Effects of Seismic Activity on Inaka spawning grounds on City Rivers

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Inaka eggs at the Avondale spawning site, April 2011, from clean (left), and silted (right) habitats

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1 Executive Summary

A survey of known inaka spawning habitats on the Avon, Heathcote, and Styx Rivers were undertaken in April and May 2011. The main objective was to establish if spawning was taking place, and the extent of damage caused by seismic activity following the September 4th 2010 earthquake. Damage to the spawning grounds on the rivers was variable, ranging from minor to severe, as outlined below.

The Lake Kate Sheppard habitat was severely damaged by the seismic activity, and requires re-contouring and replanting. Soft sediment on the bottom of the lake should also be removed if liquefaction silt has accumulated there. The inaka spawning site on Steamwharf Stream (Lower Heathcote) is also badly slumped, and the lower channel is no longer suitable for rearing inaka. The lower channel of this system needs to be narrowed and deepened.

The major inaka spawning site on the Avon River at Avondale appears to be in good order, and well managed in respect to suitable vegetation maintenance. However, weed control measures need to be maintained at this location, and precautions taken to ensure silt does not enter spawning vegetation. Weed control for yellow-flag iris, and if possible, for reed canary grass, needs to be extended to other Avon River sites at Amelia Rogers Reserve and Corsers Stream. Much of the Corsers Stream habitat was cordoned off at the time of the survey, and this remaining area needs to be re-evaluated, at least from a physical habitat perspective.

Moderate dredging of liquefaction silt from the lower main rivers is unlikely to have adverse impacts on inaka spawning provided that care is taken not to entrench the thalweg of the channel. Forming a deep gully down the centre of the river bed may cause the upstream limit of saline intrusion (i.e. the "saltwater wedge") to extend further upstream than before the September 4th event, which would influence the future longitudinal distribution of inaka spawning.

2 Objectives

The objectives of this brief field survey was:

"to record the current status of the inaka spawning grounds on the Avon and Heathcote rivers following the Feb 22 earthquake, and whether there has been any spawning activity/are any eggs present (Zoe Dewson, CCC Waterways Planner Ecologist, comm.. email 4th April 2011)."

However, after Feb 22nd, resources were available to investigate possible inaka spawning grounds on the lower Styx River. The effects of seismic activity on the Styx River spawning grounds was not the primary objective, but more towards locating additional inaka spawning grounds in the lower river, than what were already known.

3 Background

Inaka (*Galaxias maculatus*) is the adult lifestage of the most common species of whitebait. It spawns amongst tidally inundated vegetation in the lower reaches of the city rivers (Fig. 1). These locations would have been subject to organic pollution from sewage discharge, but also liquefaction silt either from overland flow across the banks or borne by stormwater discharge.

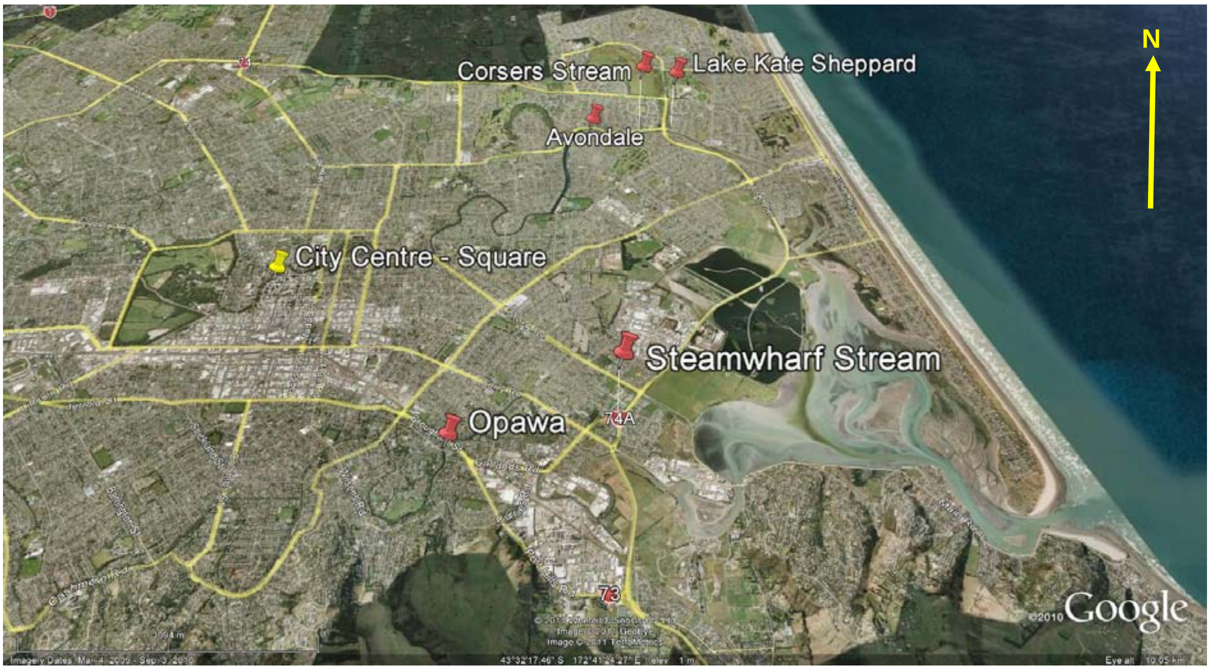

Figure 1. The 5 principal spawning habitats in Christchurch. The Opawa and Steamwharf Sites are on the mainstem of the Heathcote River, whereas the Avondale, Corsers Stream, and Lake Kate Sheppard sites are in the Avon River catchment.

4 Methods

4.1 Field methods

Field methods were similar to the many previous surveys on the City Rivers. The scope of field investigations was limited to surveying the known inaka spawning grounds within the Avon and Heathcote River catchments on two occasions. The field method was based on systematically checking known reaches, and approximately 2-3 m intervals, at middle to low tide to establish the distribution of inaka eggs. Photographs of features of seismic movement, liquefaction sediment, or other features of interest were geo-referenced with a GPS receiver. Survey dates are provided in Table 1. Mapping was undertaken with Google Earth. Kayaks were used to access reaches on the lower Styx River.

This work was also compromised by the timing of the work, being commissioned late in the inaka spawning season. A review of all known inaka spawning grounds in the South Island (Taylor *et al.* 1992), determined that most inaka spawning took place in the months of February to April, with limited spawning taking place as early as December, and as late as May. The timing in respect to peak spring tides is that spawning takes place on the successive spring tides following the full or new moon (Taylor *et al.* 1992), although the new moon spring tides in Canterbury are often weak.

Table 1. Survey dates and their relationship to lunar tide events.

Date	River	Survey Reach	Moon phase
11th April	Styx River	Reaches of interest downstream of tide gates	At low tide, 5 days after peak new moon tide (weak).
24th April	Styx River	Reaches of interest downstream of tide gates	Mid-tide, 5 days after peak full moon tide.
27th April	Avon River	Avondale, Lake Kate Sheppard	Low tide, 8 days after peak full moon tide.
28th April	Heathcote River	Opawa Bridge, Steamwharf Stream, Woolston Park	Low tide, 9 days after peak full moon tide.
18th May	Heathcote River	Opawa Bridge	Mid tide, 1 day after peak full moon tide.
18th May	Avon River	Amelia Rogers Reserve	Mid tide, 1 day after peak full moon tide.

