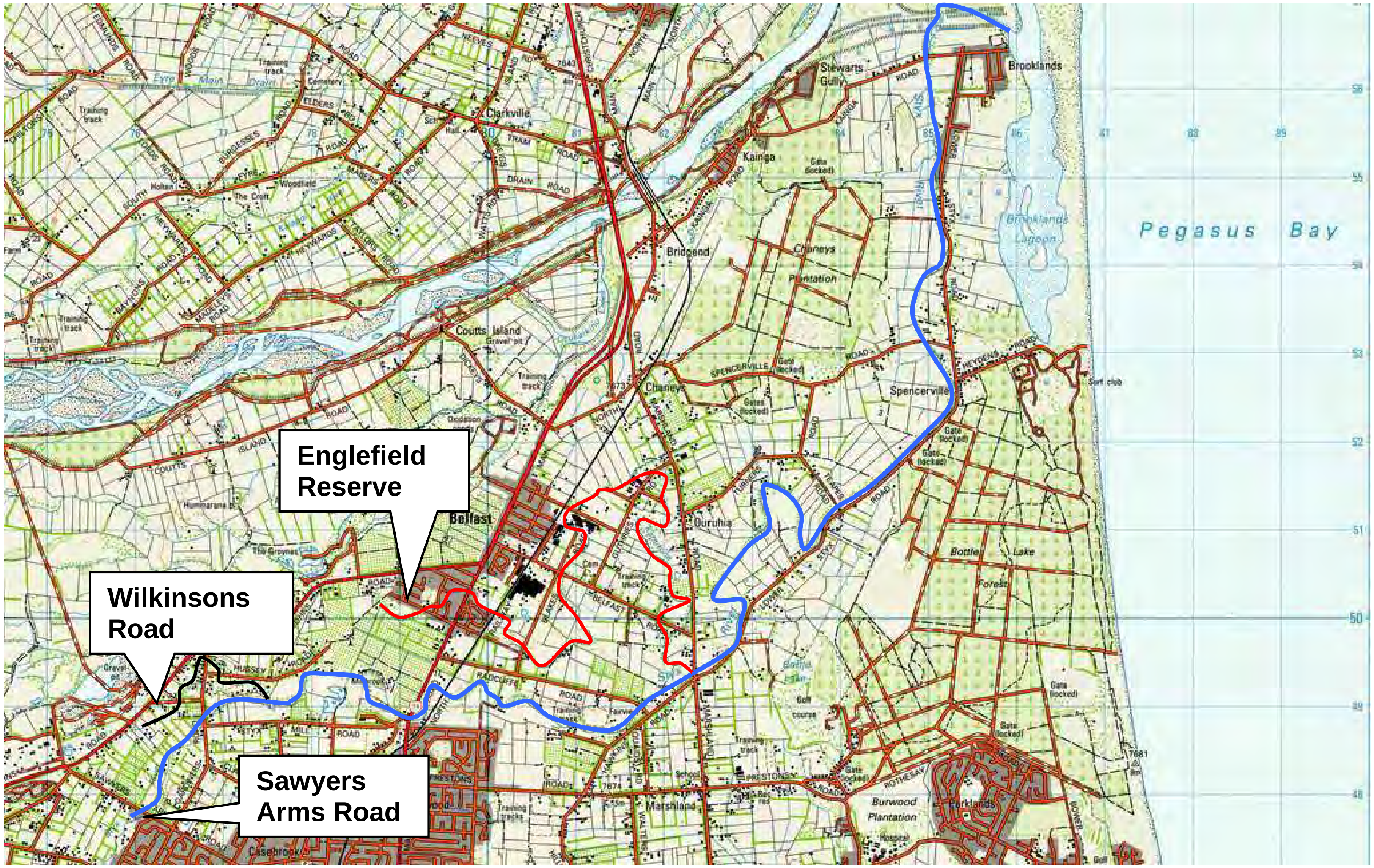


Figure 2. The Styx River catchment, with the principal tributaries highlighted: Styx River mainstem (blue), Kaputone (red), and Smacks Creek (black). Blue grid squares are 1 km^2.

3 Methods

3.1 Trout redd surveys

3.1.1 2000 trout redd survey

This survey was conducted in early July 2000, and carried out in the conventional manner, and using the same methods as that used during the June and July 1990 surveys. The extent of the survey is tabulated in Table 1. The survey covered all known reaches of spawning gravel except for the boxed drain in the Styx Mill Conservation Reserve.

Waterways were surveyed by foot in an upstream direction, with the location of redds and suitable spawning gravels logged onto a GPS receiver. Surveys were conducted between 10 am and 4 pm, when the sun was sufficiently high above the horizon, to reduce water-surface glare. Polaroid™ sunglasses were worn by observers to improve the detection of trout redds and fish. Records and waypoints were logged for redds, suitable spawning gravel, and the size of observed trout.

Table 1. The extent and timing of the trout spawning survey on the Styx River in early July 2000.

Tributary	**Downstream survey limit**	**Upstream survey limit**
Mainstem	Railway bridge	1 km downstream of Sawyers Arms Road
Smacks Stream	Styx River confluence	Wilkinsons Road
Kaputone Stream	Styx River confluence	Englefield Reserve

3.1.2 2005 trout redd survey

The trout spawning survey was conducted in early August, with the same methodology as above. Also recorded were details and locations of potential instream impediments to trout passage, and basic measurements of stream widths and mid-channel depths. Photographs of reaches, trout redds, and other features of interest were taken with a digital field camera fitted with a Polaroid ™ lens.

The survey limits were selected to include all reaches of potential value for trout spawning (Table 2). The boxed drains in the Styx Mill Basin were surveyed later than the rest of the catchment, as they were inadvertently missed during the August fieldwork.

3.2 Field measurement of IGDO levels

The dissolved oxygen level in the water within the stream gravels is termed intra-gravel dissolved oxygen (IGDO). Measurements of IGDO were obtained in 2000 from apparently freshly-excavated redds during the trout spawning survey.

Table 2. The extent and timing of the trout spawning survey on the Styx River in the winter of 2005.

Tributary	Survey Date	Downstream survey limit	Upstream survey limit
Mainstem	4 August	Railway bridge	Sawyers Arms Road
Smacks Stream	8 August	Mainstem confluence	Wilkinsons Road
Kaputone Stream	8-10 August	1.3 km upstream from mainstem confluence	Blakes Road
Boxed drains in the Styx Mill Basin Reserve.	22 September	Styx Mill Road	From Styx Mill Road

Six redds were selected from the Styx River; three between the Styx Mill Conservation Reserve and Styx Mill Road (lower reach), and three near the confluence with Smacks Creek (upper reach). IGDO readings were also obtained from three redds in the Avon River (adjacent to the Hagley Park car park), and Silverstream (a tributary of the Eyre River) on the 17 July 2000. Silverstream is a relatively silt-free stream, and served as a control in this study, with redds upstream of the hatchery and any obvious source of silt. Further, to test the relationship between IGDO and the age of the redd, a freshly-excavated redd in the lower Styx River was repeat-sampled 17 days after the first set of measurements was taken.

