AQUATIC RESEARCH CONSULTANTS

Christchurch February Earthquake

EFFECT ON INVERTEBRATES OF THE LOWER RIVERS

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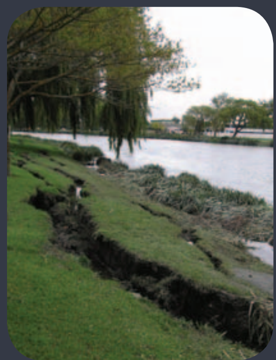

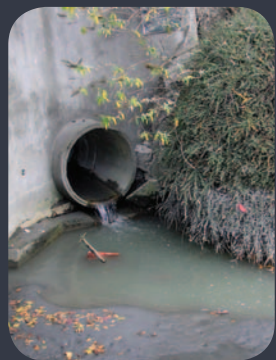


Approved for release by:
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Summary

The 22 February 2011 earthquake affected Christchurch's waterways through the inputs of liquefaction sand/silt, bank slumping, uplift of streambeds, and input of raw wastewater from broken sewage pipes. EOS Ecology was asked to find out if the sewage inputs had impacted on the City's aquatic invertebrate communities of the lower, non-wadeable, portion of the Avon and Heathcote Rivers. To determine this we undertook a bioassay experiment between the 5-17 May 2011, approximately 2.5 months after the February earthquake. Specimens of *Paracalliope*, *Potamopyrgus*, and *Paratya* were placed in cages and housed in the Avon and Heathcote Rivers at a site upstream and downstream of sewage discharges, and their survival checked after 2, 6, and 12 days.

Survival of all three species was not significantly lower at the downstream site on the Heathcote River, but there was a decrease in survival of *Paracalliope* and *Potamopyrgus* at the downstream site on the Avon River over time. The lower dissolved oxygen levels and elevated ammonia levels are the most likely cause of the decreased survival, which for *Paracalliope* dropped to around 60% after six days.

The lower levels of sewage that are continuing to discharge into the Avon River two months after the February earthquake appear to be sufficient to cause some mortality in the more sensitive invertebrate species such as the amphipod *Paracalliope*. The much higher inputs of sewage during the first few weeks of the earthquake would have presumably created a more widespread die-off of invertebrate fauna and possibly some fish. Chronic effects such as increased disease susceptibility, impaired reproduction, and altered biotic interactions could be possible in both fish and invertebrate communities should the discharges continue for several months.

With the most recent 13 June 2011 earthquake, sewage inputs to the Heathcote and Avon Rivers have returned to similar levels as what followed the 22 February earthquake. This will put additional stress on a system already stressed from months of sewage overflows. In light of this most recent event the ongoing impacts should be assessed via a bioassay experiment at the higher sewage inputs, or sampling fish and invertebrate communities over time to work out when they recover.


Removing cages from the upstream Avon River site


Removing cages from the downstream Avon River site

Assessing Earthquake Effects on the Lower River

The devastation wrought by the 22nd February 2011 earthquake extended to Christchurch's waterways. In particular, numerous broken wastewater pipes discharged untreated sewage to rivers. Such organic material input can result in a spike in oxygen-demanding bacterial activity that can deplete dissolved oxygen levels, increase ammonia levels, and in extreme situations kill aquatic life.

The significant portion of the Avon and Heathcote Rivers is non-wadeable, meaning that it is deeper than 1.5 m. For the Avon River this extends for 12 km downstream of the Fitzgerald Avenue Bridge, while for the Heathcote River it extends for roughly 7 km downstream of Beckford Road. These parts of the river have not been sampled as much as the upper wadeable sections due to the difficulty and cost of sampling in these deeper habitats. Most of the sewer overflows resulting from the 22nd February 2011 earthquake were into these non-wadeable sections of Christchurch's main rivers (the Avon and Heathcote). However, a simple before-after control-impact survey to determine the impact of these sewage inputs on the rivers' fauna was not possible because of the lack of pre-earthquake data. Thus EOS Ecology was commissioned to develop a means of determining the impact of sewage and silt inputs in the lower reaches of the rivers. We designed a controlled experiment where invertebrates with varying sensitivity to pollution were housed in cages and their survival plotted over time; known as bioassays.