5 Results

5.1 Heathcote River

5.1.1 Opawa (28th April)

No eggs were recorded from this site (Fig. 2) The banks were heavily dominated by a luxuriant sward of reed canary grass (*Phalaris arundinacea)* that extended out over the water surface as a raft. At low to mid-tide a conspicuous zone of aquatic macrophytes (dominated by P. crispus) bordered the spawning habitat, but this was overtopped during higher tides when the inaka spawn (Figs. 3 a,b). There was a conspicuous silt coating which smothered the root mat microhabitat for inaka eggs (Fig. 4), but this silt coating was absent during previous surveys at this site (Fig. 5). The silt coating had a distinct demarcation at the high tide level, which suggested the silt was water borne, rather than being transported across the banks, at least at this site, as overland flow.

There were no apparent longitudinal cracks along the banks, and we have no data to indicate how much the banks had dropped vertically, although the roads in the vicinity had some distinct dips.

Figure 2. Opawa Inaka Spawning site. Green pins = inaka egg masses logged in March 2004, red pins= negative egg searches in April 2011. Pins represent field waypoints.

Figure 3a. The Opawa inaka spawning site at mid-tide. A thick raft of canary reed grass extends out across the water surface, and into the intertidal zone.

Figure 3b. The Opawa inaka spawning site at high spring tide (15/5/11; 4:00 pm). The raft of canary reed grass tends to float over the water surface.

POST EARTHQUAKE – WOOLSTON PARK INAKA SPAWNING SITE- 28/4/11

Figure 4. The silty microhabitat at the former Opawa inaka spawning site (28/4/11).

Figure 5. Cleaner microhabitat in 2004, when the site was well utilised (19/04/04).

5.1.2 Woolston Park

This site is 960 m downstream of the former inaka spawning site at Opawa Bridge, and is a short 12 m reach. The habitat is not (yet) dominated by reed canary grass. Inaka eggs were positively identified from this site in April 2010, but during our recent visit (28/4/11) no inaka eggs were found at this small site. The current vegetation is composed of monkey musk, a soft herb, and twitch grass, both of which provide suitable microhabitats for inaka egg development. Comparing photographs from last year, it would appear the bank has slumped at this location, and the spring tide level encroached over the toe in 2012, and onto the mown esplanade strip (Fig. 6a). That was not the case in 2011, when the spring tides were well down the bank, and inaka eggs distributed below the bank toe in longer grass (Fig. 7a).

The inaka spawning microhabitat, and the intertidal zone generally, was markedly more silty in 2012 (Figs. 6b, 6c), than in the previous year (Figs. 7a, b).

POST EARTHQUAKE WOOLSTON PARK – 28/4/11

Figure 6a. The silty intertidal zone on the lower Heathcote river (28/4/11). The tidal limit was over the bank toe here.

Figure 6b. The thick silt covering the intertidal zone at the Woolston Park site.

Figure 5c. Silt covered foiliage at the Woolston Park inaka spawning site (28/4/11)

PRE EARTHQUAKE – WOOLSTON PARK INAKA SPAWING SITE (23/4/2010)

Figure 7a. Clean intertidal zone in 2010. Flags indicate inaka egg masses in longer grass well below the bank toe.

Figure 7b. Inaka egg mass amongst clean root hair mat at Woolston Park site in 2010. One of the many eggs present is arrowed.

5.1.3 Steamwharf Stream

No inaka eggs were found at the Steamwharf Stream inaka site, and the banks appeared to have slumped, and in places collapsed (Figs. 8 a, b). A thin distribution of eggs were found in March 2004 amongst a community of introduced and native vegetation, but no inaka eggs were found during the most recent check in April 2007 (Fig. 8c). The condition of the habitat when many eggs were found, are presented in Figs. 9a-c.

POST EARTHQUAKE – STEAMWHARF STREAM (28/4/11)

Figure 8a. The bed of Steamwharf Stream appeared silted more than normal, and the banks appeared slumped. Looking upstream from Dyers Road. Flags indicate 9 spot egg searches.

Figure 8b. Steamwharf Stream, looking downstream at Dyers Road. The disruption to the bed is evident here with flaxes on the banks slumped and collapsed into the channel.

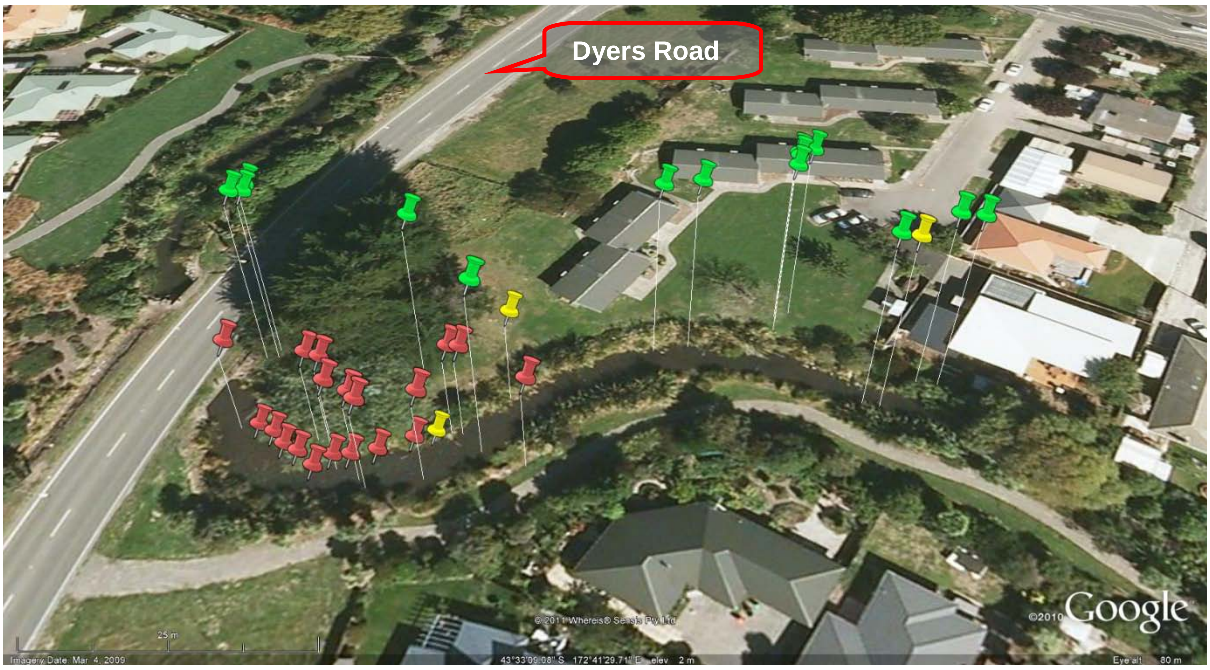

Figure 8c. Green pins (highest elevation) = inaka egg masses located in March 2004. Elevated red pins = negative egg searches in April 2007, grounded red pins=negative egg searches in April 2011. Yellow pins = upstream limit of surveys, downstream limit = Dyers Road culvert.

