COMPARISON OF RIPARIAN WILLOWS AND RIPRAP AS HABITAT FOR FISH AND INVERTEBRATES IN THE WAIKATO RIVER

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ABSTRACT

Willows (*Salix* spp.) are an abundant alien tree and have been the mainstay of river bank protection throughout New Zealand. Riprap is another method of bank stabilisation consisting of rocks used to amour shorelines to protect against erosion. There is a trend for increasing use of riprap to replace willow along the banks of large rivers in New Zealand, but there is limited information on the ecological roles of these different bank types to support management. The objectives of this research were to determine the effects of different bank habitats on nearshore fish and invertebrate communities in the Waikato River as it passes through Hamilton city. The study involves three sites situated along the river. Each site has four bank types consisting of willow, riprap, a mixture of willow and riprap, and beach. Invertebrate sampling was carried out on three occasions to assess if there was a seasonal effect on community composition. Fish were sampled bimonthly determine differences in community composition. Assessment of fish populations was carried out with using boat electrofishing, Gee minnow trapping and spotlighting, while invertebrate populations were sampled by kick netting.

Few significant differences were detected in invertebrate diversity between willow, riprap and willow/riprap habitats. However, community composition based on relative abundance was different among contrasting habitats in most seasons and Pielou’s evenness was greater for the more homogenous beach and riprap habitats. Riprap had consistently high alpha diversity but had lower species accumulation on two out of three dates suggesting there was a limited pool of taxa colonising the riprap compared to other habitats**.** Pairwise dissimilarity coefficients and PERMANOVA comparisons indicated that, although low in alpha diversity, beach habitats contributed significantly to macroinvertebrate beta diversity, and that willow and riprap habitats also supported different combinations of taxa due to different physical conditions**.** The combination of beach and willow habitats gave the highest gamma diversity. Willow habitats supported the highest number of both introduced and native fish, mainly reflecting abundances of common smelt, likely due to provision of cover, complex aquatic habitat, and riparian vegetation supplying detritus and invertebrate food resources. Riprap habitats supported the highest number of common bully. Common bully were also significantly larger in this habitat. Variations in water temperature, amount of shade, and river levels were possible factors contributing to temporal influences on biological patterns.

The findings of this study indicate that, if all banks habitats in Hamilton City were composed of a single type, invertebrate biodiversity would be reduced. While the combination of beach and willow habitats may sustain high diversity for invertebrates and fish, the novel habitat provided by riprap may also favour some native fish and invertebrates over others. Therefore, a balance of different bank habitat types would perhaps be best to sustain present-day biodiversity levels in near shore macroinvertebrate and fish communities.

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1. INTRODUCTION

1.1 Background

Many riverine species tend to aggregate around the near shore area of large Rivers with constricted channels where inputs of leaf litter from riparian vegetation and local algal production fuel macroinvertebrate productivity (Thorp & Delong 1994; 2002; Junk et al. 1989). According to Schiemer et al. (2001), the structure and retention characteristics of the near shore zone create an important habitat for phytoplankton and zooplankton production and larval fish growth, reduce the loss of larval fish to drift and reduce population loss from wash-out effects. Inshore retention zones are therefore important for biological processes and biodiversity in large rivers (Schiemer et al. 2001), but they are often modified in developed areas by the need to maintain bank stability. Modifiers to shore line zones, such as the habitat types examined in this study (riprap, willow and willow/riprap), have varying physical characteristics, including shade, substrate type and water velocity which have the potential to influence the fish and invertebrate species that can occur there.

Shade can regulate shoreline food supplies for river invertebrates. Some invertebrate are more common under shaded areas and some outside shaded areas, and this could be due to a reduction in periphyton biomass or productivity (Towns 1981; Quinn et al. 1997). Quinn et al. (1997) found reduced periphyton under shade could provide clean attachment sites for *Austrosimulium australense* and uninterrupted near-bed flows for other filter feeders. Shade can also affect the water temperature which is an important factor influencing some invertebrate abundances (Quinn et al. 1994). Plecoptera and Ephemeroptera are affected by water temperatures greater than approximately 19-20°C (Quinn et al. 1994). As well as shade, nearshore vegetation can provide inputs of organic matter, woody debris and leaf leachate that provide habitat and food resources for invertebrates (Lester et al. 1994; Mehan et al. 1977; Gregory 1991). Submerged wood is an important habitat for invertebrates such as the larvae of the tipulid fly *Limonia* (Collier & Lill 2008). However, high levels of organic matter can reduce the amount of dissolved oxygen in the water and sensitive taxa (such as some Ephemeroptera, Plecoptera and Trichoptera) can disappear from these areas (Carter 2000).

Substrate is an important factor affecting the distribution of invertebrates. Feeding mode, water quality requirements, and biotic interactions determine the invertebrate's substrate size preferences in a given river (Quinn & Hickey 1990). Many studies have found invertebrate density and taxonomic richness increases as substrate size increases from sand to cobbles and then declines with further increase to bedrock (e.g., Jowett & Richardson 1990). Larger particles provide a more stable habitat for both periphyton and invertebrates (Quinn & Hickey 1990), and also trap and retain more coarse particulate organic matter (Webster et al. 1987). Other taxa appear to prefer sandy or mixed substrates; for example, *Tanais stanfordi* has been reported to prefer a substrate dominated by a mixture of sand/silt and cobbles (Quinn & Hickey 1990).

Invertebrates occupy a range of different water velocities. A study of five gravel and cobble bottomed rivers found that *Zelandoperla* and *Aoteapsyche* spp.

were associated with coarse substrate and water velocities of more than 0.75 m s^{-1}, whereas *Pyncnocentrodes* was associated with similar substrate but lower water velocities (0.2-0.8 m.s^{-1}) (Jowett et al. 1991). In contrast, *Paratya curvirostris, Potamopyrgus antipodarum* and *Paracalliope fluviatilis* were associated with aquatic macrophytes and slow water velocities in river littoral zones (Collier & Hogg 2010).

Riverine fish species also appear to occupy edge habitats where variables such as velocity and substrate can affect their distribution along river banks. Many indigenous fish species migrate upstream at a small size and can only negotiate certain velocities, and travel certain distances before having to rest (Boubee et al. 1999). Riprap can provide areas of slower flow behind and in interstitial spaces of rocks **(**Fischenich 2003), and willows may also provide refuge from high water velocities by creating undercut banks and holes, around branches, roots and trunks in the water. Common smelt are pelagic swimmers whereas common bully are benthic (David & Spiers 2010) and can rest on surfaces in velocities up to 0.44 m s^{-1} (Mitchell 1989).

Rocks and wood also provide attachment sites and habitat for algae and invertebrates, which are food for fish. Substrate type is also important for spawning, and as shelter from terrestrial and aquatic predators. Common bully spawns on rocks and other hard substrates, whereas smelt spawn in shallow sandy areas near adult habitats (David & Spiers 2010). Eels can occupy macrophyte beds (Jellyman 1989) and interstitial spaces in rocks and between submerged tree branches or wood (personal observation), and ambush fish as they swim close (Jellyman 1989). Eels are often associated with cover (Domingos et al. 2006), such as that found to varying degrees in willow and riprap habitats. Small shortfinned eels use interstitial spaces in benthic substrates or aquatic vegetation for shelter, although larger eels may need debris or surface cover (Kohen et al. 1994).

1.2 Bank stabilisation methods

1.2.1 Willow

Willows (*Salix* spp.) are the mainstay of river bank protection throughout New Zealand where they are the most abundant and widespread exotic tree after pines (Collier 1994; Phillips & Daly 2008). Phillips & Daly (2008) surveyed regional councils and concluded that willows are likely to remain a key component in flood protection because they are the most cost-effective tool, although planting native species along waterways is increasing due to the public desire for more indigenous plantings to enhance biodiversity. There are few studies of the effectiveness of native plants for erosion control, although native plants are, or are perceived to be, slow growing, have shallow root systems, cannot be managed the same way as willows and do not perform as well in erosion prone areas (Marden et al. 2005). Native plants are mostly used in lower order streams or only in conjunction with willow planting and other stabilisation techniques in higher order streams and degrading alluvial rivers (Phillips & Daly 2008).

The environmental problems that willows cause are well known, and many councils have named willow species as plant pests and have management policies to control them (Phillips & Daly 2008). Crack willow (*S. fragilis*), grey willow (*S. cinerea*) and pussy willow (*Salix x reichardtii*) are problem species. Willows can spread vegetatively and cause big problems in wetlands such as the

Whangamarino where they invade and severely reduce the number of native species (Browne et al. 2005). Seven out of thirteen Department of Conservation conservancies listed willow as one of the 10 species that have most environmental impact on their conservancy (Froude 2002). Phillips & Daly (2008) believe that using the right kind of willows and maintaining them will keep them from becoming a pest.

There have been few studies on the effects of willows on aquatic life, especially in large rivers. Most studies on willows have been on low order streams. The few studies that have examined the impacts of willows on aquatic life indicate that the impacts can be detrimental as well as beneficial (Collier 1994). On the beneficial side, willows trees can provide habitat for many organisms including terrestrial invertebrates, fish and some bird species (HCC 2008; Collier 1994). According to Collier (1994), most studies of willow effects on wetland and aquatic birds have been on braided rivers in Canterbury where willows have reduced their feeding areas (Collier 1994; Maloney et al. 1999). Willows are beneficial to some species by providing cover, protection from predation, and nesting and molting sites (Collier 1994; HCC 2008). Roots and stems of willows growing into the water can provide habitats for aquatic invertebrates, fish and algae (Collier 1994; Benke et al. 1984; Smock et al. 1985). For example, *Potamopyrgus* was found in large numbers in willow roots by Winterbourn (1970) (cited in Flory & Milner 1999, p. 261).

The density of willows is a factor that affects their ecological impact on aquatic ecology. From New Zealand studies, it seems moderate plantings of riparian willows can improve conditions for invertebrates relative to nearby pasture sites, whereas densely willowed sections are likely to be detrimental to aquatic invertebrates. Lester et al. (1996) studied a small creek and found macroinvertebrate densities were lower in densely willowed sections. Glova & Sagar (1994) found densely willowed sites had lower mean biomass and densities of Trichoptera, Coleoptera, Diptera and total invertebrates than moderately or non-willowed sites on three small rivers in New Zealand.

Mechanisms accounting for changes in aquatic invertebrate communities under willows could be changes in physical habitat such as alteration of substrate size, changes in food supply (primary production and leaf input), and changes in water chemistry (such as input of dissolved phenolic compounds in autumn) (Collier 1994). Willow roots and branches can reduce water velocity and cause retention of fine sediment which can reduce benthic invertebrate abundance due to loss of access to interstitial spaces (Lester et al. 1994; Read & Barmuta 1999). Several studies (Read & Barmuta 1999; Glova & Sagar 1994; Lester et al. 1994) have found willows can shade out macrophytes which provide invertebrate habitat in low gradient rivers, and also shade algal production which can reduce invertebrate densities. Furthermore, some species of willow contain phenolic compounds toxic to generalist herbivores (Rowell-Rahier 1984). Lester et al. (1996) found that substrate modification and high shade by willows were not responsible for the reduced invertebrate abundance they had found previously and concluded that the chemicals known to be produced by willows inhibit invertebrate feeding (not investigated in the study) and were the probable cause of the low abundances.

Many New Zealand native trees are evergreens whereas willows are deciduous and provide pulsed inputs of leaves that, if retained for long enough periods, become palatable to invertebrates (Collier 1994). In a New Zealand study, Parkyn & Winterbourn (1997) found shedders were more abundant on weeping willow and red beech leaves than on oak, elm, mountain beech or mahoe leaves. Willow leaves had intermediate breakdown rates and phenolic compounds decreased rapidly over 60 days which may have facilitated the high shredder abundance (Parkyn & Winterbourn 1997). *Potamopyrgus* grew faster on soft leaves such as willow and poplar compared to on hard leaves such as beech and oak (Hanlon 1981). Green willow *(Salix fragilis)* leaves had thicker biofilms and possibly retained higher levels of nutrients than abscised leaves and white gum (*Eucalyptus viminalis)*, leading Yates & Barmuta (1999) to speculate that willow leaves provide a preferred source of food for some invertebrate species in Australian rivers and would be available for less time than native eucalypt detritus. A study on streams in Victoria, Australia by Jayawardana et al. (2006) found more organic pollution tolerant taxa under willow in summer and autumn when levels of coarse particulate organic matter (CPOM) were high. Large input of leaves and a lack of canopy in autumn could change food supply for invertebrates (Collier 1994), and affect seasonal fish distributions by affecting fish food supply (Collier 1994; Glova & Sagar 1994).

There is limited information on the effect of willows on fish in New Zealand. One study by Hicks et al. (2005) on the Waikato River found the greatest biomass of the exotic pest fish koi carp (*Cyprinus carpio*) at willowed sites compared to macrophyte beds and other habitats sampled. Most of the studies on fish are on small streams, and according to Meehan et al. (1977) the effect of willows on large rivers could be different. From the limited information available in New Zealand, it seems that moderate plantings are beneficial to fish by providing cover and habitat, whereas dense plantings are not beneficial possibly due to shading effects lowering primary production and densities of invertebrate food supplies. Glova & Sagar (1994) found that densely willowed sites had fewer eels *(Anguilla* spp.) than moderately and non-willowed sections, and that mean length of eels was greatest at willowed sites, possibly due to deep holes (Collier 1994). Trout were found to have higher densities in the willowed sites studied due to cover provided by willows (Glova & Sagar, 1994). Broad et al. (2002) found that, during the day, longfinned eels were shorter and less abundant in sites with willows, and suggested that willows may provide a poor diurnal resting habitat away from good nocturnal feeding habitats. Shading by willows could also reduce whitebait spawning habitat in tidal parts of rivers as there is thinner grass under willow canopies and loss of leaves in autumn renders vegetation vulnerable to frost kill (Taylor et al. 1992). Small native fish, including common bully and īnanga, were not affected by the presence or absence of riparian willows (Glova & Sagar 1994).

1.2.2 Riprap

Riprap consists of graded stones used to amour a shoreline of a waterway for erosion control (Fischenich 2003; Strayer & Findlay 2010). There have been many studies on the effects of riprap on aquatic ecology in large rivers overseas but there is a lack of information in New Zealand. Riprap can have positive and negative effects on aquatic ecology. According to Shields et al. (1995), replacing natural vegetation and bank soils with riprap has effects at all scales and can affect aquatic and terrestrial communities. On a large scale, riprap may cause habitat alteration and increased sedimentation (White et al. 2009). Additionally, riprap can reduce exchange between aquatic and terrestrial habitats, and the amount of bank vegetation (Fischenich 2003; Strayer & Findlay 2010). A lack of riparian vegetation can reduce the amount of CPOM delivered to the near shore zone (Thorp et al. 2008). CPOM, and the bacteria and fungi that grow on it, is an important food source for macroinvertebrates producing fine particulate organic matter and dissolved organic matter (Collier & Winterbourn 2000). Although invertebrate life cycles in New Zealand are not tuned to the input of leaves from deciduous trees, like they are in North American rivers, CPOM is still an important food source (Collier & Winterbourn 2000). Riprap can also provide a substrate for increased periphyton growth, resulting in increased rates of benthic primary production in the modified river reach (Thorp et al. 2008). Riprap construction usually results in an increase macroinvertebrate biomass and density in large low-gradient rivers (Fischenich 2003), most likely due to the habitat complexity provided by riprap where large rocks support higher densities of macroinvertebrates, as they tend to have larger interstitial spaces and greater physical complexity than natural substrates (Shields et al. 1995). In support of this, Schmude et al. (1998) found higher species richness in baskets with cement balls (riprap) than baskets with cement blocks in retaining walls in Wisconsin lakes. However, Brauns et al. (2007) found there was no difference in invertebrate species richness between natural and riprap shorelines in lowland lakes, although riprap and natural shorelines had different community composition. They suggested that riprap created similar habitat complexity to wood in natural lake shorelines. Shield et al. (1995) concluded that many studies on large USA rivers have shown that riprap compares favourably to natural banks as habitat for invertebrates. Le Hir & Hily (2005) studied intertidal boulder fields in Europe and suggested that species richness was driven by the provision of special microhabitats that support particularly distinctive or rich biotic communities, not just due to the physical complexity of the habitat.

Often a hardened shoreline, such as riprap, has distinctly different physical characteristics than the natural shoreline it has replaced (Strayer & Findlay 2010; Fischenich 2003). Riprap can have a different slope, particle size, physical complexity and nutrient and organic content compared to a natural shoreline, and this can lead to a largely novel shoreline biota (Strayer & Findlay 2010). A hardened shoreline may not produce different biota when it replaces a natural stone or bedrock shore (Strayer & Findlay 2010), although some studies on marine areas have found the biota on artificial rocky shorelines is often distinctive (Chapman 2003; Bulleri et al. 2005; Moschella et al. 2005). Riprap and other types of artificially hardened shorelines usually reflect more energy than natural shorelines, such as beaches or vegetation, leading to increased sediment resuspension and erosion of the near shore zone (Strayer & Findlay 2010).

Studies comparing fish assemblages in natural and riprap habitats are often not in agreement, highlighting that the effect of riprap on fish depends on many factors including fish species habitat preferences, the natural habitat the riprap replaces and other modifications to the river such as dams. White et al. (2009) found that, at a local scale, riprap did not decrease abundance of native riverine fishes in the Mississippi River, possibly because most fish were habitat generalists. In the Sacramento River, the loss of large woody debris due to the addition of riprap reduced the amount of important spawning substrate for splittail

(*Pogonichthys macrolepidotus*) and important salmon rearing habitat (U.S. Fish and Wildlife Service 2000). Eros et al. (2008) studied the river Danube and found the fish species of great conservation concern tended to be bound to natural habitats (with gravel-sand areas), whereas exotics (such as gibel carp *Carassius auratus gibelio*) were more common along riprap. According to Fischenich (2003), riprap seems to negatively affect cold-water fisheries and positively affect warm-water fisheries. The addition of riprap to warm-water systems resulted in a new habitat niche exploited by a number of species, as most of the warm-water systems had limited coarse, hard substrate (Fischenich 2003). In contrast, cold-water systems had abundant hard substrate and riprap replaced other habitat types that may have been limited, such as overhanging vegetation.

Riprap can also alter near-bank flows and this can cause shifts in species composition and relative abundance (Shields et al. 1995). A study by Li et al. (1984) found continuous riprap revetments provided a poor habitat for larval fish compared to natural banks and spur dikes due to flow patterns around the spurs. Michny & Deibel (1985) found lower numbers of juvenile salmon on riprap banks due to the rougher riprap preventing formation of low flow zones for feeding. The effects of riprap can also depend on the size of the rock particles. Larger rocks are beneficial to fish as there are more velocity refugia **(**Fischenich 2003). A study by Beamer & Henderson (1998) on the Skagit River found that rainbow trout were not adversely affected by riprap if the rocks used were large.

Riprap can favour invertebrate and fish species that use interstitial spaces between rocks for cover (Fischenich 2003). Watkinson et al. (2004) found that densities of certain species of Catostomidae and common carp (*Cyprinis carpio*) that feed on benthic invertebrates were highest on riprap. Changes in local diversity and assemblage composition can strongly affect a variety of ecosystem services and processes such as changes in predation (Eros et al. 2008; Fischenich 2003). Lyons (2005) studied a river in Wisconsin and found the index of biotic integrity scores from survey sites with natural shorelines were significantly higher than scores from rock riprap.

1.3 Diversity measures and how they might apply to bank stabilisation methods

If a general relationship exists between habitat structure/complexity and diversity, then riprap sections should increase fish diversity at the meso-habitat scale, as found by Eros et al. (2008), and also increase invertebrate diversity. An increase in diversity is not always positive, however, as it depends on the composition of the resulting assemblage. Diversity can be expressed as species richness and evenness (Rousseau & Van Hecke 1999). Evenness is the relative distribution of abundances among species (Rousseau & Van Hecke 1999). Species diversity measures can be divided into three groups (Magurran 1988). The first is species richness which uses the number of species in a sampling unit. The second group is the species abundance models which use measures of evenness. The third group is the diversity indices based on the proportional abundances of species. Examples of the third group of indices include Shannon, Margalef and Simpsons index (Magurran 1988). Margalef diversity index was chosen for this study as it is a well known index and it attempts to correct for sample size.

Diversity can be assessed on many scales, including local scale species richness (within communities or habitat patches), the landscape scale (species richness between communities and turnover of species within a landscape), the regional scale (species richness of large geographical areas within a continent), the continental scale (species richness across continents) and the global scale (Willis & Whittaker 2002). Variation of species diversity at a local scale is referred to as alpha diversity, or within-habitat diversity (Heino 2009). In this study, alpha diversity relates to the species richness in each sample. Beta diversity, or between-habitat diversity introduced by Whittaker (1960), is the variation in communities among sites (Heino 2009). Beta diversity in this study relates to the variation in communities between habitat types, such as riprap and beach habitats. Anderson et al. (2011) noted there are two types of beta diversity: turnover and variation. Turnover is the change in community structure (including abundance, biomass, identity and/or cover) from one sample unit to another along a spatial, temporal or environmental gradient, and is expressed as a rate of turnover over a specific gradient. The second type of beta diversity is defined by Anderson et al. (2011) as variation in community structure among a set of sample units within a given spatial or temporal scale or within a category of a factor. An example of this is the variation in community structure of aquatic macroinvertebrates within each of the four habitat types in this study. Gamma diversity is regional species richness (Anderson et al. 2011) and is a function of alpha diversity in each habitat type and beta diversity (turnover of taxa) between habitat types (Gray & Harding 2009). In this study gamma diversity is the species richness of the three study sites in Hamilton.

1.4 Hamilton City riverbanks

According to the Hamilton City Council (2008), most of the river banks in Hamilton City are on Hinuera or Taupo pumice alluvium or local alluvium which is prone to slips and erosion unless it is covered by vegetation. The river banks in Hamilton City have largely remained stable and have a reasonable cover of vegetation. On outer bends, the banks are subject to a greater erosion force, and if vegetation is cleared from these areas, structures, such as riprap or retaining walls, may be required (Hamilton City Council 2008).Riprap is also used on straight sections of river (personal observation). The river bed in Hamilton City is composed of acid-volcanic rock fragments, pumice and sand grains, and has been degrading at a rate of 25-30 mm /year due to the Karapiro hydro-dam reducing the sediment supply, along with the effects of historical sand and gravel extraction (Hamilton City Council 2008; Hicks & Hill 2010). Fluctuating river levels from hydro-power generation and the likely continual erosion of the river bed could increase bank erosion problems in future (Hamilton City Council 2008).Willow trees have been used for bank stabilisation in Hamilton City since early European settlement (Hamilton City Council 2008). They are an effective bank stabilisation method and provide habitat for birds and fish; however, they grow into the waterway and obstruct river access, spread vegetatively, are hard to control, and block river views (Hamilton City Council 2008). Willows are gradually being removed within Hamilton and replaced with trees such as alders or natives (Hamilton City Council 2008). Alders are not as effective as willows in creating habitat for fish and water birds as their roots do not spread into the water, although they are able to retain the river bank and survive occasional floods (Hamilton City Council 2008). The riverside ecotone between the high and low water mark is colonised by annual plants that help stabilise banks. The water level is determined by optimum power generation and varies frequently so vegetation does not thrive in this variably-wetted area, although some native species such as *Carex* may be able to survive the water level fluctuations. According to Hamilton City Council (2008), the bank stabilisation techniques that will be used in future include planting vegetation, retaining walls, gabions (wire mesh filled with stone or metal) or other engineering techniques.

1.5 Aims and objectives

Given the paucity of information on different bank stabilisation measures on aquatic life in large, low-gradient rivers in New Zealand, there is a need for ecological information to guide future management to maintain river bank stability. The aim of this study was to determine the influence of four shore zone habitat types (willow, riprap, a combination of willow and riprap, and beach) on fish and macroinvertebrates colonising edges of the Waikato River through Hamilton.

The objectives of this study were to:

1) Determine differences in physical characteristics associated with the different shore zone habitat types;

2) Compare fish and invertebrate community composition between habitats types, and relate this to differences in physical characteristics.

3) Determine spatial and temporal variation in habitat-biota relationships within Hamilton City

4) Identify the combination of habitat types that optimise diversity along shore zones.

These objectives were addressed by selecting three sites in Hamilton city with four habitat types each; riprap, willow/riprap, willow and beach. Each habitat was 50 m long and were in close proximity to each other (within 500m). Beach was chosen as a control and to provide a comparison with a completely different bank habitat. Sampling was done on three occasions to assess if there was a seasonal effect on invertebrate community composition, and bimonthly to determine differences in fish communities.

2. STUDY AREA

2.1 Waikato River

The Waikato River is the longest river in New Zealand and drains 13% of the North Island (Chapman 1996). The river starts on Mount Ruapehu as a stream that joins the Tongariro River and flows into Lake Taupo, before flowing north and entering the sea at Port Waikato. From Lake Taupo the river descends for around 185 km at a steep gradient through narrow ignimbrite terraces and eight hydro-electric dams (Collier et al. 2010; Manville 2002). At Karapiro, the River enters the Waikato basin where it becomes shallower towards Taupri and less entrenched as it flows through the Waikato basin floodplains (Collier et al. 2010).

The river's colour changes from clear blue as it leaves Lake Taupo to green and murky through Hamilton due to increasing turbidity, dissolved colour and phytoplankton (Collier et al. 2010). Nutrients, such as nitrogen and phosphorus, also increase from Taupo to the sea (Vant 2010). According to an Environment Waikato report by Beard (2010) on the water quality in Hamilton City, dissolved oxygen, pH and ammonia complied with 'excellent' ecological health guidelines, whereas turbidity and chlorophyll *a* complied with the "satisfactory" water quality guidelines for ecological health. However, out of twelve samples only six total phosphorous (TP), eight nitrogen (TN), four (out of ten) black disk (water clarity), eleven *E. coli* and nine boron samples complied with "satisfactory" ecological health standards (Beard 2010). Arsenic samples exceeded levels considered satisfactory for ecological health (Beard 2010). Nitrogen and phosphorous can cause excessive plant and algal growth whereas high turbidity can reduce light for photosynthesis and can make feeding harder for visually-feeding fish (Beard 2010). In the future, the predicted intensification of farmland will increase the nitrogen and phosphorus entering the river which may increase the risk of harmful algal blooms (Collier et al. 2010).

2.2 Bank habitats in Hamilton City

The extent of different habitat types in Hamilton City was estimated using Google Earth by measuring the length of each habitat type from high resolution satellite imagery. The river bank was also surveyed to ensure accurate identification and length of habitat type on the satellite image. From Cobham Bridge to Pukete Pedestrian Bridge the majority of the Waikato River bank habitat is vegetation consisting of willow (mostly crack willow (*Salix fragilis*) some grey willow (*Salix cineriea*) and weeping willow, (*Salix babylonica* and hybrids*)*, along with alder *(Alnus glutinosa)* and other vegetation (Beard 2010). Unvegetated riprap covers approximately 0.8 km or 5% of the river bank length (Table 2.1). Riprap combined with planted trees (willow or alder) cover 3 km or 17% of the River bank (Table 2.1). Thus riprap (including unvegetated riprap, willow/riprap and alder/riprap) is estimated to cover 21% of bank habitat through the city. For the sites used in this study, the Ann Street riprap was constructed in 2002, the Victoria Bridge riprap and willow/riprap was constructed in 2001, the Swarbrick Landing riprap was constructed in 1992 and the willow/riprap in 2002 (Greg Leigh, HCC, pers. comm.). Gabion baskets containing cobbles make up 0.5% of the habitat (Table 2.1). This is not a large amount of riprap compared to many overseas cities, for example the Kansas River where bank stabilisation structures cover 274 km of river and around 50% of the freshwater tidal Hudson River (White et al. 2009; Strayer & Findlay 2010).

Table 2.1 Extent of bank habitat in km and percent of total bank from Cobham Bridge to Pukete Pedestrian Bridge.

Habitat type	Total km	Percent of total
Willow/vegeation	10.9	59.8
Willow/riprap	2.0	11.0
Alder/riprap	1.0	5.7
Riprap	0.8	4.5
Retaining wall	0.8	4.6
Grass	0.2	1.1
Beach	2.3	12.7
Gabion basket	0.1	0.5
Total	18.2	100

2.3 Sampling site characteristics

The study involved three sites each with four habitat types along 50 m sections of river bank: willow, beach, riprap and willow/riprap. All sites are located on the Waikato River in central Hamilton and the habitats were at least 20 m apart to reduce edge effects (Figure 2.1). The Ann Street site is located off Ann St on the true left bank of the river; Victoria Bridge is on the right bank of the river before Victoria St Bridge; and Swarbrick Landing has the willow habitat on the left bank next to Saint Andrews golf course and the other habitat types on the right bank at Swarbrick Landing on River Road (Figure 2.1).

