Post-Quake Ecology of the Lower Avon River

CURRENT STATE OF THE FISH AND INVERTEBRATE COMMUNITY

EOS Ecology Report No: 11012-CIV01-01 | July 2012
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AQUATIC RESEARCH & SCIENCE COMMUNICATION CONSULTANTS

Environment Canterbury Report No. U12/6
ISBN: 978-1-927222-10-2 (print)
978-1-927222-11-9 (web)

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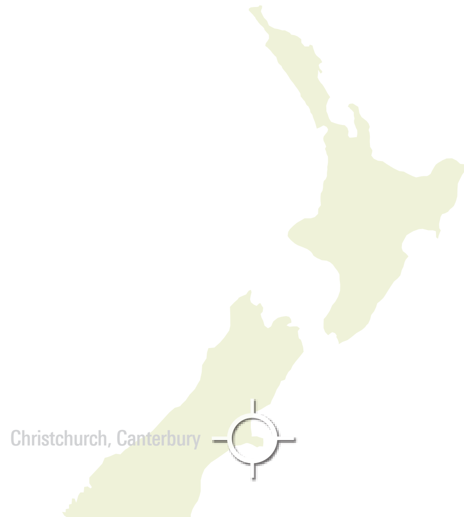
SUMMARY

The 2010–2011 Canterbury earthquakes, in particular the 22 February 2011 event, caused extreme fine sediment mobilisation and significant inputs of untreated sewage into the Avon River. The majority of these inputs occurred in the lower Avon River (for the purposes of this report defined as the section starting at the Fitzgerald Avenue Bridge and extending downstream to the mouth at Bridge Street), thus it was assumed that the impacts on the ecology of the river was also greatest in this section. EOS Ecology was therefore contracted to survey fish and aquatic invertebrates in the lower Avon River to assess the current state of the fauna some 10 months after the February 2011 earthquake. Because there was no recent pre-earthquake data it was not possible to make a direct before-after comparison to determine what impact the earthquakes have had on the ecology of the river. However, some older pre-earthquake data (from over 20 years ago) was used as a general indication as to the ongoing health of the river, and to draw some inferences to any possible earthquake effects. It was intended that our information could also be used by the Christchurch City Council to help them minimise any negative impacts of fine sediment removal and bank works needed to repair damage and reduce flooding issues caused by the earthquakes.

We surveyed fish in the lower Avon River in four study sections using seine netting, Gee minnow trapping, and fyke netting. Aquatic invertebrates were surveyed in three study sections using kick netting at margins and Petite Ponar grabs in the channel centre. We found the lower Avon River some 10 months after the 22 February 2011 earthquake to have a diverse aquatic invertebrate and fish fauna (51 and 12 taxa respectively; taxa refers to groups in a biological classification system into which related organisms are classified). The invertebrate community was dominated by snails, worms, midge larvae, and crustaceans which are the most common invertebrates in waterways throughout Christchurch and many urbanised catchments elsewhere. Invertebrate taxa richness and MCI-sb (a community health metric) were similar among sections and between 1990 and 2011, apart from taxa richness in the upstream-most section which was significantly lower in 2011. The fish fauna was dominated by species that are typical of the lower, tidally influenced reaches of many New Zealand rivers, such as shortfin eel, common bully, giant bully, common smelt, and inanga. Apart from shifts in the relative abundance of a few dominant taxa, there was generally little difference in the overall fish community among the sections or between 1992 and 2011. The exception was the upstream-most section, which had significantly fewer fish compared to the other two sections, and dramatically lower invertebrate taxa richness in 2011 than in 1990. The potentially compromised invertebrate and fish community of the upstream-most section was most likely due to a lack of macrophyte (aquatic plant) cover and presence of filamentous algae blooms, which may have been partly caused by the 2011 earthquakes (via fine sediment addition and sewage inputs).

While we cannot know what ecological impact there was on the lower Avon River immediately following the Christchurch 2011 earthquakes, our current survey indicates that there has certainly been no lasting effect—with the possible exception of the upstream-most section. Similarly it is unlikely sediment removal activities from discrete sections in the lower Avon River will have any long-lasting negative impacts on fish and invertebrates, provided that a number of mitigation measures are followed.

The current survey has established a fish and invertebrate sampling methodology for the non-wadeable portion of the Avon River, which has been overlooked in past monitoring programmes. We therefore recommend that this sampling programme form the basis for a long-term monitoring programme for the non-wadeable portion of all four main rivers in the Christchurch area (Avon, Heathcote, Styx, and Otukaikino Rivers).



Damage to the Medway Street footbridge illustrates the force of the Canterbury earthquakes.

EFFECTS OF THE CANTERBURY EARTHQUAKES ON THE LOWER AVON RIVER

The devastation wrought by the 2010–2011 Canterbury earthquakes also extended to Christchurch's waterways. The 22 February and 13 June 2011 earthquakes were particularly damaging to the lower Avon River (for the purposes of this report defined as the section between Fitzgerald Avenue Bridge and the river mouth at Bridge Street; see Fig. 1). Liquefaction sediment was washed into the city's stormwater network and into the river, while widespread damage to the city's sewerage network resulted in significant sewage overflows to this lower part of the river for over five months. The banks of the lower Avon River were subjected to lateral spread which narrowed the channel by up to 1 m in places, while uplift of the river bed occurred in localised patches.

It is hard to imagine that such upheaval did not have some impact on the fauna of the lower Avon River. Certainly a cage experiment 2.5 months after the 22 February event showed decreased survival of two common invertebrate species in the lower Avon River as a result of the large sewage inputs (McMurtrie, 2011), and modelling of dissolved oxygen levels predicted a severe impact to river life during the height of the sewage inputs immediately following the February earthquake (Rutherford & Hudson, 2011). However, a lack of recent (i.e., less than 10 years) pre-earthquake ecological data in the lower reach of the Avon River prevents us from undertaking a before-after earthquake comparison (such as what was undertaken for the upper Avon River catchment; see James & McMurtrie, 2011a,b), to see whether the fauna of the river had changed as a result of the earthquakes. This is because the lower Avon River is very deep (non-wadeable), meaning surveys of aquatic animals have been infrequent due to the difficulty of sampling. EOS Ecology was therefore contracted to survey fish and aquatic invertebrates in the lower Avon River to assess the current state of the fauna some 10 months after the 22 February 2011 event, which could act as a new baseline data set from which future community changes could be plotted through long-term monitoring. Additionally, because of fine sediment input and narrowing of the channel, the Christchurch City Council needs to remove sediment from parts of the lower Avon River bed, and to minimise the negative impacts of such activities on the ecology of the river it is important to know about the current state of the system.

Deposited sediment (liquefaction sediment) from stormwater pipe.

Bank slumping/cracking and narrowing of the river channel.

Suspended sediment in river.

Raw sewage inputs.

Some of the physical effects of the earthquakes on the lower reach of the Avon River that may have affected aquatic life.

ASSESSING THE FAUNA OF THE LOWER AVON RIVER

The lower Avon River (between Fitzgerald Avenue Bridge and Bridge Street) was split into four study sections; Fitzgerald Ave–Gayhurst Rd; Gayhurst Rd–Avondale Rd; Avondale Rd–Pages Rd; and the river mouth upstream of Bridge St (Fig. 1). Fish were surveyed on the 8-9 December 2011 from all four reaches, while invertebrates were sampled on the 13-15 December 2011 from the three most upstream mainstem reaches (i.e., excluding the river mouth reach).

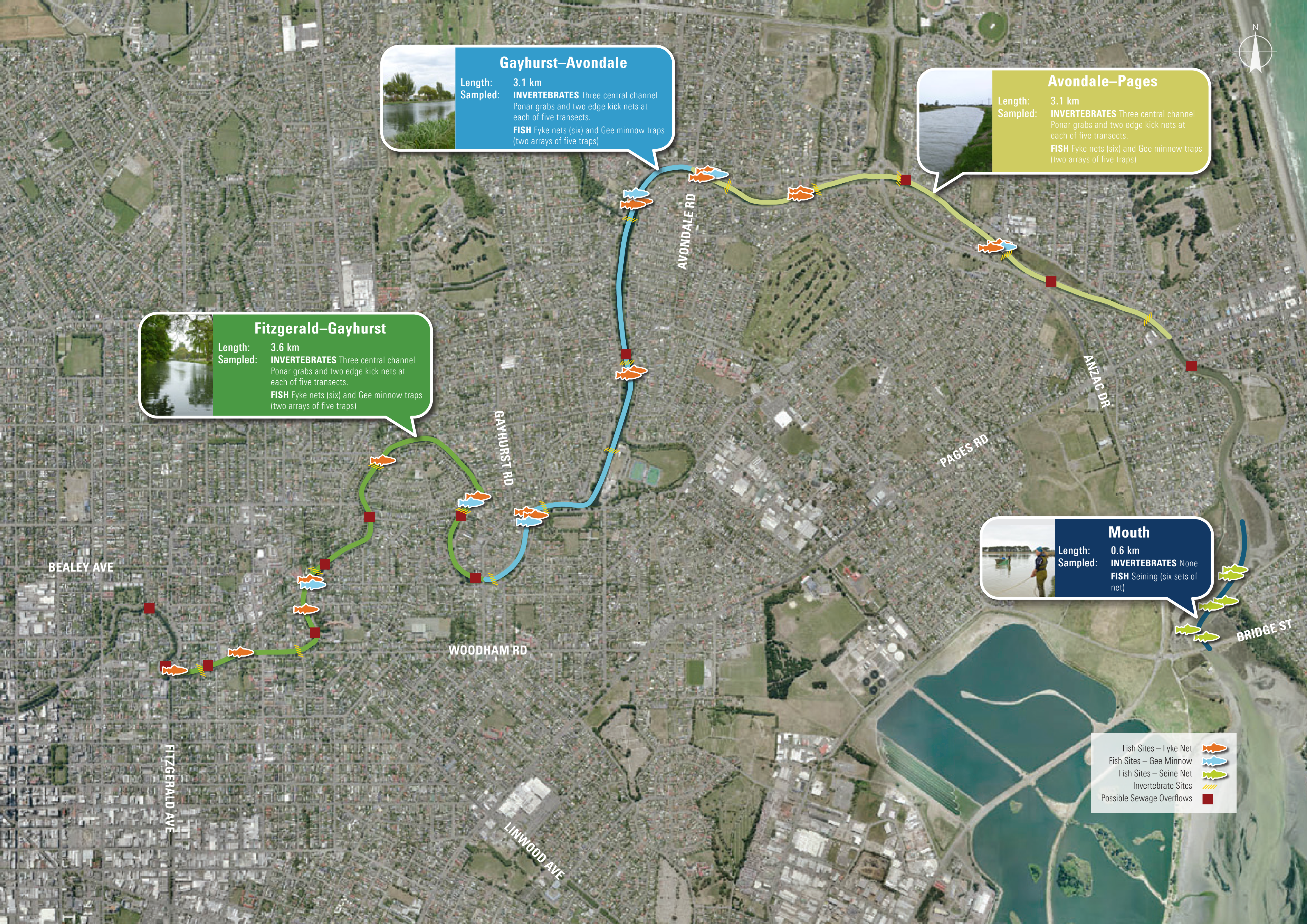
On 8 December 2011 fish were sampled in the most downstream reach (the river mouth section) via seine netting. Within this reach six sites were fished using a seine net (18 m long, 10 mm stretched mesh size), which was deployed from an aluminium dinghy and dragged up onto the shore. In the remaining three study reaches fyke nets (15 mm stretched mesh size) and Gee minnow traps (6 mm wire mesh size) were set via boat or from the shore. Within each of these three study sections six fyke nets and two Gee minnow trap lines (each consisting of five traps attached to a length of rope) were set and left overnight. Gee minnow traps were baited with bread and Marmite, while fyke nets were not baited. All nets and traps were retrieved on the following day, all captured fish were identified and their lengths measured (excepting particularly numerous species from the seine catches that were identified only). Eels were anaesthetised with clove oil to allow easier handling.