PRE-EARTHQUAKE CONDITION OF STEAMWHARF STREAM

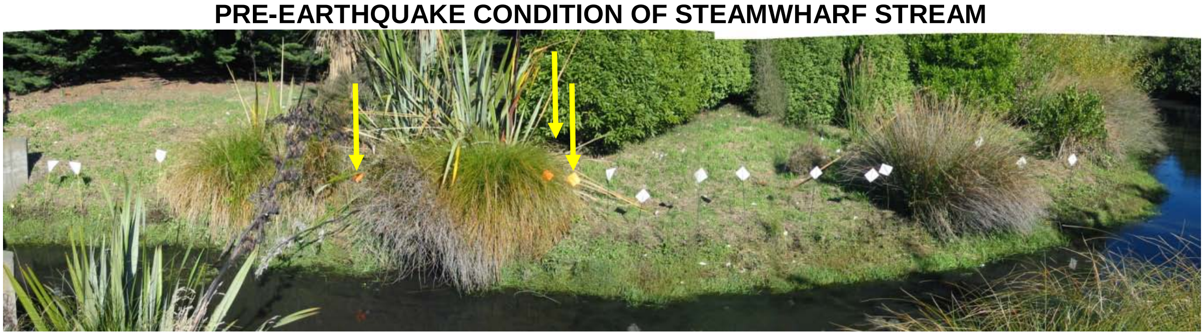
Figure 9a. Inaka egg masses at the downstream limit of their distribution in 2004.


Figure 9b. Close-up of the inaka spawning environment in March 2004.


Figure 9c. Three egg deposits amongst creeping buttercup, tall fescue, and dandelion, bordered by water-emergent *Juncus pallidus*, and flax and tall fescue (March 2004).

5.2 Avon River

5.2.1 Avondale

The Avondale spawning site on the Avon River is an extensive spawning ground which remains as one of the largest mapped spawning habitats in New Zealand, with a limited distribution of eggs first found here in April 1989 (Taylor 2002; Taylor *et al.* 1992). The distribution in 2007 extended from Sharlick Street to the Avondale Bridge, a distance of approximately 770 m (Fig. 10). In addition, inaka eggs have also been found in suitable habitats downstream of the Avondale Bridge in the vicinity of the Amelia Rogers Jetty (Fig. 10, red-ringed at bottom right).

Figure 10. Three years of survey: 2004 (highest elevation), 2007 (intermediate elevation), 2011 (ground level, and ringed). Yellow pins = limit of survey. Icons for negative egg searches have been suppressed for clarity. Yellow arrow indicates north. Imagery date is 2009.

The Avondale inaka spawning site possessed many deep cracks parallel to the banks, an artefact of the seismically-related phenomenon called lateral spread, with a particularly severe example illustrated below (Fig. 11a). Such regions could be stabilised by re-grading the slope to a shallower angle, and re-sown in grass. It was also clear from the road edge that the bank had probably buckled significantly in a vertical plane, although that was not obvious from our cursory field survey away from the roadside. In most locations along the reach, there is sufficient elevation in the managed habitat to accommodate some bank slump. Over a short distance, where eggs have been located during previous surveys, we identified two egg nests, one from a relatively clean microhabitat (Figs. 11b, 11c), and the other from a more silted environment (Figs. 12a, b). The silted eggs and microhabitat were down slope of the deep ground cracks, and the roadside. Both road runoff and silt boils were potential sources of liquefaction silt. All eggs, including those covered in silt had clear yolks, and had "eyed", a developmental stage. There was no indication of fungal infection which can occur with physical disruption.

Figure 11a. The deep cracks formed by a bank section suffering particularly severe lateral spread at the Avondale site.

Figure 11b. A 'clean' inaka spawning habitat, with tall fescue grasses, with *Hebe* shrubs further upslope. The microhabitat photo is provided in Fig. 9c.

Figure 11c. Inaka eggs from the clean Avondale microhabitat (*in situ*). One of the many eggs is arrowed. Egg diameter is c. 1 mm life size.

Figure 12a. The yellow flag (arrowed) indicates the habitat of a silty inaka nest, with upslope ground cracks indicated in yellow, obscured by the grass These were mapped seperately, using the marker sticks and were about 0.5 m deep.

Figure 12b. Inaka eggs *(in situ)* from a silted Avondale microhabitat. Egg diameter is 1 mm. These eggs are viable.

5.2.2 Lake Kate Sheppard

Lake Kate Sheppard is a constructed wetland which provides an ecological corridor to the Travis wetland. An earlier report in 1996, prior to the development of the corridor from Barkers Drain, predicted that the lower ecological corridor would become important for inaka spawning given suitable vegetation and fish access (Taylor 1996). With gradual maturation of the riparian flora the microhabitat was regarded as suitable for inaka egg development in April 2004 (Taylor 2004). In March 2006, a University of Canterbury study found inaka eggs along this shore, but mostly north of the wooden jetty, and with high egg densities (up to 4000/100 cm^2) (M. Hickford, pers. comm.). The CCC-commissioned survey in 2007 (Taylor & Chapman 2007), mapped inaka eggs and found them largely south of the jetty, and around the other side of the outlet (elevated pins in Fig. 13).

Figure 13. Elevated April 2007 waypoints illustrating the egg masses (green pins) located around Kate Sheppard. Yellow pins = survey endpoints. Grounded pins = negative egg search in May 2011.

Post-earthquake, no inaka eggs were found from the disrupted habitat, and the locations were inaka eggs were located in 2007 were largely buried in silt (Fig. 14a). Most of the riparian vegetation in 2011 was either not visible, presumably buried in silt, or those that were visible were flattened, or beginning to wilt. By way of comparison, a 2007 photograph of essentially the same vista is provided in Fig. 14b. Scraping back the coarse liquefaction silt revealed the original soil level and root hair matrix which forms the inaka egg microhabitat. The mean depth of the silt was about 10 cm (Fig. 15), but the depth varied spatially, and was up to 30 cm in some areas. Lateral spread and uplift was evident in the periphery around the southern lake edge (Fig. 16).

Figure 14a. The former inaka spawning reach south of the jetty, May 2011.

Figure 14b. The inaka spawning ground around the periphery of Lake Kate Sheppard (19 April 2007), egg masses were located below the arrows. This is essentially the same habitat as depicted in Fig. 12a.

Figure 15. At this location, the original soil level, and grass root hair matrix, has been buried under about 10 cm of liquefaction silt.

Figure 16. Both lateral spread and uplift on the eastern site of Lake Kate Sheppard. However, the esplanade has also been subject to compaction by heavy-construction vehicles.

5.2.3 Corsers Stream

The new section was cordoned off at the time of the survey, presumably for safety reasons concerning the access bridging. For this reason the new section was not surveyed, although the section appeared to have been exposed to significant liquefaction.

However, a mature remnant of the original spawning habitat downstream of the New Brighton Road culvert was checked to the confluence with the new spawning habitat. Similar to Lake Kate Sheppard, liquefaction silt within the mature bank vegetation was evident here up to a depth of 3 cm, and a conspicuous layer of silt covered the intertidal vegetation. Some of the mature vegetation had been cleared for the recent landscaping, and a significant section of the bank had also been lost to form the new channel mouth (Fig. 17, arrowed).

Figure 17. The remnant of the inaka spawning habitat on Corsers Stream. The recent landscaping for the new section of the habitat has compromised the grassy sward in the short term. The new outlet area has been subject to liquefaction. The double-arrowed section indicates the length of mature spawning habitat lost to form the new mouth.