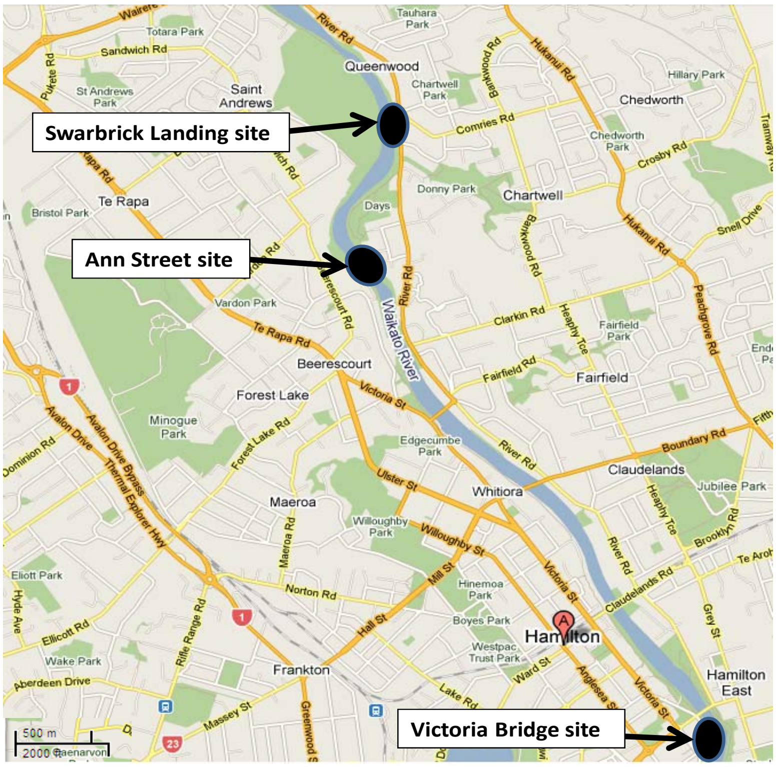

Figure 2.1. Map showing the three sampling sites in Hamilton City.

An in-depth habitat assessment was undertaken on 17/3/2010 to determine the characteristics of habitat likely to be submerged at higher flows in each habitat type. The measurements were taken when the river level was around 11.81 m to 11.9 m at the Victoria Bridge flow recorder site. Habitat assessment included measuring substrate size, willow stem density (stems >2 cm diameter) and slope at each site. Substrate was measured at 10 points along each of five transects set along each 50 m reach using a modified version of Wentworth's 6-point scale (Harding et al. 2009). Transects went from the water's edge to the start of the upper bank vegetation. Vegetation was measured using a 2 m² quadrat at each of 5 transects set along each 50 m reach. At each transect, the quadrat was placed 1 m from the water's edge, then at 5m, then every 5 m up to the edge of the bank vegetation (>9 m). The vegetation was sampled by recording species names and the diameter of stems >2 cm diameter. The slope angle was measured using an inclinometer on top of a 1.5 m measuring pole placed at the water's edge and sighting a second 1.5 m pole at the top of the bank. Any stormwater drains and stream inputs within and 50 m upstream of the sampling reach were noted.

2.4 Physical characteristics

All willow sites were characterised by silt/sand substrate with varying amounts of roots, detritus and wood. Willow branches and sometimes trunks often grew horizontally along the ground. Willow trees on the water's edge created many embayments and convoluted banks covered with thick root mat. Vegetation on the banks at 'willow' sites also included a mixture of alder, other tree species, small shrubs, groundcover and weeds. Swarbrick Landing had the widest beach at 8 m followed by Victoria Bridge (mean 6 m), and Ann Street (5 m). The slope of the lower banks at the willow sites averaged 25° at Swarbrick Landing, 28° at Victoria Bridge and 29° at Ann Street (Table 2.2.). Victoria Bridge has the steepest average upper bank slope of 70° followed by Swarbrick Landing (64.3°) and Ann Street (19°) (Table 2.2).

Table 2.2. Average bank slopes (^{o}) for all sites ('Total' refers to the angle from the water's edge to the top of the upper bank comprising beach in the non-wetted channel and steep upper banks; riprap banks did not have a lower bank or beach so only total angles were recorded).

Habitat	Bank area	Swarbrick Landing	Ann Street	Victoria Bridge
Willow	Upper bank	64.3	19	70.4
	Beach	25.2	29.2	28.2
	Total	34.8	23.2	54.4
Willow/riprap	Upper bank	65.7	60	47.7
	Beach	23.3	27	30
	Total	48.4	47.2	59.6
Beach	Upper bank	14.0	53.4	38
	Beach	12.2	17.4	18.2
	Total	11.6	31	24.8
Riprap	Total	42.2	71	51.4

Willow sites

The Ann Street willow site had two large willow trees that had fallen over and were sprouting (Figure 2.2). The other species present included mahoe (*Melicytus ramiflorus*), a cabbage tree *(Cordyline australis)* and *Coprosma* sp. The site also had ground cover species, weeds and patches of grass. The total average slope of the Ann Steet willow site was 23° (Table 2.2.). The substrate was dominated by silt (62%) with 29% organic material (Table 2.3). There was a fresh-water spring seepage 5 m inside the start of the study site.

Figure 2.2. Part of Ann Street willow site showing a willow tree growing horizontally.

Table 2.3. Percent composition of inorganic and organic substrate type measured in habitat study. (SMG = small medium gravel, MLG = medium large gravel). Values < 3% not shown.

	Swarbrick Landing	Annn Street	Victoria Bridge
Willow	Silt 32, sand 30. detritus 17, large wood 9, roots 8, small wood 4.	Silt 62. Roots 11, detritus 10, large wood 8, small wood 7.	Silt 35, sand 19. Roots 20, small wood 12, detritus 11.
Willow/riprap	Boulder 16, silt 16, small cobble 13, large cobble 13 sand 9. Roots 10.	Silt 43, boulder 8, sand 6. Roots 20, small wood 6.	Boulder 33, silt 16, concrete slab 10, sand 10. Small wood 8, roots 7.
Riprap	Small cobble 49, large gravel 15, small gravel 6, MLG 5, SMG 5.	Small cobble 42, large cobble 19, boulder 12, large gravel 7.	Boulder 21, small cobble 18, silt 16, concrete slab 9, large cobble 8, large gravel 8.
Beach	Sand 65, silt 23, small gravel 7, SMG 5	Sand 47, silt 45. Roots 3.	Sand 68, small gravel 41, boulder 3, small cobble 3, MLG 3.

The Swarbrick Landing willow site had willows that grew vertically and created many embayments and convoluted banks covered in thick root mats (Figure 2.3). Other species present included alder, totara (*Podocarpus totara*) tawa (*Beilschmiedia tawa*), *Pittosporum* sp. and *Coprosma* sp. The total average slope was steeper than the Ann Street willow site at 35º (Table 2.2). The substrate was an even mix of silt 32%, sand 30%, and organic material (38%) (Table 2.3).

Figure 2.3. Part of Swarbrick Landing willow site showing a willow tree with large root matt.

The Victoria Bridge willow site had many horizontal willow trunks and branches and also vertical standing willows (Figure 2.4). The other species present included alder, oak (*Quercus robur*), privet (*Ligustrum lucidum*), wineberry (*Aristotelia serrata*), miro (*Prumnopitys ferruginea*) and kowhai (*Sophora* sp.). There was also groundcover and grass covering parts of the site. The total slope was the highest of the three sites at 54º. The substrate was dominated by organic material (43%) followed by silt (32%) and sand (19%).

(Table 2.3).

Figure 2.4. Part of Victoria Bridge willow site showing a horizontal willow branch, ground cover and other small trees.

Willow/riprap sites

The willow/riprap sites were different from each other. All sites contained a mixture of willow and alder trees, a few other tree species, shrubs and varying sizes of rock riprap with some willow roots. All banks were around 8.5 m wide and had narrow beaches extending less than 5 m to the water's edge.

The Swarbrick Landing willow/riprap site substrate consisted mostly of boulders (16%), silt (16%), cobbles (13%) and roots (10%) (Table 2.3). Willow and alder were spaced along the bank (Figure 2.5). The average slope of the upper bank was 66° and the average slope of the beach was 23° (Table 2.2).

Figure 2.5. Part of Swarbrick Landing willow/riprap site.

The Ann Street willow-riprap site substrate consisted of mostly silt (43%) and roots (20%) with a small amount (<10%) of boulders, sand and small wood (Table 2.3). This site had a few large willows, including a weeping willow, in the middle of the reach with a large root mat (Figure 2.6). The other vegetation consisted mostly of flax bushes (*Phormium* sp.) and grass, with an occasional alder and cabbage tree. The average upper bank slope was 60º and the average beach slope was 27º (Table 2.2). There is a stream entering 20 m upstream of the start of the reach, and two small stormwater drains entered the river within the reach.

Figure 2.6. Part of Ann Street willow/riprap site showing a weeping willow.

Substrate at the Victoria Bridge willow/riprap site consisted mostly of boulders (33%), silt (16%) and large concrete slabs (10%) with a small amount of wood (8%) and roots (7%) (Table 2.3, Figure 2.7). The average slope of the upper bank was 48º and the average slope of the beach was 30º (Table 2.2). A stormwater drain (0.52 m diameter) and some piped springs/streams (0.15-0.23 m diameter pipes) entered the river within and upstream of the reach.

Figure 2.7. Victoria Bridge willow/riprap site.

Riprap sites

The Ann Street and Victoria Bridge riprap sites had the narrowest bank consisting entirely of riprap (6.5 m and 7.8 m, respectively), while the Swarbrick landing site had the widest bank at 10.9 m. Ann Street riprap had the highest slope angle of 71º followed by Victoria Bridge (51 º) and Swarbrick Landing (42º) (Table 2.2).

Swarbrick Landing riprap consisted mainly of small cobbles (49%) and smaller amounts of gravel of varying sizes (31%) (Table 2.3). There were no trees or shrubs growing among the riprap (Figure 2.8). A culvert (1.59 m diameter) with a fish pass entered the river 45 m upstream of the start of the site. There is also an iron coloured groundwater seepage entering 10 m from the start of the reach.

The Ann Street riprap site consisted of mostly of small cobbles (42%) followed by large cobbles (19%), boulders (12%) and large gravel (7%) (Table 2.3). There were flax bushes midway up the bank and small shrubs along the top of the bank along the downstream half of the reach (Figure 2.9). The Victoria Bridge riprap site consisted mainly of boulders (21%), small cobbles (18%) and silt (16%) at the bottom of the riprap bank. Alder trees grew along the middle of the riprap bank (Figure 2.3). The site had three stream pipes (one of 15 cm and two of 1.5 m diameter) entering upstream of the site.

Figure 2.8. Swarbrick Landing riprap site.

Figure 2.9. Ann Street riprap site looking south.

Figure 2.10. Victoria Bridge riprap site showing alder trees spaced along the bank at the top of the picture.

Beach sites

The beach sites were similar and had substrates made up of mostly sand, silt and small gravel (Figure 2.11). Ann Street beach had more silt (45%) compared to the other beach sites (Table 2.3).

Figure 2.11. (From left to right) Ann Street, Victoria Bridge and Swarbrick Landing beach sites.

3. MATERIALS AND METHODS

3.1 Sampling times and preceding conditions

3.1.1 Macroinvertebrate sampling

The invertebrate sampling was undertaken on three occasions at three-monthly intervals, over 9-21 December 2009, 29-31 March 2010, and 3-4 June 2010 (Figure 3.1). The June date has only two sites completed as the river level rose during sampling and the opportunity did not arise to complete sampling at suitable river levels for the rest of winter. Invertebrate sampling was doneensureing that samples were taken from habitats that had been inundated for around a month prior to sampling. During invertebrate sampling, the river level was monitored by marking the river level on the bank at the start of sampling and monitoring it for changes. The depth of sampling was adjusted if the river level changed so that samples were always taken from 0.3 m to 0.5 m, depths from mean flow, in order to keep sampling permanently wetted habitat.

Median river levels were higher over the month prior to sampling for December and March but were lower in June, although variations in 90th percentile river levels were less than 0.2 m for all dates (Table 3.1). For the December sampling date, the median river level was 0.41 m lower than the median river level for November on some occasions (Table 3.1). For the March sampling date, the river level was 0.73 m lower than the median river level for March and February on some occasions. For the June sampling, the river level on the sampling dates was up to 0.83 m higher than the median river level in May on some occasions (Table 3.1). The river level was noted to be rising and the depth at which the samples were taken was increased.

Table 3.1. River levels (m) for invertebrate sampling dates and for the month prior to sampling.

Sampling period					Month prior to sampling		
Sampling period	Daily range (8am-5pm)	90th percentile	Mean	Median	90th percentile	Mean	Median
9/12/2010	12.04-12.6						
12/12/2010	12.1-12.84	13.043	12.27	12.13	13.229	12.59	12.54
21/12/2010	11.78-11.87						
29/03/2010	11.85-12.09						
30/03/2010	11.86-12.22	12.355	11.97	11.83	13.397	12.67	12.56
31/03/2010	11.82-11.80						
3/06/2010	11.80-11.77	13.151	12.54	12.53	12.095	11.80	11.70
4/06/2010	11.75-12.22						

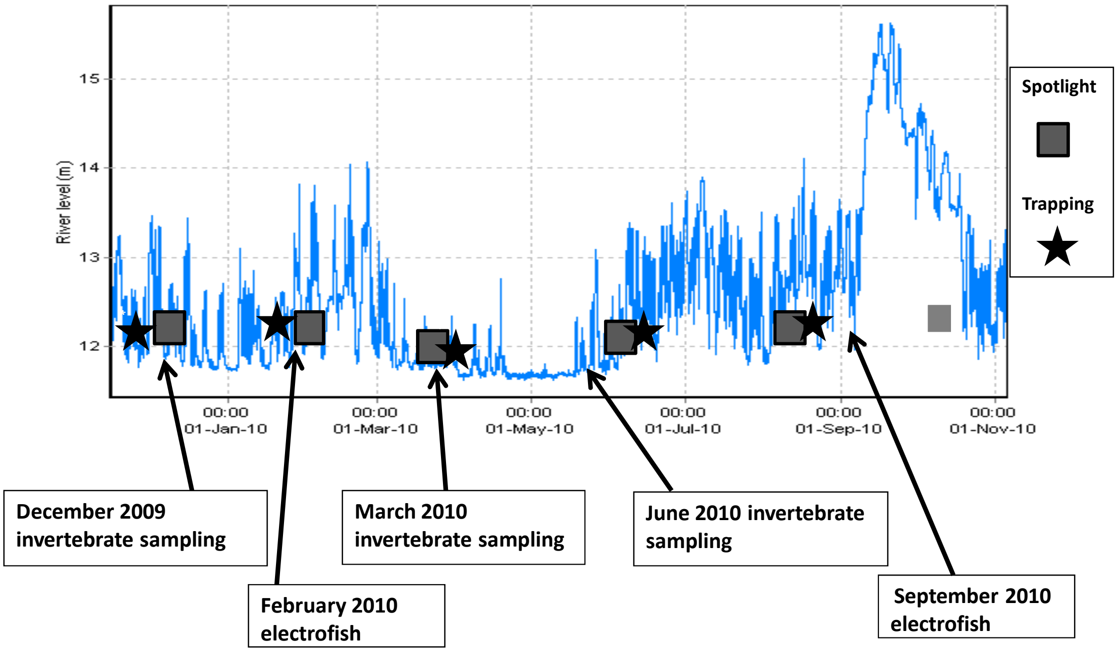

Figure 3.1. Hydrograph of river levels from Victoria Street Bridge monitoring site for December 2009 to November 2010 showing fish and invertebrate sampling dates.

3.1.2 Fish sampling

Gee minnow trapping was undertaken on five occasions; 14-22 December 2009; 21 February to 2 March 2010; 26-28 April 2010; 22-28 June 2010, and 28-30 September 2010 (Figure 3.1). Spotlighting was also undertaken on five occasions: 16-22 December 2009; 16 February to 3 March 2010; 21-24 April; 30 June to 2 July, and 27 October to 1 November. Boat electrofishing was undertaken over 9-12 February and 7- 8 August 2010 (Figure 3.1). Any effect of river level prior to fish sampling would have depended on the method used, but was not considered further for fish as they are more mobile than invertebrates.

3.2 Physicochemical measurements

Habitat and water chemistry were assessed on each occasion at each invertebrate collection site. At the commencement of sampling for each habitat type, specific conductance and temperature were measured using a YSI EC 300 meter, and dissolved oxygen (DO) was measured using a YSI 550A meter. Water velocity, depth and shade were recorded where each of the invertebrate samples was collected. Velocity was measured using a Marsh-McBirnie velocity meter (December) or a 2030R Mechanical flow meter (March and June). Shoreline length was recorded at each habitat type as a measure of shoreline complexity, by placing a100 m tape along the water's edge over a linear distance of 50 m. Shoreline sinuosity was expressed as the ratio of the water's edge distance over the linear distance (Schmeier et al. 2001). Shoreline sinuosity was also measured on four other separate occasions to investigate the effects of changing river level on this measure of habitat complexity.

Shade at each invertebrate sampling location was measured using a densiometer by noting whether overhead shade occurred on each of the 25 squares, asdescribed in Harding et al. (2009). Macrophyte dominant species and percent cover; percent of coarse particulate organic matter (CPOM); and substrate size, embededdness and compaction were assessed visually in an approximately 1 m^2 area where each of the invertebrate samples was collected. Substrate was assessed using a modified Wentworth scale: silt (<0.063 mm), sand (>0.063 to 2 mm), small gravel (>2 to 9 mm), small-medium gravel, (>9-16 mm), medium-large gravel (>16-40 mm), large gravel (>40 - 64 mm), small cobble (> 64–128 mm), large cobble (>128-256 mm) and boulder (>256 mm) (Harding et al. 2009). The category of large concrete slab was also included to record artificial bank stabilisation materials. Embeddedness is the amount of fine sediment covering the substrate and was categorised using the cover classes 1 = 0-5%; 2 = 5-25%; 3 = 26-50%; 4 = 51-75%; 5 = >75%, following Platts et al. (1983). The compaction classes used were 1 = assorted sizes tightly packed and/or overlapping; 2 = moderately packed with some overlap; 3 = mostly a loose assortment with little overlap; 4 = no packing/loose assortment easily moved, following Pfankuch (1975).

3.3 Macroinvertebrate collection

3.3.1 Pilot study

A pilot study was undertaken in October 2009, prior the main sampling programme, to determine the level of effort required using integrated kick net sampling to represent site macroinvertebrate taxa richness accurately. The invertebrate pilot study involved collecting 10 one-minute samples over a similar area, at the Swarbrick Landing riprap site and the Ann Street willow site. The willow samples were taken 5 m apart along a 50 m reach by sweeping a D-frame kick net (0.5 mm mesh) over willow roots and branches near the shoreline and brushing branches and other substrate upstream of the net. In the riprap site, invertebrates were sampled at the same intervals, by disturbing stones and scrubbing them with a stiff bristled broom upstream of the net. The samples were stored in plastic screw-top jars and preserved with 70% ethanol. Macroinvertebrates were removed in the laboratory and described using the keys listed in Section 3.3.2.

The pilot study showed that the number of invertebrates in each one-minute sample ranged from 2-34 in riprap samples and 1-70 in willow samples (Figure 3.2). There was a slower rate of taxa increase on the riprap species aggregation curve (Figure 3.3) compared to the willow curve which levelled off at 14 taxa after eight samples. Based on this analysis it was decided that five 2-minute samples would be an appropriate level of effort to achieve a balance between the number of individuals and taxa collected at a site. However, due to time constraints imposed by sorting the larger amount of organic material in subsequent samples, four out of the five samples collected were sorted.

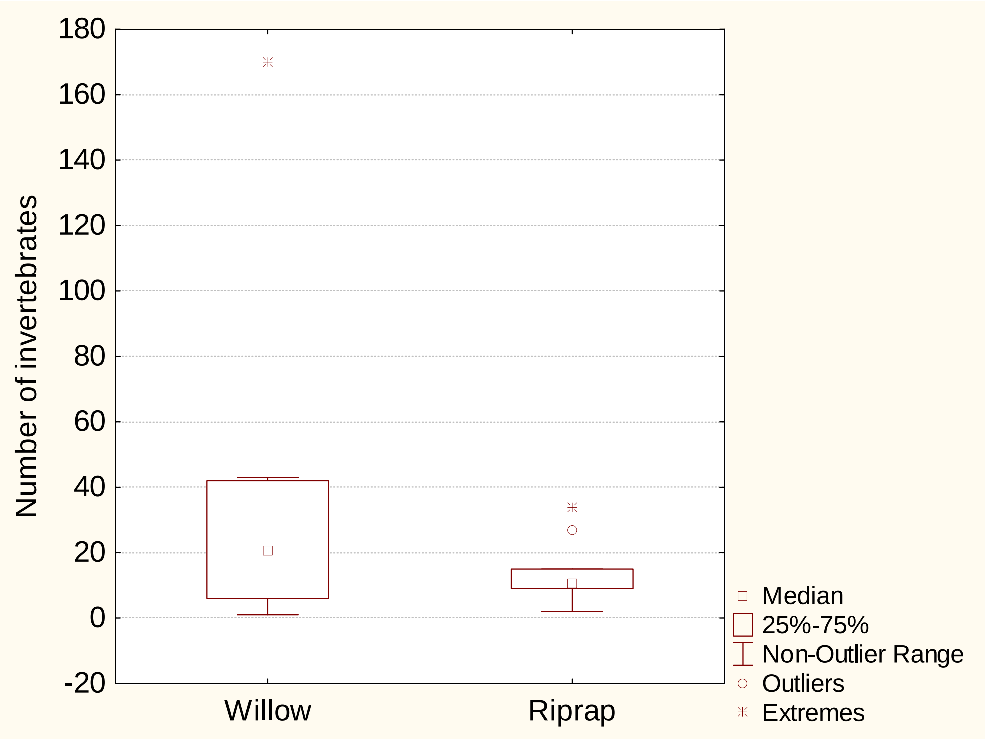

Figure 3.2. Box plot of invertebrate abundances from preliminary sampling of a willow and a riprap site in October 2009.

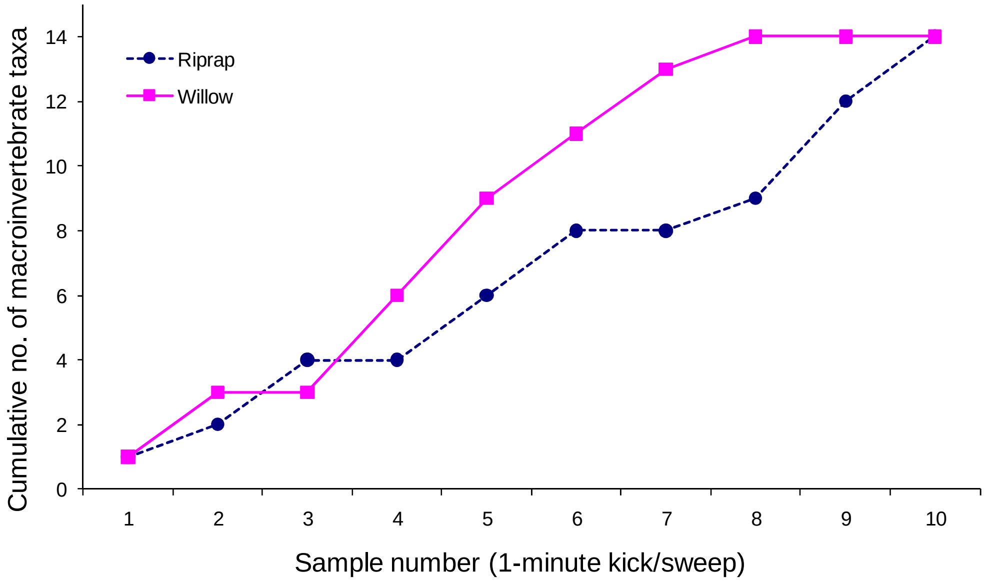

Figure 3.3. Species aggregation curve for macroinvertebrates from a willow and a riprap site in the Waikato River in October 2009.

3.3.2 Main macroinvertebrate study

Subsequent samples were collected as described above with the addition of willow/riprap and beach sites. The willow/riprap samples were taken using the broom and net on rocky parts of the reach and by sweeping and brushing other substrate types such as roots or wood. The nets used for the main study were D-frame nets (50 cm wide by 26 cm high) with 0.5 mm mesh, one of which could have the angle of the handle adjusted to make it easier to sample steep riprap slopes. Sweeping motions were used with hands and the broom to push material into the net when velocities were low. Beach samples were taken by gently disturbing sediment upstream of the net or sweeping the net through macrophytes where present.

In the laboratory, samples were elutriated in a bucket if coarse sediments were present and sieved through a 0.5 mm mesh sieve. Large organic material was removed after washing and inspection for invertebrates. The invertebrates were picked out by eye on a white tray for identification. Depending on the number of invertebrates present, the whole sample was sorted or sub-sampled if the sample was large, to obtain at least 200 invertebrates where possible. Sub-sampling was done by splitting the sample with a Folsom-type splitter and/or by counting invertebrates in randomly selected squares in the tray until the desired number had been counted or the whole sample had been processed. The whole sample was scanned for rare taxa and these were included in the total count. The Folsom splitter was made using a plastic cylindrical biscuit tin with a lid and a semi-circle divider in the middle. The sample was inverted 3-4 times to mix the contents and then split and either placed into a tray for counting or split again if the sample was large. The split samples were spread evenly over a tray with eight equal-sized squares drawn on it and a grid placed over the squares to make sure floating invertebrates remained in the squares. Following Angradi et al. (2009), randomly selected squares were processed until at least 200 individuals were removed. The invertebrates were identified to genus level where possible, using standard keys (Winterbourn 1973; Chapman & Lewis 1976; Winterbourn et al. 2000). A stereoscopic microscope was used in the invertebrate identification.

3.4 Fish assessment

3.4.1 Pilot study

Gee minnow traps, boat electrofishing, backpack electrofishing and spotlighting were trialled before the main sampling period to determine the best methods for fish assessment on steeply sloping river edges. The criteria for an efficient method included safety and applicability to all habitat types. The same two sites were used as for the invertebrate sampling pilot. The Gee minnow traps were collapsible fine nylon mesh (1 mm) traps. Eight Gee minnow traps were deployed 5 m apart along the edges of the willow and the riprap sites and left overnight. The following morning, the traps were removed and fish were placed into buckets to be identified and counted. Boat electrofishing involved probing the shore to around 2-3 m offshore along each 50 m reach from a 4.5 m long boat equipped with a 5 kW gas powered pulsator (GPP, model 5.0, Smith- Root Inc, Vancouver, Washington, USA). Spotlighting was done with a 50 W spotlight and a 12 V battery and commenced on dark with fish recorded as encountered while moving along the bank edge of the 50 m reach. Where necessary, fish were captured by netting for positive identification. Fish could be seen in the illuminated area up to about 2 m from the water’s edge depending on the water clarity and depth. An EFM 300 backpack electrofishing machine (National Institute of Water and Atmosphere Instruments) was also trialled on a beach site, but this was too dangerous to use on riprap sites due to unstable footing so was not used further.

Gee minnow trapping, spotlighting and boat electrofishing were deemed to be suitable methods for fish assessment. The pilot study showed the eight Gee minnow traps collected few fish (≤10 individuals in total per site), suggesting that the number of traps should be increased. Boat electrofishing yielded the most species in a short time (around 10 minutes per habitat) with a wide range of small and large fish species. Spotlighting yielded the second highest number of fish and fish species (20-30 minutes per habitat).

The pilot sampling indicated that each method had its advantages and limitations. The electrofishing boat was limited in willow sites due to branches and swift currents affecting accessibility. Minnow trapping was limited due to the size of the trap entry limiting the size of fish it can catch, and consequently it does not catch larger species such as koi carp and grey mullet. Spotlighting is limited by water clarity affecting visibility along steep bank slopes. Based on the results of this pilot study, three methods were selected for characterising fish communities for the main study:overnight Gee minnow trapping, spotlighting and boat-electrofishing.