Three different invertebrate species were chosen for the bioassay: the small amphipod *Paracalliope fluviatilis*; the snail *Potamopyrgus antipodarum*, and the freshwater shrimp *Paratya curvirostris* (Fig. 1). All three species are expected to be abundant in the macrophyte beds of the lower Avon and Heathcote Rivers under normal conditions, and would be a good food source for fish. All three species are regarded as being reasonably tolerant of degraded conditions typical of lowland urban or rural waterways. The amphipod *Paracalliope* and the snail *Potamopyrgus* are known to be more sensitive to ammonia. The expectation is that all three species would be tolerant to some level of dissolved oxygen fluctuation as they are found in high numbers in macrophyte beds.

Two sampling stations were chosen on the Avon and Heathcote Rivers (Fig.2). The upstream sampling stations were selected upstream of any known sewage overflow points and where there were abundant macrophyte beds. For the Avon River this was upstream of the Mona Vale weir, while for the Heathcote this was upstream of Bowenvale Ave bridge. Downstream sampling stations were located approximately 1 km downstream of a known sewage overflow point. In the Heathcote River this was opposite Aynsley Reserve while in the Avon River this was downstream of the Avondale Road bridge. The Avon River also had a temporary sewage discharge 150 m upstream of the sampling station, which operated sporadically during the experiment.

FIGURE 1

FIGURE 2

FIGURE 1
Three invertebrate species used in the bioassay experiment on the Avon River and Heathcote River approximately two months after the 22 February 2011 earthquake.

FIGURE 2
Sewage overflow locations (circles) and bioassay sites (squares) on the Avon and Heathcote Rivers where experiments were conducted between 5-17 May, 2011. Only those sewage overflows that were operating during the experiment duration are shown.

FIGURE 2


N
Avon downstream
PS 54/1
PS 39/1
Avon River
Avon upstream
PS 5/1
PS 4/1
Heathcote River
PS 19/1
Heathcote downstream
Heathcote upstream
Sewage overflow points
SITES:
Upstream
Downstream

Paracalliope, *Potamopyrgus*, and *Paratya* invertebrates were caught from waterways unaffected by the earthquake, and held in temperature-regulated tanks (stabilised at 14°C) for two days prior to deployment. A total of 30 clear plastic cages per site were constructed for *Paracalliope* (to house 10 specimens per cage), 20 cages per site for *Potamopyrgus* (10 specimens per cage), and 24 cages per site for *Paratya* (8 specimens per cage) (Fig. 3). Some macrophyte (*Potamogeton crispus*) was added to the cages housing *Potamopyrgus* and *Paratya* to provide additional surface area for grazing. Each of the cages had two rectangular windows covered with fine mesh on each side of the cage and were capped with screw-top lids.

Cages were installed in the Heathcote River on the 5^{th} May 2011 and in the Avon River on the 6^{th} May 2011 (Fig. 3). Cages were mounted between two waratahs and deployed in sets of two rows per waratah pair (five per row for *Paracalliope* and *Potamopyrgus* cages and four per row for *Paratya* cages). Cages from each sampling station were removed on three dates: 2 days, 6 days, and 12 days after deployment. However because *Potamopyrgus* is thought to be more tolerant of degraded conditions cages were removed after 6 and 12 days. On each removal date either 10 cages (for *Paracalliope* or *Potamopyrgus*) or eight cages (for *Paratya*) were removed at a time. Cages were transported back to the lab where surviving organisms were counted.

Some basic water quality parameters were measured at each site. Dissolved oxygen and temperature loggers were installed and set to log every 5-10 minutes. Salinity, conductivity, pH, water clarity (via a clarity tube) and ammonia were tested on deployment and on each removal day.

All invertebrate survival data was analysed using a two way ANOVA. Homogeneity of variances was tested using Cochran's test and where necessary data arcsin square root transformed to meet the assumptions of ANOVA. The post-hoc multiple comparison Tukey's test was used to compare groups where there was a significant result. Water quality data was analysed via two sample t-tests.

FIGURE 3

FIGURE 3

Constructing, installing, and removing cages for the bioassay experiment that was undertaken on the 5-17 May 2011. Cages were installed in the Avon River and Heathcote River at a site upstream and downstream of sewage overflows.

FIGURE 4

Survival of three different invertebrate species in the Avon and Heathcote Rivers upstream and downstream of areas affected by sewage overflows. Survival was assessed after 2, 6 and 12 days in the river.