With no national invertebrate sampling protocol for non-wadeable rivers, we adapted parts of the US EPA Large River Bioassessment Protocol (Flotemersch *et al.*, 2006) for use in the lower Avon River. Within the three most upstream reaches (excluding the river mouth section) invertebrates and habitat were surveyed across five transects (giving a total of 15 transects) at locations chosen to align with detailed cross-section surveys undertaken by the CCC in October 2011 (Fig. 1). As it was not possible to wade the full width of the channel for most sites, each transect was sampled in three parts—the wadeable marginal areas on each side of the river, and the middle of the channel.

The marginal zone on either side of the river at each transect was sampled within an approximate 5 m × 5 m area that extended from the water's edge to 5 m out into the channel. Where it was not possible to extend 5 m into the channel (due to deep water), the survey area was retained by increasing the survey length along the river bank. Aquatic benthic invertebrates were collected within each area by kick netting, which involved disturbing the substrate in an approximate 0.5 m^2 area with a conventional kick net (500 μm mesh size). Percent cover of macrophytes and substrate composition was estimated within the area, macrophyte and fine sediment depths were measured at ten random points, and general bank and riparian condition was noted. Three benthic samples were collected from the deeper mid-channel area of each transect using a Petite Ponar grab sampler lowered from an aluminium dinghy.

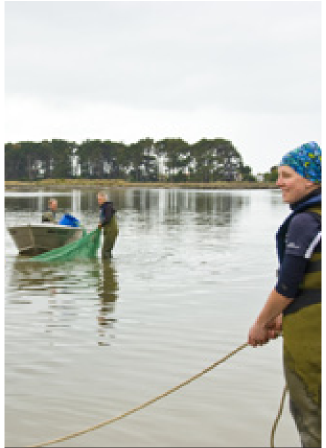
At each transect a spot reading of water temperature and conductivity was taken on both sides of the river, while multiple readings (following a depth profile) were taken at the centre channel using an YSI CastAway CTD device. Ponar and kick net invertebrate samples were preserved in 60% isopropyl alcohol, and taken to the laboratory for identification.

FIGURE 1:
The study sections and sampling locations in the lower Avon River that were surveyed for fish and invertebrates in December 2011.



Gayhurst–Avondale
Length: 3.1 km
Sampled: INVERTEBRATES Three central channel Ponar grabs and two edge kick nets at each of five transects.
FISH Fyke nets (six) and Gee minnow traps (two arrays of five traps)
Avondale–Pages
Length: 3.1 km
Sampled: INVERTEBRATES Three central channel Ponar grabs and two edge kick nets at each of five transects.
FISH Fyke nets (six) and Gee minnow traps (two arrays of five traps)
Fitzgerald–Gayhurst
Length: 3.6 km
Sampled: INVERTEBRATES Three central channel Ponar grabs and two edge kick nets at each of five transects.
FISH Fyke nets (six) and Gee minnow traps (two arrays of five traps)
Mouth
Length: 0.6 km
Sampled: INVERTEBRATES None
FISH Seining (six sets of net)
N
AVONDALE RD
GAYHURST RD
ANZAC DR
PAGES RD
BEALEY AVE
WOODHAM RD
BRIDGE ST
FITZGERALD AVE
LINWOOD AVE
Fish Sites – Fyke Net
Fish Sites – Gee Minnow
Fish Sites – Seine Net
Invertebrate Sites
Possible Sewage Overflows

SEINE NET SAMPLING


Setting seine net.


Gathering in seine net.


Emptying seine net.


Counting and measuring catch.

KICK NET SAMPLING


Kick netting channel margin.

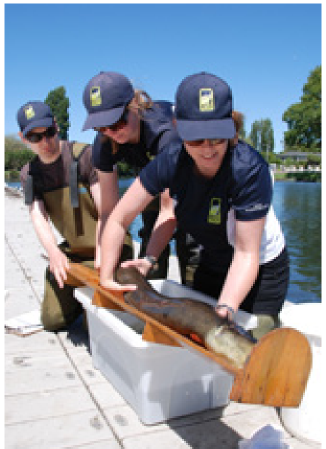

Kick net sampling.

FYKE NET SAMPLING


Setting fyke net by hand.

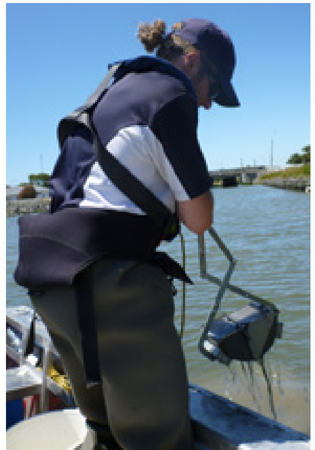

Setting fyke net by boat.


Collecting in fyke net.


Measuring the catch.

PETITE PONAR SAMPLING


Petite Ponar sampler.


Pulling up Petite Ponar with sample.

GEE MINNOW TRAP SAMPLING


Gee minnow trap in river.


Counting and measuring catch.

LABORATORY METHODS


Washing sieved invertebrate sample.


Identifying and counting invertebrates.

COMPARISONS WITH HISTORIC DATA

There was no recent pre-earthquake invertebrate or fish data from the lower Avon River to make a direct pre and post-earthquake comparison. However, older data did allow for a long-term comparison of fauna. Invertebrate presence/absence data was collected in 1989–1990 by Robb (1992) from a number of lower Avon River sites, some of which were very close to our sampling locations. Robb (1992) used a variety of invertebrate sampling techniques and from his short description of methods it is safe to assume he used a kick net, a 70 mm diameter core sampler, and/or a small dredge at his lower Avon River sampling sites. His kick net and small dredge sampling techniques were likely very similar to the methods used in this study. Fish data for the lower Avon River that was collected by Eldon & Kelly (1992) as well as a few additional records from the New Zealand Freshwater Fish Database were also available for comparison. Only fish data collected using similar methods to the current study (the overnight setting of fyke nets and seine netting) was used.

STATISTICAL ANALYSIS

Invertebrate data was summarised using the invertebrate metrics of taxa richness, relative abundance of main invertebrate groups, MCI-sb, and QMCI-sb (these are explained in detail in Fig. 4). To compare some habitat variables and invertebrate metrics among sections and between years, analysis of variance (ANOVA) or Kruskal-Wallis tests were used. Kruskal-Wallis tests were employed where the assumptions of equal variance and normal distribution of data could not be obtained even after data transformation. Where significant differences were found (5% level of significance) the Tukey post-hoc means test was used to determine which sections or years were different to the others. On the following graphs where significant differences were found, significant differences are shown next to or within the bars as letters (i.e., a, b, or c). Bars with the same letter are not statistically different from each other while they are different to those with other letters.

Invertebrate community data was also summarised using non-metric multidimensional scaling (NMS) which is a technique that is often used to examine how communities composed of many different taxa differ between locations. For this study, it graphically describes communities by representing each sampling site as a point (an ordination score) on an x–y plot. The location of each site reflects its community composition, as well as its similarity to communities in other sites.

Fish data was not subjected to statistical analysis due to the non-quantitative sampling undertaken and small number of replicates. Additionally, the small numbers of fish captured in the Fitzgerald-Gayhurst study section made many statistical analyses difficult.

OUR FINDINGS

CURRENT STATE

Habitat and Macrophytes

The Avon River generally becomes wider and deeper as it flows towards the estuary although the artificially created Kerr's Reach is abnormally wide for that part of the river. This meant our middle mainstem study section (Gayhurst–Avondale) was the widest (mean width 44.22 m) as it encompassed Kerr's Reach. The upstream-most Fitzgerald–Gayhurst section was narrowest (mean width (24.38 m) while the downstream-most Avondale–Pages section was intermediate (mean width (35.43 m). The riverbed was predominantly covered in silt and sand with no significant change from upstream to downstream (Kruskal-Wallis: $H=5.28$, $p=0.06$). The fine sediment on the riverbed was quite deep where it was measured along the margin of the river (average of 0.21 m across all reaches). Mean fine sediment depths were significantly less in the Gayhurst–Avondale section compared to the other two sites which were not significantly different (Fig. 2A), while the greatest fine sediment depth of 1.13 m was recorded in the most-upstream reach (Fitzgerald–Gayhurst). Macrophyte cover was greater along the margins of the river than within the centre of the channel (Fig. 2B) and was generally lower in the most downstream reach (Avondale–Pages). The saltwater wedge extends upstream to around the Avondale Bridge, and the resulting high salinity (as indicated via conductivity in Fig. 2C) and low water clarity in this downstream reach would naturally limit the growth of macrophytes. The influence of salinity on plant distribution was also evidenced by the replacement of the freshwater curly pond weed (*Potamogeton crispus*) by the estuarine seagrass *Zostera* in the downstream study section (Avondale–Pages) (Fig. 2B). It should also be noted that the amount of bare substrate in this study section may have been overestimated due to the low water clarity of this section. Water temperature showed minimal variability and increased from upstream to downstream (Fig. 2D).

Fine sediment and algal growth on the margins of the lower Avon River.

Sediment depth refers to the depth to which a 3 cm diameter pole can be pushed into the substratum with minimal resistance. Typically it is greatest in silt-bottomed streams and least in stony streams where measurements can be zero. It is of interest as fine sediment can smother larger substrates leading to a reduction in habitat quality. Sediment depth was only measured at the river margins.

FIGURE 2:

Mean sediment depth (A), riverbed cover (%) (B), specific conductivity (C), and water temperature (D) for three of the lower Avon River study sections surveyed 13–15 December 2011. Error bars shown are one standard error. Sediment depth was measured only at the river margins. Spot measures of specific conductivity and water temperature from the channel centre and margins were very similar, therefore were combined for analysis. Where shown, different letters in the bars denote statistically significant differences between the river sections (e.g., bars labelled 'a' are statistically not different, but are different to those labelled 'b').

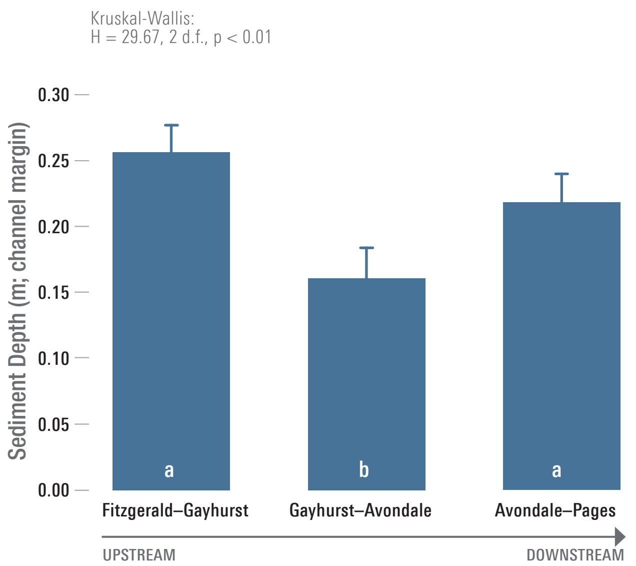


FIGURE 2A

The coverage of the river bed by several macrophyte (aquatic plant) taxa was visually estimated. Where plants were absent, the bed was considered to be bare substrate. Mean results for the channel centre and margins of each study section are presented.