3.4.2 Main fish study

Ten Gee minnow traps were set at dusk and left overnight (12-15 h). The traps were collected in the morning (from 8 am).Fish were measured and weighed using a 20 kg electronic scale, and returned to the water near to where they were caught. Fish were measured to the fork in their tail if they had one, or to the end of their tail. Eels were anesthetised using benzocaine in order to take length and weight measurements. The eels were put in a bucket of fresh water to recover from the anaesthetic and then returned to the place of capture. Spotlighting was undertaken as described above to estimate night-time abundance of fish per 100 m^2 (50 m reach and approximately 2 m wide).

Relative abundance of fish species and community composition at each site was obtained by single-pass boat electrofishing in February and August 2010. Boat electrofishing involved probing the shore to around 2-3 m offshore along each 50 m reach. Fish were removed and anesthetised with benzocaine for length measurements to be recorded. Native and exotic fish were returned to the river in the February electrofishing so that the second fish estimate was accurate. In the second electrofishing, exotic species (except trout) were disposed of by administering a lethal dose of benzocaine and placing them in a freezer.

3.5 Statistical analysis

3.5.1 Invertebrates

Number of taxa, Margalef's diversity, rarefied richness (ES=99), and Pielou's evenness were calculated using PRIMER 6 software. Margalefs diversity was chosen because it is a well known and meaningful diversity measure and attempts to correct for sample size (Magurran 2004). The diversity values were compared using ANOVA in STATISTICA with sites and habitats as factors. Separate analyses were run for each date because of the unbalanced sampling in June and to eliminate any potential effect of preceding flow regime. Factorial ANOVAs were run initially, and if there was no interaction between habitat and site a main effects ANOVA was completed. All data was assessed for normality using expected normal histograms and Lilliefors test and a Levene's test was used to assess homogeneity of variance. A Tukey post-hoc test was used to investigate differences between factors.

PRIMER 6 software was used to conduct a non metric multi-dimensional scaling (MDS) analysis based on percent abundance data. A MDS ordination plot shows a 2D or 3D spread of data points with relative distances between points representing the relative dissimilarities between the samples. Points that are closer together represent samples that have similar community composition and points that are far apart represent samples with different community compositions. The data were transformed by the fourth root before analysis in PRIMER. Vector overlays on the MDS plots of species and habitat variables (measured when invertebrate samples were taken) were used to find association between these variables and different habitats.

PERMANOVA was used to assess the partitioning of multivariate variation between invertebrate samples according to habitat type and site. PERMANOVA uses permutations (randomisation) to calculate P-values. Monte Carlo P values were used in the interpretation of the results as this value is most reliable for small numbers of permutations (Clarke & Gorley 2006). PERMANOVA was used to determine if there were significant differences in invertebrate community composition (using percent abundance data) between sites and to identify where any differences occurred. One beach sample from the Victoria site was removed from the PERMANOVA analysis on March sampling because it was an extreme outlier.

A SIMPER analysis was also done in PRIMER using fourth-root transformed percent abundance data for all dates combined This analysis was done to examine the contributions of taxa to the average Bray-Curtis dissimilarity between sites and habitat types, and contributions to the average similarity within a site or habitat (Clarke & Gorley 2006).

Species accumulation plots were constructed in PRIMER to determine the contributions of different habitats to the number of species at each site. The total abundance of invertebrates was used for this analysis. The S estimation used was Jackknife 1 which was the least biased and most precise estimator in a test by Palmer (1990). Melo & Froehlich (2001) also found the Jackknife method was a good estimator of species richness. Walther & Morand (1998) recommended Jackknife 1 as one of two estimates that should be used to control for the confounding effects of sampling effort on estimates of total species richness. Jackknife 1 estimates species richness based on the presence of 'unique species' (a species that occurs in one sampling unit) in the sampling units (Heltshe & Forrester 1983). Willow/riprap was excluded from the analysis of combinations of habitats because it is the mixture of riprap and willow.

3.5.2 Fish

Weight-length relationships (Table 3.2) were used to calculate the weights of species caught by electrofishing using the equation LnW=a+bLnL. The data was log transformed before analysis. All data was assessed for normality using expected normal histograms and Lilliefors test, and a Levene’s test was used to assess homogeneity of variance. Two-way factorial ANOVAs were used to analyse differences between habitat, site and season and density and biomass of fish. If there was no interaction a main effects ANOVA was also completed. A Tukey post-hoc test was used to analyse where the differences were for habitat and site. Species accumulation plots were constructed in PRIMER to determine the contributions of different habitats to the number of species at each site.

Spotlighting total numbers of native fish were used in this analysis. The S estimation used was Jackknife 1. Willow/riprap was excluded from the analysis of combinations of habitats because it is the mixture of riprap and willow. Boat electrofishing was excluded from the analysis because difficulty sampling willow habitats and trapping results were excluded because they were inconsistent and provided lower numbers of fish.

Table 3.2. Weight-length relationship values used in calculation of weights of fish caught by boat electrofishing, showing a, b, r^2 and N (number of fish used in creating values).

Species	*a*	*b*	r^2	*N*	Source
Shortfin eel	0.000000366	3.270	0.982	370	B. Hicks, unpublished data
Longfin eel	0.000000271	3.353	0.996	113	Hicks and McCaughan 1997
Grey mullet	0.0000146	3.012	0.969	112	B. Hicks, unpublished data
Rudd	0.00000296	3.365	0.990	294	B. Hicks, unpublished data
Brown trout	0.0000496	2.785	0.779	14	B. Hicks, unpublished data
Inanga	0.00000212	3.220	0.894	128	B. Hicks, unpublished data
Catfish	0.00000450	2.978	0.956	281	B. Hicks, unpublished data
Common bully	0.00000823	3.096	0.976	115	B. Hicks, unpublished data
Common smelt	0.000000339	3.724	0.916	2037	B. Hicks, unpublished data
Goldfish	0.0000115	3.1442	0.983	2006	B. Hicks, unpublished data
Koi carp	0.0000264	2.9758			B. Hicks, unpublished data

4. INVERTEBRATES

4.1 Results

4.1.1 Physicochemical conditions

Conductivity, dissolved oxygen and water temperature were similar for each habitat within a site on each date, and habitat differences are therefore not shown (Table 4.1). In December the specific conductance was lowest at Ann Street and highest at Swarbrick Landing and the dissolved oxygen was above 100% saturation. The average water temperature in December ranged from 19.1-20.8ºC. In March the specific conductance and temperature did not vary greatly between sites and were similar to December, whereas dissolved oxygen was lower at this time (Table 4.1). In June, Ann Street and Victoria Bridge had similar dissolved oxygen levels (mg L^{-1}) and Victoria Bridge had had slightly higher percent concentration of dissolved oxygen (Table 4.1). The temperature in June ranged from 13.5 to 14.3ºC.

Average velocity was highest at the beach and lowest at the willow habitats (Table 4.2). Average shade (%) was highest for the willow and willow/riprap, intermediate at the riprap sites and lowest for the beach sites (Table 4.2). The velocity in the riprap habitats was highest at Victoria Bridge (0.08 m s^{-1}) and similar at Swarbrick Landing and Ann Street (0.03-0.03 m s^{-1}). The shade for beach and riprap did not vary greatly over the three sampling periods; however, Victoria Bridge riprap had more shade (51%) compared to Ann Street (7%) and Swarbrick Landing (2%) due to alder trees lining the upper bank. The average shade at the willow/riprap decreased from 6-67% in December and March to 34% in June. The average shade for the willow decreased slightly from 77 % in December to 67% March and then decreased to 28% in June (Table 4.2). The decrease in average shade in June is due to the deciduous riparian trees (including willows) losing their leaves.

The substrate sampled at the beach habitats was mostly sand and silt, whereas the at willow habitats it was mostly organic material comprising roots and wood (Table 4.2). There was some seasonal variability in substrate sampled under willows with a mixture of sand/silt, roots and wood in December and mostly roots and wood in March and June. At riprap habitats the substrate sampled was mostly cobbles and boulders, and for willow/riprap habitats , it was a mix of organic and inorganic substrates (Table 4.2). There was no compaction of the substrate at beach habitats (compaction class 4) whereas in the riprap habitats rock was mostly moderately to loosely packed (compaction classes 2-3). The willow/riprap habitats at each site were all different in terms of compaction and highly variable; Ann Street ranged from compaction class 2-4, Victoria Bridge from 1-3 and Swarbrick Landing from 1-4. Compaction was not assessed for the willow sites where organic substrates predominated.

Embeddedness was low all year for beach habitats (0-5%), where natural substrates were sand and velocities were relatively high; and for riprap habitats embeddednesss was highest in March at all three sites (26-50% at Ann Street, 51-75% at Victoria Bridge and 5-25% at Swarbrick Landing). In December, Ann Street riprap was mostly 0-5% covered in fine sediment, and Victoria Bridge and Swarbrick Landing were mostly 5-25% covered. In June, Ann Street and Swarbrick Landing were mostly 5-25% covered in fine sediment and at Victoria Bridge cover was 0-5%. Eembeddedness for the willow/riprap was lowest in June at Ann Street and Victoria Bridge (Swarbrick Landing was not sampled in June).

In March and December, embeddedness at Ann Street and Swarbrick Landing was mostly 5-25 % and was slightly lower in March for Victoria Bridge (0-25%). In December, the embeddedness at Swarbrick Landing varied widely with sampling sites ranging from 0-5% to >75% embeddedness, whereas at Victoria Bridge it was mostly 5-25% embedded. The willow habitat was predominantly silt and roots so embeddedness was difficult to assess. Most willow samples were collected where embeddedness was 0-5%, except two samples at Ann Street in December where they were 5-25% embedded. The average shoreline sinuosity was higher in March in all sites (1.21-1.28) compared to December (1.13-1.22) and June (1.13-1.16). In higher flows (data not shown) willow habitat shoreline sinuosity decreased with increasing River level. Beach habitats increased in shoreline sinuosity, while riprap habitats showed minimal change with river level. Willow/riprap habitats were variable with Ann Street showing little change as the bank was convoluted in the upper and lower slopes, while Swarbrick Landing and Victoria Bridge with more boulders and alder trees showed a decrease in shoreline sinuosity with River level.

Table 4.1. Average and range of specific conductance, dissolved oxygen, water temperature and shoreline sinuosity for all habitats combined at each site and date.

Site	Specific conductance (μS cm^{-1})	Dissolved oxygen DO %	DO mg L^{-1}	Temperature (^{o}C)	Shoreline sinuosity (M)
December					
Ann Street	156.5	107.3	9.8	19.5	1.22
	156-157	105-108	9.02-9.75	19.2-20.8	1.14-1.34
Swarbrick Landing	165.8	103.6	9.5	19.9	1.18
	165-166	97-107	9.3-9.8	19.1-20.8	1.0-1.53
Victoria Bridge	163.7	106.7	8.8	20.6	1.13
	163.3-163.7	104-109	6.58-9.8	20.4-20.8	0.98-1.36
March					
Ann Street	158.3	88.6	8.2	19.6	1.28
	157-158	85-94	7.8-9.02	19.5-20	0.96-1.57
Swarbrick Landing	155.4	91.0	8.6	19.6	1.21
	148-158	85-96	7.9-9.6	19-20.3	0.99-1.56
Victoria Bridge	158.0	90.3	8.4	20.0	1.24
	156-159	77-96.7	8.1-8.6	19.5-20.5	0.99-1.52
June					
Ann Street	170.4	88.5	9.6	13.8	1.13
	170-171.4	82-91	9.2-10	13.5-14.1	1.04-1.22
Victoria Bridge	167.8	113.8	9.1	14.2	1.16
	167-168	99-149	7.6-10.4	14-14.3	0.95-1.48

Table 4.2. Mean (±1 SE) shade and velocity, and average substrate composition for locations where invertebrate samples were taken for each habitat over all sampling dates and sites combined (values < 3% not shown).

Habitat	Shade (%)	Velocity (m s^{-1})	Substrate
Beach	<1 +/- 0.28	0.12 +/- 0.02	53% sand, 21% silt, 12% small gravel, 6% macrophyte.
Willow	62 +/-3.8	0.01 +/- 0.01	55% roots, 33% wood, 5% sand, 4% silt.
Willow/riprap	57 +/- 3.7	0.03 +/- 0.02	26% roots, 30% cobble, 14 % large gravel, 9% boulder, 9% silt, 7% wood.
Riprap	23 +/- 4.1	0.05 +/- 0.02	68% coble, 12% boulder, 4% wood, 3% sand.

4.1.2 Diversity patterns

Differences in diversity patterns among habitats are shown for each sampling date and site in Figures 4.1-4.4. The average number of taxa across all sites was lowest in March and was similar in December and June. In December, taxa richness was highest for riprap ranging from 11-18 taxa with an average of 14.2 across all sites taxa. The next highest number of taxa across all sites was in the willow/riprap with an average of 12.4 (range 8-16), and then willow with 11.5 taxa (6-14) and beach with 9.8 taxa (7-15). The pattern was similar in March when riprap had the highest number of taxa with an average of 9.3 (3-17 taxa), followed by willow /riprap (8.4; 4-16), willow (6.5; 4-9) and beach (4.5; 1-11). In June the highest number of taxa overall was under willow (12.9) and willow/riprap (13.4) ranging from 9-18 taxa. Riprap and beach had a lower average number of taxa with 11.8-12.3 ranging from 7-16 taxa.

The ANOVA analysis for December indicated no significant difference in the number of taxa between sites but a habitat effect which varied across sites (Table 4.3 and Figure 4.1A). Tukey post-hoc tests showed there were significant differences between Swarbrick Landing beach (low richness) and Swarbrick Landing riprap (highest richness), and Victoria Bridge willow/riprap and Victoria Bridge willow (low richness). There were no significant differences between habitats at Ann Street.

In March there was a significant difference in the number of taxa between sites and habitat, but no interaction between the two, whereas in June there were no significant differences between either factor (Table 4.3 and Figure 4.1B & C). Post-hoc tests following the main effects ANOVA for March showed beach was different to riprap and willow/riprap, riprap was not different to willow/riprap, willow was not different to beach, and riprap was not different to willow. The Tukey post-hoc test for sites in March showed Victoria Bridge was significantly different to Ann Street and Swarbrick Landing, and Ann Street was not significantly different to Swarbrick Landing.

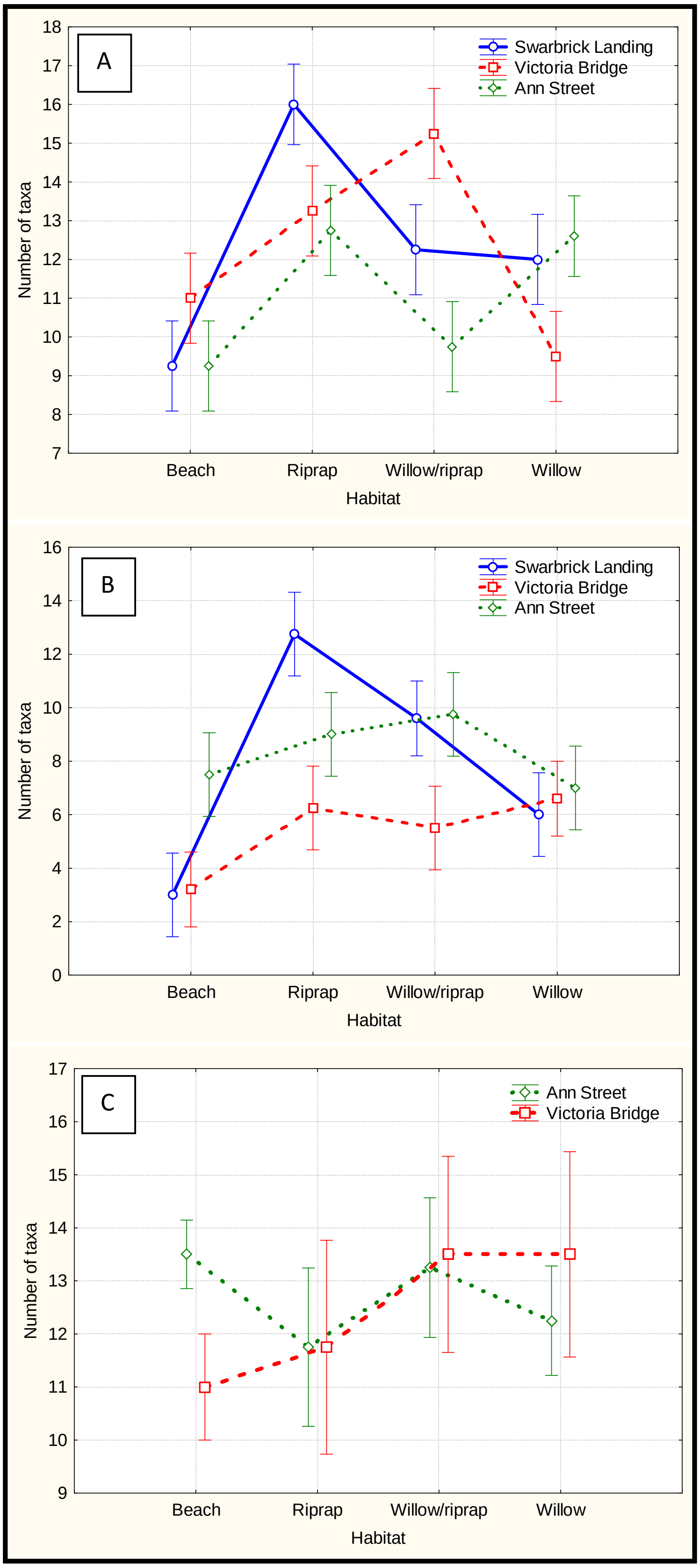

Figure 4.1. Mean (± 1 SE) number of taxa for each site and habitat for A, December; B, March; and C, June.

Table 4.3. Summary of ANOVA results for number of taxa in December, March and June showing sum of squares (SS), degrees of freedom (d.f.), mean squares (MS), F values and probability value (p) .

	SS	d.f.	MS	F	p
		December			
Intercept	7036.594	1	7036.594	1301.487	0
Site	16.878	2	8.439	1.561	0.223
Habitat	114.766	3	38.255	7.076	0.001
Site X Habitat	104.748	6	17.458	3.229	0.012
Error	205.45	38	5.407		
		March			
Intercept	2604.148	1	2604.148	266.2519	0
Site	84.782	2	42.391	4.3341	0.020
Habitat	164.408	3	54.803	5.6031	0.003
Site X Habitat	110.197	6	18.366	1.8778	0.109
Error	381.45	39	9.781		
		June			
Intercept	5050.125	1	5050.125	571.712	0
Site	0.5	1	0.500	0.057	0.814
Habitat	12.125	3	4.042	0.458	0.714
Site X Habitat	15.25	3	5.083	0.576	0.637
Error	212	24	8.833		

The rarefied richness data did not meet the assumptions of normality so ANOVA was not carried out. In December, the highest average rarefied richness was on the riprap at 10 (Figure 4.2A) consistent with the average number of taxa found in each sample, although the average number of taxa found was higher (average 14.2 species) (Figure 4.1A). All other habitats were similar with averages ranging from 8.5-8.7, with highest variability at beach sites (7.1-10.6 taxa; Figure 4.2). For March, Victoria Bridge willow and beach, and Swarbrick Landing beach, had sample sizes lower than 99 and so could not be included in the rarefaction analysis. Ann Street beach had rarefied richness of 8.9 at this time, higher than any other habitat type at that site (Figure 4.2B). Riprap sites had average rarefied richness of 7.1-7.3 across all sites in March, whereas willow had the lowest average with 5.1 (Figure 4.2B). This pattern is generally consistent with the average number of taxa in each sample in March (although low numbers in the beach habitats prevents its comparison) (Figure 4.1) indicating these comparisons were not affected by species-abundance relationships. In June, the rarefied richness was similar for beach (9.4), willow/riprap (9.1) and riprap (9) and again was lowest at the willow with an average of 7 taxa (Figure 4.2C). This pattern was similar to the average number of taxa in each sample where there were no significant differences over habitats or sites (Figure 4.1).

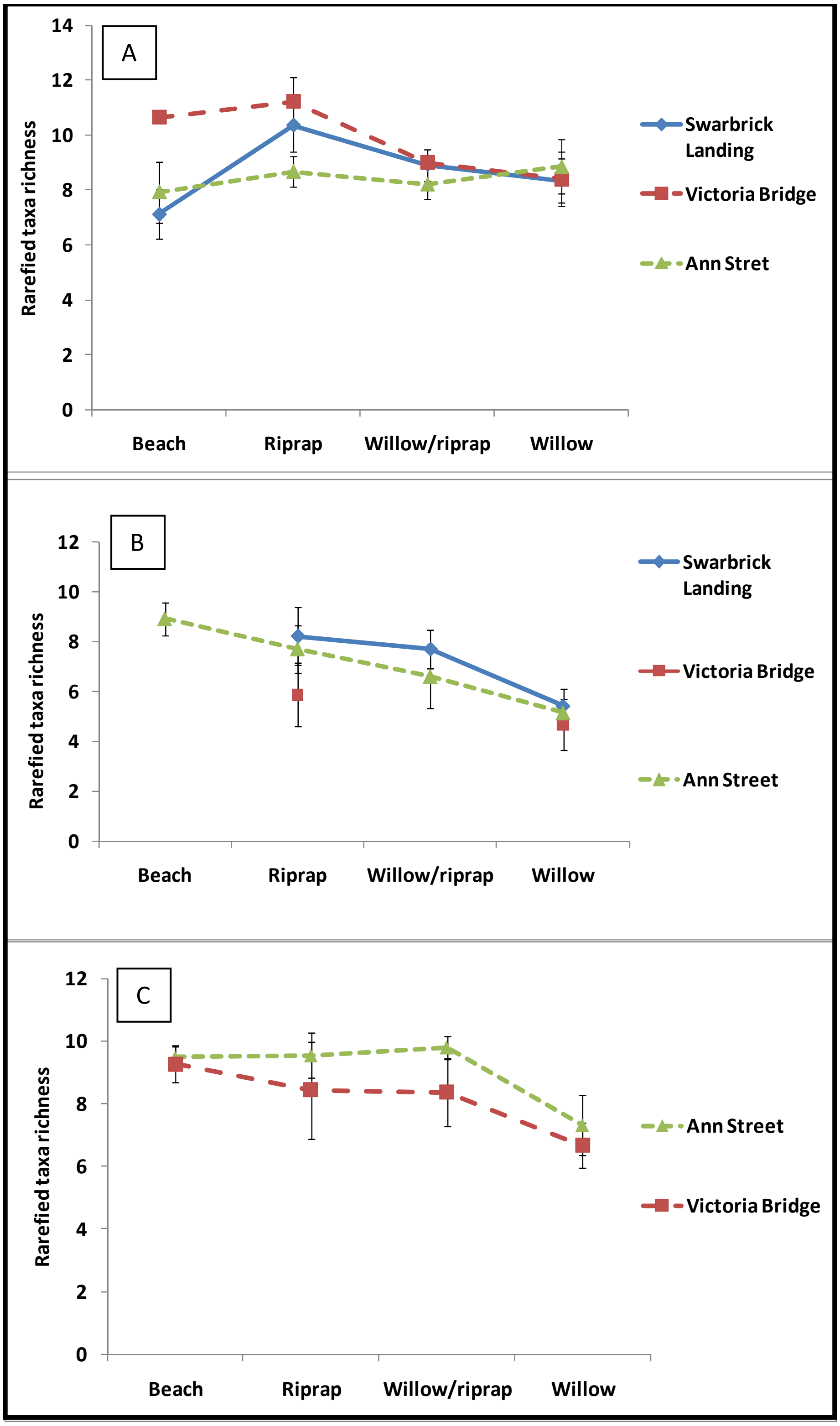

Figure 4.2.Mean (± 1 SE) rarefied richness (ES=99) at each site and in each habitat for A, December; B, March; and C, June.

In December, the average Margalef's diversity value across all sites was highest at the riprap at 1.94 followed by willow/riprap and willow (1.82-1.83), and then beach (1.76) (Figure 4.3A). In March, riprap and willow/riprap had the highest Margalefs diversity value (1.44-1.45), followed by willow at 1.06 and beach at 0.93 (Figure 4.3B). In June, highest diversity was for beach and willow/riprap (2.03-2.04), then willow at 1.86 and riprap at 1.83 (Figure 4.3C). The ANOVA indicated a significant difference in Margalef's diversity between sites but not between habitat types, and no interaction between factors, for December and March (Figure 4.3 and Table 4.4). In June there were no significant differences in Margalef's diversity between sites or habitats (Figure 4.3 and Table 4.4). Post-hoc tests following the main effects ANOVA showed Swarbrick Landing and Victoria Bridge were significantly different in December, whereas Victoria Bridge and Ann Street were significantly different in March.

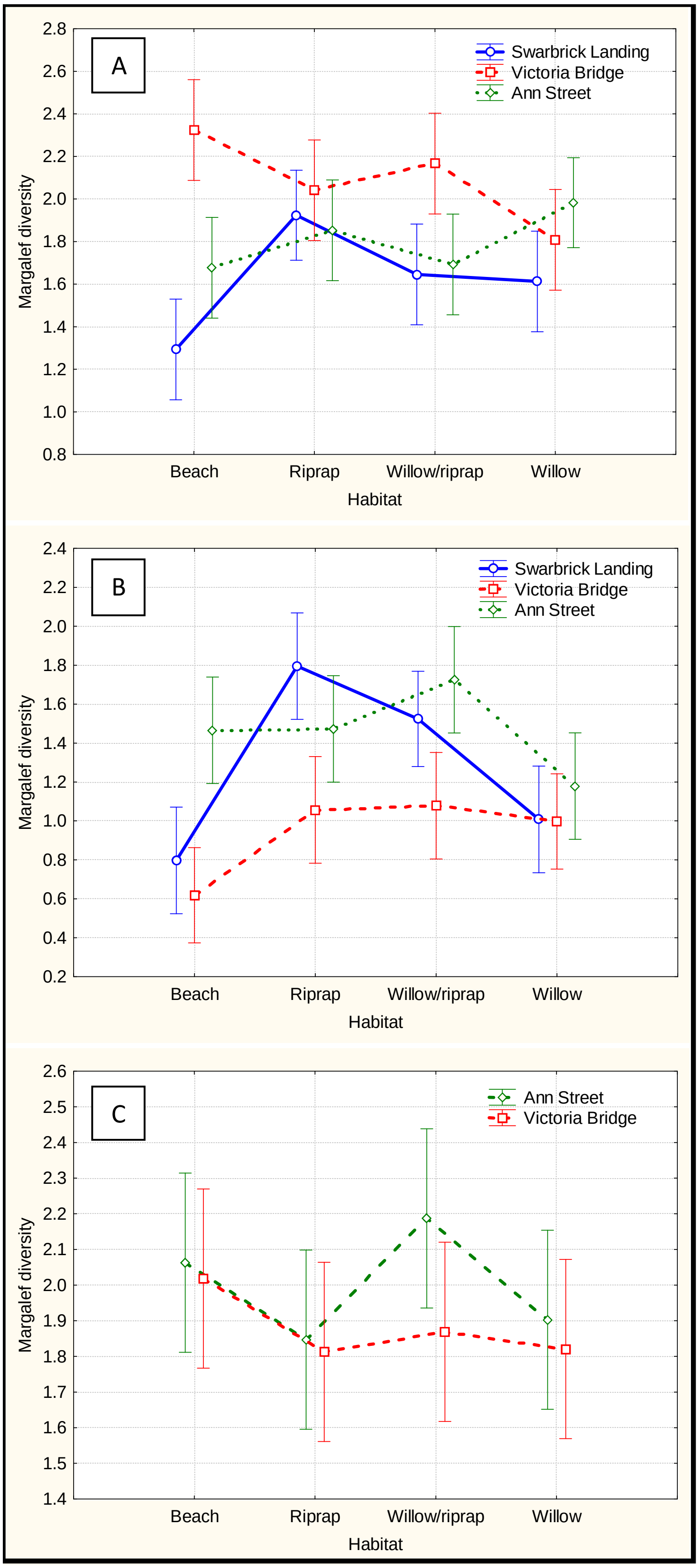

Figure 4.3. Mean (± 1 SE) Margalef diversity at each site and in each habitat for A, December; B, March; and C, June.