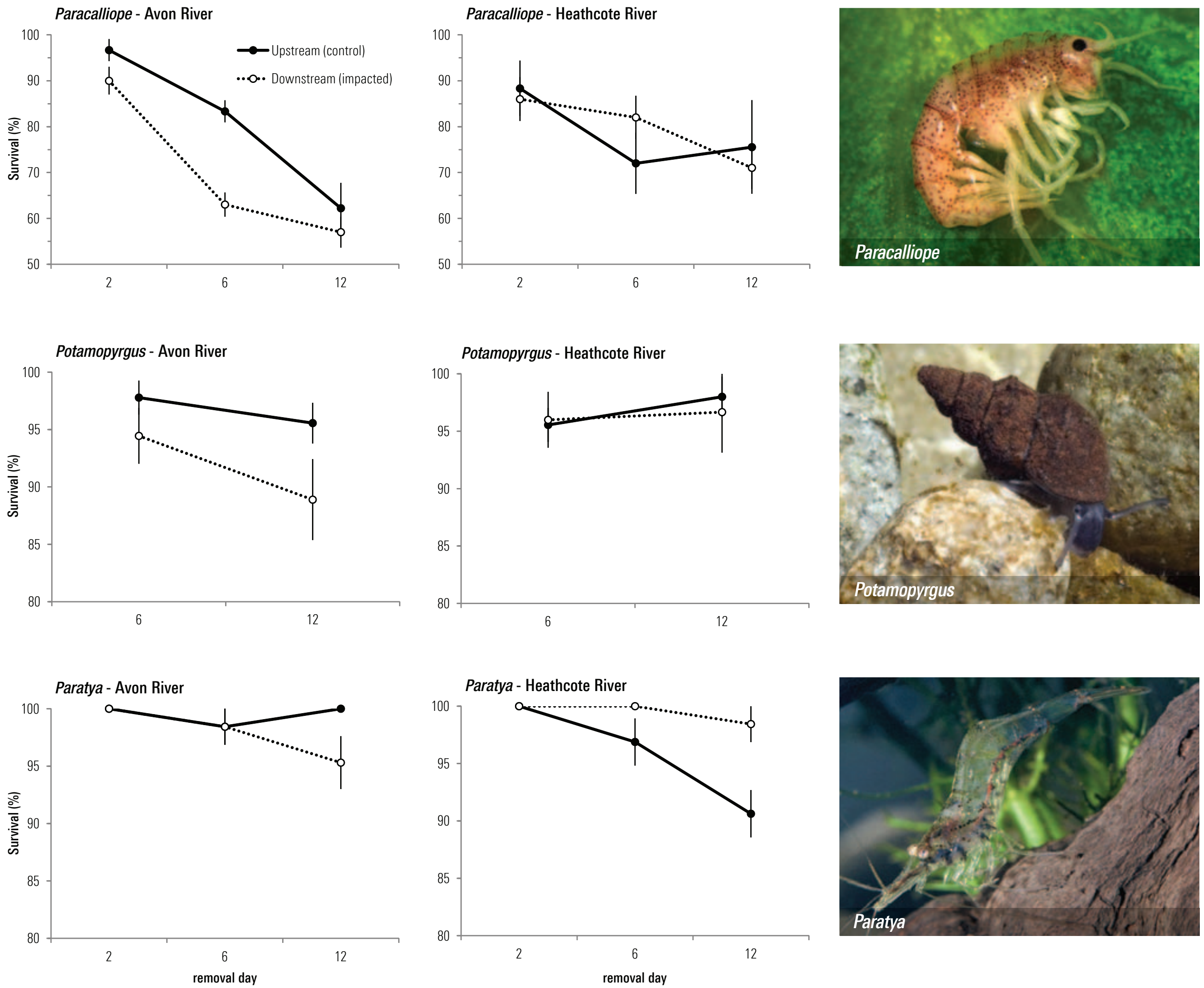
Our Findings

During the 12 day experiment there was an estimated daily overflow volume of 4,800 m^3/day of raw sewage from four overflow points to the Avon River between Fitzgerald Avenue and Avondale Bridge, with the nearest discharge 1 km upstream of the downstream experiment site. In addition there were two temporary discharges that operated intermittently during the experiment, with the most downstream only 150 m upstream of the experiment site. On the Heathcote River 2,700 m^3/day discharged from one overflow point (PS19/1) at Beckford Road, approximately 1 km upstream of the downstream experiment site.