Specific conductivity refers to the ability of water to conduct electricity at a standardised temperature (25°C). It is a good measure of the concentration of total dissolved solids and salinity. In the lower Avon River it indicates the extent of seawater influence. Measurements from the channel margin and centre channel were the same so have been pooled here.

The temperature of the water at the time of sampling. As with specific conductivity, the measures from the channel margin and centre channel were the same so have been pooled here.

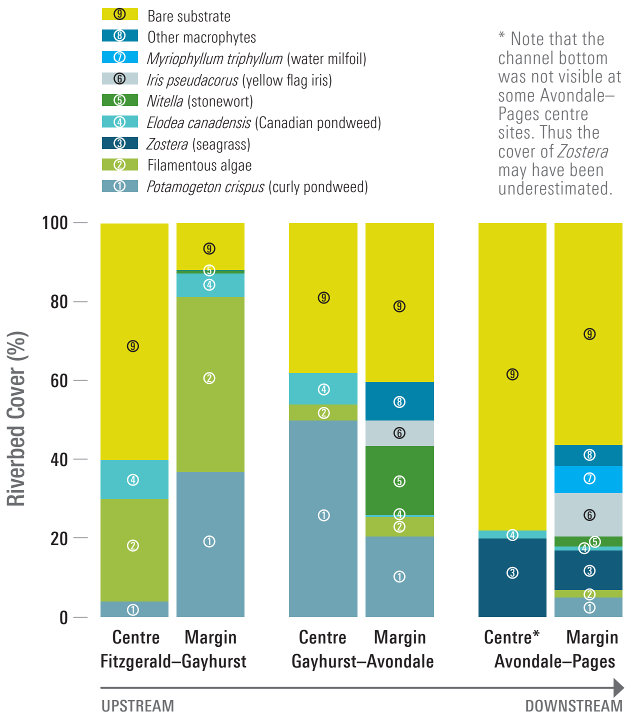


FIGURE 2B

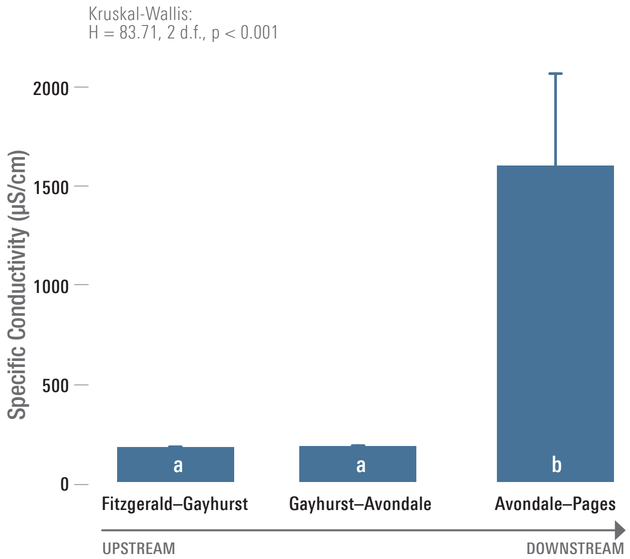


FIGURE 2C

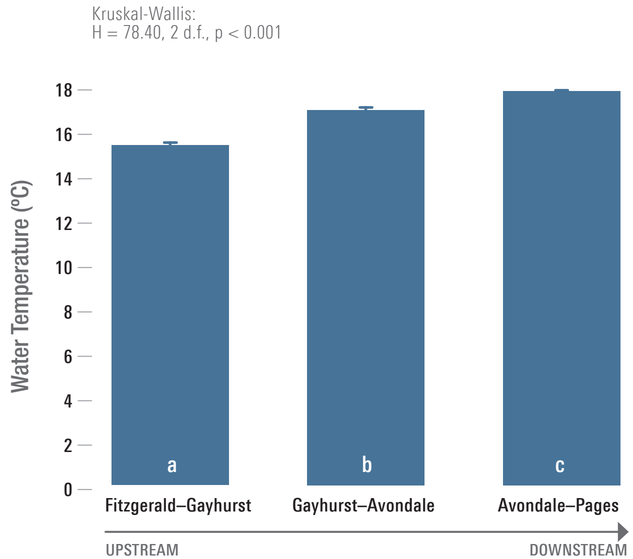


FIGURE 2D

Invertebrates

Overall 51 aquatic invertebrate taxa were found in the lower Avon River in 2011. Of these, the eight most common accounted for 88% of all invertebrates captured (Fig. 3). A number of estuarine taxa were present in the downstream-most section (Avondale–Pages), indicating the influence of salt water on this section (Fig. 3). Four main taxonomic groups dominated, albeit in varying proportions among the study sections (Fig. 4A). The proportion of Mollusca (snails) increased in a downstream direction, while Diptera (true fly larvae) tended to decrease with distance downstream (Fig. 4A). Crustaceans (amphipods, isopods, and ostracods) were most prominent in the downstream-most section (Avondale–Pages). Oligochaete worms were most prominent in the middle section (Gayhurst–Avondale) (Fig. 4A).

Taxa richness was similar among the study sections (Fig. 4B). MCI-sb and QMCI-sb scores (refer to Fig. 4, page 11-12 for an explanation of these terms) from the downstream-most section (Avondale–Pages) were significantly greater than the other two study sections (Fig. 4C & 4D). MCI-sb scores indicated the Fitzgerald–Gayhurst and Gayhurst–Avondale sites were both well within the 'poor' water quality category of Stark & Maxted (2007) while the Avondale–Pages site was at the boundary of the 'poor' and 'fair' categories (Fig. 4C). The QMCI-sb indicated all three sites were well within the 'poor' water quality category of Stark & Maxted (2007) (Fig. 4D). However, it must be remembered that the MCI and QMCI were developed for wadeable rivers and freshwater environments and have not been extensively tested in deep, non-wadeable environments, including those that are tidally influenced. Thus their interpretations of water quality for environments such as the lower Avon River must be taken with caution.

Ordination (see page 13 for details) of the invertebrate

FIGURE 3:
Common invertebrates (and their percentage contribution of all invertebrates captured) found in the lower Avon River and estuarine taxa only found in the downstream-most study section (Avondale–Pages). Sites were sampled 13–15 December 2011. The eight common taxa accounted for 88% of all invertebrates captured.

community data showed separation of the three study sections (Fig. 5). Along Axis 1 the downstream-most site (Avondale–Pages) was separated from the other two sections predominantly because of the abundance of *Potamopyrgus* snails and diversity of crustaceans present in that section. These included a number of estuarine taxa that did not penetrate any further upstream than this section (e.g., the isopods *Exosphaeroma* and *Munna*, and amphipods *Melita* and *Paracorophium*). The other two study sections were separated along Axis 2 predominantly by the relative abundance of mites and midge larvae in the upstream-most (Fitzgerald–Gayhurst) section and relative abundance of oligochaete worms and snails (*Gyraulus*, *Physa*, and *Ferrissia*) in the middle (Gayhurst–Avondale) section (Fig. 5). For each of the study sections those samples taken from the channel margins overlapped with those taken from the channel centre indicating that there were no invertebrate community differences between the two sampling locations (Fig. 5).

Relative contributions of higher-level taxonomic groupings to the total invertebrate community. Relative abundance graphs can show if there are shifts in the relative numbers of major taxonomic groups between study sections.

Taxa richness refers to the number of different animals captured at a site. A large decrease (or increase) in taxa as a result of some disturbance may indicate an effect. However, differences often are a result of the collecting or missing of rare taxa, rather than changes in the core taxa that make up most of the community at a site.

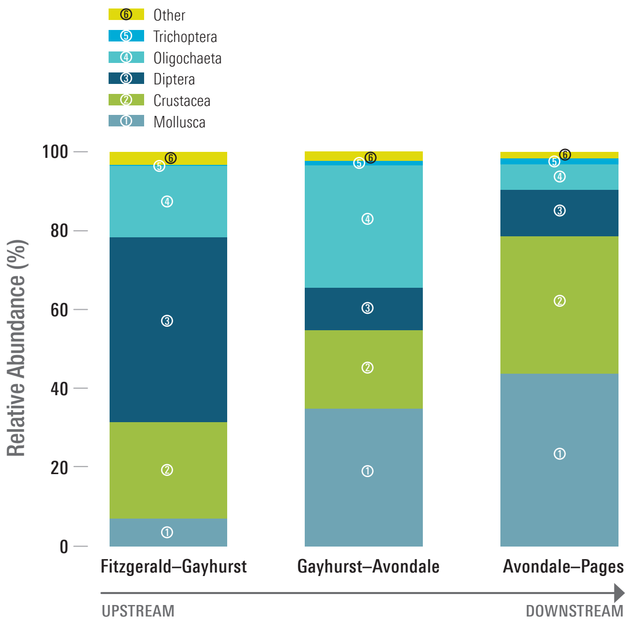


FIGURE 4A

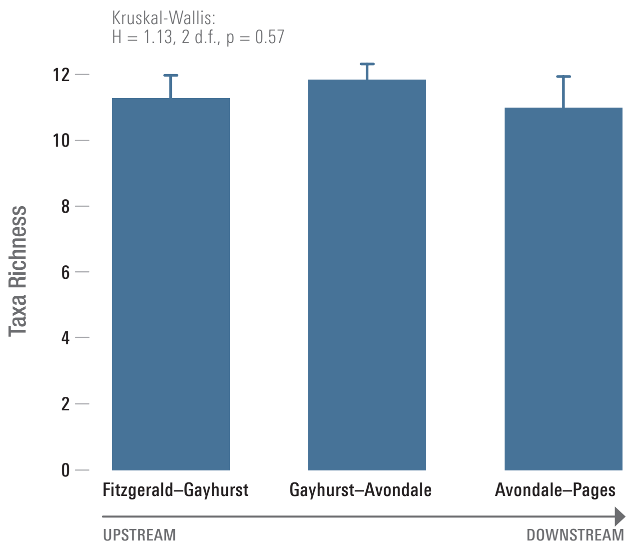


FIGURE 4B

FIGURE 4:

The relative abundance of invertebrate groups (A) and invertebrate community metrics (taxa richness (B), MCI-sb (C), and QMCI-sb (D)) for each lower Avon River study section sampled between 13–15 December 2011. Error bars shown are one standard error. The MCI-sb and QMCI-sb graphs (over page) have the water quality categories of Stark & Maxted (2007) superimposed. Where shown, different letters in the bars denote statistically significant differences between the river sections (e.g., bars labelled ‘a’ are statistically not different, but are different to those labelled ‘b’). (Continued over page...)

The Macroinvertebrate Community Index (MCI) is a metric derived from a pollution-tolerance score that has been assigned to all the commonly encountered aquatic invertebrates in New Zealand (Stark & Maxted, 2007). It gives an indication of organic pollution and is often used as a proxy for water quality. Higher scores indicate higher water quality (i.e., a community with a greater abundance of invertebrates that are sensitive to degraded water quality). MCI is based on taxa presence/absence (not abundance) while QMCI is a derivative that takes into account the abundance of taxa as well. The "-sb" suffix indicates the soft-bottomed (sand or silt bottomed waterway) variants are being used. The MCI was designed for use in wadeable, freshwater waterways, thus its interpretation of water quality in non-wadeable, tidally influenced environments such as the lower Avon River must be taken with caution.