Table 4.4. Summary of ANOVA results for Margalef diversity in December, March and June showing sum of squares (SS), degrees of freedom (d.f.), mean squares (MS), F values and probability value (p)

	SS	d.f.	MS	F	p
December					
Intercept	167.216	1	167.216	746.832	0
Site	1.804	2	0.902	4.028	0.026
Habitat	0.214	3	0.071	0.318	0.812
Site X Habitat	1.495	6	0.249	1.113	0.373
Error	8.508	38	0.224		
March					
Intercept	76.012	1	76.012	253.9712	0
Site	2.409	2	1.204	4.024	0.026
Habitat	2.413	3	0.804	2.6879	0.060
Site X Habitat	1.441	6	0.240	0.8022	0.574
Error	11.673	39	0.299		
June					
Intercept	120.440	1	120.440	476.910	0
Site	0.115	1	0.115	0.454	0.507
Habitat	0.290	3	0.097	0.382	0.767
Site X Habitat	0.107	3	0.036	0.142	0.934
Error	6.061	24	0.253		

Pielou’s evenness was highest in December for riprap and beach (0.61-0.63), followed by willow/riprap and willow (0.51- 0.53) over all sites combined. In March, Pielou’s evenness was also highest for beach and riprap (0.58-0.60), although there was considerable variability among beach sites, then willow/riprap at 0.55 and willow at 0.45. In June, beach had the highest evenness score with 0.65 followed by riprap with 0.60, willow/riprap with 0.50 and willow with 0.36 across all sites. ANOVA analysis indicated there was no significant difference in Pielou’s evenness between sites or habitats in December (Figure 4.4A and Table

4.5). In March, data for Pielou’s evenness did not meet assumption of homogeneity of variance so ANOVA was not carried out. In June there was a significant difference between habitats and an interaction between site and habitat (Figure 4.4C and Table 4.5). The Tukey post-hoc test for the interaction showed: Ann Street riprap was different to Ann Street willow, Ann Street willow was different to Ann Street riprap, and Victoria Bridge beach was different to Victoria Bridge willow.

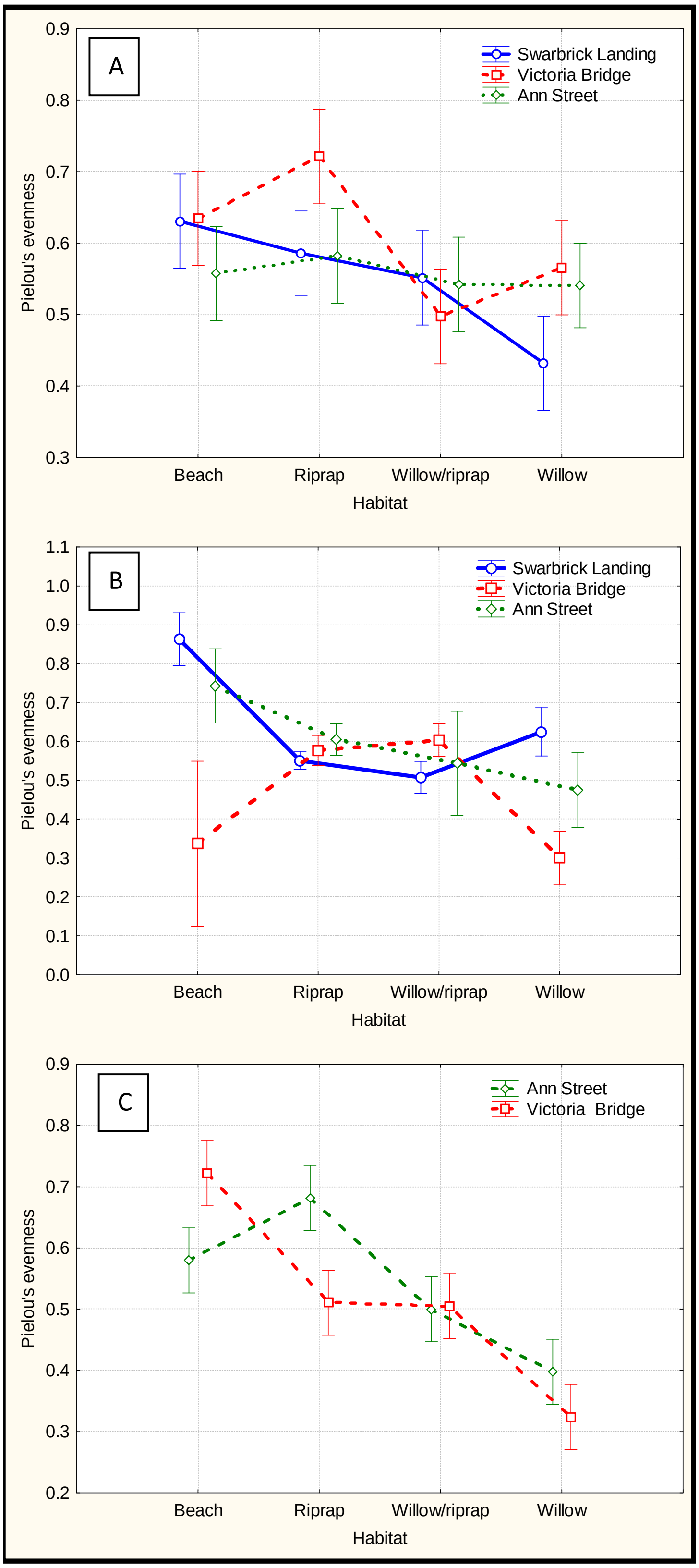

Figure 4.4.Mean (± 1 SE) Pielou’s evenness at each site and in each habitat for A, December; B, March; and C, June.

Table 4.5. Summary of ANOVA results for Pielou's evenness in December and June showing sum of squares (SS), degrees of freedom (d.f.), mean squares (MS), F values and probability value (p).

	SS	d.f.	MS	F	p
			December		
Intercept	16.135	1	16.135	924.013	0
Site	0.030	2	0.015	0.847	0.437
Habitat	0.124	3	0.041	2.366	0.086
Site X Habitat	0.086	6	0.014	0.819	0.562
Error	0.664	38	0.017		
			June		
Intercept	8.904	1	8.904	790.479	0
Site	0.005	1	0.005	0.425	0.521
Habitat	0.386	3	0.129	11.425	0.000
Site X Habitat	0.105	3	0.035	3.112	0.045
Error	0.270	24	0.011		

4.1.3 Taxonomic composition

Macroinvertebrate communities were dominated by Crustacea, mainly *Paracalliope* (51-79% of total numbers), on all dates except for beach in December when Diptera dominated (51%) (Figure 4.5A). The next most common invertebrate groups at beach habitats in December were Oligochaeta (28%) and Crustacea (16%). At willow habitats, Oligocheata comprised 19% of numbers and Mollusca and Diptera comprised 9-10%. Diptera and Trichoptera comprised 13-15% of numbers at the willow-riprap habitats, and Mollusca and Diptera comprised 10-23% of numbers at the riprap habitats (Figure 4.5A).

In March, the second dominant invertebrate group at all sites was Mollusca (1-31%), except for the beach sites which were dominated by Oligocheata (19%) (Figure 4.5B). For the June sampling, the second dominant invertebrate group at all sites was Diptera (13- 27%) except for the willow sites which had more Trichoptera (13%) than Diptera (6%) (Figure 4.5C). The other groups at the beach site in June included Trichoptera (7%), Plecoptera (6%), Oligocheata (6%) and then Mollusca (4%). At the willow/riprap and riprap sites in June, Trichoptera and Mollusca both comprised 5% of numbers (Figure 4.5C).

Percentages of Mollusca and Oligocheata were lower in June compared to December and March, whereas Diptera were more common in December and June compared to March (Figure 4.5). Trichoptera were relatively less abundant in March, while Plecoptera were more abundant in June, especially at the beach habitats (Victoria Bridge and Ann Street) where *Zelandobius* was relatively common (Figure 4.5). There were far more Trichoptera at willow/riprap habitats in December with 13% compared to 2-3% in other habitats. This pattern was consistent in March when Trichoptera comprised 3% in willow/riprap habitats, 2% in beach and around1% in other habitats. In June, however, there were by far more Trichoptera in the willow habitats with 12% compared to 5-7% in other habitats. The Trichoptera comprised mostly *Aoteapsyche colonica* followed by *Orthopsyche* in December and *Oxyethira* in March and June.

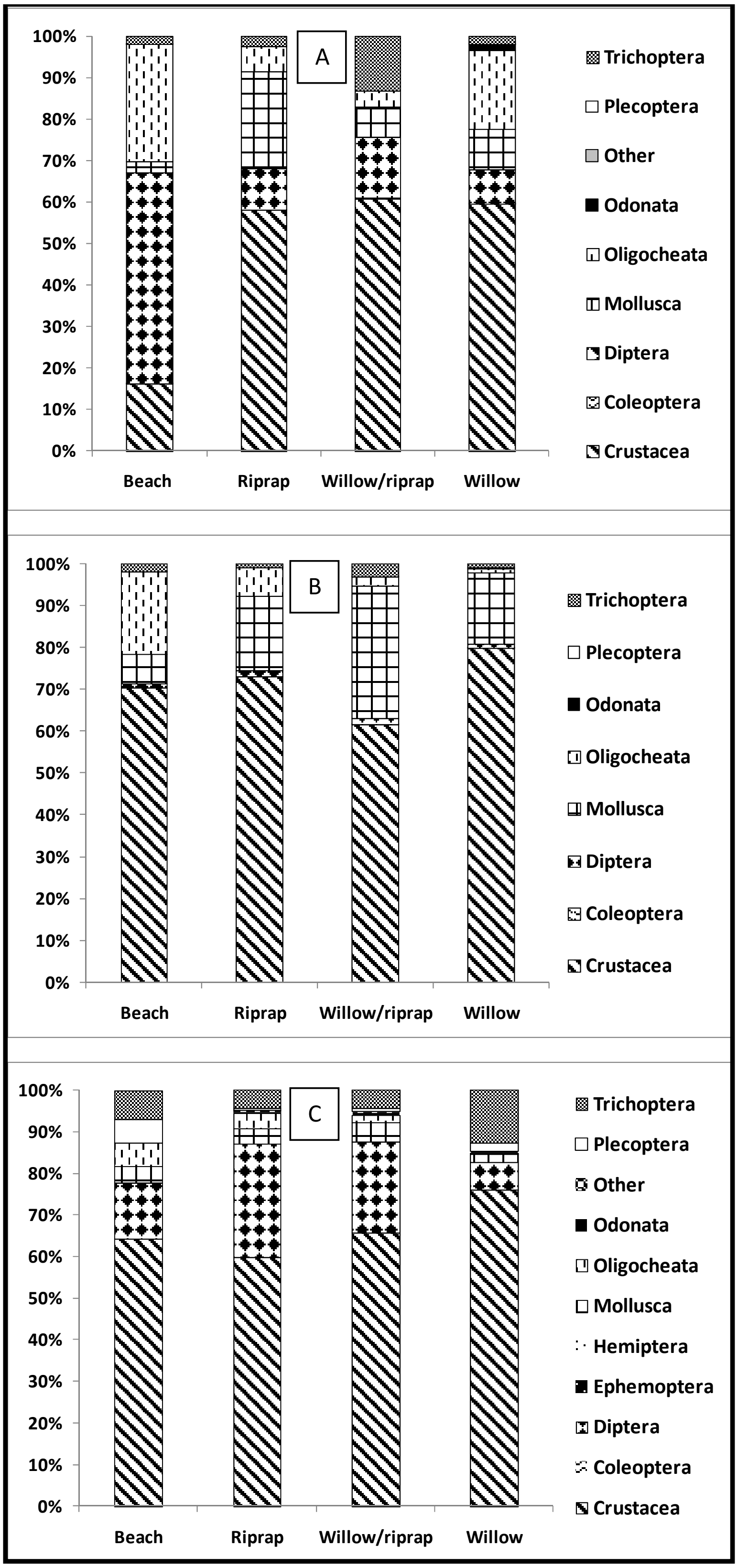

Figure 4.5. Percent composition of invertebrate taxa for A, December; B, March, and C, June for each habitat type for all sites combined.

4.1.4 Habitat and site differences

The non-metric multi dimensional scaling (MDS) plots had two dimensional stress values ≥0.2 and patterns were unable to be determined in two dimensions (McCune & Grace 2000). The three dimensional MDS analysis yielded stress values of 0.14 to 0.15 which are considered to provide useable representation of biological pattern (McCune & Grace 2000). The stress value shows how well the high dimensional relationships among samples are represented in the 2D or 3D plots (Clarke & Gorley 2006). For the purpose of presenting results, three dimensional analyses are presented as a series of graphs depicting axes 1 and 2, 1 and 3, and 2 and 3.

PERMANOVA was used to determine the significance of differences among sites and habitats. PERMANOVA is an analysis of variance of samples based on resemblance measures (Bray Curtis in this instance) using permutation (randomisation) measures (Clarke & Gorley 2006). The analysis indicated that there was a habitat effect in December and June, a site effect in all months, and an interaction between these factors in December and March (Table 4.6). In December, beach and riprap were significantly different in all sites and riprap and willow/riprap were not significantly different at any site (Table 4.6). The MDS plot for December shows the difference between beach and riprap most clearly on axes 2 vs. 3, and in all plots riprap and willow riprap are intermingled reflecting the lack of a significant difference found in PERMANOVA (Figure 4.6). Riprap and willow, and beach and willow, were significantly different at Swarbrick Landing and Ann Street (Table 4.7). The difference in riprap and willow at two sites is shown in axis 1 vs. 2 and axis 2 vs. 3, and the difference at two sites between beach and willow is shown at axes 2 vs. 3 (Figure 4.6A). Willow and willow/riprap were only significantly different at Swarbrick Landing (Table 4.7).

In March, riprap and willow were significantly different at Swarbrick Landing and Ann Street and borderline at Victoria Bridge (Table 4.7). Only Swarbrick Landing had significant differences between beach and riprap at this time, and only Ann Street showed differences between willow and beach. The differences between riprap and willow are shown on MDS axes 1 vs. 3 and 2 vs. 3 (Figure 4.7B and C). Willow and willow/riprap were significantly different at Swarbrick Landing and Victoria Bridge. In June, there were significant differences among all habitat comparisons at Ann Street, whereas only beach and willow, and willow and willow/riprap showed differences at Victoria Bridge (Table 4.6). This is shown on MDS axes 1 vs. 2 and 1 vs. 3 (Figure 4.8A and B). Overall, willow and riprap had significantly different assemblages on five out of the eight sampling date/site combinations. Victoria Bridge willow and riprap were only borderline significantly different ($P = 0.05$) in March. Willow and willow/riprap had similar assemblages (i.e., they were not significantly different) in three out of eight comparisons. Riprap and willow/riprap had similar assemblages on six out of eight comparisons, while willow and beach were significantly different in five comparisons.

4.1.5 Taxa associations

In December, axis 1 vs. 2 of the taxa vector overlay shows *Gyraulus* were associated with willow habitats at the top of the plot and Oligocheata spp. A and B and Tanypodinae were associated with the beach samples at the bottom left of the plot (Figure 4.6A). *?Ecnomina* and Tanitarsini were associated with the beach samples at the bottom right of the plot. The beach samples on the bottom left of axis 1 vs. 3 were associated with Oligocheata spp. A and B and Orthocladiinae (Figure 4.6B). *Amarinus lacustris* and *Parachironomus* were associated with the riprap samples on the bottom right of the plot (Figure 4.6 B). *Tanais stanfordi* was associated with the beach samples in the bottom left of axis 2 vs. 3, and *?Ecnomina* and Diptera were associated with the beach samples at the top left of the plot (Figure 4.6C).

The MDS vector overlay of taxa in March (axis 2 vs. 3) shows Oligocheata spp. A and B were associated with the willow samples on the far left of the plot (Figure 4.7C). *Gyraulus* spp. was associated with the willow/riprap in the bottom left of the plot (Figure 4.7C). *Oxyethira albiceps*, *Orthopsyche* and Tanitarsini were associated with the willow and willow/riprap samples at the bottom right of the plot (Figure 4.7C). *Potamopyrgus* and *Tanais stanfordi* were associated with the willow and beach samples in the top right of the plot (Figure 4.7C). On axis 1 vs. 3 *Tanais, Aoteapsyche colonica* and *Preatogammarus* were amongst the taxa associated with riprap samples at the top left of the plot (Figure 4.7B)

The MDS taxa vector overlay for June (axis 1 vs. 3) shows *Ferrissia* and Hirudinea were associated with the willow/riprap samples at the bottom of the plot (Figure 4.8B). The *Paracalliope* and *Oxyethira* were associated with the willow samples on the far right of axes 1 and 2 (Figure 4.8A). *Paraoxyethira hendersoni* was associated with the willow and willow/riprap samples at the right of the plot (Figure 4.8B). *Gyraulus* spp. was associated with the beach samples the bottom right of axis 1 and 3(Figure 4.8B). *Potamopyrgus* was associated with the riprap samples on the left of axes 1 vs. 2 and 1 vs. 3 (Figure 4.8A and B).

Table 4.6. PERMANOVA analysis of all sites showing degrees of freedom (d.f.), sum of squares (SS), mean squares (MS), F values , the permutation P value, number of permutations (unique perms) and the Monte Carlo (MC) P value.

Source	d.f.	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
December							
Habitat	3	11499	3832.9	1.9989	0.0235	9929	0.0225
Site	2	8443.7	4221.8	6.0627	0.0001	9927	0.0001
Habitat X Site	6	11518	1919.7	2.7567	0.0001	9853	0.0001
Residual	38	26462	696.37				
Total	49	58314					
March							
Habiatat	3	9124.8	3041.6	1.7214	0.0983	9930	0.0929
Site	2	8635.4	4317.7	5.5194	0.0001	9947	0.0001
Habitat X Site	6	10612	1768.7	2.261	0.0004	9891	0.0008
Residual	38	29727	782.28				
Total	49	58330					
June							
Habitat	3	7074.2	2358.1	3.16	0.0358	840	0.0051
Site	1	2303.1	2303.1	4.2179	0.0004	9932	0.0006
Habitat X Site	3	2238.6	746.21	1.3666	0.095	9899	0.1342
Residual	24	13105	546.04				
Total	31	24721					

Table 4.7. Post-hoc habitat comparisons showing significant differences for each site and date.

Habitats	Swarbrick Landing	Victoria Bridge	Ann Street
December			
Beach, riprap	<0.001	<0.05	<0.01
Beach, willow	<0.01	-	<0.01
Beach, willow/riprap	<0.01	0.05	-
Riprap, willow	<0.001	-	<0.01
Riprap, willow/riprap	-	-	-
Willow,willow/riprap	<0.05	-	-
March			
Beach, riprap	<0.01	-	-
Beach, willow	-	-	<0.01
Beach, willow/riprap	0.05	-	-
Riprap, willow	<0.001	0.05	<0.05
Riprap, willow/riprap	<0.05	.	-
Willow,willow/riprap	<0.05	<0.05	-
June			
Beach, riprap	Not sampled	-	0.05
Beach, willow	Not sampled	<0.05	<0.01
Beach, willow/riprap	Not sampled	-	<0.05
Riprap, willow	Not sampled	-	<0.01
Riprap, willow/riprap	Not sampled	-	<0.05
Willow,willow/riprap	Not sampled	<0.05	0.05

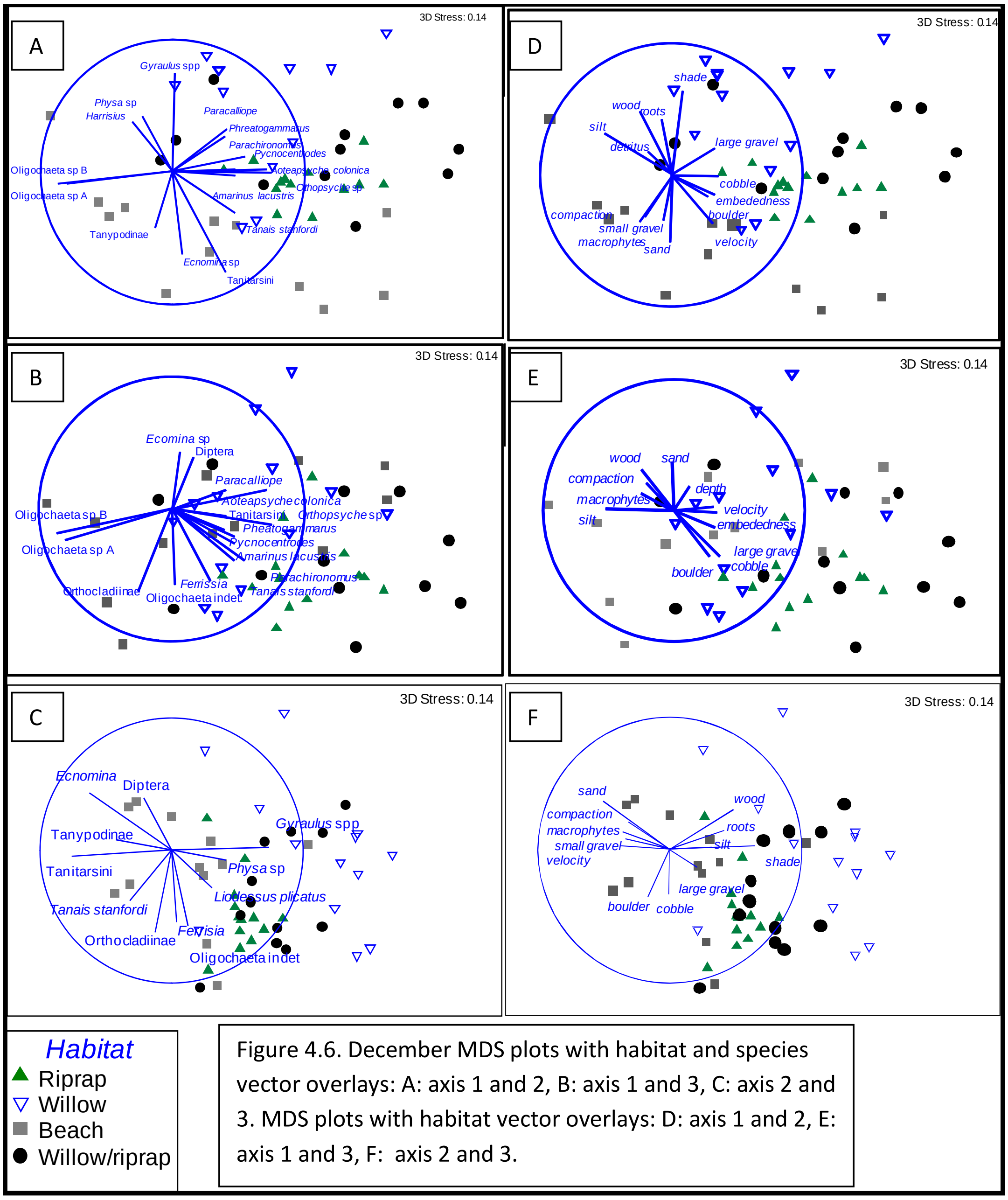

Figure 4.6. December MDS plots with habitat and species vector overlays: A: axis 1 and 2, B: axis 1 and 3, C: axis 2 and 3. MDS plots with habitat vector overlays: D: axis 1 and 2, E: axis 1 and 3, F: axis 2 and 3.

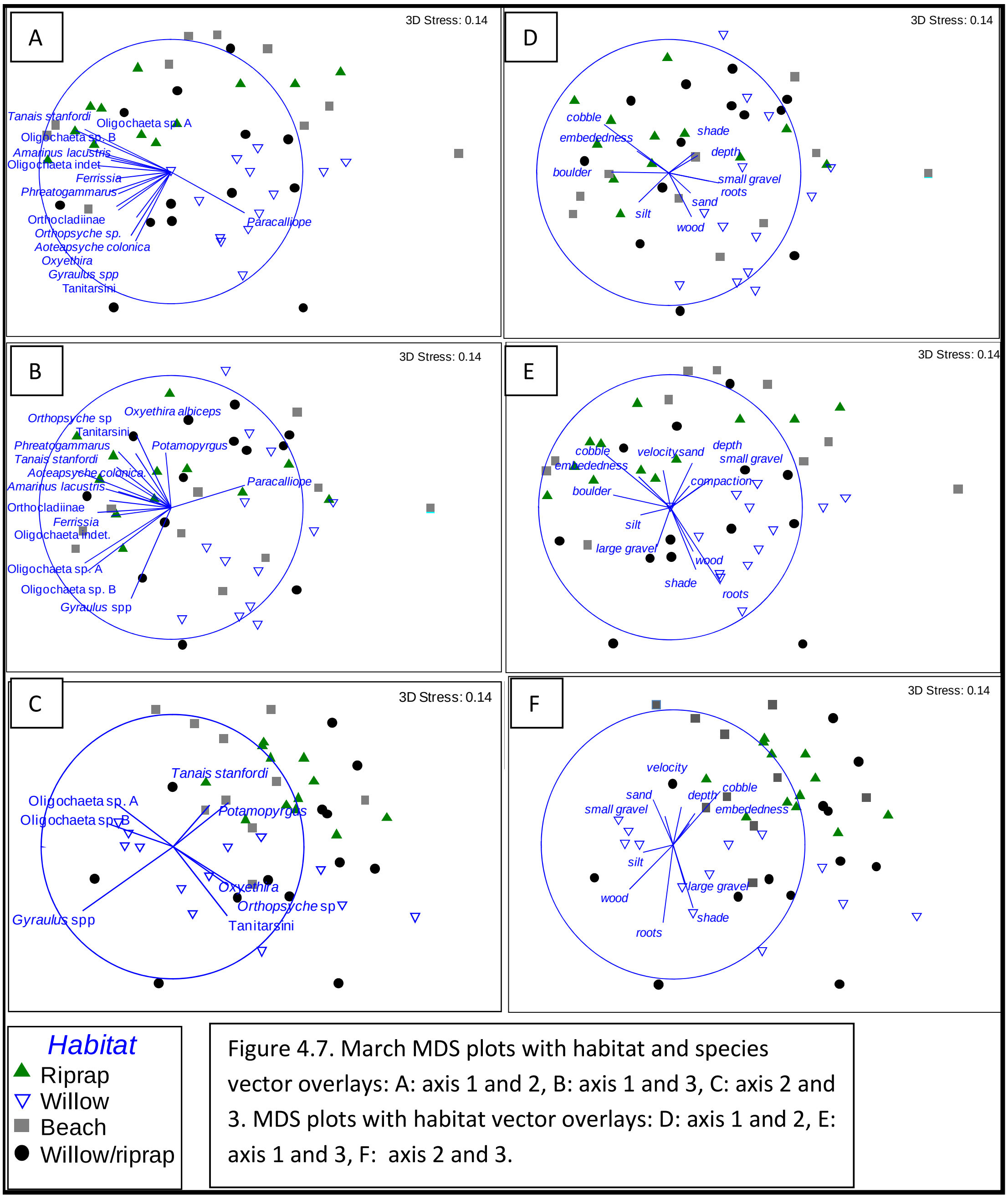

Figure 4.7. March MDS plots with habitat and species vector overlays: A: axis 1 and 2, B: axis 1 and 3, C: axis 2 and 3. MDS plots with habitat vector overlays: D: axis 1 and 2, E: axis 1 and 3, F: axis 2 and 3.