Survival of all three species was not significantly lower at the downstream site over time for the Heathcote River (*Paracalliope*: $F_{2, 49} = 0.79$, $P > 0.05$; *Potamopyrgus*: $F_{1, 34} = 0.18$, $P > 0.05$), indicating no impact from the sewage overflows in this river (Fig. 4). Survival of *Paratya* was however, significantly less at the upstream site on day 12 ($F_{2, 42} = 4.29$, $P < 0.05$), which would indicate that they were affected by other conditions at the upstream site that exclude any sewage-related impacts.

In contrast there was a difference in survival of all three invertebrate species at the downstream site on the Avon River (Fig. 4). The survival of *Paracalliope* was significantly lower at the downstream site on all three removal dates ($F_{2, 51} = 51.76$, $P < 0.001$), although by day 12 the survival in the upstream control site had also diminished (Fig. 4). The greatest difference in survival was on day 6 where the survival of *Paracalliope* in the downstream Avon River site was at 63% survival compared to 83% survival at the upstream site. Survival of the snail *Potamopyrgus* was significantly lower in the downstream site on both day 6 and 12 ($F_{1, 32} = 4.26$, $P < 0.05$), although survival still remained at 89% by day 12. Survival of the shrimp *Paratya* was only different at the downstream site on day 12, where their survival dropped marginally to 95% survival compared to 100% in the upstream site (Fig. 4). However this difference was not statistically significant ($F_{2, 42} = 2.17$, $P > 0.05$).

FIGURE 4



Dissolved oxygen was significantly lower at the downstream sites on both the Avon and Heathcote Rivers (Avon: $t_{1, 6762}=245.99$, $p<0.0001$; Heathcote: $t_{1, 6951}=40.29$, $p<0.0001$) (Fig. 5). Whereas this difference was only slight on the Heathcote River (median value of 4.8 ppm vs 6 ppm at the upstream site), the difference was more dramatic on the Avon River, where the median dissolved oxygen level was 2.43 ppm at the downstream site compared to 7.43 ppm at the upstream site (Fig. 5). Water clarity was significantly lower on the Avon River at the downstream site ($t_{1, 6}=-2.50$, $P < 0.05$) (Fig. 6). Ammonia was also greater at both downstream sites but the difference was particularly dramatic at the Avon River site, where ammonia levels reached as high as 0.77 mg/l at the downstream site (Fig. 6). The high variation in the ammonia levels in the Avon River downstream site was due to the sporadic discharge of raw sewage from the temporary pump installed 150 m upstream, with levels spiking during the operation of this pump.

Water temperature was slightly higher at the upstream site on the Avon River ($t_{1, 6760}=30.67$, $p<0.0001$) and at the downstream site on the Heathcote River ($t_{1, 2232}=-21.66$, $p<0.0001$), but these upstream-downstream differences were within half a degree (Fig. 7). Water temperature also decreased over the course of the experiment, with the median temperature dropping from around 14 °C to 11 °C over the 12 days (Fig. 7). The other water quality parameters tested (conductivity, salinity, and pH) were not significantly different ($P > 0.05$) between the upstream and downstream sites in each river, although both conductivity and salinity fluctuated greatly in the downstream sites due to the tidal influence. The median pH value ranged from 7.1 to 7.5 between the sites.