DO was firstly measured from open water at the stream bed surface, and IGDO readings were then obtained from duplicate water samples at a depth of 0.15 m and 0.25 m within each redd. The 0.15 m depth represents a mid-point on measured gravel depths for brown trout egg pockets on the Selwyn River (0.1 m – 0.2 m) (Hardy 1963). The 0.25 m depth would represent a possible value for redds excavated by particularly large fish. Water samples were collected from open-ended, stainless steel wells (15 mm internal diameter), driven into the stream bed using a steel driving rod (Boulton *et al.* 1997). A hand-operated bilge pump was used to extract water from the well, with the first, turbid litre of withdrawn water discarded (Fig. 3a). The IGDO reading was then determined by pumping water in an unbroken stream until a small container overflowed. A YSI dissolved (DO) probe was then inserted and DO recorded in the field once readings had stabilised (Fig. 3b).

3.3 Statistical methods

Maps of trout redd distribution were produced by downloading the GPS data into TopoMap Pro® (ver. 2.0), and Aerial Map Pro® software. IGDO data were compared between depths and rivers and tested for statistical significance using parametric and nonparametric statistics with the program SYSTAT® ver. 10. Frequency distribution graphics were outputs from SYSTAT® or EXCEL®.

Figure 3a. Pumping water samples from stainless wells driven into a trout redd.

Figure 3b. Field measurement of IGDO. Two readings were recorded from water samples taken from two depths at each of two trout redds. The YSI® DO meter is in the foreground.

4 Results

4.1 Physical habitat as assessed in the winter of 2005

4.1.1 Styx Mainstem

At the time of the survey (4 August, 2005), the 200 m reach downstream of Sawyers Arms Road comprised puddles of water overlying a shaded silty bed. However further downstream, the bed profile was fully submerged, with a channel width of 1.5 m, and a depth of 0.5 m. Small starwort (*Callitriche* sp.) beds were present, but there was no perceptible flow or trout spawning habitat. Approximately 550 m downstream of Sawyers Arms Road, the channel became overgrown with blackberry, bamboo, and a blocked culvert impounded the stream.

Below this blockage, while the stream was still shaded, the undergrowth was less dense, and the channel widened to 2 m, with a depth of approximately 0.6 m. The bed remained silted, and the habitat unsuitable for trout spawning. However, a single isolated riffle bed, with a gravel substrate, was recorded 1.2 km downstream of Sawyers Arms Road (420 m upstream from Gardiners Road). Approaching Gardiners Road, the channel became more engorged, slightly narrower (to 1.8 m) and deeper (0.8 m). Some gravel was visible, but most of the substrate surface comprised silt.

Downstream of Gardiners Road, the Styx River was entrenched by several metres below the pastoralised banks, a condition which persisted for most of its length to the Smacks Creek confluence. Some bed gravel was visible, but silt obscured most of the channel substrate. The channel width was approximately 4 m, with a mean mid-channel depth of about 0.6 m. Silt depth was 0.2 m. Banks were stable, vegetated (with grass and bracken), and although unfenced, the near-vertical 2 m drop to the waters edge possibly prevented bank damage by local stock. Large beds of monkey musk (*Mimulus guttatus*) and other macrophytes became increasingly dense with distance downstream. Approaching the confluence, the Styx River flow accelerated out of its gully, and the channel broadened, with some substrate gravel emerged. A single trout redd was recorded, with an attendant trout, upstream of the confluence with Smacks Creek.

Downstream of the significant inflow from Smacks Creek (which is described separately below), the channel widened to 6 m with a mean mid-channel depth of approximately 0.4 m. The bed was predominantly gravel, interspersed with patches of aquatic macrophytes (mostly Canadian pondweed). Downstream of the confluence, the riparian margin was a mixture of willow, native vegetation, and occasional gorse.

The channel narrowed again further downstream from the Smacks Creek confluence, eventually to a width of between 3 and 4 m, although the depth remained at 0.4 m. In this reach substrate gravel dominated over the macrophyte beds, and both trout and redds were frequently observed. In reaches with a wider profile, with a wetted width of 5 m or more, silt and macrophytes obscured the bed.

Below the outfall from the excavated ponds in the Styx Mill Conservation Reserve, the channel was wider (c.a. 7 m), deeper (0.8 – 1.0 m), and the flow sluggish. Silt was visible at the margins, although gravel was present in the mid-channel. The riparian margins were heavily grassed, and fenced from stock. Towards the Main North Road, channel width decreased slightly to between 5 and 6 m, and with a mean mid-channel depth of 0.5 m.

For a distance of 75 m downstream of the Main North Road, the fast riffle/run flow continued, but the river deepened and slowed eastwards of that point. The consequent reduction in velocity caused bed siltation and thus lacked suitability for trout spawning. Towards the railway bridge, grazing unfenced cattle were present on both banks of the river, with some consequent bank damage. At the end of the surveyed section, the channel was 6 m wide, with a mid-channel depth exceeding one metre.

4.1.2 Minor tributaries of the Styx Mainstem

Three minor tributaries of the Styx River were also surveyed, two boxed drains, and Mill Stream. The two boxed drains feed the excavated ponds in the Styx Mill reserve (Fig. 8). The eastern drain had an entirely silted substrate, sluggish flow, and was of no value for trout spawning. In contrast, the western boxed drain had a gravel substrate, with a moderately fast flow. Several trout redds were present within the boxed section immediately downstream of the Styx Mill Road culvert. The 90 m boxed section had a width of 1.5 m, and a depth of approximately 0.2 m and a predominantly coarse gravel substrate. Downstream of the boxed section, the banks were grassed, and channel was approximately 2 to 3 m in width, with a mid-channel depth ranging between 0.2 and 0.3 m. This section was silted, slow-flowing, and discharged into the main excavated pond in the Styx Mill Conservation Reserve. The ponds were linked to each other, by gravel-substrate rapids, before the flow discharged into the Styx River mainstem. A shallow concrete ford in the lower reach may present a problem for trout access, and this impediment is discussed in Section 5.6.

Mill Stream is a natural spring-fed tributary which enters the Styx River downstream of the Styx Mill Conservation Reserve. Only the lower 340 m was evaluated, but in its uppermost surveyed reaches, Mill Stream was wide (5m) and slow-flowing, with a substrate obscured by silt. Both banks were pastoralised, but were fenced from stock. Downstream of a vehicle ford, the channel narrowed to a width of 3.5 m; with a fast shallow (0.15 m) riffle flow suitable for trout spawning. However, this habitat was not utilised by spawning trout. Near the confluence with the Styx River, the channel broadened to a width of 5 m, and the gravel substrate was blanketed with sediment to a depth of 0.2 m.

4.1.3 Smacks Creek

Downstream of Wilkinsons Road, Smacks Creek flows through a private reserve, and the riparian border had been planted in native shrubs. In this unshaded reach, watercress had infilled the channel and the flow was sluggish. The bed was silt with underlying gravel.