5.2.4 **Amelia Rogers Reserve**

In May 2011, some seismic movement was indicated by deep wide cracks near Avonside Drive, a side effect of lateral spread, and the piles of the jetty were off vertical. Approximately a dozen egg searches through the intertidal zone were undertaken, all negative. Reed canary grass is becoming more prevalent at this site, but not yet at the density as at the Opawa spawning site. At the time of the survey, the reed canary grass stand was browning off, prior to winter (Fig. 18). A low sward of creeping buttercup (*Ranunculus repens*) was also present, which is associated with suitable inaka microhabitat (Fig. 19). Upon inspection, the potential inaka spawning microhabitat appeared clean of liquefaction silt, and numbers of snail eggs were found at this location, indicatory of humid conditions (Fig. 20).

Figure 18. Negative egg searches (white makers) around the Amelia Rogers jetty.

Figure 19. A sward of creeping buttercup around the bases of Carex, and reed canary grass

Figure 20. The microhabitat at the Amelia Rogers jetty was clear of silt. Note the deposition of creamy white snail eggs in this photo, which are about 5 mm in diameter, too large to be confused with the 1mm inaka eggs. The GPS receiver is 110 mm high.

5.3 Styx River downstream of the tide gates

Seismic effects on the inaka spawning grounds on the Styx River were not part of the scope of the city river study, but are included here to complement the information from the other rivers. Environment Canterbury requested assistance with evaluating a possible inaka spawning site downstream of the tide gates (Dr Philip Grove, ECan scientist, pers. comm.), an extensive brackish wetland which is largely a salt marsh. The basis for suspecting a particular area may be suitable for inaka spawning was that there was a localised botanical zonation which suggested a freshwater interface, or at least a zone of reduced salinity. Inaka are known to spawn near the interface between saline and freshwaters (Burnet 1965; Taylor *et al.* 1992). The waterways of interest were composed of two tidal feeding tributaries to the mainstem of the Styx River (Fig. 21).

The southern channel, Channel 1, was investigated first. In this branch the riparian vegetation was composed of spike rush (*Eleocharis acuta*), jointed wire rush (*Leptocarpus similus*), and three square (*Schoenoplectus pungene*) common inhabitant of salt marsh, but with the common grass tall fescue well above the low tide level (Fig. 22). Further upstream, the channel appeared to diffuse into a raupo wetland (*Typha orientalis*)(Fig. 23). The draining channel on the low and ebbing tide was narrow (c. 1m), shallow (c 5 cm), and fast flowing. No inaka were observed in this channel.

The northern channel (Channel 2) was more substantial in respect to width and depth variation, and inaka shoals, composed of hundreds of fish, were observed, particularly in the deeper pools. Approaching the northern tip of the channel, the vegetation changed from salt marsh type vegetation to swards of the grass creeping bent (*Agrostis stolonifera*) and tall fescue (*Schedonorus phoenix*) (Figs. 24, 25).

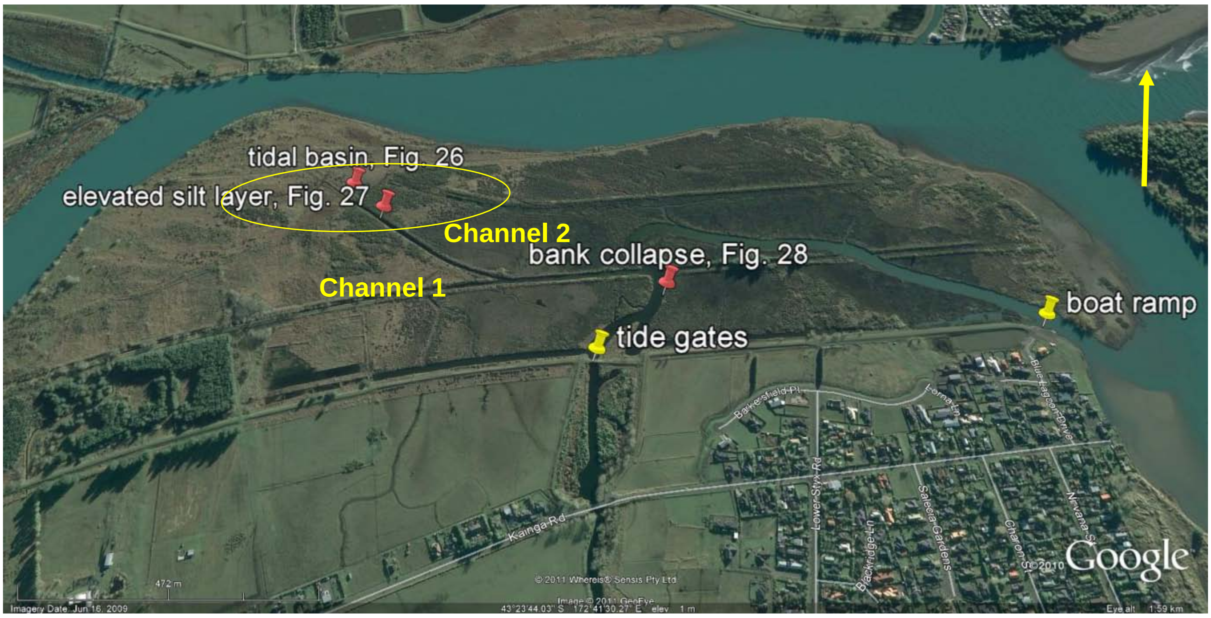

Figure 21. The location of suspected inaka spawning habitat on the lower Styx River (ringed). North arrow indicated.

Figure 22. Southern channel, with stands of tall fescue with gorse in the background. The feeding channel was shallow and fast flowing on the low and ebbing tide.

Figure 23. Near the terminus of the southern channel the riparian flora was dominated by raupo.

Figure 24. Northern channel with a riparian zone composed of creeping bent and tall fescue.

Figure 25. Northern channel, with high terraces composed of dense stands of tall fescue, adjacent to a deep pool with inaka.

A second visit to the northern channel of the lower Styx River was undertaken on a falling high tide after the April springs (i.e. 24/4/11). Of interest was that a large shallow tidal basin (Fig. 24), which included inaka, was discharging into the channel. The conductivity of this water was 6.3 mS/cm, and at 15.8 ^{o}C. However, a search around the periphery of the tidal basin failed to locate inaka eggs.

Figure 26. A shallow tidal wetland contained schools of inaka.

Noted along the channel intertidal zone, was that a layer of silt was suspended several centimetres above the root hair mat, and this layer was supported by the stems of surrounding rushes and grasses (Figs. 27, 28). Around this location, about 125 m downstream of the tidal basin, the conductivity had increased to 8.2 mS/cm, 16.7 ^{o}C, and the root-hair complex was unsuitably (for inaka spawning) muddy and wet. It was also noticed that at a location in the main channel, a long (c. 100 m) section of the bank has collapsed, and from its jagged-edge appearance, quite recently (Fig. 29). The conductivity here was much lower (1.1 mS/cm, 15.9 ^{o}C), and lower again (0.27 mS/cm, 16.4 ^{o}C), at the tidegates.

Figure 27. The unusual layer of silt suspended above ground level.

Figure 28. The unusual layer of silt suspended above the root-hair mat.

Figure 29. A large section of bank of the lower Styx River appears to have collapsed recently. There is no stock in the area, nor walking tracks.