FIGURE 5

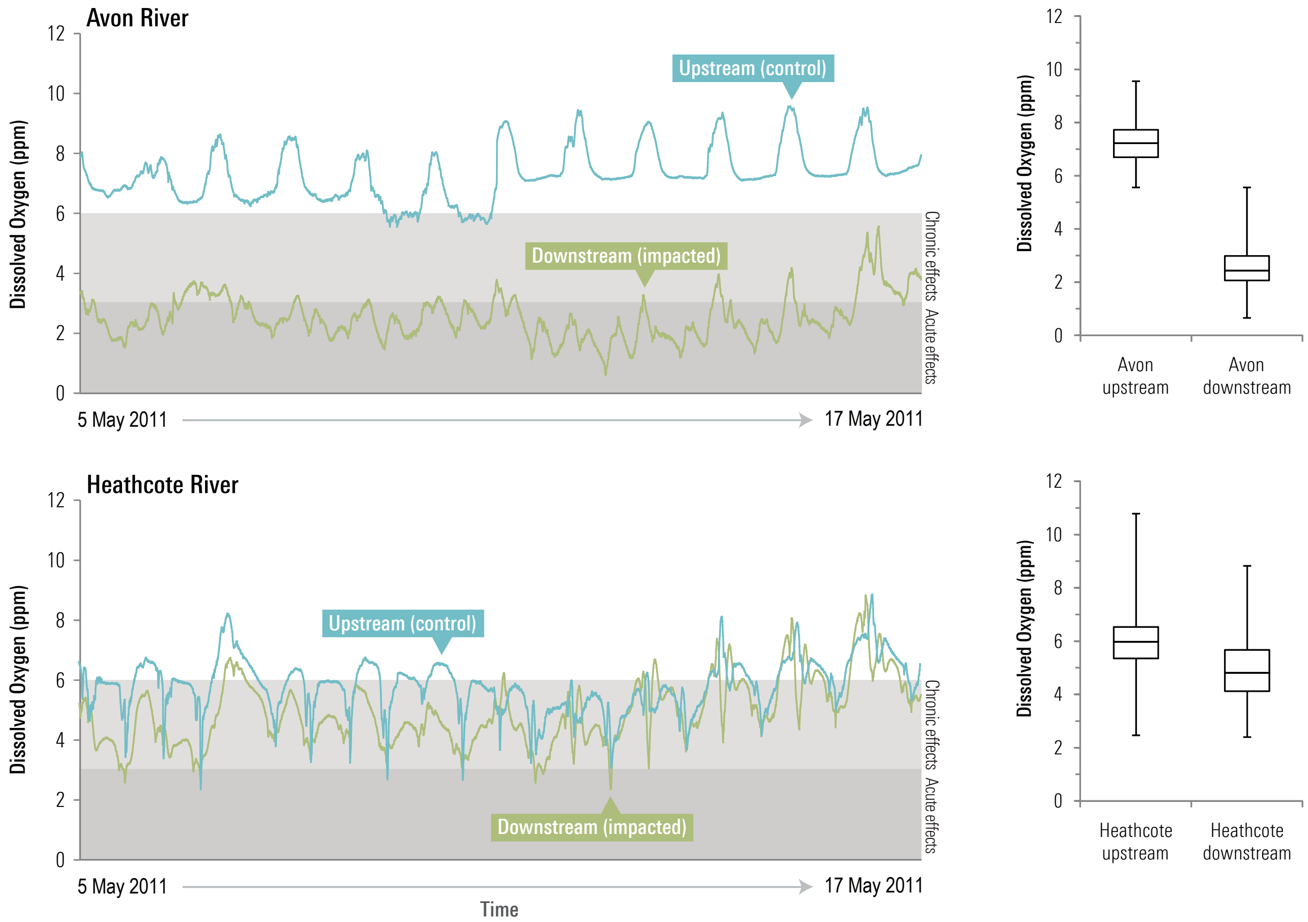


FIGURE 5

Dissolved oxygen (ppm) levels at the upstream and downstream sites on the Avon and Heathcote Rivers, as logged every five minutes over the 12 day experiment. Left: dissolved oxygen levels plotted over time, Right: box plots showing the median, first and third quartiles, and minimum/maximum values. The guideline value of 6 ppm for chronic and 3 ppm for acute effects, as presented by Rutherford *et al.* (2011) is used here. Note that ppm is the equivalent to mg/l.