At the downstream end of the reserve, an ornamental waterwheel impounds the flow. Downstream of this structure, the tree-shaded channel was approximately 2.5 m wide, with a silt-embedded cobble and gravel substrate. The flow was a moderate run, but shallow (depth 0.15 m). Two trout parr were observed in a short channelised section through a horse paddock opposite the Husseys Road intersection. Downstream of this section, the level of embeddedness decreased, and the substrate became a mixture of large and fine gravel, with a water depth of 0.15 m depth. The flow was a moderate run, and several trout redds were found in the vicinity. A local resident and angler (Mr O'Neill, pers. comm.) expressed concern that silt, periodically dislodged from behind the waterwheel by maintenance crews, caused large sediment plumes downstream.

Approximately 120 m upstream of Gardiners Road, the flow slowed, and both banks were lined with ferns and native shrubs. Trout parr were also observed in this section. Approaching Gardiners Road, Smacks Creek flows through a firewood yard, and the substrate became obscured under sawdust and silt. The sawdust appeared to originate from the true right bank (TRB) where the sawdust appeared to have been distributed across the riparian strip.

Downstream of Gardiners Road, Smacks Creek flows through the Smacks Creek Esplanade Reserve, which was still undergoing a native planting program. Within the reserve, wood chips and sawdust obscured the gravels in slow-flowing reaches, but patches of gravel were evident amongst beds of curly pondweed (*Potomogeton crispus*).

Downstream of the access bridge to Redwood Aquatics, Smacks Creek narrowed to 2 m, with a depth of 0.4 m, and flowed through private grounds with banks vegetated in established overhanging native shrubbery. The coarse substrate consisted of unembedded small cobbles and large gravel. Two large trout were observed presiding over a large redd in this reach. Downstream of Husseys Road, the channel broadened to 2.5 m, and deepened (0.3 m), with a consequent increase in bed sedimentation. Both banks were still vegetated in native vegetation (flax and tussock sedge) to the upstream boundary fence of the Willowbank Reserve.

Smacks Creek has been modified into a series of interlinked ponds where it flowed through the Willowbank Reserve, and did not provide any fast flowing-water habitat suitable for trout spawning. Trout access through the reserve, including under the boundary fences, was found to be adequate for migrating trout.

Downstream of the Willowbank Reserve, the shaded channel flowed through riparian borders of native vegetation. Initially the stream was placid, with a width ranging between 4 and 5 m, but the flow accelerated towards the confluence with the Styx River mainstem and the substrate became coarser. Near the confluence of the Styx River, Smacks Creek had a mean width of 2 m, and a water depth of 0.2 m.

4.1.4 Kaputone Stream

The Kaputone Stream rises on the western margins of Belfast, near Johns Road. Upstream of the Main North Road, the waterway is silted, and flow has become largely ephemeral in recent years (Taylor & McMurtrie 2004). Perennial flow is apparent after the input of springs in the vicinity of the Shenley Reserve (pers. obs.), downstream of the Main North Road.

Downstream of Blakes Road, the river was silted, approximately 4.5 m wide, and lined with mature deciduous trees, mainly willows. The banks were stable, grassed, and mostly fenced from stock. Some river gravel was present 160 m downstream of Blakes Road, but the bed was largely comprised of silt. In some unfenced locations, stock-accelerated erosion of the channel was evident, widening the channel from a mean of 6 m to a width of 10 m.

Approximately 500 m downstream of Blakes Road, the channel narrowed to about 1.5m, with a depth of 0.25 m, with a consequent increase in flow. Although gravel was present, it was obscured with silt, with some evidence that the gravel bed had been excavated in the recent past. Approaching Belfast Road, the willow-lined channel was approximately 2.5 m wide, with a slow, slightly meandering flow. Silt depth was approximately 0.2 m over a hard substrate.

Downstream of Belfast Road, a murky discharge entered the river, which had widened to a width of approximately 3 m, and a depth of 0.5 m. Stock access to the TLB (true left bank) was evident, causing some bank trampling. The flow was slow and laminar, and silt depth was measured as 0.35 m. Riparian vegetation was comprised of willow and alder trees.

Significant stock-accelerated bank erosion was evident between the end of Blakes Road and the PPCS works. However, within the grounds, the river and riparian margins were modified to that of a garden and lawn setting. Downstream of the open sluice gate, the channel narrowed to about 1.5 m, and some gravel was present in places, but was silt-embedded.

Downstream of the PPCS works, the river continued to flow sluggishly over a silted bed, but with a variable width (2 - 4 m) and bank treatment. Downstream of Factory Road, the TLB was unfenced and accessible to stock, whereas the TRB was vegetated with willows. The channel width ranged between 5 to 6 m, with a mid-channel depth of approximately 0.5 m. Towards, Fords Road, the channel narrowed to approximately 4 m, although the nature of the banks and the river profile remained unchanged.

Downstream of Fords Road, both banks were unfenced and pugged from stock access. There were patches of gravel, although none had sufficient flow to be suitable for spawning. Approaching the Guthries Road culvert, landuse changed to residential with some lifestyle blocks, and the channel narrowed to approximately 2.5 m. Downstream of Guthries Road culvert, landuse reverted back to pasture, and the channel widened to 4 m. Silt obscured gravels, but riparian stock fencing (deer) became more evident, although banks were exposed to grazing from horses.

About 1.3 km downstream of Guthries Road, the river looped around the Everglades Country golf course, where the channel width was approximately 2.5 m, and a baseflow mid-channel depth of 0.5 m. The bed was heavily silted, with a silt depth of 0.3 m. The TLB was vegetated in trees, but opposite to the golf course (i.e. TRB) significant stock-accelerated erosion was manifest, and around a spring head.

Downstream of the golf course, willows lined both banks, and the gravel bed remained heavily silted. The channel width was approximately 3.5 m, with a depth of 0.4 m. The thickly treed sections hid several depositories of domestic and agricultural rubbish.

4.2 IGDO measurements

There were significant differences in IGDO levels between rivers, and at different gravel depths within the same river (Fig. 4, raw data in App. I). IGDO levels at the lower Styx River redds were significantly lower than at redds measured from the upper Styx River, the Avon River, or Silverstream.

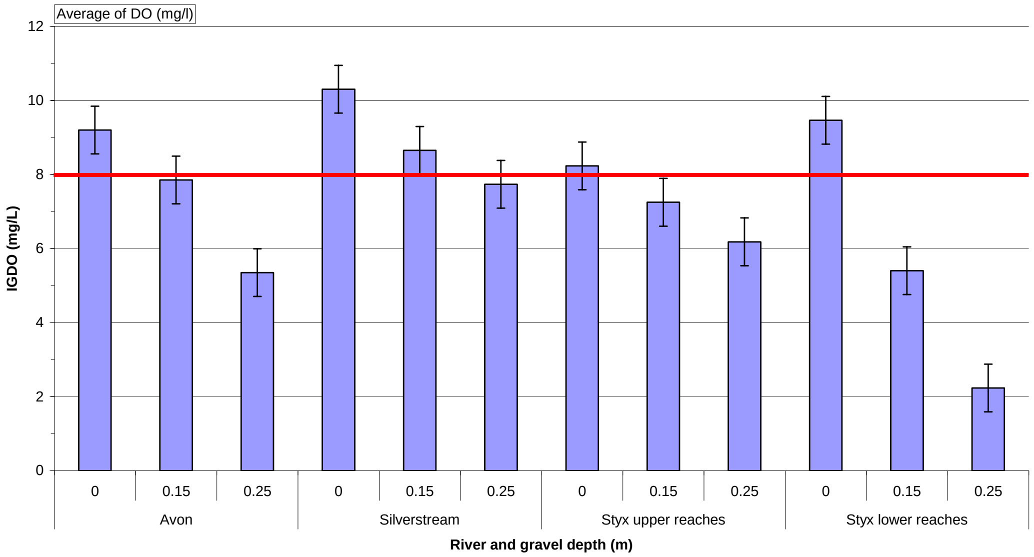


Figure 4. IGDO levels from freshly excavated brown trout redds. Error bars = one standard error. Red line equals the minimum mean IGDO level for acceptable egg survival (Maret *et al.* 1993).