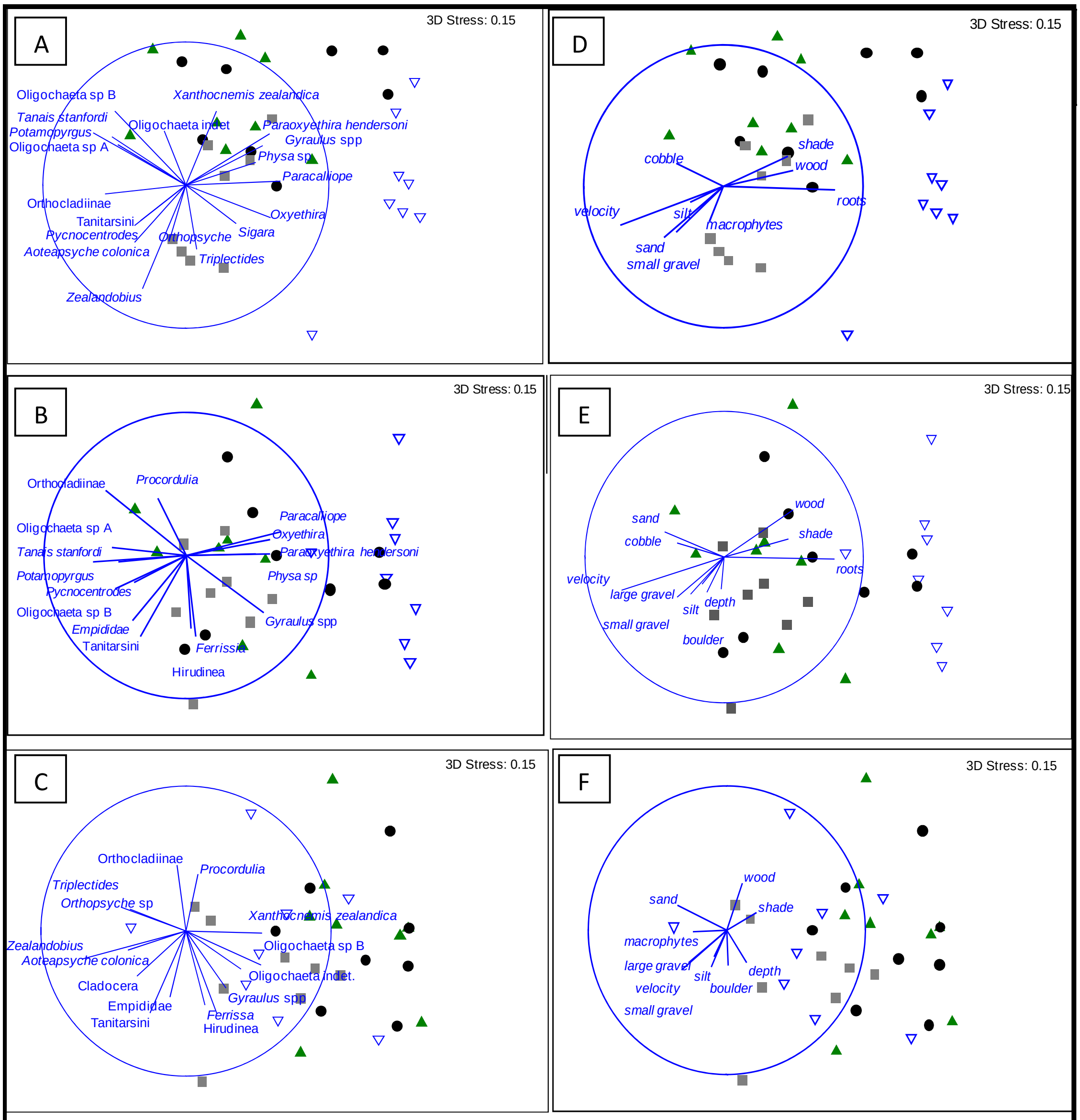

Figure 4.8. June MDS plots with habitat and species vector overlays: A: axis 1 and 2, B: axis 1 and 3, C: axis 2 and 3. MDS plots with habitat vector overlays: D: axis 1 and 2, E: axis 1 and 3, F: axis 2 and 3.

4.1.6 Physiochemical associations

The vector overlay of the habitat data for December shows the beach samples in the left top corner of the habitat vector plot for axis 2 vs. 3 were associated with more sand, small gravel and macrophytes, lower compaction (loose assortment = compaction class 4) and higher velocity (Figure 4.6F). The willow samples on the right were associated with more wood/ roots and higher shade, and the willow and willow/riprap samples on the right were associated with silt (Figure 4.6F).

The MDS habitat vector overlay for March shows the samples towards the bottom right of the plot on axis 1 vs. 3 were associated with wood, roots and shade (Figure 4.7E). The mixed riprap samples at the top right of the plot were associated with cobbles, depth and embeddedness (Figure 4.7F). The riprap samples on the top left of axis 1 vs. 2 and 2 vs. 3 were also associated with cobbles and embeddedness (Figures 4.7D and F). The willow/riprap samples at the bottom of axis 2 vs. 3 were associated with large gravel and the willow samples on the bottom right of the plot were associated with wood, shade and roots (Figure 4.7E). The habitat vector overlay for June shows the willow/riprap and willow samples in the far right of the plot were associated with wood, shade and roots (Figure 4.8E). The riprap samples on the left of the plot were associated with cobbles and sand (Figure 4.8E). The beach samples at the bottom of axis 1 vs. 2 were associated with macrophytes (Figure 4.8D).

A SIMPER analysis was done on the data for all dates combined to compare species abundance contributions between pairs of habitats. SIMPER examines the contributions to the average Bray-Curtis dissimilarity between sites and habitat types, and contributions to the average similarity within a site or habitat (Clarke & Gorley 2006). The habitats that were most dissimilar were beach and willow (55.4), beach and willow/riprap (54.7) and beach and riprap (53.2). Riprap and willow were 51.2 dissimilar and willow and willow/riprap (48.9) and riprap and willow/riprap (45.7) were the least dissimilar.

Tanais stanfordi was consistently more abundant in habitats with riprap (including willow /riprap) (Table 4.8). Oligocheata spp. A and B were more abundant in beach or riprap habitats compared to sites with willow. *Potamopyrgus antipodarum* was more abundant in habitats containing riprap or in willow compared to beach. Tanitarsini was more abundant in beach habitats with riprap and was slightly more abundant in riprap compared to beach and lowest in sites containing willow (Table 4.8). Orthocladiinae was more abundant in riprap and least abundant on willow. *Oxyethira* was less abundant in beach compared other habitats and was slightly more abundant in willow compared to other sites. *Gyraulus* was markedly more abundant in willow habitats (Table 4.8). *Physa* was slightly more abundant in willow habitats (although it contributed less to the differences between the sites and is not included in the SIMPER table).

Table 4.8. SIMPER analysis of all habitat comparisons for all dates and sites showing taxa contributing > 5% to the dissimilarity.

Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
	Beach	Riprap				
Tanais stanfordi	0.81	1.55	4.62	1.35	8.68	8.68
Oligochaeta sp B	1.31	1.04	4.1	1.33	7.71	16.39
Potamopyrgus antipodarum	1.17	1.84	4	1.02	7.51	23.9
Tanitarsini	1.12	1.17	3.89	1.14	7.31	31.21
Orthocladiinae	0.68	1.02	3.62	0.96	6.8	38.01
Oligochaeta sp A	0.89	0.84	3.11	1.18	5.84	43.85
Oxyethira	0.76	0.86	2.82	1.16	5.3	49.15
	Beach	Willow/riprap				
Oligochaeta sp B	1.31	0.82	3.95	1.23	7.23	7.23
Tanitarsini	1.12	1.05	3.92	1.23	7.17	14.39
Potamopyrgus antipodarum	1.17	1.57	3.84	0.95	7.03	21.42
Tanais stanfordi	0.81	0.88	3.78	1.07	6.92	28.34
Orthocladinae	0.68	0.63	3.17	0.88	5.8	34.14
Oxyethira	0.76	0.83	3.1	1.08	5.67	39.81
Oligochaeta sp A	0.89	0.55	2.93	1.14	5.36	45.17
	Riprap	Willow/riprap				
Tanais stanfordi	1.55	0.88	3.42	1.26	7.5	7.5
Tanitarsini	1.17	1.05	3.42	1.29	7.48	14.98
Orthocladiinae	1.02	0.63	3.08	1.21	6.76	21.74
Oligochaeta sp A	0.84	0.55	2.75	1.26	6.01	27.75
Oligochaeta sp B	1.04	0.82	2.7	1.18	5.9	33.66
Potamopyrgus antipodarum	1.84	1.57	2.45	1.19	5.36	39.02
	Beach	Willow				
Potamopyrgus antipodarum	1.17	1.45	3.93	1.07	7.09	7.09
Oligochaeta sp B	1.31	0.81	3.92	1.16	7.08	14.17
Tanitarsini	1.12	0.81	3.89	1.21	7.03	21.19
Oxyethira	0.76	0.88	3.56	1.14	6.42	27.62
Gyraulus spp	0.21	1.09	3.5	0.84	6.31	33.93
Tanais stanfordi	0.81	0.2	3.3	0.94	5.96	39.89
Orthocladiinae	0.68	0.44	3.2	0.78	5.78	45.67
Oligochaeta sp A	0.89	0.54	2.99	1.06	5.39	51.06
	Riprap	Willow				
Tanais stanfordi	1.55	0.2	4.87	1.77	9.52	9.52
Tanitarsini	1.17	0.81	3.47	1.32	6.79	16.31
Orthocladiinae	1.02	0.44	3.33	1.2	6.5	22.82
Gyraulus spp	0.21	1.09	3.16	0.97	6.17	28.99
Oligochaeta sp B	1.04	0.81	3.15	1.27	6.15	35.14
Oligochaeta sp A	0.84	0.54	2.78	1.27	5.44	40.58
Oxyethira	0.86	0.88	2.76	1.21	5.39	45.98
	Willow/riprap	Willow				
Tanitarsini	1.05	0.81	3.16	1.23	6.47	6.47
Tanais stanfordi	0.88	0.2	3.04	1.05	6.22	12.7
Oxyethira	0.83	0.88	2.91	1.21	5.95	18.64
Oligochaeta sp B	0.82	0.81	2.88	1.21	5.9	24.55
Potamopyrgus antipodarum	1.57	1.45	2.55	1.29	5.22	29.77
Orthocladiinae	0.63	0.44	2.53	1.02	5.18	34.95
Oligochaeta sp A	0.55	0.54	2.48	1.01	5.08	40.03

Among sites, Victoria Bridge and Ann Street were 52.8 dissimilar and Swarbrick Landing and Victoria Bridge were 50.40 dissimilar. Swarbrick Landing and Ann Street were the least dissimilar (48.93). Tanitarsini and *Potamopyrgus antipodarum* were more abundant at Victoria Bridge and Swarbrick Landing (Table 4.9). Oligocheata sp. B and *Gyraulus* were more abundant at Ann Street or Swarbrick Landing. Orthocladiinae was least abundant at Swarbrick Landing. *Oxyethira* and *Tanais stanfordi* were more abundant at Victoria Bridge or Ann Street (Table 4.9).

Table 4.9. SIMPER analysis comparing sites for all dates combined. Taxa contributing <5% to the dissimilarity are shown.

Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
	Swarbrick Landing	Victoria Bridge				
Tanitarsini	1.12	1.2	3.96	1.1	7.85	7.85
Oligochaeta sp B	0.98	0.7	3.78	0.92	7.51	15.36
Potamopyrgus antipodarum	1.72	1.45	3.38	0.87	6.71	22.06
Orthocladiinae	0.34	0.81	3.05	0.73	6.06	28.12
Gyraulus spp	0.68	0.06	2.85	0.72	5.65	33.77
Oxyethira	0.75	0.94	2.84	0.95	5.63	39.4
	Swarbrick Landing	Ann Street				
Tanitarsini	1.12	0.81	3.34	1.28	6.83	6.83
Oligochaeta sp B	0.98	1.3	3.32	1	6.79	13.61
Oligochaeta sp A	0.59	0.97	3.05	1.03	6.23	19.84
Tanais stanfordi	0.56	0.93	2.92	0.79	5.98	25.82
Potamopyrgus antipodarum	1.72	1.42	2.89	1.22	5.9	31.72
Oxyethira	0.75	0.78	2.83	1.14	5.78	37.5
Orthocladiinae	0.34	0.81	2.59	1.07	5.29	42.8
	Victoria Bridge	Ann Street				
Oligochaeta sp B	0.7	1.3	4.09	1.08	7.75	7.75
Tanitarsini	1.2	0.81	3.65	1.31	6.91	14.66
Gyraulus spp	0.06	0.93	3.5	1.09	6.64	21.29
Oligochaeta sp A	0.53	0.97	3.46	1.08	6.55	27.84
Tanais stanfordi	0.98	0.93	3.43	1.01	6.49	34.33
Orthocladiinae	0.81	0.81	3.25	1.01	6.15	40.48
Oxyethira	0.94	0.78	2.97	1.17	5.62	46.11
Potamopyrgus antipodarum	1.45	1.42	2.82	1.09	5.35	51.45

4.1.7 Taxa accumulation curves

The taxa accumulation curves are based on total abundances of invertebrates. The curves show the increasing total number of different taxa observed from successively pooled samples with samples entered in random order (permuted). Beach plus riprap, beach plus willow, willow plus riprap, and willow plus beach plus riprap habitats were combined to investigate the combinations of habitats that yielded the most taxa compared to gamma diversity with all habitats combined.

In December, taxa aggregation curves were similar for willow (54), beach (52), and willow/riprap (50) and markedly lower for riprap alone (45) (Figure 4.10A). Combining habitats indicated similar diversity at comparable sample numbers, although beach+riprap was the highest at 64 taxa (Figure 4.9A). In March the willow/riprap had by far the most taxa with 46 followed by willow at 28 and then riprap (26) and beach (23) (Figure 4.9B). Beach+willow produced the highest number of cumulative taxa for combined habitats, with 35 taxa (Figure 4.10B). In June the pattern for individual habitats was similar to December with the lowest number of taxa in riprap (32), and similar numbers in willow (41), beach (40) and willow/riprap (39) (Figure 4.9C). For combined habitats, beach+riprap produced the highest number of species with 47 followed by beach+willow with 43, at a similar number of samples (Figure 4.9C), although all habitat combinations appeared broadly similar. For all sites and dates combined, the individual habitats had similar numbers of taxa with the highest found in the willow (65) and beach (64) followed by riprap (60) and willow/riprap (59) (Figure 4.10). Overall, there was little difference among combinations of habitats at similar numbers of samples for all data combined (Figure 4.10).

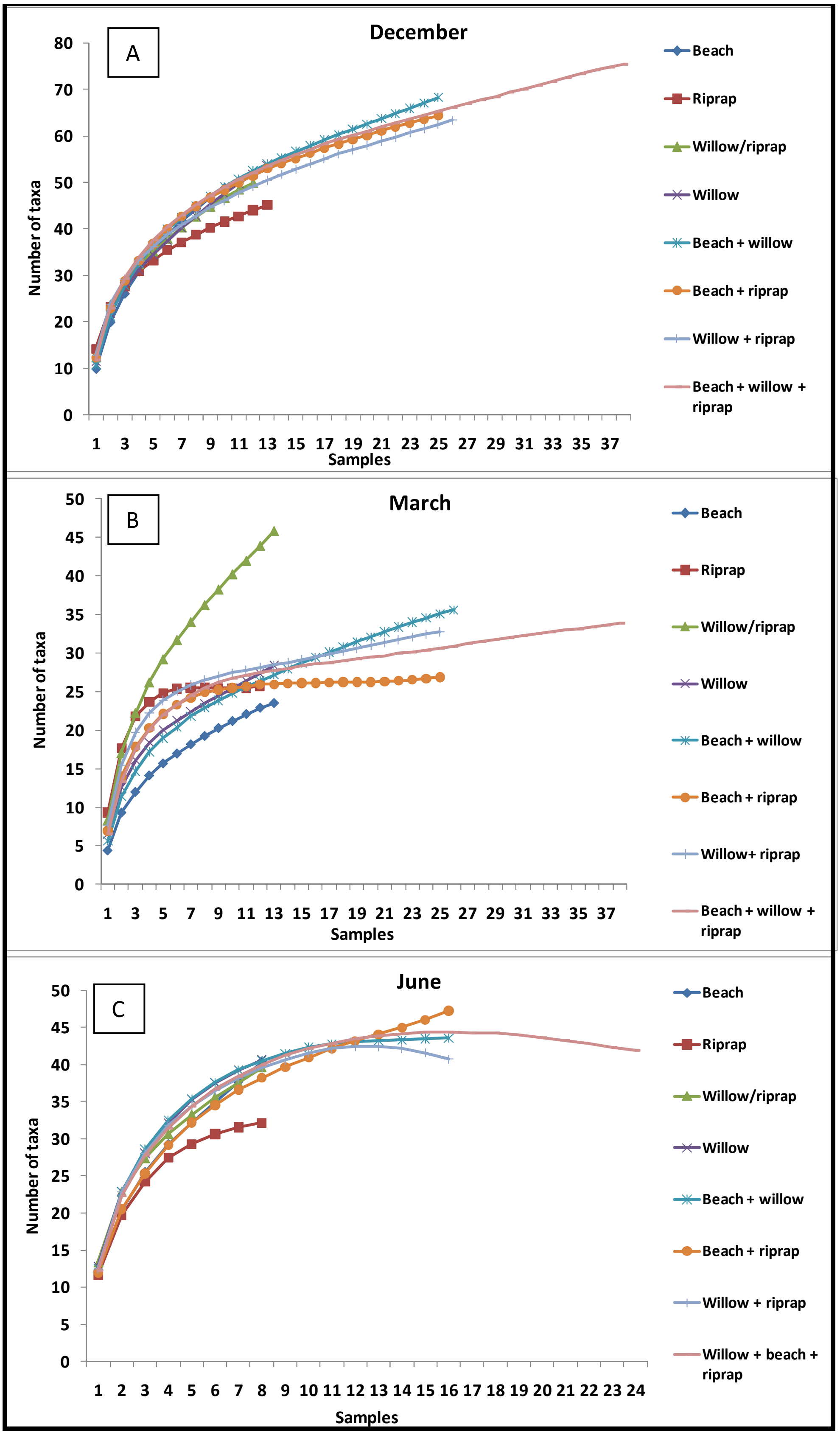

Figure 4.9. Species accumulation curves for A, December; B, March; and C, June.

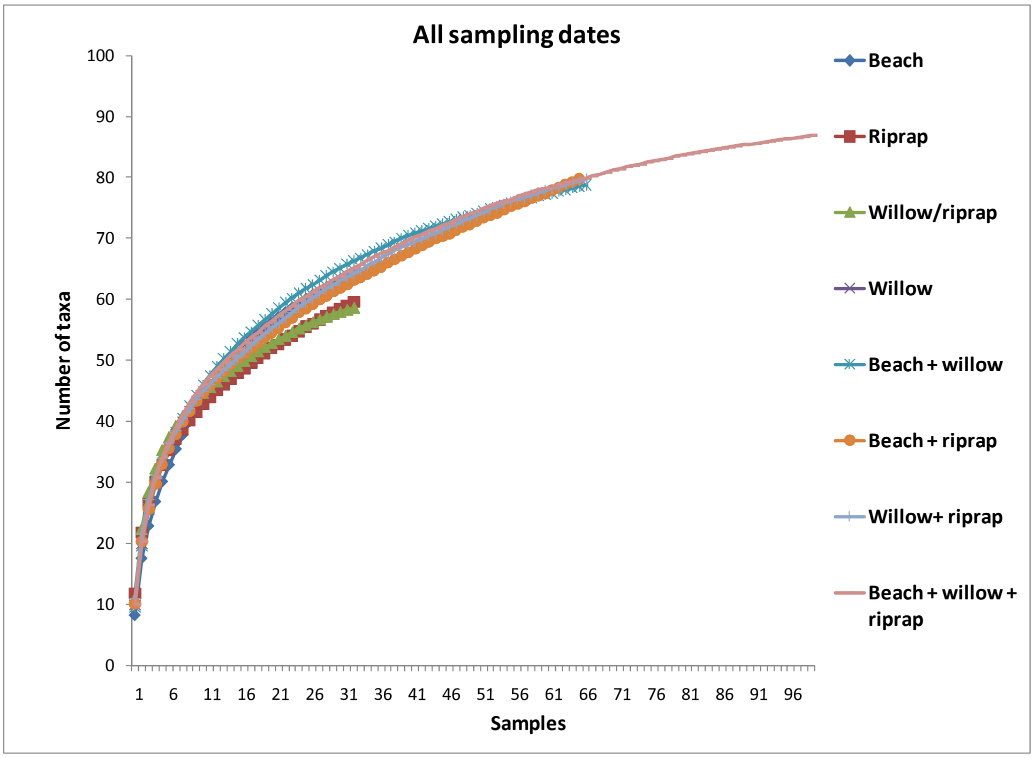

Figure 4.10. Species accumulation plots for all dates and sites combined.

4.2 Discussion

4.2.1 Physical characteristics

The habitat types had different physical characteristics that contributed to the observed differences in macroinvertebrate community composition. Beach sites were characterised by higher velocity (mean 0.12 m s^{-1}) than other habitat types, and had minimal shade and mostly sand and silt substrates with loose compaction (compaction class 4) and low embeddedness. However, there was some spatial variability, with Ann Street beach for example having more silt and detritus compared to Victoria Bridge and Swarbrick Landing beach habitats. Willow sites were characterised by very low velocity (0.01 m s^{-1}) and high shade which decreased from 77% in December to 28% in June after autumn leaf-fall. The substrate in willow habitats was dominated by organic material comprising roots and wood, with some silt present in December.

Riprap habitats were also characterised by low velocity (0.05 m s^{-1}) due to cobbles and boulders breaking up the flow of water and creating low flow zones behind rocks. Average shade was low, although Victoria Bridge had moderate shade (51%) where alders lined the top bank. The substrate sampled was mostly moderately to loosely packed and embeddedness was highest in March at all three sites following a period of higher river flows. Finally, the willow/riprap habitats were characterised by low velocity, moderate average shade which declined from 61-67% in December and March to 34% in June, similar to that observed at sites entirely in willow. The substrate was a mix of organic and inorganic substrates and compaction was highly variable.

At very low flows, for example during June, part of Victoria Bridge riprap and Swarbrick Landing willow/riprap became disconnected from the River, meaning that samples were taken from shallow riverbed areas dominated by sand substrate. Surveys of bank habitats indicated that, at higher flows, the bank substrate type, size and vegetation differed in some habitats. For example, in willow and willow/riprap habitats there were less willow roots, different vegetation and more soil than silt on the upper banks. Shoreline sinuosity at the willow habitats decreased with increasing river level, and it also increased at beach habitats due to convoluted upper grass banks. Riprap habitats showed minimal change in shoreline sinuosity with river level, due to lack of vegetation and convolution of the bank. Willow/riprap habitats were variable, with Ann Street showing little change as the bank was convoluted in the upper and lower slopes, while Swarbrick Landing and Victoria Bridge with more boulders and alder trees showed a decrease in shoreline sinuosity with rising River level. Studies overseas have shown shoreline sinuosity is an important measure of habitat type and complexity (e.g., Sheimer et al. 2001; van der Nat et al. 2002; Benke 2001).

Collectively, the physical measurements carried out indicate variations in the combination of water velocity, shade, substrate size and shoreline sinuosity among different bank habitats. This is consistent with studies by Sanders et al. (1985) and Burress et al. (1982), who found rock riprap had higher velocities and large substrate, whereas natural banks (comparable to willow habitats in the present study) comprised fine substrate, had underwater structure from fallen trees and scrub, and low velocities in the near shore zone.

4.2.2 Habitat-biota associations

Macroinvertebrates responded to the various combinations of substrate type and size, water velocity, and shade resulting in different community composition in each habitat. Several taxa were indicative of these habitat associations, as indicated by the SIMPER analysis and associations of particular taxa and physical factors in MDS plots. Oligocheates were found in all habitats, although the SIMPER analysis showed some were more abundant in beach samples where fine substrates dominated. Oligocheata are deposit feeders and fine substrate provides the most suitable conditions for this group (Winterbourn 2000). *Tanais stanfordi* was consistently more abundant in beach and riprap habitats, as also indicated on some of the MDS plots (e.g., December and March). *Tanais* shrimps prefer sand, silt and cobble substrates (Quinn & Hicky 1990) and can inhabit these contrasting substrates due to their good walking and clambering abilities, and their ability to burrow into sediment or hide in rock crevices (Chapman & Lewis 1976). Some beach samples (e.g., December) were also associated with a trichoptertan, tentatively identified as *?Ecnomina* sp., although the only described species in this genus is associated with seepages (Smith 2007).

Oxyethira (Hydroptilidae) was relatively more abundant in willow compared to other habitats, and also more abundant on riprap compared to willow/riprap. The MDS plots indicated *Oxyethira* was associated with willow and willow/riprap samples in March, in June when the willows had lost their leaves, as well as on riprap samples in March and June. *Oxyethira* larvae are algal piercers and use filamentous algae for food and shelter (Suren 2000). Towns (1981) found O*xyethira w*as more abundant outside shaded areas of a stream because shade reduced the amount of algae that they feed on. The willow and willow/riprap habitats in this study had open areas that allowed algal growth, particularly after leaf-fall; whereas riprap areas were not heavily shaded and filamentous algal growths were observed on most sampling occasions.

The snail *Gyraulus* was also relatively more abundant in willow habitats and showed an association with willow and willow/riprap samples on all dates. *Gyraulus* is a grazing mollusc and both native and introduced taxa were found in this study. Another introduced mollusc, *Physa acuta,* also tended to be more abundant in willow habitats, although this was highly variable with this species showing associations with a range of willow, beach, riprap and willow/riprap samples in December and June. *Physa* is common in the lower Waikato River where it grazes algae growing on macrophytes and hard surfaces (Collier & Hogg 2010). In contrast, the hydrobiid snail *Potamopyrgus antipodarum* was more abundant in habitats with riprap and was more abundant in riprap compared to willow/riprap, notably in March and June. *Potamopyrgus* is a grazer and ingests material off a variety of hard surfaces (Winterbourn 2000).

In willow habitats, Crustacea (mostly *Paracalliope*: Amphipoda), Mollusca and Diptera were the dominant invertebrate groups in March and June when mostly roots and wood were sampled. These taxa groups were similar to those found by Sanders (1985) at natural banks (trees and silt substrate) in the Arkansas River, where tubificid oligocheates, chironomid larvae and amphipods were dominant. In a study by Jayawardana et al. (2006), Amphipoda (Crustacea), *Potamopyrgus antipodarum* (Mollusca), Hydropsychidae (Trichoptera), *Simulium* (Diptera), and Megadrili (Oligocheatea) were highly associated with willow root habitats.

Amarinus lacustris was associated with riprap samples on the MDS plots in December and March, mainly at Swarbrick Landing riprap and willow/riprap, although smaller numbers were also caught on Ann Street riprap in June. *Amarinus* has a sparse distribution in northern New Zealand, and is occasionally found associated with a variety of habitats including macrophytes, roots and rocks (Collier & Hogg 2010). *Aoteopsyche colonica* was also associated with riprap samples on all dates. *Aoteopsyche* has a strong preference for large cobbles and boulders and higher velocities (Quinn & Hicky 1990; Jowett et al. 1991; Winterbourn & Harding 1993). The velocity was high on parts of Swarbrick willow/riprap with more gravels than cobbles and on riprap where many *Aoteapsyche* were found. Some areas of riprap and willow/riprap, such as flat cobbles and gravels can provide an uninterrupted near-bed flow which is important for filter feeding invertebrates such as *Aoteopsyche* (Quinn et al. 1997). In contrast, Hydropsychidae were one of the species highly associated with willow root habitats in streams in Australia sampled by Jayawardana et al. (2006).

Although not shown on MDS associations, riprap had relatively low average velocities (0.05 m s^{-1}) overall; however, this was patchy depending on the configuration of substrates and exposure of sites to the main river flow. The dominant invertebrate groups on riprap were Crustacea, Mollusca and Diptera. In a study on the Arkansas River, Sanders et al. (1985) found current velocity was an important factor determining invertebrate community composition generally. In that study, the invertebrates on riprap in fast flowing areas were filter-feeding Trichoptera relying on currents for delivery of food supplies, whereas on riprap with lower velocities the communities consisted of polycentropodid caddisflies and Chironomidae (Diptera). Chironomidae have also been reported as common on riprap in other USA rivers (Burress et al. 1982). In the present study, Orthocladiinae and Tanitarsini tended to be associated with beach and riprap habitats, notably in June. Orthocladiinae and Tanitarsini consume fine particulate matter (Collier 1993), and riprap and sand can trap particulate matter, which would provide them with food. Orthocladiinae larvae are found in stony streams and rivers (Death 2000), and also on macrophytes (Golder & Associates 2009) in non-shaded areas (Towns 1981; Lester at al. 1994), and can show a preference for sand (Quinn & Hicky 1990), indicating that this group has broad habitat preferences. Oligocheata were associated with riprap samples in March and June, and the SIMPER analysis showed them to be relatively more abundant in riprap and beach habitats. The fine organic matter deposited in the interstitices of riprap in low velocity areas can provide detritus for oligocheate feeding and habitat. Burress et al. (1982) also found oligocheates were more common on riprap in lower velocity areas.

Willow/riprap sites were a mixture of two habitat types that did not display clear differences among taxa contributing to the SIMPER analysis, and samples were usually spread widely through the MDS plots so that species associations were harder to ascertain. Willow/riprap shares species associations with riprap because of the rock substrate present. The introduced snail *Physa* was associated with willow/riprap samples in December and June. *Oxyethira* was associated with samples in March and the hydropsychid *Orthopysche* was associated with willow/riprap in December and March, contributing to the high percentage of Trichoptera in December. *Orthopysche* is another filter-feeder and is found on stable substrate (Smith et al. 2006), often in small stony streams (Winterbourn et al. 2000).

4.2.3 Spatial and temporal variation in biological patterns

There were differences in invertebrate community composition between seasons and between habitats at each site. For example, Trichoptera were relatively less abundant in March, while Plecoptera were more abundant in June when water temperatures were cooler. Mayflies, stoneflies and predatory caddisflies are usually associated with cooler water temperatures (Quinn & Hicky 1990).