FIGURE 6

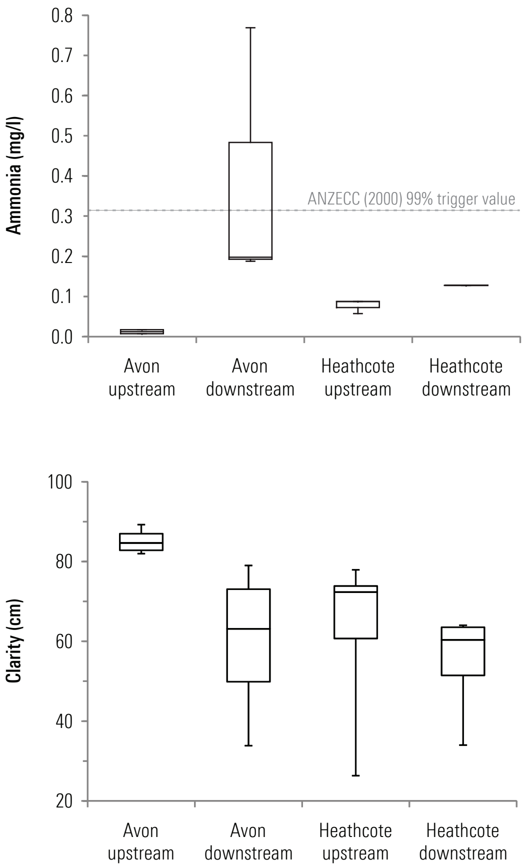


FIGURE 7

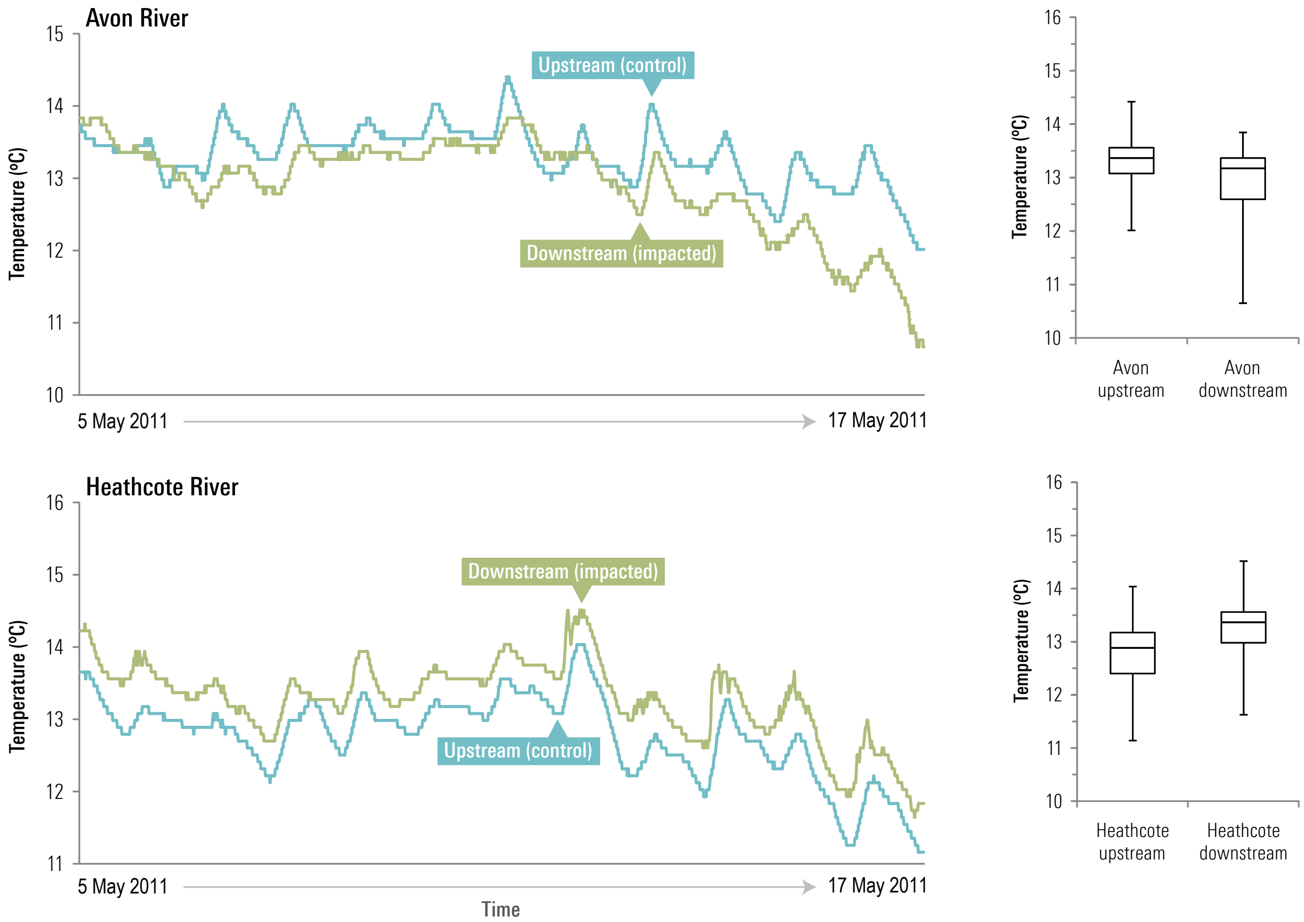


FIGURE 6

Water quality parameters that differed between the upstream and downstream sites on the Avon and Heathcote rivers during the course of the 12 day experiment. The ANZECC (2000) ammonia chronic trigger value for the protection of 99% of species (at pH 8) is also indicated.

FIGURE 7

Water temperature (°C) at the upstream and downstream sites on the Avon and Heathcote Rivers, as logged every 5-15 minutes over the 12 day experiment. Left: temperature levels plotted over time, Right: box plots showing the median, first and third quartiles, and minimum/maximum values.

Discussion

It appears that the 2,700 m^3/day of sewage entering the Heathcote River is not sufficient to have any acute affect on the invertebrate fauna of the river 1 km downstream of the discharge point, with survival of all three invertebrate species similar at the upstream and downstream sampling points. In contrast the greater discharge of 4,800 m^3/day entering the Avon River is sufficient to have a moderate impact on the survival of the amphipod *Paracalliope*, and a minor impact on the snail *Potamopyrgus*. The significantly lower dissolved oxygen levels and elevated ammonia levels at this site are the most likely cause of the decreased survival, which for *Paracalliope* dropped to around 60% at the downstream site after six days. The dissolved oxygen levels at the downstream site were below the acute guideline value of 3 ppm (Rutherford *et al.,* 2011) for the duration of the 12 day experiment (median value of 2.43 ppm). Ammonia levels fluctuated widely at this site but at times reached levels greater than the concentration found to be toxic to at least *Paracalliope* and *Potamopyrgus* (Richardson *et al.,* 2001).

Laboratory studies testing the acute toxicity of ammonia on nine New Zealand invertebrate species have shown that invertebrates are more sensitive than fish, with the amphipod *Paracalliope* and snail *Potamopyrgus* the most sensitive and the shrimp *Paratya* one of the least sensitive invertebrate species. This pattern is interesting given that the two former species are commonly found in modified lowland streams and typically regarded as being less sensitive than 'cleanwater' EPT taxa. The laboratory-based toxicity sensitivity levels reflects well with our results, which showed the greatest effect on *Paracalliope* followed by *Potamopyrgus*, and little effect to *Paratya* survival.