The IGDO levels in Silverstream redds were significantly higher than that from the city rivers (ANOVA, F=16.4, $p < 0.01$).

To facilitate statistical analysis, the IGDO data were squared to overcome significant negative skewness in the untransformed IDGO dataset necessary to satisfy the assumptions of a parametric ANOVA approach (i.e. data subsets categorised by river/location and gravel depth, n = 6). Using the transformed data, IGDO varied significantly between redd locations (Fig. 5a, F = 13.2, p < 0. 01), and gravel depth (Fig. 5b, F = 15.32, $p < 0.01$).

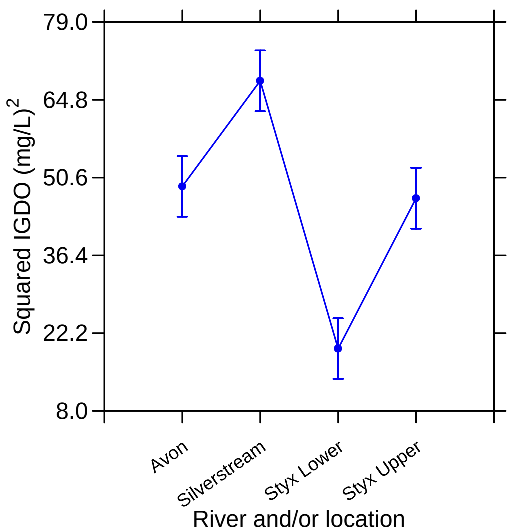


Figure 5a. Least squares means of IGDO by location.

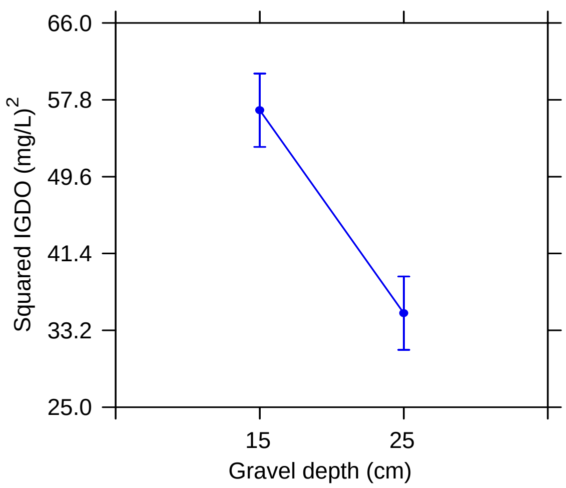


Figure 5b. Least squares means of IGDO by gravel depth.

Within the one redd measured in the Styx lower reaches, mean IGDO also declined significantly over the 17 days between measurements (Kruskal Wallis, Mann Whitney U = 16, $p < 0.05$, n=8). The decline in IGDO was most marked in the four measurements obtained at the deeper gravel depth (i.e. 25 cm).

4.3 Trout redd distribution in 2000

A total of 26 redds were recorded from the Styx River in early July 2000 (Table 3, Fig. 6), 23 redds were located in the mainstem, and 3 within Smacks Creek. The boxed drain in the Styx Mill Conservation Reserve was not surveyed on this occasion. Most (15) mainstem redds were located in a winding gravel reach, 850 m long, which extended from the confluence of Smacks Creek downstream (Fig. 6, Reach 1). Two redds were located just within the downstream boundary of the Reserve, and six redds were located in the reach behind the Metro Refuse station extending 500 m upstream of the Styx Mill Road culvert (Fig. 6, Reach 2). Some sections along this reach were unfenced from stock, whereas other areas had riparian fencing but grazing took place between the riparian fence line and the waters edge. Downstream of the residential area near the Main North Road, and towards the railway bridge the true right (south) bank was unfenced and grazed by sheep, goats, and cattle. No redds were recorded in Kaputone Stream.

4.4 Trout redd distribution in 2005

A total of 47 fully excavated redds, and 9 partially excavated redds were recorded from the Styx River catchment (Table 3).

Table 3. Redd counts for the trout redd survey of the Styx River (August 2005). No data = n.d.

Tributary	**Survey date**	**No. partially-excavated redds**	**No. fully-excavated redds**	**No. trout**
Styx River mainstem	2000	n.d.	23	18
Styx River mainstem	2005	5	31	10
Boxed drains in Styx Mill Conservation Reserve	2000	n.d.	n.d.	n.d.
Boxed drains in Styx Mill Conservation Reserve	2005	0	4	1
Smacks Creek	2000		3	5
Smacks Creek	2005	4	12	11
Kaputone Stream	2000	n.d.	0	0
Kaputone Stream	2005	0	0	0
Totals	**2000**	**n.d.**	**26**	**23**
Totals	**2005**	**9**	**47**	**22**

Almost all redds were conspicuous and appeared freshly excavated. Redds in the mainstem were mainly concentrated in four reaches, with an addition reach within a boxed tributary drain (Fig. 7). No redds, or trout were observed in the surveyed section of Kaputone Stream.

The most upstream reach was in Smacks Creek (Reach 1, Fig. 7), from upstream of Gardiners Road, through the new Esplanade Reserve adjacent to Hussey Road. The second spawning reach (Reach 2, Fig. 8) extended upstream from the Smacks Creek confluence for approximately 370 m. The third spawning reach (Reach 3, Fig. 7) was mainly within the Styx Mill Conservation Reserve, and extended for approximately 500 m. The fourth spawning reach extended approximately 400 m upstream from the Main North Road (Reach 4, Fig. 7). Subsequent to earlier surveys, this reach had been fenced from stock, and the riparian vegetation was lush and overhung the waters edge (Fig. 8). Several redds were found in between these reaches, and four redds were found in a boxed drain which feeds the lakes in the Styx Mill Conservation Reserve (reach 5, Fig. 7, and Fig. 9). A single trout redd was recorded in the mainstem of the Styx River immediately upstream of the Smacks Creek confluence.