Other factors potentially influencing spatial and temporal patterns include influences of tributary inflows and proximity to stormwater inputs, and the variable water levels encountered during sampling and between dates. The river level was slightly lower in March compared to December and June and varied daily during sampling (within 0.3-0.5m sampling depth) although the sampling depth was altered to minimise the influence of water level variation. The March invertebrate sampling occurred during the lowest river flow and followed a period of high flows at the start of the month which could have affected the invertebrate communities by increasing drift. When sampling was undertaken, the river flow varied around the mean and habitats were not recorded as being disconnected as they were in June. The average number of taxa was lowest in March and similar in December and June, whereas Diptera were more common in December and June compared to March. Percentages of Mollusca and Oligocheata were lower in June compared to December and March. Low river flows before the June sampling may have contributed to this pattern as, in periods of low flows, some areas of riprap habitats became disconnected from the river. For example, Victoria Bridge was sampled in June in a period of low flows and the riprap habitat was disconnected from the water in some areas so that some sand and silt (average 30% from 4 samples) substrates were sampled at the targeted water depth on this date. The river bed is degrading (Hamilton City Council 2008) and this may cause an increase in disconnection of riprap habitats in the future.

Pyncnocentrodes (Trichoptera) was abundant on Swarbrick Landing riprap and willow/riprap habitats in December, and to a lesser extent in Swarbrick willow/riprap in March, compared to other habitats and dates when it was rarely found. This period is close to the peak summer emergence period for Trichoptera which is November to January (Collier & Smith 1995), suggesting that some species may move from the riverbed, where they can be abundant (Collier & Hogg 2010), to lateral habitats prior to emergence. Alternatively, Bankwood Stream, which flows into the river between the riprap and willow/riprap habitats at Swarbrick Landing has clear water, cobble-gravel substrate and is partially shaded (Aldridge & Hicks 2006), and provides conditions that are known to suit *Pyncnocentrodes* (Boothroyd &Stark 2000; Jowett et al. 1991; Towns 1981; Quinn et al. 1997), and some may drift down into the riprap site. Thrichoptera also use riparian vegetation to complete their lifecycle after emergence (Collier & Smith 1998) and Bankwood stream has a riparian margin of native scrub (Aldridge & Hicks 2006). *Amarinus lacustris*, the rare fresh water crab, was also mostly found at Swarbrick Landing riprap and willow/riprap. It is unclear why this species appears more abundant at Swarbrick Landing although they were observed to occur on larger rocks.

There were more Plecoptera at the beach habitats June compared to <1% in other habitats and in other months, with *Zelandobiu*s the dominant plecopteran. *Zelandobius* nymphs were common in autumn in a study on West Coast streams by Cowie (1980). *Zelandobiu*s may not have been found in December and March because they were in the riparian vegetation alongside the river as adults or because nymphs were inhabiting deeper parts of the river where water temperatures may have been cooler. Most aquatic insects emerge as adults in summer (Collier & Smith 1995) which was the period the other two samples were taken, although *Zelandobius* appears to emerge in spring on the Waikato River (Collier & Hogg 2010). *Zelandobiu*s was often associated with macrophytes which were present at Ann Street and Victoria Bridge beach (although they were only found in the samples from Ann Street beach) suggesting habitat availability may also affect spatial variations in relative abundance. *Zelandobiu*s was also present on Victoria Bridge willow where there was a small amount of macrophytes in more open areas and many leaves from willow leaf fall in autumn. *Zelandobiu*s is a large particle detrivore that can feed on woody detritus and leaves (Winterbourn 2000), and also on sooty mould (Collier 1990) .Its abundance in June suggests it was taking advantage of detrital food resources after leaf fall.

The shade provided by willows, in all months except June, enabled only a small amount of macrophytes and algae to persist under willows, and this may also have limited the range of species that could colonise this habitat type. Several studies (Read & Barmuta 1999; Glova & Sagar 1994; Lester et al. 1994) have found willows can shade out macrophytes which provide invertebrate habitat in low gradient rivers, and also shade algal production which can reduce invertebrate densities. In support of this theory is the higher abundance of algal piercer *Oxyethira* in willow and willow/riprap habitats June, when the willows had lost their leaves. Algae is generally assumed to be a preferred food source compared to leaves as it has higher food quality (Lester et al 1994; Ward &

Cummins 1979) and is a major source of energy to the invertebrate community in many rivers (Thorp 2002).

Willow leaves that have been incubated for around 50 days are most palatable to invertebrates (Lester et al. 1994; Mutch & Davies 1984; Collier & Winterbourn 1986). Lester et al. (1994) suggested this could be due to the loss of phenolic compounds from the leaves or the increase in food quality from colonisation by microbes. In a study by Parkyn & Winterbourn (1997), willow leaves had intermediate breakdown rates and phenolic compounds decreased rapidly over 60 days which may have facilitated the high shredder abundance found in the study. Lester et al. (1996) found that substrate modification and high shade by willows were not responsible for the reduced invertebrate abundance they had found previously and concluded that the chemicals known to be produced by willows, that inhibit invertebrate feeding (not investigated in the present study) were the probable cause of the low macroinvertebrate abundances in Henly Creek in the South Island of New Zealand.

4.2.4 Diversity patterns

Generally, over all sites and seasons, riprap and willow/riprap had high average number of taxa and were significantly different to some beach and willow habitats, although patterns varied spatially and temporally. For example, in December Swarbrick Landing beach had low richness whereas riprap had highest richness, in contrast to Victoria Bridge where willow/riprap richness was high and willow richness was low. Rarefied richness showed a similar pattern to total richness whereby richness was highest on riprap and willow/riprap, and lowest for willow habitats in March and June, indicating abundance-richness relationships were not an issue. Margalef's diversity, which corrects for sample size (Margurran 2004), was not significantly different between habitats although it followed the same general pattern as taxa richness in two out of three months, showing high diversity in riprap and willow/riprap and lower diversity in willow and beach. The lack of a site affect in June, for Margalef's diversity and average taxa richness, may suggests that factors associated with leaf-fall or lower water temperature may have reduced site differences between Victoria Bridge and Ann Street (the only sites sampled) in winter.

Pielou's evenness was generally high in riprap and beach and lower in willow/riprap and willow; although, differences were only significant in June, when Ann Street willow was different to riprap at the same site, and Victoria Bridge beach was different to willow at the same. Pielou's evenness showed a different pattern to species richness and diversity and indicated riprap and beach had a more even spread of individuals among the different species recorded while willow and willow/riprap had a more uneven spread of individuals among the different species. Pielou's evenness indicates a relationship with substrate, as beach and riprap are both comprised mainly of homogenous inorganic substrate while willow and willow/riprap comprise a mix of inorganic (silt, rocks, gravels) and organic substrates (roots, wood). There was no consistent pattern in the differences between sites for the diversity measures, although Victoria Bridge was always different to one or both of the other sites. There was more shade on Victoria Bridge riprap due to alder tree lining the upper bank and more silt and detritus at Ann Street beach, which may have contributed to the differences between sites.

Alpha diversity

From the diversity measures, it seems riprap had consistently high average numbers of taxa, rarefied richness, and Margalef's diversity. Alpha diversity is variation within a sample (Heino 2009) and this was measured by average taxonomic richness in each habitat at each site. One explanation for the high alpha diversity on riprap is that it comprises more stable and larger substrate compared to sand and silt that dominate beaches and roots that dominate willow habitats. Moreover, the bed of the lower Waikato River through Hamilton comprises sands and gravels (Hicks & Hill 2010), meaning that boulders and cobbles along river banks create a novel habitat for macroinvertebrate colonisation. Larger substrate provides a more stable habitat for both periphyton and invertebrates (Quinn & Hickey 1990).Many studies have found invertebrate density and taxonomic richness increase as substrate size increases from sand to cobbles, and then declines with further increase to bedrock (e.g., Jowett & Richardson 1990). Riprap construction usually results in an increase macroinvertebrate biomass and density (Fischenich 2003) and this could be due to the habitat complexity provide by large rock riprap as they have larger interstitial spaces and physical complexity (Shields et al. 1995). Several studies support this; for example, Schmude et al. (1998) found higher species richness in baskets with cement balls (riprap) than baskets with cement blocks in retaining walls in Wisconsin lakes, and Shields et al. (1995) concluded that many studies on large USA rivers have shown that riprap compares favourably to natural banks as habitat for invertebrates. Boulders can be good habitats for filter feeders because they are stable, have large interstitial spaces and can produce turbulent near bed flows.

Boulders are also a good habitat for shredders because they retain coarse particulate organic matter (Quinn & Hickey 1990). Brunke et al. (2001) found riprap supported a high invertebrate diversity and abundance in the River Spree, Germany, similar to coarse woody debris and slightly higher than alder roots. Similarly, a study by Sanders et al. (1985) found winged dyke, dyke fields and revetments were more productive areas than natural banks with fine substrate and vegetation falling in the water. Winged dykes and riprap provided a variety of habitats for invertebrates while natural (vegetated) banks had low densities because of high current velocity and fine substrate. Another reason for the high taxa numbers and diversity could be the lack of shade on riprap allowing algae periphyton to grow and provide food for invertebrates.

Willow had lower average number of taxa compared to riprap in two sites in December and March, and lower rarefied richness in December and June. Lower diversity under willows in autumn-winter could in part be due to leaf input and associated changes in water chemistry from leaching of dissolved phenolic compounds (Collier 1994). Willow roots and branches can reduce water velocity and cause retention of fine sediment which can reduce benthic invertebrate diversity due to loss of access to interstitial spaces (Lester et al. 1994; Read & Barmuta1999). Fine sediment deposition may have been a factor in the low invertebrate numbers found in willows in this study. Root mats were thick around willows where average velocity was low and submerged branches in low flow areas were often observed to have a coating of fine sediment. However, fine sediment deposition would not be expected to be as high as in some other rivers due to the Karapiro Dam detaining sediment inputs (Hamilton City Council 2008; Hicks & Hill 2010).

Once conditioned, willow leaves are palatable to invertebrates. However, the dominant willow species along the Waikato River (grey and crack willow) are known to produce compounds that are toxic to generalist herbivores (Rowell-Rahier 1984). The retention of leaves was relatively low in this study, as the Waikato is a large river that experiences high variable flows; however, willow leaf accumulations were observed in low flow areas.

Willow/riprap habitats also had consistently high taxa numbers and diversity and in many cases were not significantly different to riprap. The combination of riprap and vegetation, including willows and other tree species, such as alders, provides large habitat variability which might be expected to increase macroinvertebrate diversity. Deciduous vegetation at the willow/riprap habitats provided inputs of CPOM and wood, and the boulders and cobbles provided retention structures to trap organic matter, as well as providing interstitial spaces for habitat, hard surfaces for grazers and attachment sites for other invertebrates. As the willow/riprap in this study had a mixture of tree species the possible effects on invertebrates from shading and toxic leaf compounds would have been less than in willow habitats. Beach sites had the lowest number of taxa and diversity. This could be due to the lack of habitat complexity, or the fine substrate and high velocity creating an unstable substrate. As noted earlier, many studies have found larger substrate usually supports higher invertebrate densities (e.g., Jowett & Richardson 1990).

Beta diversity

There are two types of beta diversity: turnover and variation. Turnover is the change in community structure from one sample unit to another along a spatial, temporal or environmental gradient, and is expressed as a rate of turnover over a specific gradient (Anderson et al. 2010). The second type of beta diversity is variation in community structure among a set of sample units within a given spatial or temporal scale or within a category of a factor. In this study, beta diversity was the variation in community structure among habitat types. Beta diversity was assessed by dissimilarity coefficients between habitat types and the distribution of sites along non-metric multidimensional scaling analysis (MDS) axes (Anderson et al. 2010).

Pairwise dissimilarity coefficients indicated that beach was dissimilar to all other habitats, riprap and willow were quite dissimilar, willow/riprap and willow and willow/riprap and riprap were the least dissimilar. This indicates that, although low in alpha diversity, beach habitats contribute significantly to beta diversity, and that willow and riprap habitats also support different combinations of taxa due to different physical conditions. This result was supported by the pairwise PERMANOVA comparisons which showed willow and beach habitats were significantly different in five comparisons out of eight comparisons, and willow and riprap had significantly different assemblages on five comparisons Whereas, willow and willow/riprap had similar assemblages on only three out of eight comparisons. However, riprap and willow/riprap had similar assemblages on six out of eight comparisons, suggesting that the novel habitat provided by cobbles and boulders was having a dominant contribution to beta diversity.

Overall, the taxa accumulation plots showed individual habitats under similar sampling effort had generally similar accumulated taxa richness, although patterns were highly variable in March. However, accumulation plots were lower for riprap on two dates despite alpha diversity being generally higher on riprap, suggesting that similar combinations of taxa occurred across all riprap habitats. The accumulation plots were different in March, perhaps due to the period of high river flows in the month prior to sampling which may have increased invertebrate drift in some habitats.

Gamma diversity

Gamma diversity is regional species richness (Anderson et al. 2010), and in the context of this study refers to the diversity within Hamilton City across all sites and habitats combined, as expressed by the beach+willow+riprap taxa accumulation plots. Combinations of habitats that yielded taxa accumulation similar to beach+willow+riprap with similar sampling effort were beach+willow in December and March and beach+riprap in June. Overall there were low numbers of Ephemeroptera, Plecoptera and Trichoptera (EPT) found, as also reported by Carter (2000) who concluded this could be due partly to interruption of the natural hydrology by hydro-peaking, and urban and agriculture development of the catchment (Carter 2000). EPT taxa can often be naturally less abundant in sections of large rivers with low gradients and therefore contribute little to gamma diversity (Collier & Hogg 2010). Nevertheless, of the taxa present in this section of the River, the taxa in the beach and willow combined together may sustain high diversity. Beach and riprap taxa combined and willow and riprap taxa combined may also provide high gamma diversity. If all banks habitats in Hamilton City were composed of a single habitat type the gamma diversity would be reduced. This may especially be the case for riprap which showed lower taxa diversity compared to other habitats in two out of three seasons. A balance of different habitats would perhaps sustain present day gamma diversity levels in near shore macroinvertebrate communities. The historical diversity of the Waikato Rivers invertebrate communities is unknown and natural bank habitat would need to be assessed against the habitat types in this study to ascertain if their contribution to gamma diversity could be greater.

5. FISH

5.1 Results

The number of fish and fish species found in each habitat varied with method. Boat electrofishing yielded the highest number of fish (5969) and fish species (13) followed by spotlighting (787 fish and 12 species), and minnow trapping yielded the fewest fish (307) and fish species (8) (Table 5.1 and 5.2). The highest number of crayfish was recorded by spotlighting and the highest number of *Paratya* by trapping (Table 5.2). For boat electrofishing, riprap and willow/riprap habitats had the most fish species whereas spotlighting and minnow trapping yielded similar numbers of fish species in all habitats (Table 5.1). Boat electrofishing caught the most fish in the willow habitats whereas trapping caught the most in the willow/riprap and spotlighting found the most in riprap and willow, although all habitats were relatively similar (Table 5.2). The highest total number of fish was found in the willow and the lowest in the beach. The highest number of common bully, shortfin eel and *Paratya* was found in the riprap. The highest number of common smelt was found in in the willow and the highest number of crayfish in the willow/riprap (Table 5.3A). Spotlighting recorded the largest number of common bully, common smelt and koi carp, trapping caught the most *Paratya* and boat electrofishing caught the most grey mullet (Table 5.3B). *Paratya*, common smelt and common bully were the most numerous species (Table 5.3). The largest common bully (based on length) were found in the riprap (Table 5.4) (ANOVA $P < 0.001$) and the Tukey post-hoc test showed beach was different to riprap, and riprap was different to willow and willow/riprap. The largest crayfish (weight in grams) were caught in the willow/riprap (ANOVA $P = 0.009$) with willow/riprap different to riprap and willow. The largest grey mullet (weight) were caught in the willow and willow/riprap habitats (ANOVA P < 0.001) which had higher biomass than beach and riprap. The largest shortfin eels were caught in the willow habitats and smallest in the beach, although the differences were not significant (Table 5.4). There was no significant difference in the size of smelt or inanga in each habitat.

Table 5.1. Number of fish species caught, (excluding shrimp and crayfish), by each method at each habitat in each month, and total number of species caught for each month by method in the Waikato River in Hamilton City.

	Number of species				
Method	Beach	Riprap	Willow	Willow/riprap	Total of month
Boat electrofishing					
February 2010	5	10	6	9	11
September 2010	4	8	4	7	10
Total	6	11	8	11	13
Spotlighting					
December 2009	3	6	6	4	7
February/March 2010	4	4	8	6	8
April 2010	6	7	8	4	9
June/July 2010	5	3	5	6	9
October/November 2010	5	3	5	3	8
Total	9	8	10	9	12
Trapping					
December 2009	3	3	3	5	5
February/March 2010	3	5	5	3	5
April 2010	2	4	4	2	5
June 2010	3	1	2	3	4
September 2010	1	2	3	2	4
Total	5	5	7	6	8

Table 5.2. Total number of fish, crayfish and *Paratya* shrimp caught by each method, at each habitat for all seasons combined, in the Waikato River in Hamilton City.

	Beach	Riprap	Willow	Willow/riprap	Total
No. fish					
Boat Electrofishing	939	1335	2346	1349	5969
Spotlighting	187	228	218	154	787
Trapping	32	67	68	140	307
Total	1158	1630	2632	1643	7063
No. Crayfish					
Boat Electrofishing	0	0	0	1	1
Spotlighting	1	4	5	23	33
Trapping	3	7	4	7	21
Total	4	11	9	31	55
No. *Paratya*					
Boat Electrofishing	4	142	127	22	295
Spotlighting	189	330	94	222	835
Trapping	317	616	554	373	1860
Total	510	1088	775	617	2990

Table 5.3. Total number for each species of fish, shrimp and crayfish in all seasons and methods combined in the Waikato River in Hamilton City.

A. Total number of fish, shrimp and crayfish by habitat.

	Total number				
Species	Beach	Riprap	Willow	Willow/riprap	Total
Native species					
Common bully	213	501	255	314	1283
Common smelt	831	1014	2194	1213	5252
Longfin eel	6	13	9	15	43
Shortfin eel	7	24	14	10	55
Eel - unidentified	32	5	46	18	101
Galaxiid - inanga	21	35	30	9	95
Galaxiid - unidentified	4	1	35	10	50
Grey mullet	37	20	21	30	108
Crayfish	4	11	9	31	55
Paratya shrimp	510	1088	775	617	2990
Introduced species					
Koi carp	1	4	9	8	22
Goldfish	1	6	0	3	10
Gambusia	0	1	3	6	10
Rudd	4	5	9	4	22
Catfish	0	1	5	1	7
Rainbow trout	0	0	1	2	3
Brown trout	1	0	1	0	2
Total	1672	2729	3416	2291	10108

B. Total number of fish, shrimp and crayfish by method.

	Total number			
Species	Boat electrofishing	Spotlight	Trapping	Total
Native species				
Common bully	65	1075	143	1283
Common smelt	493	4646	113	5252
Eel - longfin	6	19	18	43
Eel - shortfin	42	0	13	55
Eel - unidentified	1	96	4	101
Galaxiid - inanga	46	42	7	95
Galaxiid - unidentified	2	48	0	50
Grey mullet	98	10	0	108
Crayfish	1	33	21	55
Paratya shrimp	295	835	1860	2990
Introduced species				
Koi carp	7	15	0	22
Goldfish	7	3	0	10
Gambusia	0	5	5	10
Rudd	14	5	3	22
Catfish	2	4	1	7
Rainbow trout	3	0	0	3
Brown trout	1	1	0	2
Total	1083	6837	2188	10108

Table 5.4. Mean length and weight of fish caught by electrofishing in each habitat.

	N	Beach	Riprap	Willow/riprap	Willow
Species			mean length (mm)		
Common bully	208	43.8	60.0	43.5	46.2
Common smelt	546	61.8	60.0	60.6	59.0
Inanga	53	58.4	56.1	52.5	56.6
Grey mullet	98	305.5	296.5	354.3	359.9
Longfin	24	256.0	360.4	324.1	299.6
Shortfinn	55	344.9	393.5	386.5	442.9
			Mean weight (g)		
Common bully	208	3.1	4.7	2.6	2.7
Common smelt	546	1.9	1.5	1.6	1.5
Inanga	53	1.2	1.4	0.9	1.0
Grey mullet	98	472.0	425.7	716.2	743.4
Longfin	24	187.4	128.4	231.2	130.2
Shortfinn	55	54.7	143.1	103.6	191.1

5.1.1 Boat electrofishing

The total density of fish was highest in summer (February) in willow followed by riprap habitats, and was comprised mostly of common smelt (Table 5.5). In spring (September), the highest density of fish was in the riprap and beach habitats. At this time, common smelt densities were much lower than in summer. Common bully was most abundant in the riprap in both seasons and contributed to the high density in this habitat. The lowest density of fish was caught at willow habitats in spring and this is probably due to the difficulty of fishing this habitat in swift river currents at high spring flows. The highest density of shortfin eels was also in the riprap habitats, probably in response to the large number of interstitial spaces between rocks (Table 5.5). High densities of grey mullet at beach habitats in spring contributed to the high overall density in that habitat (Table 5.5). Trout (tagged hatchery rainbow trout) were found in spring at sites with cover provided by willows (willow and willow/riprap), but only at the Victoria Bridge site. There was no significant effect of habitat in summer, but an effect was detected in spring (Table 5.6A) when Tukey post-hoc test showed that beach was significantly different from willow, and riprap was different to willow (Table 5.6 B). The highest density of native fish was beneath willow in February (67 fish 100 m^{-2}), followed by riprap (53 fish100 m^{-2}), then beach and then willow/riprap (37-43 fish 100 m^{-2}). In September, the beach and riprap habitats had most natives (19 fish 100 m^{-2}), followed by willow/riprap (10 fish 100 m^{-2}) then willow (4 fish 100 m^{-2}).

Table 5.5. Mean density of fish caught by boat electrofishing in summer (February) and spring (September) 2010 from three sites combined in the Waikato River in Hamilton City.

	Density (fish 100 m^{-2})				
Species	Beach	Riprap	Willow	Willow/riprap	Mean
February 2010					
Common bully	0.0	14.3	0.3	1.0	3.9
Common smelt	36.0	24.7	59.0	29.3	37.3
Longfin eel	0.0	1.0	0.0	0.7	0.4
Shortfin eel	0.3	5.7	2.0	2.7	2.7
Catfish	0.0	0.3	0.0	0.3	0.2
Galaxiid - inanga	4.0	5.7	2.7	1.7	3.5
Galaxiid - unidentified	0.3	0.3	0.0	0.0	0.2
Goldfish	0.0	1.7	0.0	0.0	0.4
Grey mullet	1.3	1.3	1.7	1.7	1.5
Koi carp	0.0	0.0	0.0	1.7	0.4
Rudd	0.0	1.0	2.0	0.7	0.9
Total density	42.0	56.0	67.7	39.7	51.3
September 2010					
Common bully	0.0	5.7	0.0	0.3	1.5
Common smelt	7.3	6.3	0.0	1.7	3.8
Longfin eel	0.0	0.3	0.0	0.0	0.1
Shortfin eel	1.3	1.3	0.0	0.7	0.8
Eel - unidentified	0.0	0.0	0.0	0.3	0.1
Galaxiid - inanga	0.0	1.3	0.0	0.0	0.3
Goldfish	0.0	0.3	0.0	0.3	0.2
Grey mullet	11.0	4.3	4.0	7.3	6.7
Koi carp	0.0	0.3	0.0	0.3	0.2
Rudd	0.7	0.0	0.3	0.0	0.3
Brown trout	0.0	0.0	0.3	0.0	0.1
Rainbow trout	0.0	0.0	0.3	0.7	0.3
Total density	20.3	20.0	5.0	11.7	14.3

Table 5.6. Summary of ANOVA results for fish density of measured in summer and spring in the Waikato River caught by boat electrofishing.

A. Sum of Squares (SS), degrees of freedom (d.f.), mean squares (MS), *F* values and Probability value (*P*).

	SS	d.f.	MS	F	*P*
February					
Intercept	178.00	1	178.00	695.96	0
Habitat type	0.39	3	0.13	0.51	0.688
Error	2.05	8	0.26		
September					
Intercept	76.53	1	76.53	309.71	0
Habitat type	3.76	3	1.25	5.07	0.030
Error	1.98	8	0.25		

B. Pairwise Tukey post-hoc test for fish density for electrofishing in spring

	***P* values**			
Habitat type	**Beach**	**Riprap**	**Willow**	**Willow/riprap**
Beach		1.000	0.042	0.626
Riprap	1.000		0.038	0.585
Willow	0.042	0.038		0.231
Willow/riprap	0.626	0.585	0.231	

For boat electrofishing, the highest biomass was caught in the willow/riprap habitats in both seasons, and was mostly grey mullet and koi carp (Table 5.7). Biomass of common bully was greatest for riprap on both dates. Comparing habitats, biomass was greatest in willow/riprap, than in beach in summer (Tukey post-hoc test P= 0.0122; Table 5.8B). In spring, there were no differences between habitats (Table 5.8 A). Willow/riprap had the highest biomass of native fish in February (1687 g 100 m^{-2}), then riprap (1569 g 100 m^{-2}), willow (1370 g 100 m^{-2}) and beach (278 g 100 m^{-2}). In September, beach and willow/riprap had the highest density of native fish (5236-5724 g 100 m^{-2}), followed by willow and riprap (222-3330 g 100 m^{-2}).

Table 5.7. Mean fish biomass caught by boat electrofishing in summer (February) and spring (September) 2010 for three sites combined in the Waikato River in Hamilton City.

	Biomass of fish (g 100 m^{-2})				
Species	Beach	Riprap	Willow	Willow/riprap	Mean
February 2010					
Common bully	0.0	62.4	0.0	7.5	17.5
Common smelt	60.3	36.9	86.2	43.0	56.6
Longfin eel	0.0	224.7	0.0	76.3	75.3
Shortfin eel	17.8	917.8	399.5	295.4	407.6
Catfish	0.0	65.8	0.0	65.0	32.7
Galaxiid - inanga	4.8	7.6	2.9	1.0	4.1
Galaxiid - unidentified	0.3	0.1	0.0	0.0	0.1
Goldfish	0.0	294.3	0.0	0.0	73.6
Grey mullet	194.9	319.7	882.1	1264.0	665.2
Koi carp	0.0	0.0	0.0	4987.6	1246.9
Rudd	0.0	12.6	66.4	10.6	22.4
Total Biomass	278.2	1941.9	1437.1	6750.3	2601.9
September 2010					
Common bully	0.0	28.4	0.0	0.6	7.2
Common smelt	22.7	10.8	0.0	4.5	9.5
Longfin eel	0.0	31.8	0.0	0.0	8.0
Shortfin eel	76.0	57.7	0.0	49.9	45.9
Eel - unidentified	0.0	0.0	0.0	0.0	0.0
Galaxiid - inanga	0.0	1.6	0.0	0.0	0.4
Goldfish	0.0	108.9	0.0	51.3	40.1
Grey mullet	5625.9	2092.6	3330.8	5181.7	4057.7
Koi carp	0.0	250.8	0.0	1628.4	469.8
Rudd	134.0	0.0	5.3	0.0	34.8
Brown trout	0.0	0.0	53.8	0.0	13.4
Rainbow trout	0.0	0.0	28.7	72.8	25.4
Total Biomass	5858.6	2582.7	3418.6	6989.3	4712.3

Table 5.8. Summary of ANOVA results for biomass for electrofishing in summer and spring. A. Sum of Squares (SS), degrees of freedom (d.f.), mean squares (MS), *F* values and Probability value (*P*).

	SS	d.f.	MS	F	*P*
February					
Intercept	598.31	1	598.31	653.09	0
Habitat type	16.75	3	5.58	6.09	0.018
Error	7.33	8	0.92		
September					
Intercept	730.51	1	730.51	332.76	0
Habitat type	4.64	3	1.55	0.70	0.576
Error	17.56	8	2.20		

B. Pairwise Tukey post-hoc test for number of species for electrofishing in summer.

	***P* values**			
Habitat type	**Beach**	**Riprap**	**Willow**	**Willow/riprap**
Beach		0.130	0.138	0.012
Riprap	0.130		1.000	0.376
Willow	0.138	1.000		0.356
Willow/riprap	0.012	0.376	0.356	

5.1.2 Spotlighting

The total density of fish estimated by spotlighting was lower in June/July than any other month except October (Tukey post-hoc test *P*< 0.02; Table 5.10 B), and highest in the willow habitat over all months (Tukey post-hoc test *P*< 0.01; Table 5.10 C) mostly comprised of common smelt (Table 5.9) There was no significant interaction between season and habitat (ANOVA P=0.995; Table 5.10 A).The highest density of common bully was consistently found in the riprap and the highest density of smelt was in the willow habitats (Table 5.9). The density of eels was consistently high in the willow habitats and was also high in beach habitat. Willow habitats had the highest density of native fish due to high numbers of smelt. Willow/riprap had the second highest density of native fish on three dates and riprap on two dates. Eleven larval smelt were found in June in all habitats and sites.