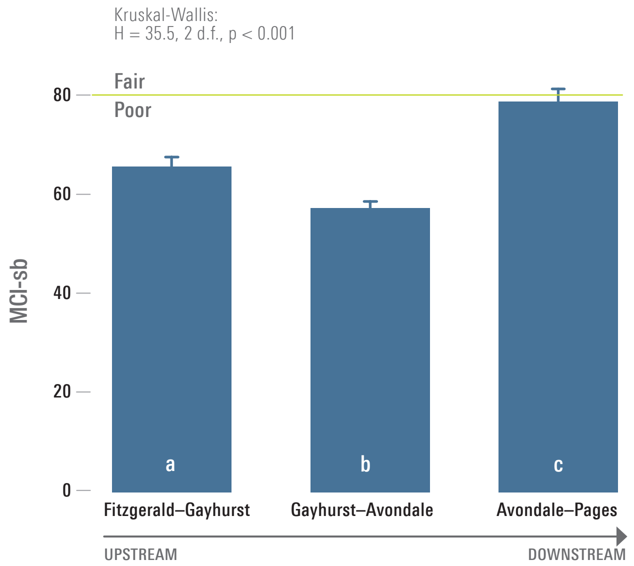


FIGURE 4C

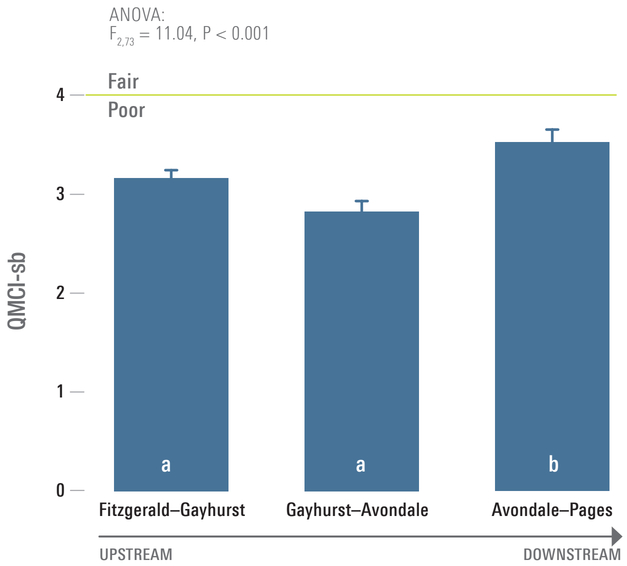


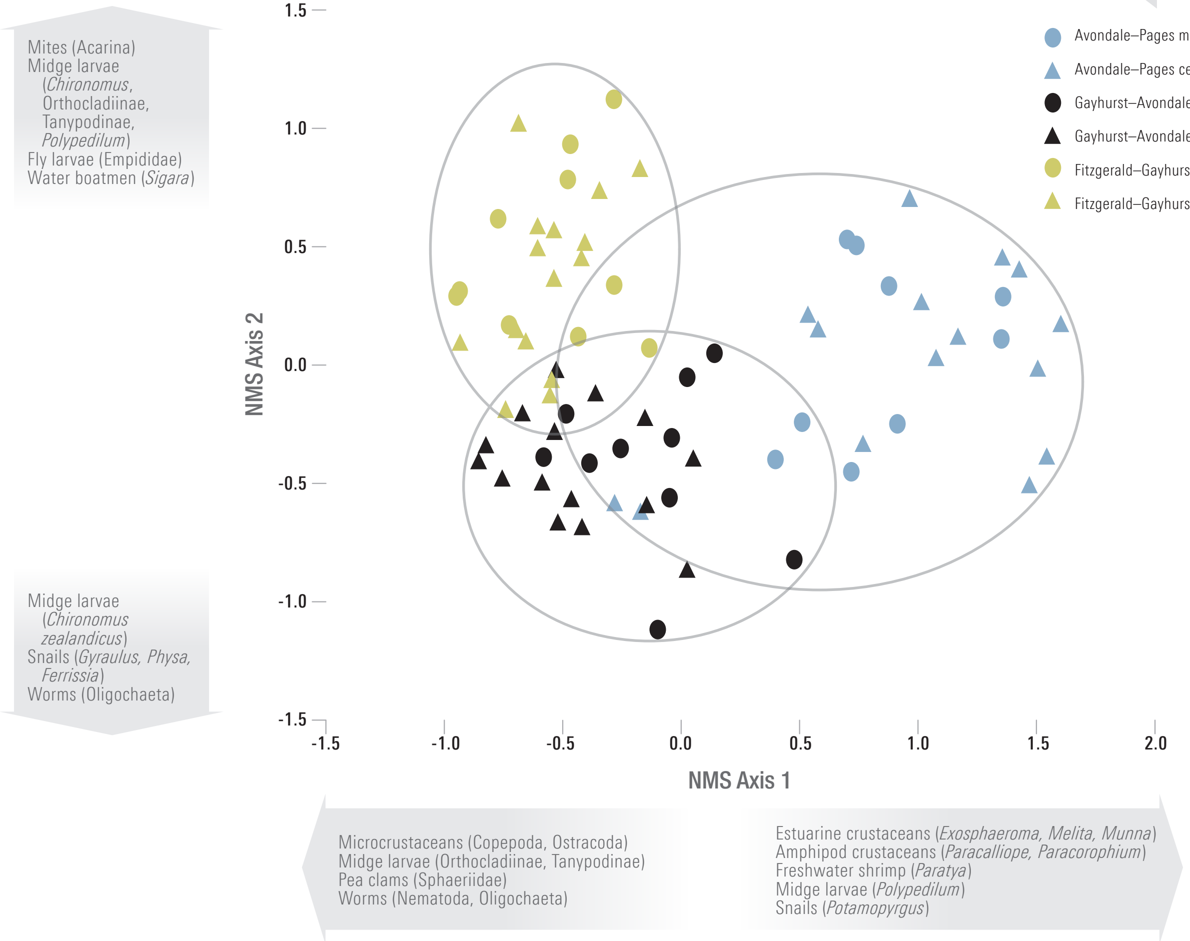
FIGURE 4D

FIGURE 4: Continued...

FIGURE 5:

Non-metric multidimensional scaling (NMS) ordination of invertebrate community data from three study sections in the lower Avon River sampled 13–15 December 2011. Invertebrate taxa correlated with the axes are shown. Ellipses enclose the samples from each study section.

Ordination of data is used to examine how communities composed of many different taxa differ between sites. It graphically describes communities by representing each site as a point (an ordination score) on an x–y plot. The location of each point/site reflects its community composition, as well as its similarity to communities in other sites/points. Points closer together have more similar invertebrate communities than ones further apart.



Fish

A total 3100 individual fish of 12 species were captured in the lower Avon River. The 12 species were common smelt (*Retropinna retropinna*), common bully (*Gobiomorphus cotidianus*), giant bully (*Gobiomorphus gobioides*), yellow-eyed mullet (*Aldrichetta forsteri*), inanga (*Galaxias maculatus*), shortfin eel (*Anguilla australis*), longfin eel (*Anguilla dieffenbachii*), estuarine triplefin (*Grahamina*), yellow-belly flounder (*Rhombosolea leporina*), kahawai (*Arripis trutta*), sole (*Pletorhampus novaezeelandiae*), and stout sprat (*Sprattus muelleri*). Of these species four (yellow-belly flounder, kahawai, sole, and stout sprat) were found exclusively at the river mouth just upstream of Bridge St. The seine netting catch at the river mouth caught a vast number of fish (2669 in total) and was dominated by common smelt, which accounted for over half of all fish caught overall (1538 caught), followed by common bully (430 caught), yellow-eyed mullet (395 caught), and inanga (150 caught) (Fig. 6). Fyke net and Gee minnow trap catches in the other three study sections were dominated by giant bully (142 caught), common bully (128 caught), shortfin eel (100 caught), and inanga (30 caught) (Fig. 6). The fact that common bully and inanga were among the most common fish species captured at both the mouth and sites further upstream despite the differing fishing methods used, would indicate they are prominent throughout the lower Avon River.

The relative abundance of fish taxa (combining fyke nets and Gee minnow traps) were quite similar among the three Avon River mainstem sites with the community dominated by common bully, giant bully, and shortfin eel (Fig. 7A). The only notable difference among these three study sections was the occurrence of the estuarine triplefin exclusively in the downstream-most section (Avondale–Pages), indicating it probably only penetrates as far upstream as the saline water influence (Fig. 7A). The river mouth fish community (which cannot be directly compared to the other sections because of the differing fishing method used), was dominated by high numbers of common smelt (58%) as well as many common bully (16%) and yellow-eyed mullet (15%) (Fig. 7A). Species richness was similar among the three mainstem sections (five or six species) and greatest at the river mouth site (10 species) (Fig. 7B). The greater species richness at the mouth was likely due to the more active seine netting sampling methodology undertaken there (compared to the more passive trapping in the mainstem sections) and its proximity to the estuary meaning some marine/estuarine species were encountered (e.g., kahawai, stout sprat, and yellow-belly flounder).

Fyke nets had a higher catch per unit effort (CPUE) than Gee minnow traps in all three mainstem study sections meaning fyke nets were more successful at capturing fish than Gee minnows traps in the lower Avon River. The CPUE in the upstream-most section (Fitzgerald–Gayhurst) was markedly lower than the downstream study sections for both fyke netting and Gee minnow trapping (Fig. 7C). This may indicate there are less fish present in that part of the river (Fig. 7C). The middle (Gayhurst–Avondale) section had the greatest fyke net CPUE of all sites, indicating fish may have been more abundant there than at the other two sections (Fig. 7C).

COMMON FISH SPECIES IN THE LOWER AVON RIVER CAPTURED BY FYKE NETTING AND GEE MINNOW TRAPPING (excludes river mouth site)

COMMON FISH SPECIES AT THE AVON RIVER MOUTH CAPTURED VIA SEINE NETTING (excludes other study sections)

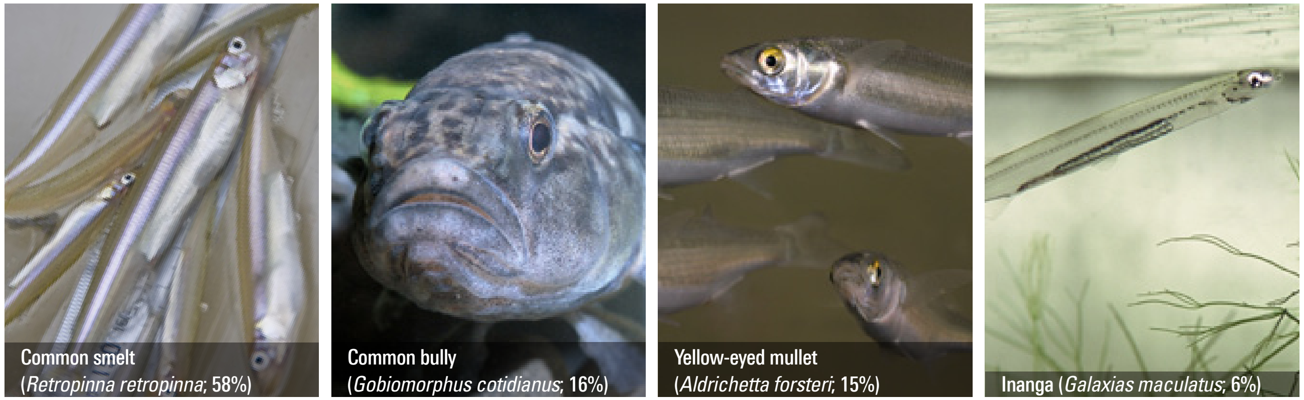


FIGURE 6:
Common fish (and their percentage contribution of all fish captured) found in the lower Avon River. Those fish that accounted for at least 5% of all fish captured at either the river mouth or three mainstem study sections combined are shown. The river mouth section is shown separately as a different fishing method was used there (seining) than in the other three study sections (fyke nets and Gee minnow traps). Study sections were sampled for fish 8–9 December 2011.