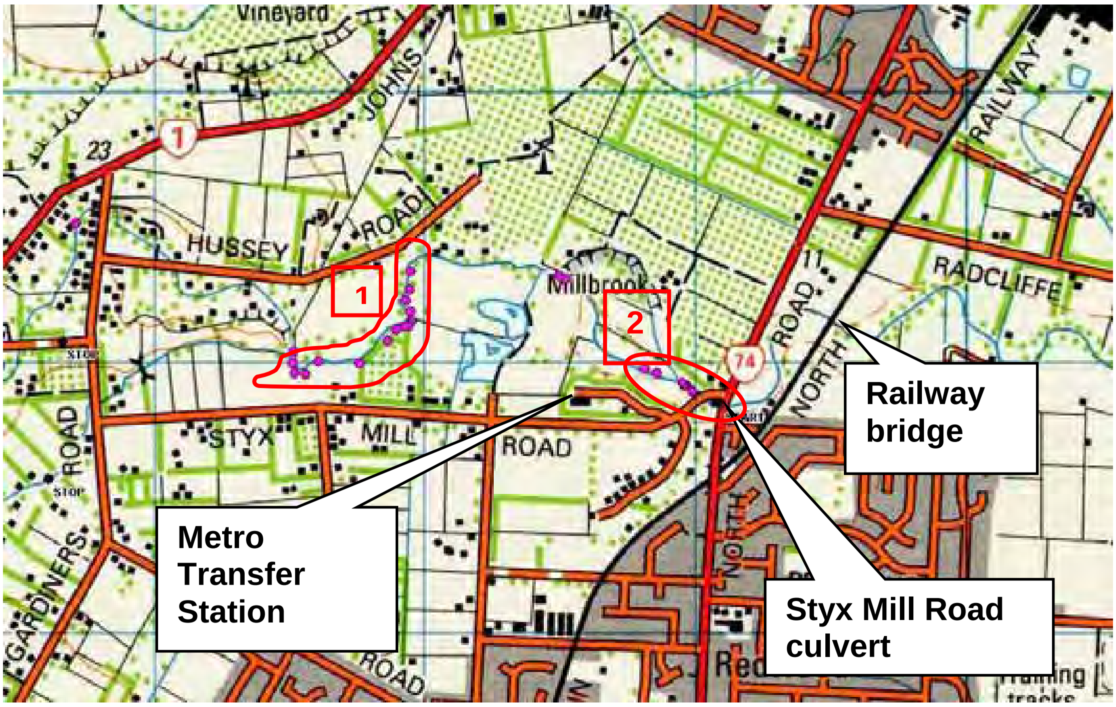


Figure 6. The distribution of trout redds (violet dots) as recorded in July 2000. Some superimposition of icons has occurred at this scale, blue grid squares = 1 km^2. Encircled regions = main spawning areas.

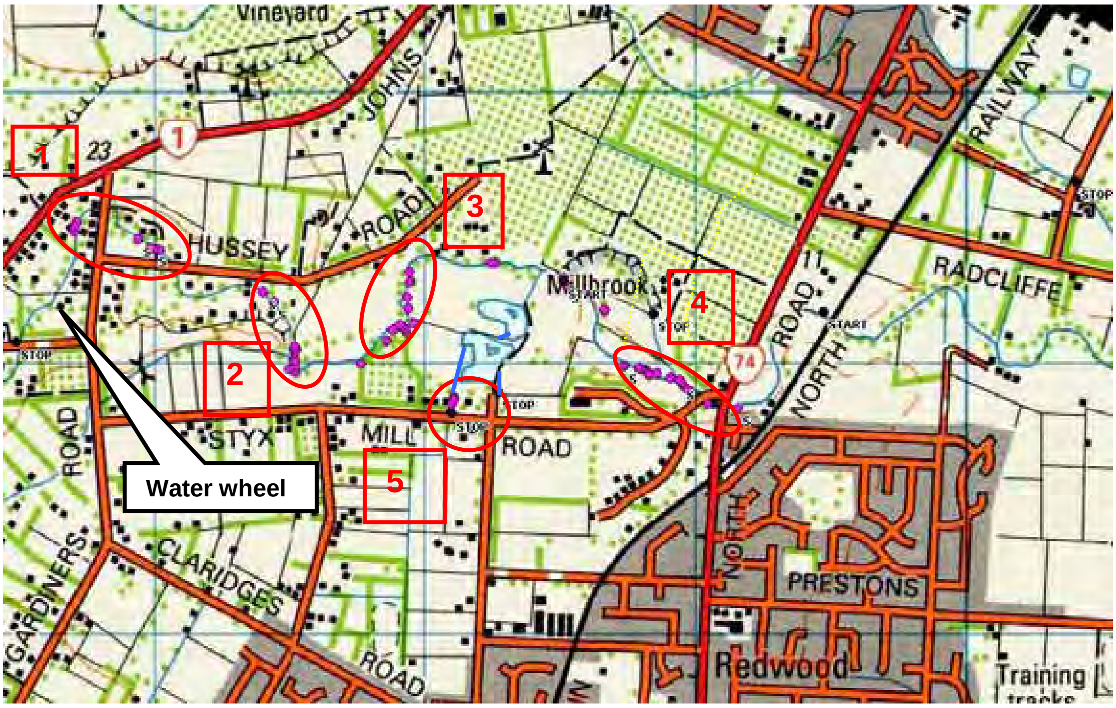


Figure 7. The distribution of trout redds (violet dots) in August 2005. Those marked "S" are partially excavated redds. Some superimposition of icons has occurred at this scale, blue grid squares = 1 km^2. Encircled regions = main spawning areas.

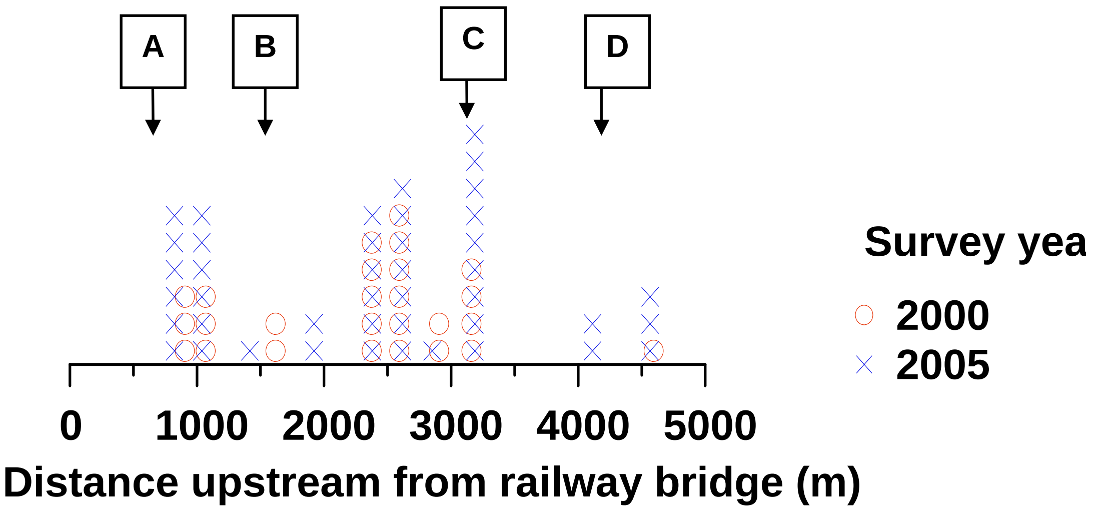
Figure 8. The fenced reaches of the Styx River mainstem.