Table 5.9. Mean density of fish species for each month and all sites combined for spotlighting in the Waikato River in Hamilton City.

	Density (fish 100 m^{-2})				
Species	Beach	Riprap	Willow	Willow/riprap	Mean
December 2009					
Common bully	6.7	16.7	4.3	9.0	9.2
Common smelt	69.7	82.7	218.0	113.7	121.0
Eel - unidentified	2.3	1.0	6.3	1.3	2.8
Galaxiid - inanga	0.0	0.7	1.3	0.7	0.7
Catfish	0.0	0.0	0.7	0.0	0.2
Grey mullet	0.0	0.7	0.0	0.0	0.2
Koi carp	0.0	0.7	1.3	0.0	0.5
Total density	78.7	102.3	232.0	124.7	134.4
February/March 2010					
Common bully	18.3	31.0	18.0	23.0	22.6
Common smelt	81.0	116.7	194.3	68.3	115.1
Longfin eel	1.3	1.0	1.0	0.7	1.0
Eel - unidentified	4.0	0.0	4.0	2.3	2.6
Galaxiid - inanga	0.7	1.3	1.7	0.3	1.0
Galaxiid - unidentified	0.0	0.0	1.0	0.3	0.3
Catfish	0.0	0.0	0.3	0.0	0.1
Koi carp	0.0	0.0	0.7	0.7	0.3
Rudd	0.0	0.0	0.7	0.0	0.2
Total density	105.3	150.0	221.7	95.7	143.2
April 2010					
Common bully	12.67	39.33	19.67	25.67	24.33
Common smelt	37.00	40.33	102.00	48.33	56.92
Longfin eel	0.00	0.67	0.33	1.33	0.58
Eel - unidentified	1.67	0.67	1.67	0.33	1.08
Galaxiid - inanga	2.33	1.00	4.00	0.00	1.83
Galaxiid - unidentified	0.00	0.00	6.00	3.00	2.25
Gambusia	0.00	0.33	0.67	0.00	0.25
Grey mullet	0.00	0.33	1.33	0.00	0.42
Koi carp	0.33	0.00	0.33	0.00	0.17
Rudd	0.33	0.33	0.00	0.00	0.17
Total density	54.33	83.00	136.00	78.67	88.00
June/July 2010					
Common bully	19.0	28.0	17.3	20.7	21.3
Common smelt	11.0	10.3	63.0	39.0	30.8
Eel - unidentified	0.3	0.0	1.7	0.7	0.7
Galaxiid - unidentified	0.3	0.0	2.0	0.0	0.6
Gambusia	0.0	0.0	0.0	0.7	0.2
Goldfish	0.3	0.0	0.0	0.7	0.3
Grey mullet	0.0	0.0	0.0	0.7	0.2
Koi carp	0.0	0.0	0.7	0.0	0.2
Rudd	0.0	0.3	0.0	0.0	0.1
Total density	31.0	38.7	84.7	62.3	54.2
October/November 2010					
Common bully	6.7	19.0	11.7	11.7	12.3
Common smelt	33.7	51.7	91.7	76.3	63.3
Eel - unidentified	2.3	0.0	1.3	0.0	0.9
Galaxiid - unidentified	0.7	0.0	2.7	0.0	0.8
Brown trout	0.3	0.0	0.0	0.0	0.1
Catfish	0.0	0.0	0.3	0.0	0.1
Grey mullet	0.0	0.0	0.0	0.3	0.1
Koi carp	0.0	0.3	0.0	0.0	0.1
Total density	43.7	71.0	107.7	88.3	77.7

Table 5.10. Summary of ANOVA results for number of fish in each habitat and season for spotlighting in the Waikato River in Hamilton City.

A .Sum of Squares (SS), Degrees of freedom (d.f.), Mean squares (MS), F values and Probability value (p).

	SS	**d.f.**	**MS**	**F**	***P***
Intercept	1155.28	1	1155.28	3771.82	0
Habitat	7.48	3	2.49	8.14	< 0.001
Season	8.61	4	2.15	7.03	<0.001
Habitat type X Season	0.87	12	0.07	0.24	0.995
Error	12.25	40	0.31		

B. Tukey post-hoc test for fish density in each season for spotlighting.

	***P* values**				
Season	**Dec-09**	**Feb-10**	**Apr-10**	**Jun-10**	**Oct-10**
Dec-09		1	0.383	0.000	0.055
Feb-10	1		0.384	0.000	0.055
Apr-10	0.383	0.384		0.025	0.862
Jun-10	0.000	0.000	0.025		0.226
Oct-10	0.055	0.055	0.862	0.226	

C. Tukey post-hoc test for number of fish in each habitat for spotlighting.

	***P* values**			
Habitat	**Beach**	**Riprap**	**Willow**	**Willow/riprap**
Beach		0.316	0.000	0.174
Riprap	0.316		0.004	0.986
Willow	0.000	0.004		0.011
Willow/rip	0.174	0.986	0.011	

5.1.3 Trapping

The total numbers trapped in June and September were lower than in summer and autumn (Table 5.11). Willow/riprap had consistently high numbers, beach had consistently low numbers, and willow and riprap had similar numbers in each month. Common bully numbers in traps did not show a clear pattern, although they were high in willow in 3 out of 5 months and high in willow/riprap in 2 out of 5 months (Table 5.11). The total biomass of fish trapped in June and September was lower than in other months (Table 5.12). The biomass of fish caught was highest under willow on two dates, and highest in the willow/riprap habitats on 2 dates when biomass was dominated by eels. The highest biomass of common bully was on the riprap in 3 out of 5 months and beneath willow in 2 out of 5 months (Table 5.12).

Table 5.11. Mean density of species caught by trapping for all sites combined in the Waikato River in Hamilton City. (* Also refers to number of fish per 10 traps per night).

	Density (fish 100 m^{-2} / or fish 10 traps^{-1} night^{-1})				
Species	Beach	Riprap	Willow	Willow/riprap	Mean
December 2009					
Common bully	4	3	5	3.3	3.8
Common smelt	0.7	1.7	0.3	0.3	0.8
Longfin eel	0.3	0.0	1.0	0.7	0.5
Eel - unidentified	0.0	0.0	0.0	0.7	0.2
Galaxiid - inanga	0.0	0.7	0.0	0.3	0.3
Rudd	0.0	0.0	0.0	0.7	0.2
Total density	5.0	5.3	6.3	6.0	5.7
February/March 2010					
Common bully	0.7	2.7	1.0	5.0	2.3
Common smelt	0.7	1.0	1.0	2.3	1.3
Longfin eel	0.0	0.3	0.3	0.3	0.3
Shortfin eel	0.3	0.3	1.0	0.0	0.4
Eel - unidentified	0.0	0.0	0.3	0.3	0.2
Galaxiid - inanga	0.0	1.0	0.3	0.0	0.3
Total density	1.7	5.3	4.0	8.0	4.8
April 2010					
Common bully	0.7	3.7	3.7	0.7	2.2
Common smelt	0.0	2.3	2.0	25.0	7.3
Longfin eel	0.0	0.7	0.0	0.0	0.2
Shortfin eel	0.3	0.7	1.7	0.0	0.7
Gambusia	0.0	0.0	0.3	0.0	0.1
Total density	1.0	7.3	7.7	25.7	10.4
June 2010					
Common bully	1.3	1.7	1.3	2.3	1.7
Longfin eel	0.3	0.0	0.3	0.7	0.3
Gambusia	0.0	0.0	0.0	1.3	0.3
Rudd	0.3	0.0	0.0	0.0	0.1
Total density	2.0	1.7	1.7	4.3	2.4
September 2010					
Catfish	0	0	0.3	0.0	0.1
Common bully	1	2	2.7	2.0	1.9
Common smelt	0	0.3	0.0	0.0	0.1
Longfin eel	0	0.3	0.0	0.7	0.3
Total density	1	2.7	3.0	2.7	2.3

Table 5.12. Mean biomass of fish caught by trapping for all sites combined in the Waikato River in Hamilton City. (* Also refers to number of fish per 10 traps per night).

	Biomass of fish (g 100 m^{-2} / or g 10 traps^{-1} night^{-1})				
Species	Beach	Riprap	Willow	Willow/riprap	Mean
Decembr 2009					
Common bully	8.8	7.0	12.5	7.4	8.9
Common smelt	0.7	1.5	0.6	0.7	0.9
Longfin eel	81.6	0.0	129.9	367.3	144.7
Eel - unidentified	0.0	0.0	0.0	0.3	0.1
Galaxiid - inanga	0.0	2.9	0.0	0.8	0.9
Rudd	0.0	0.0	0.0	1.7	0.4
Total biomass	91.0	11.4	142.9	378.2	155.9
February/March 2010					
Common bully	0.9	26.4	3.6	10.6	10.4
Common smelt	1.4	0.9	1.5	4.2	2.0
Longfin eel	0.0	50.3	43.5	153.3	61.8
Shortfin eel	32.3	81.9	172.4	0.0	71.6
Eel - unidentified	0.0	0.0	0.0	0.0	0.0
Galaxiid - inanga	0.0	0.4	0.1	0.0	0.1
Total biomass	34.6	159.9	221.1	168.2	146.0
April 2010					
Common bully	0.3	5.7	3.8	0.5	2.6
Common smelt	0.0	4.1	3.7	7.7	3.9
Longfin eel	0.0	23.2	0.0	0.0	5.8
Shortfin eel	1.5	87.7	320.0	0.0	102.3
Gambusia	0.0	0.0	0.0	0.0	0.0
Total biomass	1.8	120.7	327.4	8.2	114.5
June 2010					
Common bully	8.8	17.5	10.6	5.9	10.7
Longfin eel	43.3	0.0	43.7	90.0	44.2
Gambusia	0.0	0.0	0.0	0.1	0.0
Rudd	1.4	0.0	0.0	0.0	0.4
Total biomass	53.5	17.5	54.3	96.0	55.3
September 2010					
Common bully	4.9	5.6	7.9	5.0	5.9
Common smelt	0.0	0.3	0.0	0.0	0.1
Longfin eel	0.0	12.2	0.0	6.7	4.7
Catfish	0.0	0.0	3.3	0.0	0.8
Total biomass	4.9	18.1	11.3	11.7	11.5

5.1.4 Crayfish and shrimp

Over all methods, crayfish were most abundant at willow/riprap habitats followed by riprap habitats, and were most common in April (Table 5.13). For spotlighting the highest density of crayfish was seen in the willow/riprap followed by the willow. For trapping, the highest numbers of crayfish were caught in the riprap and willow/riprap habitats equally. The highest biomass of crayfish caught by trapping was also in the willow/riprap (67.1 g 100 m^{-2}) followed by the riprap (25.7 g 100 m^{-2}) (Table 5.10).

Table 5.13. Crayfish numbers and biomass for all methods and dates, and all sites combined in the Waikato River in Hamilton City.

A. Density of crayfish.

	Density of crayfish (no. 100 m^{-2})				
Method	Beach	Riprap	Willow	Willow/riprap	Mean
Boat electrofishing					
February 2010	0.0	0.0	0.0	0.0	0.0
September 2010	0.0	0.0	0.0	0.3	0.1
Mean density	0.0	0.0	0.0	0.2	0.0
Spotlighting					
December 2009	0.0	0.0	0.0	1.0	0.3
February/March 2010	0.0	0.0	0.0	0.3	0.1
April 2010	0.3	1.0	1.0	4.0	1.6
June/July 2010	0.0	0.3	0.7	1.0	0.5
October/November 2010	0.0	0.0	0.0	1.3	0.3
Mean density	0.1	0.3	0.3	1.5	0.6
Trapping *					
December 2009	0.0	1.3	0.0	0.3	0.4
February/March 2010	0.0	0.0	0.3	0.0	0.1
April 2010	1.0	1.0	0.7	1.7	1.1
June 2010	0.0	0.0	0.0	0.3	0.1
September	0.0	0.0	0.3	0.0	0.1
Mean density	0.2	0.5	0.3	0.5	0.4

B. Biomass

	Biomass of crayfish (g 100 m^{-2}/ or g 10 traps^{-1} night^{-1})				
Method	Beach	Riprap	Willow	Willow/riprap	Mean
Trapping					
December 2009	0.0	9.4	0.0	4.9	3.6
February/March 2010	0.0	0.0	3.6	0.0	0.9
April 2010	14.0	16.3	7.0	48.3	21.4
June 2010	0.0	0.0	0.0	13.9	3.5
September	0.0	0.0	0.3	0.0	0.1
Mean density	2.8	5.1	2.2	13.4	5.9

The highest number of shrimp was caught by trapping in December then September for trapping, usually in riprap sites (Table 5.14). The highest density was found in February for electrofishing and spotlighting. Electrofishing was not an efficient method of catching *Paratya* compared to spotlighting and trapping.

Table 5.14. Number of *Paratya* shrimp caught by each method in each habitat in each month in the Waikato River in Hamilton City. (* Also refers to number of *Paratya* shrimp per 10 traps per night).

		Paratya (no. 100 m^{-2})			
Method	Beach	Riprap	Willow	Willow/riprap	Mean
Boat electrofishing					
February 2010	1.0	17.3	42.3	6.7	16.8
September 2010	0.3	30.0	0.0	0.7	7.8
Mean density	0.7	23.7	21.2	3.7	12.3
Spotlighting					
December 2009	11.0	4.3	0.0	4.7	5.0
February/March 2010	45.7	59.3	12.3	42.0	39.8
April 2010	2.0	3.0	0.7	3.7	2.3
June/July 2010	2.0	41.0	18.3	20.3	20.4
October/November 2010	2.3	2.3	0.0	3.3	2.0
Mean density	12.6	22.0	6.3	14.8	13.9
Trapping*					
December 2009	59.3	69.3	60.0	25.7	53.6
February/March 2010	20.7	65.0	26.7	39.0	37.8
April 2010	1.7	6.7	3.0	5.7	4.3
June 2010	17.3	13.0	27.0	14.0	17.8
September 2010	6.7	51.3	68.0	40.0	41.5
Mean density	21.1	41.1	36.9	24.9	31.0

5.1.5 Diversity

The accumulation plots for all seasons combined for spotlighting indicate willow had the highest accumulation of species for single habitat types, and willow/riprap has the lowest. Beach+willow had the highest species accumulation for combined habitats (Figure 5.1)

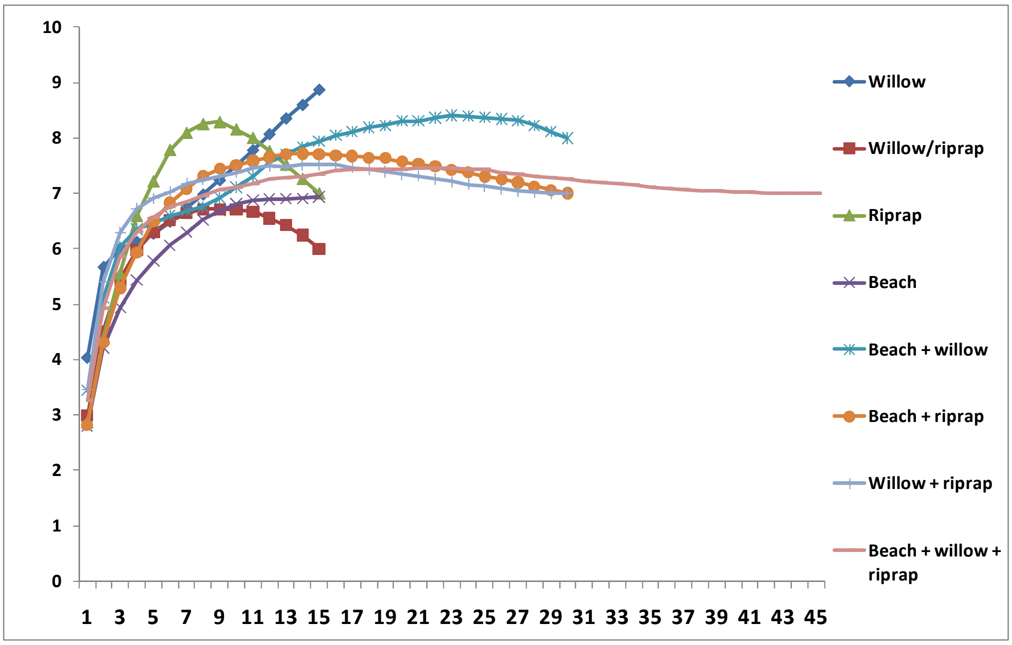

Figure 5.1. Species accumulation curve for native fish species from all dates and sites combined for spotlighting.

5. 2 Discussion

5.2.1 Methods comparison

Boat electrofishing yielded the highest number of fish and fish species. However, this method was not able to sample all habitats equally because branches and swift currents affected access to the willow habitats. Spotlighting yielded the second highest number of fish and fish species, and small and large fish were recorded. This method was the best for recording smelt and common bully, but eels and some galaxiids could not be identified to species level. This method seemed to be the least biased as all habitats could be sampled with equal effort and there was no bias with capture method. However, spotlighting was limited due to water clarity affecting visibility, and fish species which were more often seen further then 2 m from the bank were not recorded as often as they were for electrofishing (e.g., grey mullet, koi carp and goldfish).

Minnow trapping yielded the fewest fish and fish species, and did not record larger species (koi, carp, grey mullet, large eels and goldfish) due to the size of the entry to the trap. This was the least efficient method and was also affected by daily river level variations. When the river level is high, newly-inundated nearshore areas on beaches are very shallow, and there may be less invertebrate food supplies to attract fish. The unpredictable timing and scale of hydropeaking could also affect trapping. For example, on one occasion the traps were irretrievable in the early morning because they were too far under water in some places, and on another occasion traps were stranded in a few centimetres of water. One site was re-sampled because the water level receded overnight and no fish were caught. Early morning retrieval prevented any fish deaths when water receded. However, trapping appeared to be the best method for recording *Paratya* shrimp and crayfish which were infrequently caught in invertebrate sampling (see Chapter 4).

5.2.2 Species richness, density and biomass

Overall, the number of fish species recorded was similar between habitats and all native fish were found in each habitat. However, the density and biomass of each species were varied in each habitat. High numbers of both native and introduced fish were found in the willow. Common smelt were most commonly found in willow habitats. There were also high numbers of Koi carp and rudd in the willow habitats. The sites with cover (i.e., willow and willow/riprap) had the highest total number of fish. Numbers in traps were consistently high in these habitats. Densities were significantly higher in willow for spotlighting and for willow and riprap in summer for boat electrofishing. Furthermore, willow/riprap had the highest biomass for boat electrofishing in summer and highest biomass in trapping on 2 dates. Willow may have supported high numbers of fish because of a combination of cover provided by riparian trees, areas of complex habitat provided by submerged branches, and detritus from trees providing food for invertebrates and ultimately fish. The provision of cover by riparian trees is important for many fish species. Studies in New Zealand have found trout are more abundant under willows due to provision of cover (Glova & Sagar 1994; Latta 1974), and, as noted above, koi carp appear to prefer areas with cover (Growns et al. 1998).

Riprap habitats with cover provided by interstitial spaces in rocks had the second highest total number of fish and equally high numbers with willow in summer electrofishing, the second highest density in spotlighting on 2 dates and consistently high density for trapping. Many studies have shown riprap supports high density of fish especially in rivers with limited hard substrate (like the Waikato River) (Fischenich 2003). Riprap supported the second highest number of native fish (with willow/riprap). Riprap may not reduce the abundance of native species if most fish are habitat generalist. White et al. (2009) in the Mississippi River found, at a local scale, riprap did not decrease abundance of native riverine fishes, possibly because most fish were habitat generalists.

5.2.3 Habitat associations

Common bully were more abundant in riprap habitats for all sampling methods combined; electrofishing and spotlighting found this pattern, although trapping showed no clear pattern. Common bully may not have been sampled as well in willow habitats due to camouflage amongst leaves and the limitations of the electrofishing boat in the willow in swift currents, particularly in September. However, trapping recorded the highest biomass of common bully on riprap on 3 out of 5 occasions and in willow on 2 out of 5 occasions. Common bully could be more abundant on riprap in this study because they are a benthic species and riprap provides a complex habitat with many hiding places, and they spawn on rocks and hard substrate (David & Spiers 2010). Common bullies were significantly longer in the riprap compared to other habits and these could be large males which are territorial and guard eggs (Stephens 1982). The prey items preferred by common bully are also common in riprap habitats. Common bully consumes a wide range of aquatic invertebrates including insect larvae, crustaceans and snails; although chironomid larvae are their dominant prey (Rowe

1999). Chironomids have been found to be common on rock riprap habitats overseas (Burress et al. 1982) and in this study. *Paratya* was most abundant in riprap in this study in all methods, and large common bullies were found to be a major predator of *Paratya* shrimp by Carpenter (1982).

Overall, crayfish densities were highest at willow/riprap habitats followed by riprap habitats. Studies in New Zealand have found crayfish were associated with tree roots, woody debris, leaf litter, undercut banks and stony substrate (Parkyn & Collier 2004; Jowett et al 2008) suggesting they preferred cover provided by trees and rocks in habitats with riprap. Crayfish were also significantly larger in willow/riprap habitats, a finding supported by Jowett et al. (2008) who found small crayfish were associated with finer substrates, lower velocities and shallower habitats, whereas larger crayfish were associated with cobbles. Furthermore, interstitial spaces in riprap accumulate detritus and are colonised by invertebrates upon which crayfish feed (Hicks 1997; Jowett et al. 2008). Thus, the detritus from riparian vegetation may have provided more food in willow/riprap compared to riprap habitats, and the cobbles comprising the riprap could have provided habitat for larger crayfish. Crayfish were found sheltering among willow roots by (Parkyn & Collier 2004) although none were seen on willow roots in this study. This could have been partly due to differences in methods as Parkyn & Collier (2004) used daytime backpack electrofishing which can directly access particular habitats, whereas this study used a coarser method of boat electrofishing, which could not directly access this habitat, and spotlighting at night time, when crayfish are actively foraging.

The highest density and biomass of eels was in the riprap habitats for electrofishing, and willow and willow/riprap habitats for trapping and spotlighting. Eels are often associated with cover (Domingos et al. 2006), and eels were seen hiding beneath rocks in riprap and around submerged trees in willow habitats in this study. Eels can occupy macrophytes, interstitial spaces in rocks and between submerged tree branches or wood (personal observation), and ambush fish as they swim close (Jellyman, 1989). Shortfin eels were larger in the willow compared to the riprap and willow/riprap, although the differences were not significant. This is the consistent with the finding by Glova & Sagar (1994) a who found the mean length of eels was greatest at willowed sites compared to areas with no riparian trees, possibly due to deep holes (Collier 1994). Similarly, Cadwallader (1975) found larger eels associated with undercut banks and deep pools with cover, and Kohen et al. (1994) found small shortfin eels used interstitial spaces in benthic substrates or aquatic vegetation for shelter, whereas larger eels require debris or surface cover.

The highest biomass of koi carp was caught in the willow/riprap in February and September by electrofishing, and highest numbers were recorded in willow and willow riprap (although there were low numbers recorded overall). This habitat association is supported by Hicks et al. (2005) who found higher biomass of koi carp in willow-lined sections of the Waikato River compared to macrophytes and littoral shelves, suggesting they prefer areas with cover. Carp often occur in large numbers among dense stands of willows in the Murry–Darling River in Australia (Gehrke & Harris 1996, as cited in Kohen et al. 2000, p. 29), and Growns et al. (1998) found koi carp were more abundant on vegetated banks with willow, she-oaks (*Casuarina cunninghamiana*) and trees falling into the water compared to degraded banks with sand and gravel. Carp feed by sucking sediment into their mouths and expelling inedible particles and this mode of feeding requires fine sediment (Kohen et al. 2000). This feeding method results in chironomids and oligochates being frequently consumed by carp (Hume et al. 1983), and both of these are common in silt substrates which can accumulate under willows (Lester et al. 1994). Oligocheates were abundant under willow in the present study in December when more silt was sampled compared to the other months, and chironomids were also abundant in willows although they were more abundant in riprap (see Chapter 4).

Smelt were most common in willow for all methods combined. Spotlighting and electrofishing found this pattern; however, no clear pattern was seen for trapping although there were high numbers at willow/riprap habitats. Chironomids and unidentified adult insects were found to be the main prey of smelt in Hamilton and other parts the lower Waikato River by Boubee & Ward (1997). Adult insects use riparian vegetation to complete their lifecycles (Collier & Scarsbrook 2000) and the large amount of riparian vegetation provided by willow may have supported more adult insects which could be eaten by smelt during emergence or oviposition. Low velocity areas may also be important since high densities of smelt were observed in embayments (0.01 m s^{-1} average velocity) created by willows. Smelt sustained swimming occurs at 0.19 m s^{-1} with no response shown at 0.05 m s^{-1} (Mitchell 1989) suggesting smelt may prefer areas requiring less swimming effort. Grey mullet were found in the beach habitats in September and this could be due to feeding off macrophytes, which present at all beach sites 2-3 m offshore. Grey mullet eat a wide range of algae and plant detritus, as well as some gastropods (Wells 1984).

5.2.4 Temporal variation in biological patterns

Overall lower densities and biomass of fish were found in winter and spring compared to summer. The water clarity (1.35 m) and temperature (22.2º C) was higher in February compared to September (12.8 º C and 0.67 m) suggesting that reduced activity or visibility in more turbid and cooler waters may have affected estimates of abundance. Fish have lower metabolic demands in cooler water temperatures and many fish, such as trout and salmon, have reduced activity over cooler months and also prefer deeper water (Heggenes et al. 1993; Bremset 2000; Fraser et al 1993). In New Zealand, the native giant kōkopu was found to be active only at night in winter and selected low velocity zones and deep water (David & Closs 2003). Crayfish were most common in April and this is supported by Parkyn et al. (2002) who found crayfish were more abundant in late summer when all the juveniles had entered the population. There were eleven larval smelt found in June. Booker (2000) found larval smelt in mid-winter in the Waikato River at Cambridge, and concluded that they may have been washed out from lake Karapiro hydrodam where spawning occurs in spring. The highest density of grey mullet was caught at the beach in September compared to February by electrofishing. Grey mullet migrate to the sea to spawn from November to February so may have been migrating back from the sea or lower down the river in February. Migration and life history largely did not affect the pattern of species abundance in each habitat.

2.2.5 Diversity

The accumulation plots for all seasons combined for spotlighting indicates willow had the highest accumulation of native species for single habitat types.

Beach+willow had the highest species accumulation for combined habitats indicating the different physical characteristics in each habitat support different assemblages and that the combination of these habitat types maximise gamma diversity of native fish species.

6. SYNTHESIS

The aim of this study was to determine the physical characteristics of three different approaches (riprap, willow and willow/riprap) used to stabilise banks along the Waikato River in Hamilton City compared to beach habitats, and to investigate associations between habitat type and fish and shoreline invertebrate abundance, diversity and community composition. Beach habitats were included to provide a natural habitat type with low physical complexity for comparison. Spatial and temporal variability in habitat-biota associations were examined by sampling each combination of habitats at three locations over three seasons. Sites with some form of riprap comprise 21% of the 18 km of Waikato River bank length studied in Hamilton city compared to 60% lined by willow. Although this is less than many overseas large rivers (50-60% in riprap; Strayer & Findlay 2010; Schiemer & Waidbacher 1992), there is a trend for increasing riprap along the banks of the river in Hamilton.

Three methods of fish sampling were used and the relative merits and limitations of each were assessed. Spotlighting was the best method overall as it yielded the highest number of all species (fish, crayfish and *Paratya)*, and had least habitat bias. Boat electrofishing was also a good method as it measured the highest number of fish, but was not an efficient method for collecting crayfish or *Paratya* and did not adequately sample willow habitats. Trapping was the least efficient method of sampling fish, in terms of fish numbers, although it was the best method for catching *Paratya* and crayfish.

6.1 Habitat-biota associations

Fish sampling indicated willow habitats supported the highest number of fish overall, including native fish and introduced fish such as koi carp. The high overall numbers in the willow were largely due to smelt. The provision of cover, complex aquatic habitat, and the role of riparian vegetation supplying detritus and potentially invertebrate food resources may have contributed to the high number of fish under willow.