If discharges occur for only a short period of time, animals can often tolerate a higher concentration of associated contaminants, but if these continue over time, their ability to cope is often reduced. For example, Hickey & Vickers (1994) found that the threshold toxicity (EC_{50}: the concentration at which 50% of organisms die) for *Paracalliope* decreased from 0.3 mg/l ammonia over 24 hours to 0.18 mg/l over 96 hours. Richardson (1997) found that the threshold toxicity (LC_{10}: the concentration as which 10% of organisms die) for adult *Paratya* decreased from 1.23 mg/l ammonia over 24 hours to 0.45 mg/l over 96 hours. Given the long duration of the sewage overflows into the Avon and Heathcote Rivers (over three months at the time of this report), it would be safe to assume that the tolerance of invertebrates would be at, or below, their lower known thresholds.

The ammonia levels at the downstream Avon River site fluctuated greatly over the 12 day experiment due to the sporadic discharge of raw sewage 150 m upstream, with a median value of 0.4 mg/l and a maximum value of 0.77 mg/l. Given that *Paratya* survival remained above 95% during the experiment it is unlikely that ammonia levels remained elevated for long enough during the experiment to have any lasting impact on them, and based on the literature (Richardson *et al.,* 2001) they are quite tolerant of the low dissolved oxygen levels of around 2 ppm (mg/l). In contrast the ammonia levels, in combination with the low dissolved oxygen levels, would have been sufficiently high to have impacted on the survival of the amphipod *Paracalliope*. The known ammonia toxicity levels for *Potamopyrgus* vary widely between laboratory tests (an EC_{50} over 24 hours of 0.32 mg/l to 0.5 mg/l of ammonia, depending on water pH; Hickey & Vickers, 1994), but it is possible that ammonia (in combination with the low dissolved oxygen levels) could have been responsible for the decreased survival of this snail at the Avon River downstream site; although at 10% the mortality level was still low.