Relative abundance shows the percentage contributions of each fish species to the total fish community. Relative abundance graphs can show if there are shifts in the relative proportion of the various fish species over time or among study sections.

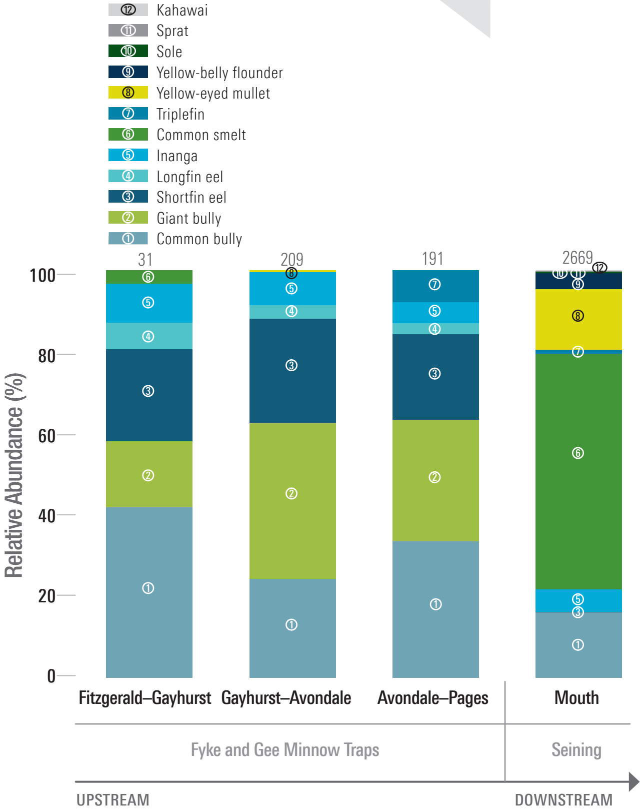


FIGURE 7A

Species richness refers to the number of different types of fish captured at a site. A large decrease (or increase) in species as a result of some disturbance may indicate an effect. However, differences often are a result of the collecting or missing of rare species, rather than changes in the core species that make up most of the community at a site.

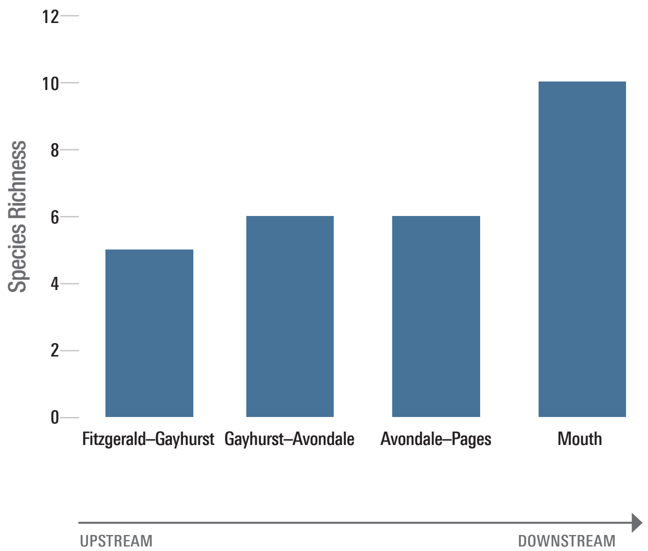


FIGURE 7B

CPUE refers to the number of fish captured per unit of effort expended. In this case effort is the number of nets or traps set. Here the CPUE for fyke nets and Gee minnow traps are shown separately.

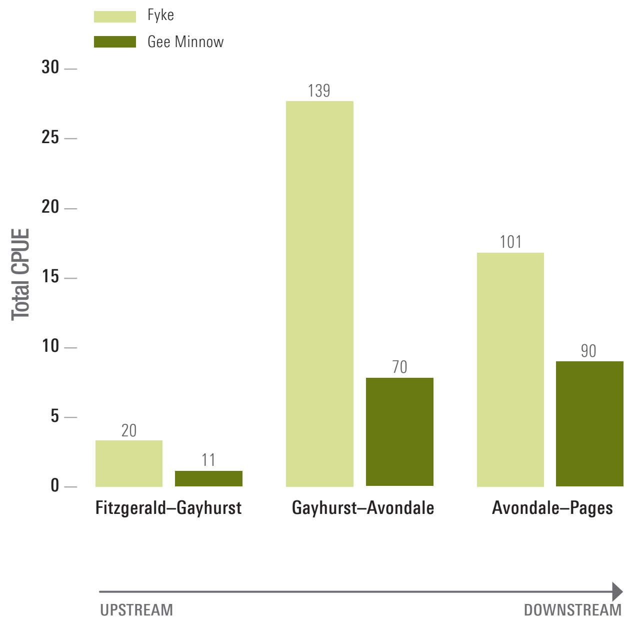


FIGURE 7C

FIGURE 7:
Fish community relative abundance (A), species richness (B), and catch per unit effort (CPUE; fyke nets and Gee minnow traps shown separately)(C). The numbers above the relative abundance and CPUE bars indicate the total number fish captured in each study section or trap type, respectively. Study sections were sampled for fish on 8–9 December 2011.

Box plots show the size (body length) distribution in a format that allows easy comparison between study sections. What each box plot element signifies is shown on the shortfin eel graph. Below each study section label is the total number of that species that were captured in that section.

The size distributions of the three most abundant fish speices, shortfin eel, giant bully, and common bully were not greatly different among the three mainstem study sections (Fig. 8A–C). However, the few very large individual shortfin eels (>700 mm) and giant bullies (>120 mm) which were statistical outliers that were captured tended to be found further downstream (Fig. 8A & 8B). Few fish of any species were captured in the upstream-most section (Fitzgerald–Gayhurst: 31 fish captured) compared to the other study sections (Gayhurst–Avondale and Avondale–Pages: 209 and 191 fish captured respectively) meaning the size distributions for this section are based on small numbers of fish (Fig. 8A–C).

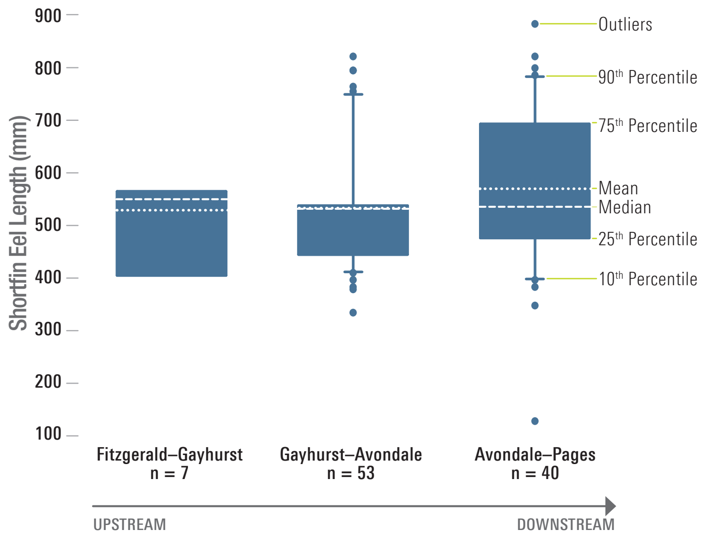


FIGURE 8A

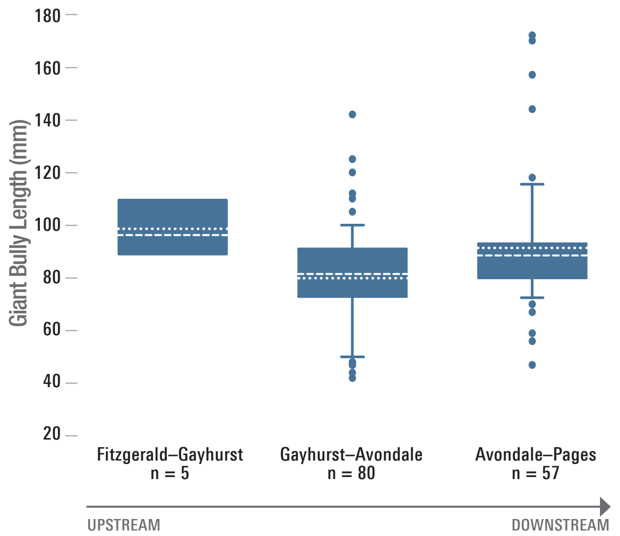


FIGURE 8B

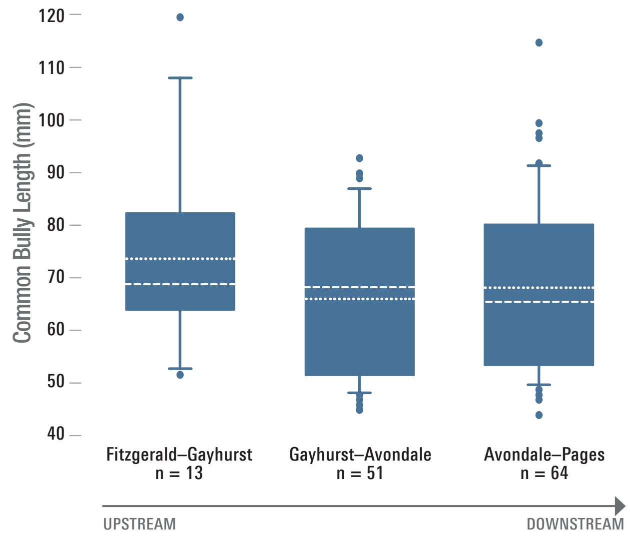


FIGURE 8C

FIGURE 8:
The length distributions of three common lower Avon River fish (shortfin eel (A), giant bully (B), and common bully (C)) for each of the three mainstem study sections. Fish were sampled on 8-9 December 2011.

HISTORICAL COMPARISON

Invertebrates

The most recent comprehensive pre-earthquake survey of invertebrates in the lower Avon River was undertaken 22 years ago by Robb (1992) who used similar methods to this study (e.g., a kick net and small dredge/grab sampler) over the 1989-1990 summer. Because he only reported broad abundance categories, historical comparisons are limited to taxa richness and MCI-sb; both of which are derived from presence-absence data. Overall Robb (1992) found fewer taxa than the current study when his data was converted to the same level of identification (33 taxa vs. 51 taxa). While Robb (1992) provides limited information on his sampling effort it is highly likely the current study had a more rigorous sampling methodology, and thus was more likely to collect rare and uncommon taxa. Hence this is probably why we encountered more taxa in 2011. When his sampling sites were split into the study sections of the current study it showed that taxa richness declined in a downstream direction in 1990 while in 2011 it was similar among the three study sections (Fig. 9A). Taxa richness was significantly greater in 1990 than in 2011 for the Fitzgerald–Gayhurst section, but was not different between years for the other two study sections (Fig. 9A). MCI-sb was not significantly different between 1990 and 2011 for any of the study sections (Fig. 9B).