Figure 9. The boxed drain which feeds the excavated ponds in the Styx Mill Conservation Reserve. The drain gravels were used for trout redd excavation.

4.5 Comparison of trout redd distributions and trout numbers

The number of trout redds was greater in 2005 with 47 fully-excavated redds counted, compared to 26 redds in 2000. Four of the redds recorded in 2005 were found in a boxed drain not surveyed in 2000.

The redd distribution along the waterway had four distinct modes, with redd numbers in 2005 greater in each mode (Fig. 10). In the upper reaches, Smacks Creek had a much greater proportion of total redds in 2005 (12/47 or 26%) than in 2000 (3/26, 11%). The lower mainstem reach between the Styx Mill Reserve and Styx Mill Road was also well utilised with more redds (12) in 2005 than in 2000 (6), and the proportion of redds in this reach rose slightly from 23% in 2000 to 28% in 2005. A single redd was recorded downstream of Styx Mill Road in 2005, but none were recorded in this reach in 2000. No redds were found in Kaputone Stream in 2005, similar to the findings during the 2000 survey.



A = Main North Road, B = Contemplation Point, C = Smacks Creek confluence, D = Gardiners Road (on Smacks Creek).

Figure 10. Longitudinal frequency distribution of redds from the 2000 survey, and fully-excavated redds from the 2005 survey.

The number of trout observed during the 2005 survey was almost the same as in 2000 (Table 3). A number of large brown trout on equally large redds were observed in the lower reaches of Smacks Creek.

4.6 Impediments to trout passage

There were few impediments to trout passage in the Styx River catchment recorded during the 2005 survey. A shallow (mean mid-channel depth = 0.072 m, length c.a. 8 m) concrete ford on the outlet from the ponds to the Styx River may impede upstream trout passage to the upstream spawning grounds (Fig. 11). On its downstream side, there is also a reach of fast shallow (c.a. 0.20 m) rapid water.

In the upper reaches of the Styx River mainstem, approximately 640 m downstream of Sawyers Arms Road, a blocked culvert was considered totally impassable to trout, and probably other fish (no photo available). Two small weirs were also present in the upper reaches of the mainstem, but both were probably passable to trout (Fig. 12). In any case, these three structures were upstream of any potential spawning gravel.

In the upper reaches of Smacks Creek, downstream of Cavendish Road, a water wheel (Fig. 13, indicated as “water wheel” on Fig. 7) was considered capable of blocking fish passage, but again this was well upstream of suitable spawning habitat. On Kaputone Stream, the sluice weir within the PPCS freezing works, which had been a significant barrier to fish passage in the past, was open at the time of the survey (Fig. 14).

5 Discussion

5.1 IGDO Levels

A North American study (Maret *et al.* 1993) demonstrated a fall in IGDO was associated with high levels of interstitial silt, and consequent low egg survival in brown trout redds. Low IGDO levels were considered due to several factors, including reduced exchange with oxygen-rich surface waters and possibly higher biological oxygen demand (BOD) associated with finer substrates. This study suggested that egg survival was negligible when mean IGDO was below 8.0 mg/L, and less than 80% saturation, a situation when interstitial fines (i.e. particles < 2 mm) exceeded 15% of substrate mass.

Considering the above benchmarks, it is clear that conditions for trout egg development in the Styx River, especially the lower river, were most unsatisfactory in 2000. The redds in the lower Styx, at least in the winter of 2000, had means well short of an IGDO of 8 mg/L at a mean egg deposition (gravel) depth of 0.15 m (Fig. 4). The most downstream redd in the Styx at the time (Redd No. 3, Appendix I) had an IGDO levels far below that required for egg survival.

Figure 11. Concrete ford across lake outlet. Water depth was c.a. 7 cm.

Figure 12. One of two small weirs in the upper reaches of the Styx River mainstem.

Figure 13. The ornamental mill wheel and weir on the upper reaches of Smacks Creek.

Figure 14. Sluice gate on the middle reaches of the Kaputone Stream.

Such is the perceived importance of IGDO in North American salmonid redds, that benchmark levels of IGDO have been set at both the federal and state levels. A recommended IGDO minimum for salmonid spawning in Idaho was 6.0 mg/L, while the U.S. Environmental Protection Agency (USEPA) suggested a minimum of 5.0 mg/L to protect early stages of coldwater biota levels. However, Maret *et. al* (1993), concludes these levels are rather low, based on their results.

In Canterbury, there are no environmental criteria on IGDO levels. The Proposed Natural Resources Regional Plan (NRRP) explains and considers the importance of dissolved oxygen in lowland rivers under Chapter 4 (Water quality, page 4-264)(Environment Canterbury 2004). However, while it set strict conditions for dissolved oxygen for surface waters (i.e. 90% saturation at all times between May and September), it does not consider the state of the water quality within the substrate. Some environmental protection could be afforded by a maximum acceptance value of 40% substrate embeddedness for gravel in lowland rivers (Water quality, page 4-50, (Environment Canterbury 2004)), although this may not protect gravel spawning reaches in predominantly silty rivers like the Styx. An experimental study on sedimentation rates on Styx River trout spawning reaches indicated that the lower reaches were particularly prone to sedimentation (Dolphin 2000).

Given the low IGDO values in Styx River trout redds in the past, and the demonstrated importance of this parameter for egg survival, it would be advisable to continue to monitor this important variable in the Styx River, and possibly other rivers where indicative IGDO levels appear marginal (i.e. Avon River (Taylor & Burrell 2003). While probably beyond the resources of community volunteers, the data is not difficult to collect, and is considered relatively non-damaging to trout redds.

5.2 Temporal changes in trout spawning

At least two spawning surveys have been conducted prior to the surveys presented here. The inaugural fisheries study on the Styx River incorporated a trout spawning survey in the winter of 1989 (Eldon & Taylor 1990). This was the only study in which repeated surveys of the spawning reaches were undertaken during the one winter. Trout redd numbers in the mainstem increased through June to the last survey in early July when 55 redds were counted; mostly from 300 m downstream of the Smacks Creek confluence to the large culvert under Styx Mill Road. The lower 0.5 km of this reach was considered to have "good gravel substrate between stands of gorse, which provided bank cover for fish'. A single foot survey in Smacks Creek in late June revealed no trout redds, but one partially-excavated redd. No redds were recorded from the upper reaches of Smacks Creek in 1989.

Another trout spawning survey was undertaken in late June 1999, by the North Canterbury Fish and Game Council (Ross 1999). Over the same surveyed reach as 1989, the redd count in 1999 (25 redds), was much lower than that in 1989, with most redds adjacent to the Husseys Road entrance to the Styx Mill Reserve. The reach behind the Metro Refuse Station (which is approximately the same locality as the good spawning habitat described in (Eldon & Taylor 1990)) was then described as having "excessive damage being done to the riverbank margin by cattle, which have unrestricted access to the river here. This situation is most undesirable as there is already much silt deposited in the river in this area." Smacks Creek was described at the time as 'quite silty in many places' and no redds were recorded from the vicinity. Interestingly, four redds were recorded downstream of the Main North Road, the only time redds have been recorded in that locality in recent years. In the following year (2000), similar redd numbers were recorded (23) over this reach (as discussed in this report) during the first GPS survey (Fig. 15).