6 Discussion

6.1 Effects of seismic activity on inaka

6.1.1 Increase in river level for inaka spawning

The general seasonality of the main seismic events (September and the following February) is of significance to inaka. September coincides with the inaka whitebait run (McDowall & Eldon 1980), and February falls within the inaka spawning period, both nationally and locally (Burnet 1965; Taylor *et al.* 1992).

The impacts of the major seismic event on September 4th, during the whitebait run, can be seen in the flow record for the Heathcote River (Fig. 30). Several weeks before the first earthquake, river, turbidity and SS levels were high at Opawa Road, with a turbidity level of 150 NTU/150mg/L (9th August 2010). After the Sept 4th earthquake, TSS levels remained slightly elevated, but no higher than levels recorded the previous year. Heathcote baseflow river levels and turbidity (at Opawa Road) remained slightly elevated after the 2010 winter and September 4th earthquake, and this effect may have been exacerbated by the aftershock sequences. Summer 2010/11 flow levels remained elevated (10.6-10.7 m RL) compared to the pre-earthquake summer 2009/10 levels (10.5-10.6), and the same is true with the TSS level. After the Feb 22nd event, baseflow levels and turbidity remained slightly elevated in the Heathcote River until 15 February 2011, but not at an ecologically significant level. The lack of weed harvesting in the lower Heathcote over the 2011 summer (Owen Southen, pers. comm., CCC) probably explains the gradual rise in baseflow level. The impact of weed harvesting on baseflow levels can be seen in the flow record prior to the earthquake, and is manifested by a sudden drop in level of about 0.2 m. Therefore, there is no indication of water level increase that can be solely attributed to seismic activity.

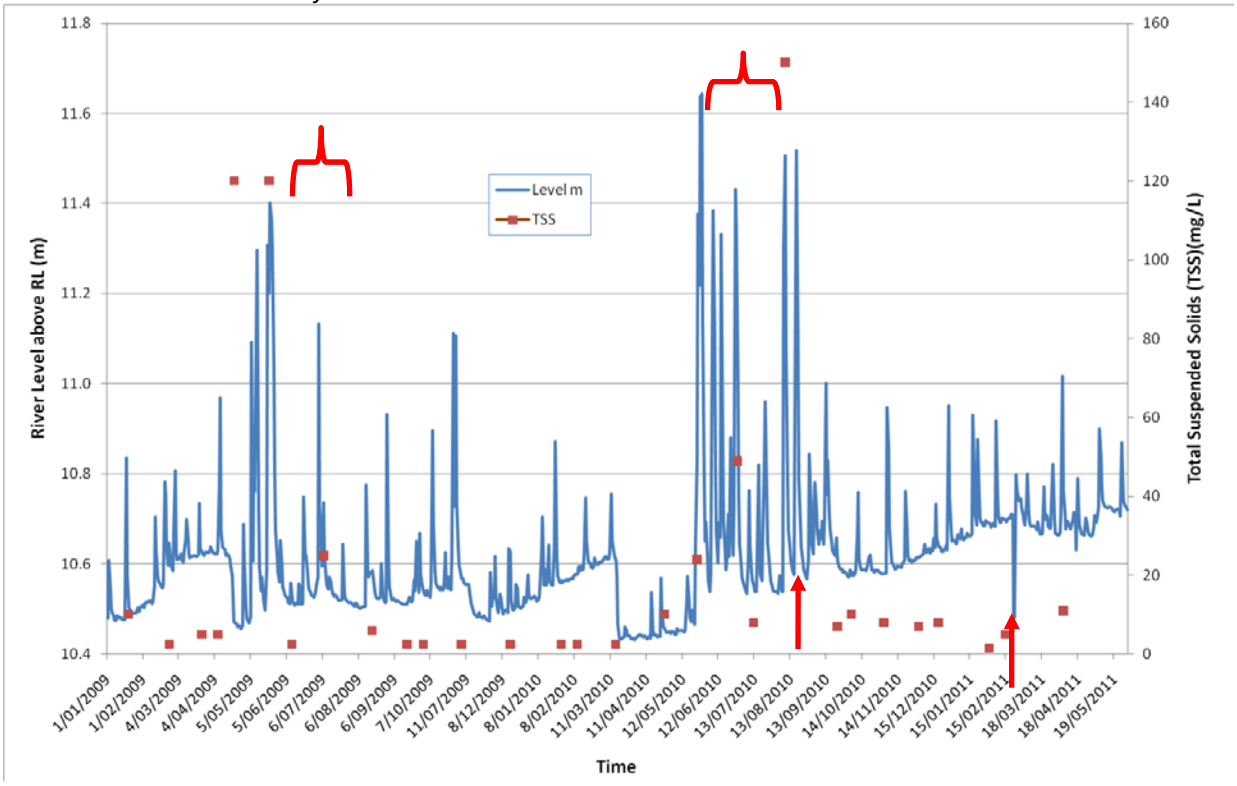

Figure 30. Monthly spot TSS records (red icons) and daily river level (blue line) from the Heathcote River from 1st January 2009 to 19th May 2011. Major earthquake events are arrowed, and winter high flows are bracketed. The significant down-spike in the river level record coincided with the Feb 22nd earthquake and is probably an anomaly. The Jan-April 2011 data is still provisional.

However, in the Avon River dataset, seismic activity is more apparent in the data record, and the generally much lower TSS levels as recorded at Gayhurst Road (Fig. 31). After the Sept 4th earthquake, a high turbidity level is recorded at Gayhurst Road on the 21st September (6 mg/L), but TSS levels drop back to negligible levels by mid-November. However, after the Feb 22nd 2011 event, turbidity levels increased as did the baseflow river levels from RL. However, it is unknown if this is because the level recorder device has sunk in relation to the RL, or whether it is due to general bed rise, or the deposition of sedimentation silt.

Whatever the cause of the increase in river level, this is likely to mean spring tide levels will be potentially higher in relation to banks, than those recorded prior to the seismic activity; especially if the banks have sunk in relation to RL. The relative river level rise would have ecological significance for some inaka spawning habitats, especially on banks of low gradient, because a vertical rise of 20 cm could shift the intertidal zone of inaka deposition about a metre away from the rivers in some locations (i.e. where bank angle c. 20%). Potentially, this could place inaka egg deposition zones into vegetation not suitable for inaka spawning, or into the esplanade grass sward which is regularly mowed by the C.C.C.

However, displacement of the inaka egg zone higher up the bank into the mowing strip is unlikely to be a problem at the Avondale site because there remains a significant swathe of suitable grass up gradient of the spring tide level. It would appear that the clean viable inaka egg mass we found was higher up the bank compared to the egg distribution from 2004 (Fig. 32). The second egg mass is too difficult to place accurately on the 2004 photo.