FIGURE 9:

A comparison of taxa richness (A) and MCI-sb (B) values between Robb (1992) and the current study. Robb (1992) only used course abundance categories thus we were unable to generate QMCI-sb scores from 1990. The MCI-sb graph has the water quality categories of Stark & Maxted (2007) superimposed. Two-way ANOVA was performed and results shown are only those that were significantly different. Where shown, different letters in or above the bars denote statistically significant differences between the river sections (e.g., bars labelled ‘a’ are statistically not different, but are different to those labelled ‘b’).

Taxa richness refers to the number of different animals captured at a site. A large decrease (or increase) in taxa as a result of some disturbance may indicate an effect. However, differences often are a result of the collecting or missing of rare taxa, rather than changes in the core taxa that make up most of the community at a site.

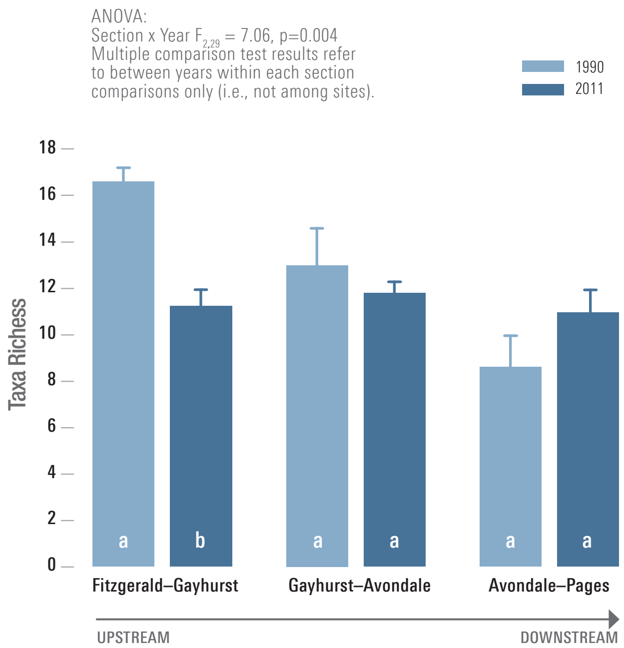


FIGURE 9A

The Macroinvertebrate Community Index (MCI) is a metric derived from a pollution-tolerance score that has been assigned to all the commonly encountered aquatic invertebrates in New Zealand (Stark & Maxted, 2007). It gives an indication of organic pollution and is often as used as a proxy for water quality. Higher scores indicate higher water quality (i.e., a community with a greater abundance of invertebrates that are sensitive to degraded water quality). MCI is based on taxa presence/absence (not abundance) while QMCI is a derivative that takes into account the abundance of taxa as well. The “-sb” suffix indicates the soft-bottomed (sand or silt bottomed waterway) variants are being used. The MCI was designed for use in wadeable, freshwater waterways, thus its interpretation of water quality in non-wadeable, tidally influenced environments such as the lower Avon River must be taken with caution.

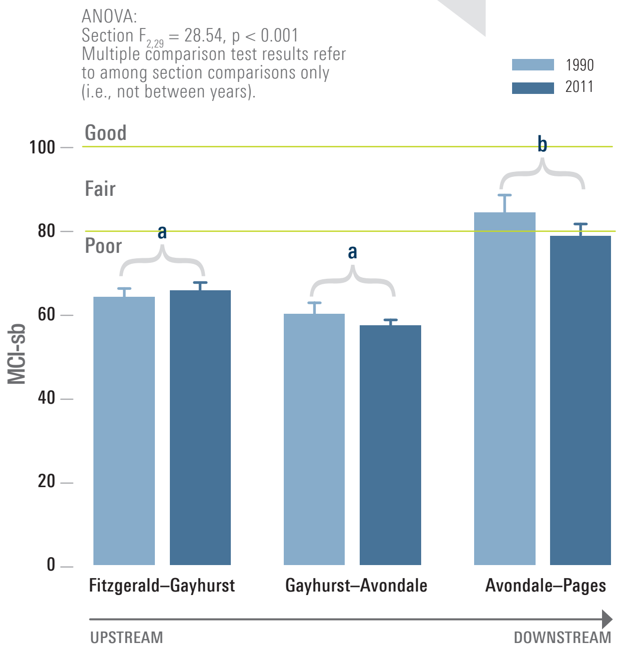


FIGURE 9B

Fish

Historical fish data from 21 years ago, collected by Eldon & Kelly (1992) over the 1991–1992 summer, as well as New Zealand Freshwater Fish Database entries from the same time were available for comparison. These surveys used seine netting near the river mouth and fyke netting further upstream, just as we did in the current study. They also recorded fish numbers and fishing effort (for fykes nets only), meaning we were able to make useful comparisons of species richness, catch per unit effort (for fyke nets only), and relative abundance. There were some methodological differences however, as they sampled later in summer and used paired v-wing fykes (one facing upstream and one downstream) with the wings being set by a diver in deep water. Such a setup may have had greater capture efficiency than the current study.

Overall eight fish species were captured in 1992 compared to 12 in 2011. Fish species richness in each study section was similar between 1992 and 2011 (i.e., the same or a difference of one species) apart for the river mouth study section (Fig. 10A). The high species richness at the river mouth in 2011 is probably more to do with our sampling site being closer to the estuary (i.e., near Bridge Street in 2011 vs. 600 to 1000 m further upstream in 1992) and thus would have been more likely to capture the more marine species observed (e.g., kahawai and stout sprat). Also there may have been greater sampling effort in 2011 (six seine sets) increasing the probability of capturing additional species (although no effort data is given with the 1992 records, from the total numbers of fish captured we have assumed more seine sets were deployed in 2011).

In contrast, the total CPUE (for fyke nets only and excluding the river mouth) was variable between study sections and years (Fig. 10B). The CPUE of the upstream (Fitzgerald–Gayhurst) section was dramatically lower in 2011 than in 1992 (Fig. 10B), possibly reflecting the lack of cover for fish, with the riverbed predominantly being limited to bare fine sediment and filamentous algae blooms in the 2011 survey (Fig. 2). Macrophyte abundance as recorded by Robb (1992) indicated that in 1989–1990 filamentous green algae was present at only six of 14 survey sites he visited in the Fitzgerald–Gayhurst section, and only in moderate abundance. In contrast, the macrophytes *Potamogeton crispus* and *Elodea canadensis*, and the charophyte *Nitella hookeri* were much more widespread and prolific through this section at that time. While there are no recent pre-earthquake records of macrophyte abundance in this part of the river with which to directly compare, anecdotal accounts do indicate large macrophte beds. Thus it is probable the earthquakes may have been partly responsible for the loss of macrophyte cover. Parts of the riverbed through this section had been subjected to inputs of liquefaction sediment and sewage discharges which may have resulted in some of the prolific filametous algae growths and die off of macrophytes. Between-year differences in total CPUE for the other two study sections were less dramatic, although for the Gayhurst–Avondale section the 2011 CPUE was almost twice that of 1992, meaning that for this section fish were easier to catch in the current study than in 1992 (Fig. 10B).

A comparison of relative abundances between 1992 and 2011 indicates that while there were some shifts in the proportions of a few common taxa, overall there were no great differences between 1992 and 2011 in any of the study sections. There was no disappearance (or appearance) of any prominent species, however it is interesting to note that in the Gayhurst–Avondale and Avondale–Pages sections, longfin eel now account for a much lower proportion of fish captured via fyke netting in 2011 than they did in 1992, while giant bully make up a higher proportion of fish captured in 2011 than they did in 1992 (Fig. 10C).

Sample of fish collected in seine net.

FIGURE 10:
A historic comparison of fish species richness (A), catch per unit effort (CPUE; fyke nets only)(B), and community relative abundance (fyke and seine netting only) (C) between 1992 and 2011. The current data was collected on 8–9 December 2011. The January 1992 data is from Eldon & Kelly (1992) and the New Zealand Freshwater Fish Database and was collected using the same methods from similar locations as the 2011 data. The numbers above the relative abundance bars indicate the total number fish captured in each study section in each year.

Species richness refers to the number of different types of fish captured at a site. A large decrease (or increase) in species as a result of some disturbance may indicate an effect. However, differences often are a result of the collecting or missing of rare species, rather than changes in the core species that make up most of the community at a site.

CPUE refers to the number of fish captured per unit of effort expended. In this case effort is the number of fyke nets set. To allow comparison between our December 2011 and historic records from 1992 only fyke net data was used (i.e., Gee minnow traps excluded). A higher CPUE means fish were 'easier' to catch either because they were more abundant or more likely to be captured for some other reason.

Relative abundance shows the percentage contributions of each fish species to the total fish community. Relative abundance graphs can show if there are shifts in the relative proportion of the various fish species over time or among study sections.