Over the years in which surveys have been conducted, trout spawning had centred on the same preferred gravel reaches, except that in 2000 and 2005 greater utilisation was made of the lower reaches of Smacks Creek and the Styx River mainstem downstream of the Styx Mill Reserve. Redd counts are rising in both of these areas (Fig. 15).

Fish access to and from Smacks Creek may have been improved. In 1990, significant instream obstructions in Willowbank were reported to block the passage of migrating trout to potential spawning gravel upstream (Eldon & Taylor 1990). However, this year no such obstructions were found. Upstream of Willowbank, the reach between Husseys Road and Gardiners Road has been subject to successful private riparian restoration work near the stream, and is in the process of further restoration work by the Christchurch City Council. Thus, the numbers and distribution of spawning trout in Smacks Creek is likely be due to better access to improving habitat.

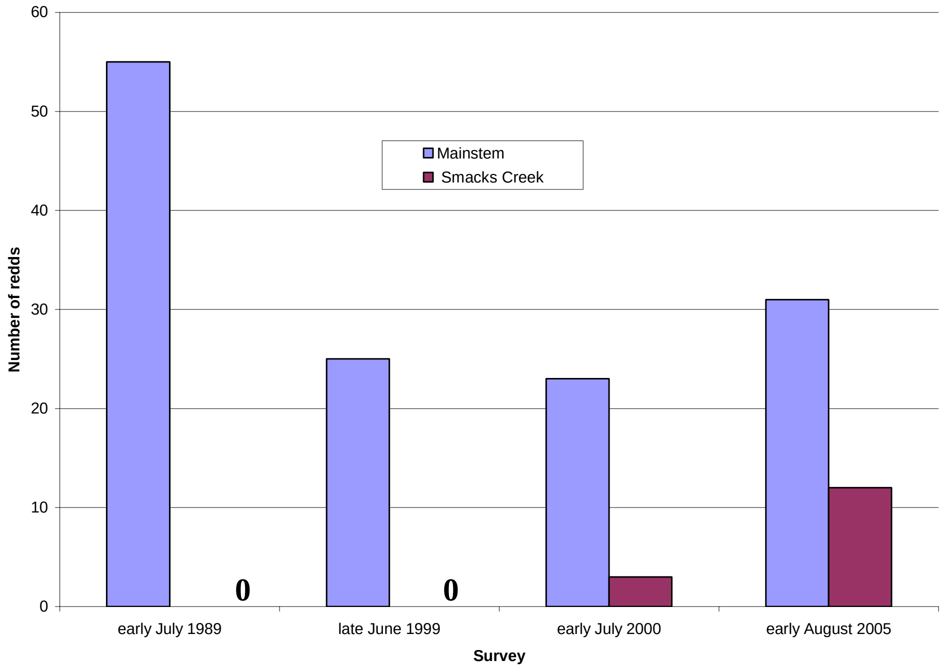


Figure 15. The frequency of redds along the mainstem of the Styx River mainstem and Smacks Creek. Redds in the upper reaches of Smacks Creek (i.e. upstream of Willowbank) are not considered in this plot.

No spawning in Mill Stream was recorded on this survey, and this tributary does not appear to have been covered during previous trout spawning surveys. The tributary now receives treated stormwater from a large subdivision (the Northwood Estate), and there is some photographic evidence that this tributary is wider in the lower reaches than in the past. Again, this tributary could be a candidate for trout spawning enhancement, as at least one suitable (but unutilised) riffle exists. However, riparian cover needs to be planted along the riffle downstream of the vehicle ford.

5.3 Timing of trout redd surveys

While temporal trends are apparent, the differing timing of the redd surveys needs to be considered. In the 1989 winter, repeat surveys indicated that the number of observed trout redds in the Styx River increased through June, with the highest recorded at the final survey in early July. It is possible that further spawning could have occurred after that date.

The substantial decline in redds numbers in the Styx River mainstem between 1989 and 2000 (Fig. 15), is probably accurately reflected in the results, as both surveys were undertaken in early July. The decline probably reflects the onset of stock damage along the mainstem which was not apparent in 1989, but was reported in 1999 and 2000.

In 2005, it was expected that most trout would have excavated redds by early August, following an extended period of calm weather and stable river flows. This means that comparing the 2005 survey in early August with the earlier surveys in late June/early July will be biased by the extent of unrecorded spawning activity after the previous July surveys. During the August 2005 survey, the number of partially excavated redds was low, as was the number of observed fish to redds, which indicated that most redd excavations had been completed, and spawned fish had retreated downstream to the rearing habitat.

It would seem the best strategy would be to undertake redd surveys as late in the spawning season as possible, to ensure all spawning trout have excavated redds before redds are counted. However, leaving a single trout redd survey too late in the season can also cause problems as early redds can become overgrown with algae, thus hard to see and record (Eldon & Taylor 1990). Floods between the time redds are excavated and the redd survey can also make redds hard to see.

A field investigation on the timing of trout redd surveys by the North Canterbury Acclimatisation Society indicated that late September surveys were definitely too late because of periphyton growth obscuring redds (Maindonald 1989). This report indicated that, for the flow conditions in the Selwyn River, mid-July surveys were suggested, as it was sufficiently soon after redd excavation that redds could be identified easily, yet sufficiently late that most fish would have spawned. Because flooding is rare in the Styx, and periphyton growth appears to be slow, an early August survey was chosen in this case. All redds during the August 2005 survey were easily visible at the time.

In summary, despite the difference in survey timing, and the possibility of some sampling bias between the 2000 and 2005 surveys, the magnitude of the improvement in both the numbers and distribution of redds in 2005 (65% increase since 2000) is considered to reflect improvements in trout spawning habitat since 1999/2000.

5.4 River management issues

Despite recommendations by Taylor and McMurtrie (2003) for there removal, there is still a significant quantity of bark chips Smacks Creek downstream of Gardiners Road. The source of the material is from the firewood yard immediately upstream of Gardiners Road (Fig. 16). The winter foot survey revealed there was an ongoing threat of further sawdust entering the channel and smothering the gravels (Fig. 17).

The ornamental water wheel in the upper reaches of Smacks Creek incorporates a weir which impounds silt. While not an issue for trout passage to spawning grounds (owing to its placement well upstream of trout habitat), when the silt is periodically released, large quantities of silt are released that could smother trout spawning gravels downstream (David O'Neill, pers. comm.).

The trout spawning reaches along the mainstem upstream of the Main North Road have now been fenced from stock. The bed siltation and bank damage reported during the 1989 to 2000 surveys was not apparent in 2005, and the improving suitability in this reach for trout spawning is probably responsible for the higher redd counts there.