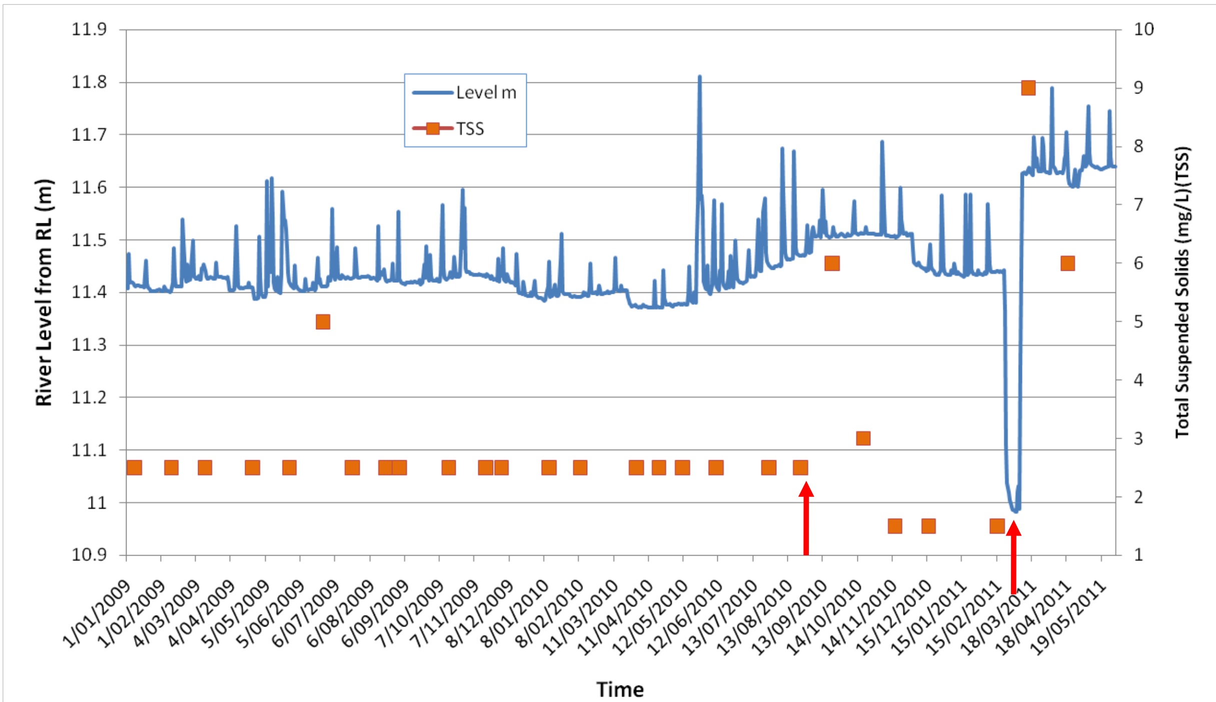

Figure 31. Monthly TSS spot records (red icons, Gayhurst Road) and daily river level (blue line) from the Avon River from 1st January 2009 to 19th May 2011. Major earthquake events are arrowed, and winter high flows are bracketed. The significant down-spike in the river level record coincided with the Feb 22nd earthquake and is probably an anomaly. The Jan-April 2011 data is still provisional.

Figure 32. The line of inaka eggs deposited in April 2004 (red arrows), vs. the approximate location of where eggs were found in May 2011 (yellow arrow).

6.1.2 Increase in turbidity for inaka whitebait immigration and inaka feeding

As mentioned above, the two major seismic events fell during the inaka whitebait season, and the spawning season, and as the turbidity record demonstrates, both rivers over the summer were subject to higher than normal levels of baseflow turbidity.

However, it has been demonstrated that inaka whitebait have a low sensitivity to suspended sediment, with 50% avoidance only at 420 NTU (Waahi silt)(Boubee *et al.* 1997). This level of sensitivity to turbid water is high compared to Avon and Heathcote River values. By order of comparison a rain-induced TSS of 150 mg/L in the Heathcote was 150 NTU on 9/8/11, and sustained levels following the earthquakes were much lower than this in both rivers. It is considered, at the time of writing, that sustained turbidity levels factor alone would not be detrimental to the whitebait run. However a range of contaminants were being discharged into the rivers (e.g. a mixture of sewage contaminants, ammonia), and the effect of these on the whitebait run is unknown.

Some fresh-run whitebait were caught in the lower Heathcote River near Opawa Road during regular monitoring work in early February before the earthquake (AEL raw data). Inaka whitebait do run outside of the whitebait season, and this lack of migration seasonality it thought to reduce the species vulnerability from extermination, both from both natural perturbations, and fishing pressure from whitebaiters.

However, juvenile and adult inaka are visual feeders, and increased turbidity decreases their feeding ability, although again, not at a sensitivity where the available river turbidity data would suggest a problem. In an experimental setting, juvenile inaka (mean length c 46 mm) demonstrated a sharp drop in feeding rate when turbidity exceeded 320 NTU (Rowe & Dean 1998). For adult inaka the feeding rate only declined when turbidity exceeded 160 NTU (Rowe *et al.* 2002).

6.1.3 Effects of sedimentation on spawning grounds and spawning activity

It was apparent from this study that several perceptible impacts were occurring at the spawning grounds, of which some, but not all, were due to seismic activity. The impacts, or effects, of separate seismic events cannot be distinguished from each other, as we have no data directly before, or between the sequence of earthquakes or aftershocks. However, based on our experience, and our knowledge of these sites, it would appear that the Heathcote River sites, in particular, are more silty than previously recorded, and silt levels are likely to be caused, or exacerbated, by seismic activity.

The typical inaka spawning microhabitat is often relatively free of conspicuous silt on surrounding foliage, and the discovery of habitats with silt-covered eggs are rare. The observation of silt-covered eggs at the Avondale site is therefore an unusual event. Inaka eggs have an adhesive outer surface (Benzie 1968a) which become coated in silt particles if suspended silt levels are high. At the levels we observed at Avondale, it would appear that egg development is not jeopardised, but a heavy coating of sediment may suffocate the eggs.

There is some information to suggest that heavily sedimented sites are avoided by spawning inaka. None of the spawning habitats listed on the National Inaka Spawning Database (NISD) were regarded as silty, but the database records that on the Shag River, in Otago, the habitat was subject to siltation from January 1997 floods, but the site was re-utilised by April. In the North Island, an embayment on the Awatere River was totally buried in flood silt, and was thereby abandoned by spawning fish. Thus, a degree of siltation, where a thin layer of sediment coats the grass root matrix, may make the habitat unattractive for spawning, but this degree of sedimentation is reversible, and the habitat reutilised. Clearly, this is distinct from the scenario where a thick layer of silt buries the eggs, as it is likely to have occurred to a significant number of the inaka eggs in the lakeside grasses at Lake Kate Sheppard.

In summary, all sedimentation is probably adverse for inaka spawning. Heavy sedimentation dooms the habitat for as long as the sediment remains trapped amongst the intertidal vegetation, and these sites are not utilised for inaka spawning. Light dustings of silt may render the site unattractive for inaka spawning, but eggs which possess a light covering of silt do appear, evidently, to have remained viable. However, buried eggs, a likely scenario at Lake Kate Sheppard, would have perished, even if suffocation didn’t take place, because the larvae would not be able to hatch.

A final point is that inanga larvae recruitment from the Avondale spawning ground, and Canterbury Rivers not affected by the earthquakes will yield whitebait which could potentially enter the Heathcote River and other rivers next spring. There is no scientific evidence that inaka home back to the natal stream, and this allows specific rivers to recolonise from neighbouring ones during major perturbations.