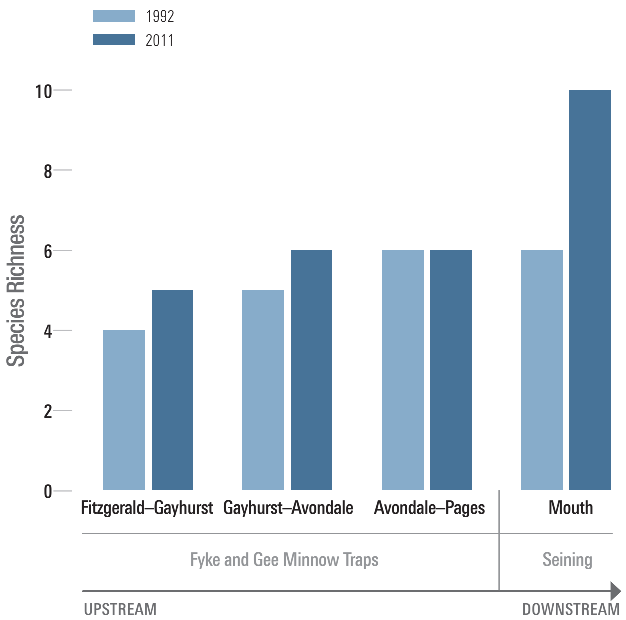


FIGURE 10A

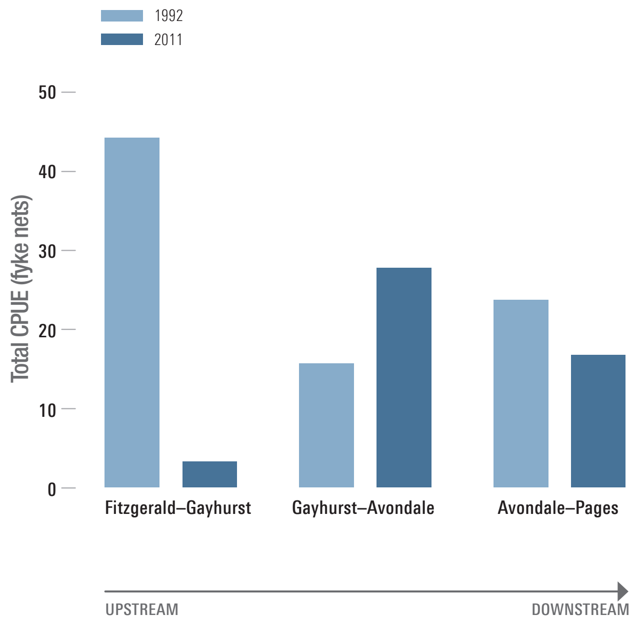


FIGURE 10B

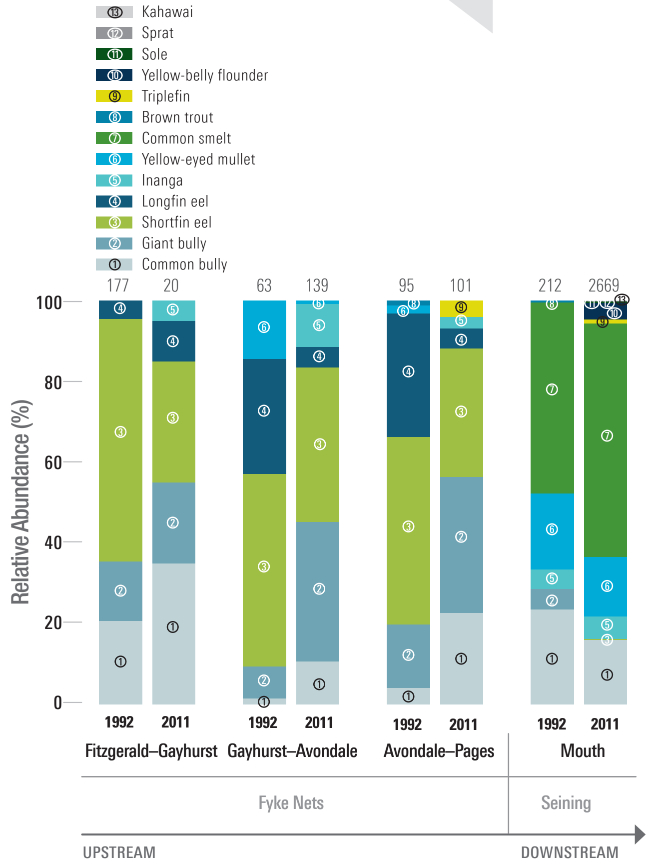


FIGURE 10C

CONCLUSION

CURRENT STATE

The lower Avon River some 10 months after the devastating 22 February 2011 earthquake supported a diverse aquatic invertebrate (51 taxa) and fish (12 taxa) community. The invertebrate community was dominated by snails, worms, midge larvae, and crustaceans which are the dominant invertebrates in waterways throughout Christchurch and indeed in many urbanised catchments elsewhere (e.g., Suren, 2000; McMurtrie, 2009; James, 2010, 2011a). These invertebrates are tolerant of, or prefer the conditions of the lower Avon River with its soft river bed (mud and sand), abundant macrophyte beds, and filamentous algae growths. They are also generally tolerant of pollutants originating from urban catchments (e.g., fine sediment and heavy metals). The MCI-sb and QMCI-sb which are water/habitat quality indices based on taxa-specific tolerances to organic pollution both indicated the lower Avon River is classified as being in the lowest or 'poor' category of Stark & Maxted (2007). However, these indices were developed for use in wadeable, freshwater waterways, thus their interpretation of water quality in the non-wadeable, tidally-influenced lower Avon River must be used with caution. There was a change in community structure longitudinally down the river, partly because of the influence of salt water on the lower study section (Avondale–Pages) allowing estuarine invertebrates to dwell there.

The fish fauna was dominated by species that are typical of the lower, tidally influenced reaches of many New Zealand rivers (e.g., shortfin eel, common bully, giant bully, common smelt, and inanga). Fish were abundant at the river mouth with over 2500 individuals captured by six beach seine net sets. Further upstream, fyke netting and Gee minnow trapping caught reasonable numbers of fish in the Gayhurst–Avondale and Avondale–Pages study sections, but the catch in the upstream-most section (Fitzgerald–Gayhurst) was very low in comparison. Invariably we would have missed some other more transient fish species that were recently recorded in the Avon River upstream of Fitzgerald Avenue, such as brown trout and yellow-eyed mullet (James & McMurtrie, 2011b). Yellow-eyed mullet were commonly caught in the river mouth seine nets but only a single individual was caught in a fyke net further upstream although we know large schools of this species penetrate up the Avon River to at least Hagley Park (authors' pers. obs). Due to their free-swimming nature yellow-eyed mullet as well as brown trout (which were also present but were not caught) are not readily captured by fyke nets and Gee minnow traps. Thus the abundance of these taxa in the lower Avon River was probably underestimated.

The most notable finding was the apparent lack of fish in the upstream-most section (Fitzgerald–Gayhurst; 31 fish captured). Despite the same sampling effort, far fewer fish were found in this section than in the Gayhurst–Avondale (209 fish captured) and Avondale–Pages (191 fish captured) study sections further downstream. The lack of fish cover observed in this section compared to the other study sections likely makes it undesirable to fish.

Native macrophyte bed (*Myriophyllum*).

HISTORICAL COMPARISONS

While there is a lack of any recent (i.e. less than 10 years old) invertebrate or fish data from the Avon River downstream of the Fitzgerald Avenue Bridge, historic data from over 20 years ago (i.e., 1989–1992) was available with which to compare the current survey's data. Robb (1992) collected invertebrate samples from along the lower Avon River from a number of sites very near to our sampling locations. He only reported invertebrate abundance as three broad categories rather than actually counting the invertebrates in his samples so we are limited to making a direct comparison of metrics that are derived from presence-absence data only (i.e., taxa richness and MCI-sb). Taxa richness was not significantly different between years at the Gayhurst–Avondale and Avondale–Pages study sections but was lower at the upstream-most (Fitzgerald–Gayhurst) section in 2011. MCI-sb (a measure of organic pollution based on taxa-specific tolerances) was not significantly different between years in any of the study sections.

The results of a freshwater fish survey undertaken by MAF 20 years ago using fyke and seine netting within each of our study sections allowed a direct comparison of fish species relative abundance and catch per unit effort (for fyke nets only) between 1992 and 2011. Apart from some shifts in the proportions of a few numerically dominant species, the relative abundance of fish species within each study section was generally similar between years. The catch per unit effort (fyke nets only) was variable between years within each study section, and in particular was markedly reduced in 2011 in the upstream-most section (Fitzgerald–Gayhurst) which may indicate reduced abundance in this section.

Overall, in terms of the invertebrate metrics and fish abundance characteristics we were able to compare there were no great differences between the fauna of current study and that of the early 1990s. In 2011 we captured a greater number of fish species and invertebrate taxa compared to the early 1990s surveys, possibly because our sampling effort was greater (meaning we picked up some of the more uncommon taxa, especially for invertebrates). The most notable finding of the historical comparison was the reduction in invertebrate taxa richness, and the dramatic reduction in catch per unit effort of fish in the upstream-most section (Fitzgerald–Gayhurst) between 1992 and 2011. Given this study section also had the least fish of all the study sections in 2011, it would appear this part of the river was unsuitable for fish at the time of sampling.

Suspended sediment in the Avon River after June 2011 earthquake.

EARTHQUAKE EFFECTS

Given the amount of fine sediment mobilised (and deposited) by the 22 February 2011 earthquake and the prolonged input of raw sewage it would be surprising to many if there had not been some impact on the fauna of the lower Avon River. Sewage inputs can have negative impacts on stream fauna through lowered dissolved oxygen levels that result from a sudden increase in microbial activity and from increased levels of toxic ammonia. A cage experiment comparing the survival of three common invertebrate taxa between the upper (no sewage inputs) and lower (numerous sewage inputs) Avon River approximately 2.5 months after 22 February 2011 found the survival of *Paracalliope* (amphipod crustacean) and *Potamopyrgus* (snail) to be reduced at the sewage impacted site (McMurtrie, 2011). This reduced survival was attributed to lowered dissolved oxygen and/or elevated ammonia concentrations. Modelling and direct measurement of dissolved oxygen during the period of overflows concluded that sensitive aquatic species may have been adversely affected by low dissolved oxygen concentrations from approximately the final kilometre of the upstream-most section (Fitzgerald–Gayhurst) all the way to the river mouth on occasions during April and May (Rutherford & Hudson, 2011). Their modelling of ammonia concentrations indicated that it was unlikely concentrations were high enough during the period of sewage overflows to have any significant adverse effects on aquatic fauna (Rutherford & Hudson, 2011). However, direct measures of ammonia from the river 2.5 months after the 22 February earthquake (during the cage experiments by McMurtrie, 2011) indicated concentrations at the downstream site did fluctuate into the range known to be toxic to some invertebrates and could infer ammonia toxicity effects at the height of sewage overflows immediately following the earthquakes.

While dissolved oxygen levels reached hazardously low levels, as no surveys were done at the time, it is impossible to know if there were any fish or invertebrate mortality in the Avon River. In the Heathcote River, there were however reports of dead fish and of eels out of the water gulping for air on the 4–5 March 2011 in the vicinity of the floodgates which were closed at the time. This would imply severely low dissolved oxygen levels and it is highly likely the Avon River had similarly low dissolved oxygen levels at this time. Thus there may well have been fish kills in the Avon River, although thankfully there are no floodgate structures in its channel to cause the stagnant conditions observed in the Heathcote River at the time of the fish kills there. All we can confidently state is that some ten months after the 22 February 2011 earthquake and seven months following the period covered by dissolved oxygen and ammonia modelling, many fish were captured in the lower Avon River with a slightly greater diversity of fish taxa than were found in the 1992 survey. Invertebrate richness and MCI-sb metrics were similar to what they were in 1990, while overall taxa richness was greater in 2011. While we cannot know for sure if there were any significant earthquake impacts on the fauna of the lower Avon River immediately following the earthquake, the current survey and the historic data implies the existing fish and invertebrate community is

Earthquake damage to the bank of the lower Avon River.

currently what one would expect to be present in an urban river.

In the weeks following the 22 February earthquake when sewage overflows and suspended sediment loads were at their maximum it is possible there were some die-offs of the more sensitive aquatic fauna. Fish may have been able to move about and thus avoid the worst affected parts of the river channel while invertebrates, generally being less mobile, would have been more likely to die. Freshwater invertebrate communities, and to some extent fish communities, especially those in urban catchments are resilient to what appear to us as severe impacts as long as there are nearby sources of colonists. It must also be remembered that long before the recent earthquakes, Christchurch's waterways and their fauna have been affected by urbanisation. With the conversion of the catchment from indigenous vegetation to a city, pollutants and fine sediment from urban run-off have accumulated in the waterways and the addition of buildings, bridges, culverts, and light pollution impede the dispersal and influence the behaviour of adult aquatic insects (Suren, 2000; Blakely *et al.*, 2006). These factors have modified the habitat of urban waterways such that they are no longer suitable for the more sensitive aquatic invertebrates and fish that would have once been found there. While we do not have any quantitative information on the aquatic fauna of Christchurch's many waterways prior to the development of Christchurch City, we do know that a number of invertebrate species have disappeared from the heavily urbanised Avon River catchment (e.g., mayflies, stoneflies, and sensitive caddisflies). Thus, in the case of the lower Avon River the existing fauna is comprised of relatively tolerant animals and in reaches where conditions did cause die-offs of certain taxa, colonisation from upstream would have been rapid.

Of the three mainstem study sections, only the upstream-most (Fitzgerald–Gayhurst) would appear to be in a poorer state in 2011 than in 1990. Invertebrate taxa richness was significantly lower in 2011 than in 1990 and fish total catch per unit effort was dramatically reduced in 2011 compared to 1992. While it is impossible to attribute this to any earthquake effects due to a lack of data just prior to the earthquake, changes to the habitat through this section could be attributed to earthquake effects. Of particular note in this section was the absence of mid-channel macrophytes and the abundance of filamentous algae which could be related to earthquake effects. There were less macrophytes and more filamentous algae than there was during the last known survey of macrophytes in 1990 by Robb (1992) and anecdotal accounts of the river before the 2011 earthquakes had more extensive macrophyte beds in this section. Inputs of liquefaction sediment or bed movement likely caused a die-off in the macrophytes through possible damage to root structure or smothering. Filamentous algal blooms often result when there are nutrients available but an absence of other plants to uptake it — being early colonisers they can take advantage of the nutrient source before larger plants can become established. Given this section of river contained the greatest number of individual sewage overflow points, there was certainly a high nutrient input for filamentous algae to take advantage of. It is thus possible the lack of fish and lower invertebrate taxa richness in 2011 in the Fitzgerald–Gayhurst section may be related to a reduction of macrophytes ultimately caused by the effects of the 22 February earthquake.