Rutherford *et al.* (2011) produced a preliminary model of predicted dissolved oxygen and ammonia levels in the Avon and Heathcote River based on the estimated inputs of sewage several months after the February 2011 earthquake. Their conclusion was that ammonia levels would not become elevated enough to cause any problem to aquatic life, but that there could be some impact as a result of low dissolved oxygen levels. However, the results of our experiment combined with the results of published laboratory tests indicate that the invertebrate fauna are more likely being affected by a combination of both low dissolved oxygen levels and elevated ammonia. The modelling by Rutherford *et al.* (2011) also predicted dissolved oxygen levels fluctuating between 3 and 6 ppm in the Avon River by the Avondale Road bridge, which were higher than the actual levels recorded during our 12 day study (median value over the 12 days of 2.43 ppm at the Avon River downstream site); meaning that there could be a greater impact on aquatic fauna than what has been predicted via the preliminary modelling report.

With an observed effect at the downstream Avon River site on two out of three invertebrate species tested, it is safe to conclude that the sewage overflows are causing some die-off of invertebrate species. The higher inputs of sewage during the first few weeks of the earthquake (immediately following the February earthquake it was estimated at 34,758 m^3/day for the Avon River and 12,409 m^3/day for the Heathcote River) would have presumably created a more widespread die-off of invertebrate fauna. However, the lower inputs of sewage that are continuing to discharge into the Avon River two months after the February earthquake appear to be sufficient to continue to cause problems for the more sensitive invertebrates such as the amphipod *Paracalliope*. Some of the larger and more mobile species, such as *Paratya*, may elicit an avoidance behaviour in response to the low dissolved oxygen levels, moving up into tributary waterways unaffected by sewage inputs. This is anecdotally supported by higher densities of *Paratya* being observed at the nearby No 2 Drain (a tributary of the Avon River near Avondale Road bridge). The smaller invertebrate species such as *Paracalliope* and less mobile taxa such as snails will have less ability to move out of the impacted area, with downstream drift merely sending then downstream to where more sewage overflows occur.

While fish are less sensitive than invertebrates to elevated ammonia levels it is possible that the ongoing low dissolved oxygen levels (median value of 2.43 ppm in the Avon River at Avondale Road bridge) could be sufficient to kill some fish and cause ongoing stress for other species. Rutherford *et al.* (2011) cited a dissolved oxygen level of 3 ppm as being the acute threshold level for New Zealand fish, meaning that the median 2.43 ppm that we recorded in the lower Avon River would be sufficient to cause localised problems. Based on anecdotal accounts, the sewage inputs in the days following the earthquake may have been sufficient to cause problems for fish species, with fish die-off and avoidance behaviour (eels moving up the river banks to avoid the water) reported in the lower Heathcote River. However, with the lower levels of sewage now entering the rivers it is likely that the high mobility of fish will allow any remaining fish to move out of problem areas of the river. Of course fish and invertebrates remaining in the lower reaches of both rivers may well be exposed to chronic (sub-lethal) effects, with long-term impacts such as increased susceptibility to disease, impaired reproduction, and altered biotic interactions.

With the most recent 13 June 2011 earthquake the sewage inputs to the Heathcote and Avon Rivers has returned to similar levels as for the days following the 22 February earthquake (immediately following the June earthquake it was estimated at 29,315 m^3/day for the Avon River and 17,010 m^3/day for the Heathcote River). This will put additional stress on a system already stressed from months of sewage overflows. It may be wise to repeat the bioassay experiment during these higher sewage inputs to ascertain the impact of these higher inputs on the invertebrate fauna. An alternative would be to sample the fish and invertebrate community at points down the non-wadeable portion of the two rivers and at various dates; to determine the state of the community following the most recent earthquake and sewer overflow event and to ascertain when the community has recovered. Because we do not have any pre-earthquake data for the lower rivers the recovery of the community can only be determined through repeat sampling to show when community composition reaches a stable state.

Cages in clear water at the Avon River upstream site

Cages in murky water at the Avon River downstream site

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