6.2 Management and remediation: Heathcote River

Opawa

Earthquake mediated silt has caused a thin coating of silt at this site, and this is probably sufficient to deter inaka from spawning. However, the thick floating raft of reed canary grass is likely to deny the spawning shoals access to this site in any case, and inaka do not appear to favour this grass. Thus, the deleterious impact of seismic activity on this spawning ground has been predated by weed invasion. The reason for the unsuitability of this grass may be at least partly due to its excessively luxuriant growth habit. Given that inaka is a communal spawning fish, and the hatched larvae have to gain access to open river water to reach the sea, the spawning behaviour of the adult inaka may be adapted to ensure shoals have reasonably easy access from open water to the egg microhabitat during the flood tides. North Island studies indicated that even suitable *Festuca* grass sites, if not managed by mowing or periodic grazing, become too rank, and the sites are abandoned by the spawning shoals (Mitchell 1990). This is why it is recommended that urban grassy spawning sites are mown in early summer (December), for example at the Avondale spawning site. In addition to controlling woody adventives, it prevents the grasses from becoming too thick.

Originally, the design was based on a two embayments, one planted in native rushes, and the other with introduced grasses (tall fescue, Yorkshire fog, creeping Jenny), and was sown in 1996. Inaka spawning commenced in 1998, and reached in a peak in 1999 with egg distribution extending downstream. However, the site was never mown or maintained. By 2000, woody saplings and reed canary *grass* invasion was apparent, and by 2004, inaka egg distribution was patchy. In 2007 the site was totally dominated by reed canary grass and no eggs were found, and this was the case this year.

It is recommended that the Opawa spawning site be regraded and replanted, although this is not a by-product of the adverse effects of earthquake effects, but a necessity caused by plant community succession. The original landscape planting strategy worked well, and the site was well utilised, until the lack of weed control became an issue. Therefore, in terms of management, weed control is critical at this site. We are unaware of herbicide sprays that would selectively kill reed canary grass but leave other suitable grasses (Tall fescue, Yorkshire fog etc.). Hand weeding unsuitable adventives from the site prior to the spawning season may be a good option at this site, especially if reed canary grass can be controlled to a manageable level where it does not dominate the intertidal zone, or form rafts over the water surface.

Woolston Park

The inter-tidal vegetation of this small site was coated with fine silt, which appeared to be sourced from river flows. There is no deep sediment at this site, and no requirement to excavate. It is expected that grasses will self-cleanse during river freshes.

The Woolston Park site is a short distance downstream of the Opawa Bridge site and remains relatively free of reed canary grass, although the habitat was heavily silted compared to last year (Fig 5a cf 5b). The apparent difference in spring tide height this year was probably due to bank slump and slightly higher preceding spring tides.

The Woolston Park site remains one of the few habitats which provides inaka good access into suitable spawning intertidal vegetation. Owing to its small size, such habitats could be effectively managed by hand weeding unsuitable vegetation, for example reed canary grass, from the spawning zone

Steamwharf Stream

Inaka spawning was first recorded from Steamwharf Stream in 1999 (Taylor 1999), three years after the waterway was converted from a boxed drain. While the habitat had never been modified to enhance its potential for spawning, inaka eggs had been reported over a significant distance (70 m) the true right bank (Taylor 2004). Due to gradual sedimentation of the bed, the habitat now looks insufficiently deep to support a resident adult inaka population, which were once abundant in this tributary. Therefore, I suspect that the decrease in utilisation of the spawning habitat may be linked to the lack of adult habitat. Given the large scale physical damage to the site due to the earthquake, I would recommend that the bed be dredged, the banks consolidated, and the channel narrowed. The beds of tall *Juncus pallidus* at this location were well suited for inaka, and these could also be replanted. Physical habitat restoration for adult inaka has been previously described, but include a minimum water depth of 0.4 m, and a 50/50 mixture of open water and macrophyte beds (Richardson & Taylor 2002).

6.3 Management and remediation: Avon River

Avondale

In the case of the Avondale site, it is quite likely that at the time of the February 22nd event, inaka eggs would have been in the grasses, and subject to the high suspended silt levels during the high tides which followed. Silt binds to the eggs as they have an adhesive layer which allows the eggs to adhere to the intertidal vegetation (Benzie 1968a). The eggs that we recorded were likely to have been deposited after the February earthquake; this is known because the rate of inaka egg development at the Avondale site, as a function of microhabitat temperature, has been determined at this site (Taylor 1998). What few eggs were found, while subject to some siltation, appeared viable. Dead eggs are conspicuous even in the field, as they become opaque. The inaka egg shell is effective at preventing fungal and bacterial attack, but physical disrupted eggs are prone to infection (Benzie 1968b). While it likely that these eggs were deposited after the Feb 22nd earthquake, it would appear ongoing aftershocks have not severely compromised the quality of this important habitat.

However, there is a possibility that inaka eggs exposed to sediment during the Feb 22nd earthquake may have been killed on following high tides. In recent years, the Avondale inaka spawning site has been subject to invasion from yellow-flag iris (*Iris pseudacorus*) which is detrimental to the inaka spawning microhabitat by shading out the sward forming soft herbs and grasses (Taylor & Chapman 2007). The growth of this weed has been controlled at this site by spraying, and much of the soft herbs and grasses associated with inaka spawning have since returned. It was noted that the egg mass and foliage that was heavily coated in silt had no intervening shrubbery between the roading and the eggs, and the grass esplanade upslope was deeply cracked. We considered it possible that liquefaction silt, sourced from the roadside or ground cracks had been transported by rain downslope into the spawning habitat. In contrast, the eggs which were not coated in silt were found in the grass near the bases of the planted native shrubs (Hebes).

However, generally the Avondale inaka spawning site appeared to be satisfactory condition, and the vegetation and physical habitat looks suitable for inaka spawning. Should road or footpath reconstruction be necessary, then the precaution of a riparian fence should be installed between the habitat and the construction zone.

Corsers Stream and Amelia Rogers Reserve (jetty area)

The original Corsers Stream habitat had some liquefaction silt present, but given the short reach surveyed, it may not be ecologically worthwhile to remove it. However, apparently a thick layer of liquefaction silt has been deposited in the new inaka spawning reach of Corsers Stream, and this should be removed if possible. Options for any possible remediation measures of the new inaka spawning habitat could be considered when the new area is accessible.

The immediate area around the Amelia Rogers Reserve jetty has was proven to be a significant inaka spawning ground in the past (Taylor 2004), but appeared to less utilised by 2007 (Taylor & Chapman 2007). This may be due to encroaching dominance of reed canary grass at this site. However, this site is upstream from the Travis Wetland outlets, and is somewhat protected for road runoff by thick vegetation. These factors may protect the habitat from ingress of silt. While no inaka eggs were found, a number of snail eggs were found, where suggests a moist microhabitat is available. There is no need to remediate this site in terms of the effects of seismic activity, although control of the reed canary grass would be recommended, possibly by hand-weeding.

Lake Kate Sheppard

In contrast to the Avondale site, the Lake Kate Sheppard habitat has been badly damaged, and buried in silt to a variable depth. It is expected that the basin of the lake has also proved to serve as a sediment trap for silt transported downstream from the Travis Wetland catchment. The removal of as much silt as possible from the intertidal zone is recommended, because, while vegetation will grow through the silt over time, the development of a humid microhabitat would take a considerable period of time to develop. This is because the silt is coarse, and its moisture retention is low, and inaka eggs are not found in sandy soils which lack a humid microhabitat, but rather loam soils with a mixture of mineral and organic content. Field testing has demonstrated that in suitable microhabitats humidity near 100% can be retained near the egg masses even when the open-air ambient humidity is as low as 20% (Taylor 1998).