Flotsam found in the lower Avon River during sampling.

DREDGING

The Christchurch City Council is intending to undertake riverbed sediment dredging from parts of the Avon River and its tributaries where lateral spread and liquefaction sediment inputs are causing issues with drainage, recreational, and ecological values. In the lower Avon River (i.e., downstream of the Fitzgerald Avenue Bridge) dredging will most likely be by bank or barge-based excavator. An estimated 2–2.5 km of river will be affected (of a total length of around 12 km) although this is based on only preliminary investigations and is subject to change (Owen Southen, CCC, pers. com.). The CCC has determined it is not practical or financially viable to dredge the river in one go, thus it is anticipated dredging activities will be spread over five years and it is likely only one site will be worked on at a time in the lower Avon River (Owen Southen, CCC, pers. com.).

Given the nature of dredging sediment from the bed of a river, there are unavoidable effects such as the suspension of fine sediment, disruption of instream habitat, and accidental removal of fish and invertebrates. The aquatic fauna of the Avon River has been shown to be resilient to the effects of a major earthquake event and thus will certainly be resilient to dredging activities which will have more minor effects in comparison. There will, however, be a direct impact on the aquatic fauna in the actual areas where dredging occurs, especially if macrophytes beds are present and are removed as well. Studies have shown that macrophyte removal can have negative impacts on fish and invertebrates usually through direct removal of animals from the waterway (Engel, 1990; Serafy *et al.*, 1994; Young *et al.*, 2004; also see review by James, 2011b). Just as a reduction in macrophyte cover appeared to be the cause of low fish numbers in the Fitzgerald–Gayhurst study section, a similar effect is expected in areas where dredging also involves the loss of macrophyte beds. In the short-term, the area would be denuded of aquatic life as animals either move away from the work area or are removed from the river in the spoil. Over time, as macrophyte beds regrow, the dredged areas will be recolonised by fish and invertebrates from nearby areas of riverbed that were not subjected to dredging. Any short to medium-term, impacts could be minimised where possible by other procedures, such as the returning of larger fauna caught in the dredged spoil to the river (e.g., eels), and working in an upstream to downstream direction to avoid cleared sections being unduly re-exposed to fine sediment and to ensure an upstream source of colonist invertebrates (although this will not always be practical).

Overall, dredging from the lower Avon River will be unlikely to result in any dramatic measurable ecological benefits. The riverbed was predominantly soft mud and silt before the earthquakes with the fish and invertebrates present tolerant or preferring such conditions. Therefore dredging discrete sections will not vastly alter the prevailing habitat or its existing fauna. However, the Avon River has been accumulating fine sediment over many years and because of its urban origin it contains contaminants such as heavy metals and hydrocarbons, thus its removal may well be beneficial in the long-term. In the upper Avon River catchment where the riverbed is predominantly stony, the removal of deposited fine sediment is more likely to have direct beneficial ecological effects by exposing the stony riverbed, thus reinstating the habitat to a pre-earthquake condition.

Related to dredging is the issue of bank stabilisation. Extensive parts of the lower Avon River have had gabion baskets installed to minimise bank erosion and reduce channel migration, however lateral spread has shifted these in places such that they may need to be replaced. At this stage decisions on exactly how damaged river banks will be reinstated (especially where red-zoned land is involved) have not been made. Once red zone land issues are resolved (e.g., land use and ownership) then the CCC will be able to plan long-term management solutions for the banks (Owen Southen, CCC, pers. com.). If significant sections of gabion baskets require replacing, then this would be an opportunity to investigate using methods of bank stabilisation that may provide greater ecological benefits (e.g., increase fish cover). Ideally, wider naturalised riparian areas will be developed and more natural methods of bank stabilisation such as sloped banks and revegetation will be used rather than hard engineering solutions.

Any dredging or bank stabilisation work needs to take into account the inanga spawning sites in the lower Avon River, in particular the extensive area in the vicinity of the Avondale Road Bridge. While this area was assessed as being in good order following the 22 February 2011 earthquake by Taylor & Blair (2011), this important reach would benefit from the development of increased inanga spawning area by the removal of gabion baskets on the true-left bank, regrading of both banks, and the planting of suitable spawning vegetation. Any works within or directly upstream of this section must be done soon after egg hatching, to allow the maximum amount of time for the recovery of the area (especially spawning vegetation) prior to the following spawning season.

Fine sediment plumes rising from the river bottom.

MANAGEMENT RECOMMENDATIONS

The aim of this current study was to establish a new base-line data set for future monitoring of the non-wadeable portion of the Avon River, which for so long has been ignored in monitoring programmes. Now that this has been achieved a long-term monitoring programme (encompassing fish and invertebrates) for the lower reaches of the river should be formalised.

- The lower Avon River **MONITORING PROGRAMME FOR FISH AND INVERTEBRATES** should now be implemented at four-yearly intervals to track long-term changes in the fauna of the Avon River. As the invertebrate and fish fauna of the river appears to be within the parameters of what would be expected for an urban river (with the possible exception of the upper Fitzgerald–Gayhurst section) there is no particular reason to monitor the river on a more regular basis.

- For the invertebrate survey, there was a lack of any invertebrate community differences in samples taken from the channel margin and channel centre. Invertebrate sampling should therefore be modified to only sample the marginal areas (e.g., not sample the mid-channel), with an **INCREASE IN THE NUMBER OF MARGINAL SAMPLES** collected to ensure a similar overall sampling effort. This will be beneficial in the long-term as sampling the deeper mid-channel area is generally more costly as it requires the use of a boat.

- Similar fish and invertebrate **SURVEYS SHOULD BE UNDERTAKEN FOR THE NON-WADEABLE PORTION OF OTHER CHRISTCHURCH RIVERS**—Heathcote, Styx, and Otukaikino Rivers—and serve as the beginning of a four yearly sampling programme for the non-wadeable portion of the City's rivers.

Dredging will no doubt be required throughout the lower part of the Avon River to remove liquefaction sediment and increase channel capacity (from slumped banks and raised bed). However, given that the fish and invertebrate community has, in general, shown great resilience to such a significant pollution/disturbance event that was caused by the Christchurch earthquakes, it is similarly likely that they will also be resilient to the impacts of dredging (habitat loss via removal of macrophytes along with the sediment, and re-suspension of sediment) over time. There are also considerable long-term benefits to the river ecology by removing this fine sediment and the contaminants it contains that has built-up in the river since the European settlement of Christchurch. The loss of cover via the loss of macrophytes during the dredging process will probably have the greatest impact on fish communities, with the loss of macrophytes in the upper reach shown to support far fewer fish than would be expected for this type of river. Thus there are a number of factors that should be undertaken to reduce the impact of the dredging and to check for any lasting effects.

- During dredging activities the **SPOIL SHOULD BE SEARCHED FOR FISH, FRESHWATER MUSSELS, AND KOURA** that have been accidentally removed and these returned to the river. While this is already standard practice by CCC for works in river beds (Owen Southen, CCC, pers. com.) there may be the need for more targeted searching (or searching overseen by a qualified person) as personal observations in some areas has indicated that these animals are sometimes being missed (freshwater mussels left on the bank along Cashmere Stream and Halswell River).

- During dredging activities, any significant **NATIVE MACROPHYTE BEDS SHOULD BE AVOIDED** if at all possible. Exotic macrophytes dominate the lower Avon River thus any significant patches of native macrophytes there are worth preserving as far as is practical.

- Dredging in **AREAS WHERE *EGERIA* (OXYGEN WEED) IS THOUGHT TO BE PRESENT** (e.g., Kerrs Reach) may **REQUIRE FURTHER CONSIDERATION** for how the release of plant propagules (leading to further downstream spread) of such aggressive exotic plant colonists can be avoided.

- During dredging activities it would be preferable to **WORK IN AN UPSTREAM TO DOWNSTREAM DIRECTION** to avoid completed areas being subjected to suspended sediment from active work areas upstream. This will also ensure that upstream invertebrate colonist sources will be protected and available to colonise the recently dredged sections via downstream drift. If it is not possible to always work in a downstream direction then at least 100 m of river section upstream of a dredging reach should be un-dredged for at least five months, to provide invertebrate colonist sources to each dredged section. Limiting dredging to a predefined section length (e.g., 100 m) will also ensure there are adjacent unaffected areas that fish and invertebrates can move into for refuge. The ideal section length for dredging would need to take into account the practicalities of dredging.

- **SPECIAL CARE WILL HAVE TO BE TAKEN AROUND THE EXTENSIVE INANGA SPAWNING SITES** upstream and downstream of the Avondale Road Bridge. Any work adjacent or upstream of this area that will suspend sediment should be avoided during the spawning and egg maturation period of March to June.

Bank slumping along parts of the lower Avon River has narrowed the river channel (up to 1 m in places). Coupled with land subsidence, water levels are now higher up the bank during high tides and the adjacent residential properties and roads are now more prone to flooding. In the Avondale inanga spawning reach this may have resulted in a shift in the spawning zone up the bank. If bank works are required to either widen the channel or to fix hard-edged bank areas (gabion baskets) there are a number of factors that can be considered.

» If significant sections of gabion baskets require replacing, then this would be an opportunity to **INVESTIGATE USING METHODS OF BANK STABILISATION THAT MAY PROVIDE GREATER ECOLOGICAL BENEFITS** (e.g., increase fish cover and suitable inanga spawning vegetation). If there were sufficient room it would be preferable to remove the baskets and create a more natural bank shape. In the Avondale inanga spawning area any bank repair work will ideally involve the removal of gabion baskets on the true-left bank, regrading of both banks, and the planting of suitable spawning vegetation.

» During the design of long-term bank stability management solutions, methodology should **INCORPORATE FEATURES TO IMPROVE FISH COVER** (e.g., cracks, holes, stumps, undercuts, and overhanging vegetation). It is recommended an aquatic scientist is consulted at an early stage and can contribute to the design.

» With the development of Christchurch the lower Avon River has become disconnected from its floodplain and has had its immediate riparian zone encroached upon by roads and buildings. Where possible, any bank works in the lower Avon River should aim to **RECONNECT THE WETTED CHANNEL TO ITS FLOODPLAIN** through the retreat of roads, buildings, and stop banks. This would also provide space for the creation of backwater wetlands. Such wetland areas will provide increased habitat diversity and may provide opportunities to reintroduce fish and plant taxa that were once likely present in the Avon River (e.g., giant kokopu).


The giant kokopu could be reintroduced to the lower Avon River if backwater wetland habitat was created.

ACKNOWLEDGEMENTS

We thank Adrian Meredith (Environment Canterbury) for the loan of the YSI Castaway CTD and Petite Ponar grab sampler. We appreciated the boating skills of Alastair Suren, Julian Sykes, and Greg Kelly (NIWA), and are grateful for the Pollution Hotline information provided by Michele Stevenson (Environment Canterbury). A much appreciated review by Marty Bonnett (NIWA) enabled us to make improvements to an earlier draft.

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