Improvement in trout spawning habitat, and utilisation, has also been reported from lowland reaches in the Ellesmere catchment which were fenced from stock and the riparian borders planted in native plants (Taylor 2005) .

Figure 16. Bark chips in the Smacks Creek Esplanade Reserve downstream of the firewood store. Photo taken on 8 August, 2005

Figure 17. Sawdust (centre left) and logs perched on the bank of Smacks Creek upstream of trout spawning gravels. Photo taken on 8 August, 2005.

No trout redds were, or ever have been, reported from the surveyed section of Kaputone Stream. This is despite the lower Kaputone River being successfully angled for takeable trout (David O'Neill, pers. comm.). In the past, fish access along the Kaputone Stream was frustrated by a sluice weir within the PPCS works at Belfast (Sykes *et al.* 1998). However, in recent years the sluice gate has been left open which allows fish passage along the river.

Kaputone Stream continued to disappoint in respect to riparian management in the middle to lower reaches. However, widespread stock-accelerated bank erosion and pollution is still evident. After the 1989 survey, the river was described as a "slum" (Eldon & Taylor 1990), and although riparian management has improved slightly since that comment was made, there appear to be ongoing problems with the attitudes of some riverside landowners.

The western boxed drain feeding the ponds in the Styx Mill Conservation Reserve has provided a constantly utilised trout spawning habitat over some years. The channel profile of the lower reach (downstream of the boxed section) could be narrowed and made shallower to improve its suitability for trout spawning. Trout access should also be improved to this spawning habitat, which may be difficult through the pond outlets and vehicle ford.

6 Recommendations

AEL would like to recommend the following to Christchurch City Council, further detail is provided in the text:

1. Monitor IGDO in redds upstream of Styx Mill Road, and compare with those in a control catchment.

2. That trout redd surveys be undertaken in the Styx River every three years, with surveys undertaken in early August.

3. As recommended previously, wood debris from Smacks Creek spawning reaches should be removed, and steps taken to prevent further sawdust and wood debris entering the channel (e.g. low fencing etc.).

4. Improve access to, and the extent of trout spawning habitat in the pond feeders within the Styx Mill Conservation Reserve.

5. Consider the restoration of Mill Stream for use as trout spawning habitat.

6. That the waterwheel weir in the upper reaches of Smack Creek be removed, or so modified that it does not impound the waterway or trap silt.

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9 Appendix I. IGDO data

Table 1. IGDO and vertical hydraulic gradient data from the Styx River and other waterways.

River/locale	Redd No.	Rep	Date	Depth (cm)	DO (mg/l)	Temperature (°C)
Styx Upper	23	1	17/07/2000	15	7.3	12.6
Styx Upper	23	2	17/07/2000	15	7.4	12.5
Styx Upper	23	1	17/07/2000	25	6.2	12.8
Styx Upper	23	2	17/07/2000	25	7.3	12.5
Styx Upper	23		17/07/2000	Surface	8.8	12.8
Styx Upper	24	1	17/07/2000	15	6.4	12.2
Styx Upper	24	2	17/07/2000	15	8	12.5
Styx Upper	24	1	17/07/2000	25	3	12.2
Styx Upper	24	2	17/07/2000	25	8	12.8
Styx Upper	24		17/07/2000	Surface	8.1	13
Styx Upper	25	1	17/07/2000	15	7.9	12.5
Styx Upper	25	2	17/07/2000	15	6.5	12.5
Styx Upper	25	1	17/07/2000	25	6.1	12.5
Styx Upper	25	2	17/07/2000	25	6.5	12.3
Styx Upper	25		17/07/2000	Surface	7.8	13
Styx Lower	3	1	17/07/2000	15	3.4	10
Styx Lower	3	2	17/07/2000	15	2.3	10.5
Styx Lower	3	1	17/07/2000	25	2	10.1
Styx Lower	3	2	17/07/2000	25	1.8	10.3
Styx Lower	3		17/07/2000	Surface	9.5	11
Styx Lower	7	1	17/07/2000	15	7.1	10.8
Styx Lower	7	2	17/07/2000	15	8	10.5
Styx Lower	7	1	17/07/2000	25	2.7	10.3
Styx Lower	7	2	17/07/2000	25	2.6	11
Styx Lower	7		17/07/2000	Surface	9.5	11.2
Styx Lower	8	1	17/07/2000	15	4.5	10.6
Styx Lower	8	2	17/07/2000	15	7.1	10.9
Styx Lower	8	1	17/07/2000	25	2.1	10.5
Styx Lower	8	2	17/07/2000	25	2.2	10.9
Styx Lower	8		17/07/2000	Surface	9.4	11.4
Styx Lower	8	1	3/08/2000	15	1.44	11.8
Styx Lower	8	2	3/08/2000	15	1.43	11.2
Styx Lower	8	1	3/08/2000	25	1.02	10.9
Styx Lower	8	2	3/08/2000	25	1.22	10.9
Styx Lower	8		3/08/2000	Surface	9.93	10.8

Table 1 (cotd.) IGDO and vertical hydraulic gradient data from the Styx River and other waterways.

River/locale	Redd No.	Rep	Date	Depth (cm)	DO (mg/l)	Temperature (°C)
Silverstream	32	1	17/07/2000	15	9.9	11.7
Silverstream	32	2	17/07/2000	15	9.9	11.8
Silverstream	32	1	17/07/2000	25	6.9	11.2
Silverstream	32	2	17/07/2000	25	9.3	11.3
Silverstream	32		17/07/2000	Surface	10.3	11.8
Silverstream	33	1	17/07/2000	15	7.8	11.5
Silverstream	33	2	17/07/2000	15	7.3	11.4
Silverstream	33	1	17/07/2000	25	7.3	11.5
Silverstream	33	2	17/07/2000	25	7.3	11.5
Silverstream	33		17/07/2000	Surface	10.2	11.6
Silverstream	34	1	17/07/2000	15	7.5	11.5
Silverstream	34	2	17/07/2000	15	9.5	12
Silverstream	34	1	17/07/2000	25	7.6	11.6
Silverstream	34	2	17/07/2000	25	8	11.8
Silverstream	34		17/07/2000	Surface	10.4	12
Avon	23	1	17/07/2000	15	8.1	11.2
Avon	23	2	17/07/2000	15	8.8	11.2
Avon	23	1	17/07/2000	25	1.8	11.5
Avon	23	2	17/07/2000	25	5.7	11.2
Avon	23		17/07/2000	Surface	9.2	11.2
Avon	24	1	17/07/2000	15	9	11.2
Avon	24	2	17/07/2000	15	4.6	11.2
Avon	24	1	17/07/2000	25	6.1	11.6
Avon	24	2	17/07/2000	25	3.1	11.3
Avon	24		17/07/2000	Surface	9.2	11.2
Avon	25	1	17/07/2000	15	7.5	11.6
Avon	25	2	17/07/2000	15	9.1	11.2
Avon	25	1	17/07/2000	25	6.6	11.5
Avon	25	2	17/07/2000	25	8.8	11.2
Avon	25		17/07/2000	Surface	9.2	11.2