Many of the remaining flaxes and shrubs appeared to be in ill health probably due to root disruption. The best option may be to re-grade the periphery of this wetland habitat and replace the flaxes, cabbage trees, soft sedges and grasses with new specimens. Regrading and replanting would be an opportune time to remove the yellow-flag iris which was beginning to gain a foothold at this locality.

Removal of liquefaction silt from the basin of Lake Kate Sheppard is also recommended so that habitat depth is retained for adult inaka that are likely to rear there, or at least congregate in shoals prior to spawning. Draining the pond may be a good option during late summer when groundwater levels are low. The wetland may serve as a breeding habitat for rudd, an illegally introduced pest fish in the Travis Wetland sub-catchment. These can be removed as part of the dewatering process.

6.4 Impacts of silt removal on inaka spawning

The sensitivity of inaka spawning to saline/freshwater interfaces has been demonstrated in the Heathcote River when the Woolston Cut was first commissioned. When the Woolston Cut was operative, inaka spawned further upstream near the Wilsons Road bridge, as reported in 1989 (Eldon *et al.* 1989). The Woolston Cut was decommissioned in 1994, and inaka spawning then took place further downstream at the Opawa Road bridge in 1995, a distance approximately 3.2 km from the Wilsons Raod site (Taylor 1995). The 3.2 km downstream shift in inaka spawning is the same length of river channel that was cut off by the Woolston Cut when it was in continuous operation. It is suspected that the downstream movement of inaka spawning in the Heathcote after the Woolston Cut was decommissioned is because the saltwater wedge (the tongue of saline or brackish water which follows the mid-channel of the river upstream) also retreated a similar distance downstream.

If silt has built up in the reaches downstream of Avondale Bridge on the Avon River, and downstream of the Opawa Bridge on the Heathcote River, then this could adversely affect inaka spawning by inducing inaka to spawn further downstream, because the saltwater wedge would terminate closer to the estuary. This may place the fish in an environment where the biotic conditions (e.g. riparian vegetation, bank slope) are unsuitable for spawning. Further, the build-up of bottom silts, in addition to bank slump, may mean that spring tide levels overtop the bank crests, and inaka eggs may be deposited in unsuitable areas, including on the mown esplanade strip or even roadsides. In the pioneering accounts of inaka spawning on an Ashley River tributary, unusually high spring tides meant that some inaka spawned in neighbouring paddocks rather than the usual more suitable spawning areas (Benzie 1968a).

The effect of the over-excavation or pumping of bottom silts may therefore affect inaka spawning if it changes the terminus of the saltwater wedge in respect to the established spawning sites on the Avon and Heathcote Rivers. This could potentially occur if a distinct mid-channel gully is created with an invert lower that what was present before the seismic events. It is therefore important the rivers are not over-dredged to the point that saltwater intrusion extends further upstream, as this will modify an important spatial cue for spawning inaka. Over excavation of bottom silts may drop the inaka egg deposition zone down the bank slope, and this could pose a problem in some spawning locations, but less so for the major sites at Avondale and Opawa.

6.5 Inaka spawning on the Styx River

The 2011 survey was the third known attempt to locate inaka spawning grounds in the extensive catchment area downstream of the tide gates. The first attempt was in the period from 1988-1990 when a 'tentative' indication of inaka spawning was reported from a small grass-lined tributary (Taylor *et al.* 1992). In 2005, a survey of the main Styx River channel, and major bank invaginations was unsuccessful at finding suitable vegetation or eggs downstream of the tide gates (Taylor & Bradshaw 2005). However, a limited distribution of inaka eggs were located between the tidegates and Harbour Road.

The search zone of the latest survey was based on observations by Dr Philip Grove, who perceived vegetation zonation zones consistent with a freshwater source in the locality. While we failed to locate inaka eggs on this occasion, we are confident that inaka eggs are spawning in the vicinity. This assertion is based firstly on the salinity gradient in the area, with increasing salinity further away from the spawning site. Another, and greater, reduction in salinity was noted at the tidegates close to where inaka eggs have been found previously. Recent work on inaka spawning in estuaries in Australia (where the species is also present) confirmed that successful fertilization of inaka eggs only occurs at low salinities, from freshwater to 20 ppt, with a sharp cut-off in fertilization success in more saline conditions (Hicks *et al.* 2010). This work also predicted that estuaries with many well defined salinity gradients are more likely to have potential inaka spawning that those which are mixed to salinity levels too high to fertilise inaka eggs. They confirm earlier work in New Zealand (Richardson & Taylor 2002; Taylor 2002) that saline interfaces are a useful tool to predicting the general location of inaka spawning grounds.

Relating these findings to the lower Styx River is interesting. The tide gates effectively truncate the saltwater wedge (the saline wedge of water which runs up the river), as they close on every tide event. The sharp termination point in salinity coincides with the lower limit of inaka spawning along the mainstem. However, freshwater groundwater from the Waimakariri River is probably creating freshwater interfaces near the tidal basin and producing suitable conditions for spawning. Seawater (at around 35 ppt) has an electrical conductivity of 48 mS/cm, thus our readings of 6.3 mS/cm would represent water sufficiently fresh, based on salinity alone, to allow fertilisation of eggs.

Further field investigations are recommended to identify the spawning area in the Lower Styx, given that the principal area has been narrowed. This work would best be undertaken next February or March. At this stage any remedial action is not recommended on the Styx until the precise location and state of the inaka spawning grounds are established.

However, other biotic factors then become important, including the ability for the fertilised eggs to remain turgid and hydrated during the few weeks they are exposed to the air. The nature of the vegetation is important in that regard, and, based on our observations, this may limit spawning habitat suitability in the tidal channels. In context with seismic activity effects, we consider that the observation of unusual elevated silt layers could be explained by a single, or several events of high water level containing high levels of sediment, and which have then dried and consolidated around the foliage. The long section of bank recently collapsed is considered to be an artefact of seismic activity.

7 Recommendations

AEL accepts that CCC has many priorities in respect to the city's infrastructure rebuild. Therefore we have placed the following recommendations in order of ecological significance and financial achievability. Some of these are not necessarily related to the seismic activity, but are nevertheless important for the ecological integrity of the spawning grounds.

1. A riparian silt-control fence be used along the Avondale spawning area during road reconstruction. It is considered that liquefaction silt is being transported down gradient into the spawning vegetation.

2. The Avondale spawning site while subject to some bank slump, is still operative. Maintain the maintenance programme for yellow flag iris, which is clearly working.

3. Localised zones of severe lateral spread at Avondale should be stabilised by re-grading and re-sowing. This could enhance the potential spawning area for these sites.

4. Re-grade and re-sow the overgrown Opawa spawning site, and consider the option of manual hand weeding of small inaka spawning sites.

5. The Lake Kate Sheppard habitat area is heavily silted, remove riparian silt, and reinstate the flax and cabbage trees. Drain Lake Kate Sheppard, remove any rudd, and re-deepen the basin.

6. Dredge the Steamwharf Stream channel to a greater depth, and consolidate the slumped banks. This will provide habitat conditions more suitable for inaka rearing.

7. Revaluate Corsers Stream inaka spawning habitat when cordon lifted.

8. Further investigations be undertaken to pinpoint the location of inaka spawning sites on the Styx River. This would be useful for environmental management.

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