Riprap habitats with cover provided by interstitial spaces in rocks had the second highest total number of fish, higher numbers of *Paratya*, and significantly larger common bully, probably due to its benthic habitat requirements. Willow/riprap had similar total fish numbers to riprap and crayfish were largest and most common in this habitat type possibly due to the combined effects of detritus inputs from trees and habitat provided by cobbles.

There were differences in invertebrate community composition between seasons and between habitats at each site. The influence of water temperature, amount of shade and variable river levels were possible influences on biological pattern. Average number of taxa was lower in March compared to December and June, possibly due to high river flows prior to sampling dislodging invertebrates. In addition, some areas of riprap and willow/riprap became disconnected from the river in June due to low river flows, coinciding with lower mollusc and oligocheate relative abundance on riprap. The loss of leaves from deciduous trees in June may have also influenced food resources for some invertebrates.

Generally, over all sites and seasons, riprap and willow/riprap had high average number of taxa and were significantly different to some beach and willow habitats, although patterns varied spatially and temporally. Rarefied richness showed a similar pattern to total richness, at least in December and March, when richness was highest on riprap and willow/riprap and lowest for willow habitats, suggesting abundance-richness relationships generally did not influence interpretation of diversity patterns. Pielou’s evenness indicated that generally there was a more even spread of individuals among the different species recorded in riprap and beach habitats which were dominated by homogenous inorganic substrate, while willow and willow/riprap, which comprised a mix of inorganic and organic substrates, had a more uneven spread of individuals among the different species, although differences were only significant in June.

6.2 Spatial biodiversity patterns

Fish spatial biodiversity patterns were not explicitly analysed in Chapter 4 due to low diversity and widespread distribution of all species among habitats and sites. Nevertheless, beta diversity was likely to be similar because all species were found in all habitats. However, species accumulation lots from spotlighting indicated higher species accumulation in willow habitats and the combination of willow+beach maximised biodiversity. Riprap had consistently high macroinvertebrate alpha diversity, and this could be due to a combination of factors including high mesohabitat complexity, higher substrate stability, and is presence as a novel habitat in the river which has a predominantly gravel/sand bed. In contrast, willow had lower average number of taxa compared to riprap in two sites in December and March, and lower rarefied richness in December and June. The lower diversity of invertebrates in June could be due to leaf input and associated changes in water chemistry from leaching of dissolved phenolic compounds from leaf fall. In the other seasons, the lower diversity could be due to fine sediment accumulation and high shade, which has been found to decrease invertebrate abundance (Lester et al. 1994; Read & Barmuta1999; Glova & Sagar 1994). Willow/riprap habitats also had consistently high taxa numbers and diversity which in many cases were not significantly different to riprap. The combination of riprap and vegetation provides large habitat variability which might be expected to increase macroinvertebrate diversity. In contrast, beach sites had the lowest number of taxa and diversity, and this could be due to the lack of habitat complexity or the fine substrate and higher velocity creating an unstable habitat.

Pairwise dissimilarity coefficients and pairwise PERMANOVA comparisons indicated that, although low in macroinvertebrate alpha diversity, beach habitats contributed significantly to beta diversity, and that willow and riprap habitats also supported different combinations of taxa due to different physical conditions. Although riprap had high numbers of invertebrate species per sample, species accumulation was low on two out of three occasions indicating there was a limited pool of taxa colonising the riprap compared to other habitats. Riprap and willow/riprap had similar invertebrate assemblages on six out of eight comparisons suggesting that the novel habitat provided by cobbles and boulders was having a major contribution to beta diversity. Accumulation plots indicated a combination of Beach and riprap taxa combined and willow and riprap taxa combined may provide high gamma diversity of macroinvertebrates. Willow+Beach habitats would provide the highest gamma diversity of macroinvertebrates and fish. The willow/riprap had lower species accumulation of for all dates combined indicating this single habitat type if used extensively, would reduce gamma diversity of fish.

6.3 Management recommendations

Changes in local diversity and assemblage composition can affect a variety of ecosystem processes and services at different scales and these effects are largely unstudied (Eros et al. 2008). The findings of my study indicate that, if all bank habitats in Hamilton City were composed of a single type, invertebrate biodiversity would be reduced. And this is supported by Jennings et al. (1999), who suggested that replacing a whole shoreline of riprap in Wisconsin lakes, would cause a reduction in biodiversity of fish. Taxa accumulation curves suggest that the combination of beach and willow habitats may sustain high diversity for invertebrates and fish, while the novel habitat provided by riprap may favour some native fish and invertebrates over others. Therefore, a balance of different bank habitat types would perhaps be best to sustain present-day biodiversity levels in near shore macroinvertebrate and fish communities.

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8. APEDICIES

Table 8.1. Total abundance of invertebrates in each habitat in each site and totals for each habitat for each sampling date. A Decmeber beach and riprap, B December willow and willow/riprap and grand total for Decmeber, C March beach and riprap, D March willow and willow/riprap and grad total for March, E June all habitats and grand total for June.

A

	Total abundance of invertebrates in December							
Habitat	Beach				Riprap			
Site	Swarbrick Landing	Victoria Bridge	Ann Street	Total	Swarbrick Landing	Victoria Bridge	Ann Street	Total
Ephemeroptera								
Neozephlebia	0	0	0	0	0	0	0	0
Deleatidium	0	0	0	0	0	0	0	0
Zephlebia	1	0	0	1	0	0	0	0
Leptophlebiidae indet.	0	0	0	0	0	0	0	0
?Ephemeroptera indet.	0	0	1	1	0	0	0	0
Plecoptera								
Acroperla	0	0	0	0	0	0	0	0
Zelandobius	4	0	0	4	0	0	0	0
Trichoptera								
Aoteapsyche colonica	0	6	0	6	189	0	0	189
Conoesucidae indet.	0	0	0	0	0	0	2	2
Ecnomidae	0	0	0	0	0	0	0	0
?Ecnomina	13	5	0	18	0	0	4	4
Orthopsyche	0	3	0	3	165	0	0	165
Oxyethira albiceps	52	2	1	55	43	83	31	157
Paroxyethira hendersoni	0	0	0	0	16	0	3	19
Polyplectropus	0	0	0	0	8	0	0	8
Pycnocentrodes	0	1	0	1	88	9	2	99
Tiphobiosis	0	0	0	0	8	0	0	8
Triplectides	1	0	0	1	5	0	1	6
Odonata								
Aeshna	0	0	0	0	0	0	0	0
Hemicordulia australiae	0	0	0	0	0	0	0	0
Procordulia	0	0	0	0	0	0	0	0
Xanthocnemis zealandica	0	0	0	0	0	0	0	0
Zygoptera indet.	0	0	0	0	0	0	0	0
Coleoptera								
?Colymbetinae	0	0	0	0	0	0	0	0
Dytiscidae	0	1	0	1	0	0	0	0
Elmidae	0	0	0	0	0	0	0	0
Homalaena	0	0	0	0	0	1	0	1
Lancetes	0	0	0	0	0	0	0	0
Liodesus plicatus	0	0	0	0	0	0	0	0
Scirtidae	0	0	0	0	0	0	0	0
Coleoptera indet	0	0	0	0	0	0	0	0
Hemiptera								
Ainsops	0	0	0	0	0	0	0	0
Mesoveliidae	0	0	0	0	0	0	0	0
Sigara	0	0	0	0	0	0	0	0
Diptera								
?Thaumaleidae	0	0	0	0	0	0	0	0
Austrosimulium	0	0	0	0	0	0	0	0
Empididae	0	3	0	3	8	8	0	16
Eropterini	0	0	2	2	0	0	4	4
Harrisius	0	0	0	0	0	2	5	7
Limonia nigrescens	0	1	1	2	0	1	6	7
Mischoderus	0	0	0	0	0	0	0	0
Molophilus	0	0	2	2	0	0	0	0
Muscidae	0	0	1	1	0	0	0	0
Orthocladiinae	28	0	20	48	147	114	107	368
Parachironomus	0	1	0	1	123	105	10	238
Polypedilum	0	0	0	0	5	8	0	13
Psychodidae	0	0	0	0	0	0	0	0
Sciomyzidae	0	0	0	0	0	0	0	0
Tanitarsini	1903	142	18	2063	3061	472	379	3913
Tanypodinae	20	6	0	26	0	0	0	0
Tipulidae	0	0	2	2	0	0	0	0
Tipulinae	0	0	0	0	0	0	0	0
Zelandotipula	0	0	1	1	0	0	0	0
?Diptera	0	3	0	3	0	0	0	0
Crustacea								
Amarinus lacustris	0	0	0	0	117	0	0	117
Cladocera	0	0	0	0	0	0	0	0
Paracalliope	1944	149	46	2139	7211	1233	1216	9660
Paratya curvirostris	0	0	1	1	0	1	7	8
Pheatogammarus	8	4	0	12	176	43	19	238
Tanais stanfordi	0	9	0	9	789	518	21	1328
Mollusca								
Ferrissia	0	0	0	0	48	3	2	53
Gyraulus spp.	0	0	0	0	11	0	0	11
Musculium novaezealandiae	0	0	0	0	13	0	2	15
Physa acuta	4	0	2	6	0	0	8	8
Potamopyrgus antipodarum	71	73	7	151	3973	390	479	4842
Oligochaeta								
?Branchiura	0	0	1	1	0	0	0	0
Oligochaeta sp. A	135	11	125	271	163	181	86	429
Oligochaeta sp. B	919	3	384	1306	272	422	129	823
Oligocheta sp. C	0	1	5	6	0	0	0	0
Oligocheta sp. D	11	0	0	11	0	0	0	0
Oligocheta sp. E	0	1	0	1	0	0	0	0
Oligochaeta other	0	0	7	7	67	26	8	101
Nematoda	0	1	0	1	0	0	1	1
Nemertea								
Nemertea indet.	0	0	0	0	0	1	0	1
Prostoma sp.	0	0	0	0	0	0	0	0
Hirudinea	0	0	0	0	0	0	0	0
Acari	0	0	1	1	0	1	0	1

B

	Total abundance of invertebrates in December								
Habitat	Willow				Willow/riprap				
Site	Swarbrick Landing	Victoria Bridge	Ann Street	Total	Swarbrick Landing	Victoria Bridge	Ann Street	Total	Grand total December
Ephemeroptera									
Neozephlebia	0	0	0	0	0	0	0	0	0
Deleatidium	0	0	0	0	0	0	0	0	0
Zephlebia	0	0	0	0	0	0	0	0	1
Leptophlebiidae indet.	0	0	0	0	0	0	0	0	0
?Ephemeroptera indet.	0	0	0	0	0	0	0	0	1
Plecoptera									
Acroperla	0	0	0	0	0	0	0	0	0
Zelandobius	0	0	0	0	0	0	1	1	5
Trichoptera									
Aoteapsyche colonica	41	4	0	45	581	9	0	590	830
Conoesucidae indet.	0	0	0	0	0	0	0	0	2
Ecnomidae	0	0	0	0	0	0	0	0	0
?Ecnomina	0	1	0	1	0	0	0	0	23
Orthopsyche	4	0	0	4	234	9	0	243	415
Oxyethira albiceps	44	4	3	52	8	23	1	32	296
Paroxyethira hendersoni	0	0	2	2	0	0	1	1	22
Polyplectropus	0	0	0	0	0	0	0	0	8
Pycnocentrodes	0	2	2	4	32	11	0	43	147
Tiphobiosis	0	0	0	0	0	0	0	0	8
Triplectides	1	0	3	4	0	0	0	0	11
Odonata									
Aeshna	0	0	0	0	0	0	0	0	0
Hemicordulia australiae	0	0	0	0	0	0	0	0	0
Procordulia	0	0	0	0	0	0	0	0	0
Xanthocnemis zealandica	73	0	0	73	0	5	0	5	78
Zygoptera indet.	0	0	0	0	0	0	0	0	0
Coleoptera									
?Colymbetinae	0	0	1	1	5	0	0	5	6
Dytiscidae	0	0	0	0	0	0	0	0	1
Elmidae	0	3.2	0	3.2	0	0	0	0	3.2
Homalaena	0	0	0	0	0	0	0	0	1
Lancetes	0	0	1	1	0	1	0	1	2
Liodesus plicatus	0	0	3	3	0	0	0	0	3
Scirtidae	0	0	0	0	0	0	0	0	0
Coleoptera indet	0	0	0	0	8	0	0	8	8
Hemiptera									
Ainsops	0	0	0	0	0	0	0	0	0
Mesoveliidae	0	1	0	1	0	0	0	0	1
Sigara	0	0	0	0	0	0	0	0	0
Diptera									
?Thaumaleidae	0	0	0	0	0	0	0	0	0
Austrosimulium	0	0	0	0	0	1	0	1	1
Empididae	0	0	0	0	0	0	0	0	19
Eropterini	0	0	1	1	0	0	0	0	7
Harrisius	24	3	7	35	0	0	1	1	43
Limonia nigrescens	0	2	5	7	0	6	6	12	28
Mischoderus	0	0	0	0	5	0	0	5	5
Molophilus	0	0	0	0	0	0	0	0	2
Muscidae	0	0	3	3	0	0	0	0	4
Orthocladiinae	56	16	4	76	5	41	3	50	542
Parachironomus	34	6	0	41	66	68	10	144	423
Polypedilum	11	0	0	11	2	4	0	6	30
Psychodidae	0	0	0	0	0	0	0	0	0
Sciomyzidae	0	1	0	1	0	0	1	1	2
Tanitarsini	79	162	11	252	431	832	28	1291	7518
Tanypodinae	0	3	1	4	0	0	0	0	30
Tipulidae	0	0	0	0	0	0	0	0	2
Tipulinae	0	0	0	0	8	0	0	8	8
Zelandotipula	0	1	0	1	0	0	0	0	2
?Diptera	0	1	0	1	0	0	0	0	4
Crustacea									
Amarinus lacustris	0	0	0	0	19	0	0	19	136
Cladocera	0	0	0	0	0	0	0	0	0
Paracalliope	3147	316	877	4340	1829	1723	463	4016	20154
Paratya curvirostris	0	0	0	0	0	2	2	4	13
Pheatogammarus	17	0	18	36	38	17	12	67	353
Tanais stanfordi	0	29	0	29	19	77	2	98	1464
Mollusca									
Ferrissia	0	0	2	2	24	3	0	27	82
Gyraulus spp.	328	0	131	458	165	0	4	169	638
Musculium novaezealandiae	0	0	0	0	0	0	0	0	15
Physa acuta	38	0	13	51	0	9	0	9	74
Potamopyrgus antipodarum	156	75	248	480	569	144	49	763	6235
Oligochaeta									
?Branchiura	0	0	0	0	0	0	1	1	2
Oligochaeta sp. A	110	71	118	299	4	55	78	137	1137
Oligochaeta sp. B	143	55	634	832	4	58	68	130	3091
Oligocheta sp. C	0	0	6	6	0	1	1	2	14
Oligocheta sp. D	0	0	0	0	0	0	0	0	11
Oligocheta sp. E	0	0	0	0	0	1	0	1	2
Oligochaeta other	0	0	2	2	59	10	9	78	188
Nematoda	0	0	0	0	0	0	2	2	4
Nemertea									
Nemertea indet.	0	0	0	0	0	0	0	0	1
Prostoma sp.	0	0	0	0	0	0	0	0	0
Hirudinea	0	0	0	0	0	0	0	0	0
Acari	0	1	3	4	0	0	2	0	0

C

	Total abundance on invertebrates in March							
Habitat	Beach				Riprap			
Site	Swarbrick Landing	Victoria Bridge	Ann Street	Total	Swarbrick Landing	Victoria Bridge	Ann Street	Total
Ephemeroptera								
Neozephlebia	0	0	0	0	0	0	0	0
Deleatidium	0	0	0	0	0	0	0	0
Zephlebia	0	0	0	0	0	0	0	0
Leptophlebiidae indet.	0	0	0	0	0	0	0	0
?Ephemeroptera indet.	0	0	0	0	0	0	0	0
Plecoptera								
Acroperla	0	0	0	0	0	0	0	0
Zelandobius	1	0	0	1	0	0	0	0
Trichoptera								
Aoteapsyche colonica	0	1	0	1	5	0	0	5
Conoesucidae indet.	0	0	0	0	0	0	0	0
Ecnomidae	0	0	0	0	0	0	0	0
?Ecnomina	0	0	0	0	0	0	0	0
Orthopsyche	0	1	0	1	22	0	0	22
Oxyethira albiceps	1	1	11	13	18	7	1	26
Paroxyethira hendersoni	0	0	0	0	0	0	0	0
Polyplectropus	0	0	0	0	0	0	0	0
Pycnocentrodes	0	0	0	0	0	0	0	0
Tiphobiosis	0	0	0	0	0	0	0	0
Triplectides	0	0	0	0	0	0	0	0
Odonata								
Aeshna	0	0	0	0	0	0	0	0
Hemicordulia australiae	0	0	0	0	0	1	0	1
Procordulia	0	0	0	0	0	0	0	0
Xanthocnemis zealandica	0	0	0	0	1	3	1	5
Zygoptera indet.	0	0	0	0	0	0	0	0
Coleoptera								
?Colymbetinae	0	0	0	0	0	0	0	0
Dytiscidae	0	0	0	0	0	0	0	0
Elmidae	0	0	0	0	0	0	0	0
Homalaena	0	0	0	0	0	0	0	0
Lancetes	0	0	0	0	0	0	0	0
Liodesus plicatus	0	0	0	0	0	0	0	0
Scirtidae	0	0	0	0	0	0	0	0
Coleoptera indet	0	0	0	0	0	0	0	0
Hemiptera								
Ainsops	0	0	0	0	0	0	0	0
Mesoveliidae	0	0	0	0	0	0	0	0
Sigara	0	0	0	0	0	0	0	0
Diptera								
?Thaumaleidae	0	0	0	0	0	0	0	0
Austrosimulium	0	0	0	0	0	0	0	0
Empididae	0	0	0	0	0	0	0	0
Eropterini	0	0	0	0	0	0	0	0
Harrisius	0	0	2	2	2	0	0	2
Limonia nigrescens	0	0	0	0	0	0	0	0
Mischoderus	0	0	0	0	0	0	0	0
Molophilus	0	1	0	1	0	1	0	1
Muscidae	0	0	0	0	0	0	0	0
Orthocladiinae	0	1	0	1	30	0	3	33
Parachironomus	0	0	0	0	4	0	3	7
Polypedilum	0	0	0	0	0	0	0	0
Psychodidae	0	0	0	0	0	0	0	0
Sciomyzidae	0	0	0	0	0	0	0	0
Tanitarsini	0	3	0	3	32	0	2	34
Tanypodinae	0	0	0	0	0	0	0	0
Tipulidae	0	0	0	0	0	0	0	0
Tipulinae	0	0	0	0	0	0	0	0
Zelandotipula	0	0	0	0	0	0	0	0
?Diptera	0	0	0	0	0	0	0	0
Crustacea								
Amarinus lacustris	0	0	0	0	70	0	5	75
Cladocera	0	0	0	0	0	0	0	0
Paracalliope	26	37	88	151	1508	374	336	2218
Paratya curvirostris	0	0	0	0	0	0	0	0
Pheatogammarus	0	0	0	0	69	3	1	73
Tanais stanfordi	0	13	353	366	737	68	480	1285
Mollusca								
Ferrissia	0	0	7	7	11	0	3	14
Gyraulus spp.	0	2	5	7	2	0	16	18
Musculium novaezealandiae	0	0	0	0	4	0	0	4
Physa acuta	0	0	0	0	0	0	4	4
Potamopyrgus antipodarum	10	5	23	38	449	149	244	842
Oligochaeta								
?Branchiura	0	0	0	0	0	0	0	0
Oligochaeta sp. A	2	1	23	26	43	3	13	59
Oligochaeta sp. B	30	10	58	98	138	15	20	173
Oligocheta sp. C	0	0	3	3	40	3	11	54
Oligocheta sp. D	0	0	0	0	0	0	0	0
Oligocheta sp. E	0	0	0	0	0	0	0	0
Oligochaeta other	0	0	18	18	53	2	0	55
Nematoda	0	0	0	0	0	0	0	0
Nemertea								
Nemertea indet.	0	0	0	0	0	0	0	0
Prostoma sp.	0	0	0	0	0	0	0	0
Hirudinea	0	0	0	0	0	0	0	0
Acari	0	0	0	0	0	0	0	0

D

	Total abundance on invertebrates in March								
Habitat	Willow				Willow/riprap				
Site	Swarbrick Landing	Victoria Bridge	Ann Street	Total	Swarbrick Landing	Victoria Bridge	Ann Street	Total	Grand total
Ephemeroptera									
Neozephlebia	0	0	0	0	0	0	0	0	0
Deleatidium	0	0	0	0	0	0	0	0	0
Zephlebia	0	0	0	0	0	0	0	0	0
Leptophlebiidae indet.	0	0	0	0	1	0	0	1	1
?Ephemeroptera indet.	0	0	0	0	0	0	0	0	0
Plecoptera									
Acroperla	0	0	0	0	0	0	0	0	0
Zelandobius	0	0	0	0	0	0	0	0	1
Trichoptera									
Aoteapsyche colonica	0	0	0	0	22	0	2	24	30
Conoesucidae indet.	0	0	0	0	0	0	0	0	0
Ecnomidae	0	0	0	0	0	0	0	0	0
?Ecnomina	0	0	0	0	0	0	0	0	0
Orthopsyche	0	1	0	1	7	0	2	9	33
Oxyethira albiceps	6	30	4	40	39	4	2	45	113
Paroxyethira hendersoni	0	0	0	0	0	0	0	0	0
Polyplectropus	0	0	0	0	0	0	0	0	0
Pycnocentrodes	0	0	0	0	35	0	0	35	35
Tiphobiosis	0	0	0	0	0	0	0	0	0
Triplectides	0	0	0	0	0	0	0	0	0
Odonata									
Aeshna	0	0	0	0	0	0	0	0	0
Hemicordulia australiae	0	0	1	1	0	0	0	0	2
Procordulia	0	0	0	0	0	0	0	0	0
Xanthocnemis zealandica	1	5	0	6	1	0	2	3	14
Zygoptera indet.	1	0	0	1	0	0	2	2	3
Coleoptera									
?Colymbetinae	0	0	0	0	0	0	0	0	0
Dytiscidae	0	0	0	0	0	0	0	0	0
Elmidae	0	1	0	1	0	2	0	2	3
Homalaena	0	0	0	0	0	0	0	0	0
Lancetes	0	0	0	0	0	0	0	0	0
Liodesus plicatus	0	0	0	0	0	0	0	0	0
Scirtidae	0	0	0	0	0	0	0	0	0
Coleoptera indet	0	0	0	0	0	0	0	0	0
Hemiptera									
Ainsops	0	0	0	0	0	0	0	0	0
Mesoveliidae	0	0	0	0	0	0	0	0	0
Sigara	0	0	0	0	0	0	0	0	0
Diptera									
?Thaumaleidae	0	0	1	1	0	0	0	0	1
Austrosimulium	0	0	0	0	1	0	0	1	1
Empididae	0	0	0	0	0	1	0	1	1
Eropterini	0	0	0	0	0	0	0	0	0
Harrisius	0	2	4	6	0	1	2	3	11
Limonia nigrescens	0	0	0	0	0	0	0	0	0
Mischoderus	0	0	0	0	1	0	0	1	1
Molophilus	0	0	0	0	0	0	0	0	2
Muscidae	0	0	0	0	0	0	0	0	0
Orthocladiinae	0	0	0	0	2	0	3	5	39
Parachironomus	0	3	1	4	0	0	2	2	13
Polypedilum	0	0	0	0	0	0	3	3	3
Psychodidae	0	0	0	0	0	1	0	1	1
Sciomyzidae	0	0	0	0	0	0	0	0	0
Tanitarsini	1	22	0	23	24	0	6	30	90
Tanypodinae	0	0	0	0	0	0	0	0	0
Tipulidae	0	0	0	0	0	0	0	0	0
Tipulinae	0	0	0	0	0	0	0	0	0
Zelandotipula	0	0	0	0	0	0	0	0	0
?Diptera	0	0	0	0	0	0	0	0	0
Crustacea									
Amarinus lacustris	0	0	0	0	2	0	0	2	77
Cladocera	0	0	0	0	0	0	0	0	0
Paracalliope	271	1751	688	2710	680	152	448	1280	6271
Paratya curvirostris	0	0	0	0	2	0	0	2	2
Pheatogammarus	0	1	0	1	15	0	0	15	89
Tanais stanfordi	0	23	4	27	3	14	824	841	2166
Mollusca									
Ferrissia	0	0	3	3	7	0	0	7	24
Gyraulus spp.	193	0	128	321	10	0	133	143	484
Musculium novaezealandiae	0	0	0	0	0	0	0	0	4
Physa acuta	1	8	1	10	1	0	4	5	19
Potamopyrgus antipodarum	82	133	32	247	737	76	135	948	2052
Oligochaeta									
?Branchiura	0	0	0	0	1	0	0	1	1
Oligochaeta sp. A	0	0	5	5	1	0	10	11	78
Oligochaeta sp. B	8	2	9	19	15	3	17	35	267
Oligocheta sp. C	9	0	1	10	4	1	10	15	79
Oligocheta sp. D	0	0	0	0	0	0	0	0	0
Oligocheta sp. E	0	0	0	0	0	0	0	0	0
Oligochaeta other	0	0	0	0	5	2	6	13	68
Nematoda	0	0	0	0	0	0	0	0	0
Nemertea									
Nemertea indet.	0	0	0	0	0	0	0	0	0
Prostoma sp.	1	0	0	1	0	0	0	0	1
Hirudinea	0	0	0	0	0	0	1	1	1
Acari	0	0	0	0	0	0	0	0	0

E

Total abundance on invertebrates in June

Habitat	Beach			Riprap			Willow			Willow/riprap			
Site	Victoria Bridge	Ann Street	Total	Victoria Bridge	Ann Street	Total	Victoria Bridge	Ann Street	Total	Victoria Bridge	Ann Street	Total	Grand total
Ephemeroptera													
Neozephlebia	0	0	0	0	0	0	0	0	0	0	0	0	0
Deleatidium	1	0	1	0	0	0	0	0	0	0	0	0	1
Zephlebia	0	0	0	0	0	0	0	0	0	0	0	0	0
Leptophlebiidae indet.	0	0	0	0	0	0	0	0	0	0	0	0	0
?Ephemeroptera indet.	0	0	0	0	0	0	0	0	0	0	0	0	0
Plecoptera													
Acroperla	0	0	0	0	0	0	0	0	0	0	0	0	0
Zelandobius	84	67	151	6	8	14	105	7	112	25	8	33	310
Trichoptera													
Aoteapsyche colonica	3	2	5	0	0	0	1	0	1	2	0	2	8
Conoesucidae indet.	0	0	0	0	0	0	0	0	0	0	0	0	0
Ecnomidae	0	0	0	3	0	3	1	0	1	0	0	0	4
?Ecnomina	0	0	0	0	0	0	0	0	0	0	0	0	0
Orthopsyche	1	0	1	0	0	0	2	0	2	0	0	0	3
Oxyethira albiceps	36	129	165	41	90	131	457	240	697	102	65	167	1160
Paroxyethira hendersoni	0	1	1	0	8	8	8	9	17	3	26	29	55
Polyplectropus	0	0	0	0	0	0	0	0	0	0	0	0	0
Pycnocentrodes	5	0	5	1	0	1	2	0	2	0	0	0	8
Tiphobiosis	0	0	0	0	0	0	0	0	0	0	0	0	0
Triplectides	2	0	2	0	0	0	2	1	3	0	0	0	5
Odonata													
Aeshna	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemicordulia australiae	0	0	0	0	0	0	0	0	0	0	0	0	0
Procordulia	0	0	0	3	0	3	0	0	0	0	0	0	3
Xanthocnemis zealandica	0	0	0	5	2	7	12	2	14	6	15	21	42
Zygoptera indet.	0	0	0	0	0	0	0	0	0	0	0	0	0
Coleoptera													
?Colymbetinae	0	0	0	0	0	0	0	0	0	0	0	0	0
Dytiscidae	0	0	0	0	0	0	0	0	0	0	0	0	0
Elmidae	0	0	0	0	0	0	2	0	2	1	0	1	3
Homalaena	0	0	0	0	0	0	0	0	0	0	1	1	1
Lancetes	0	0	0	0	0	0	0	0	0	0	1	1	1
Liodesus plicatus	0	0	0	0	0	0	0	0	0	0	0	0	0
Scirtidae	0	0	0	0	0	0	0	0	0	0	0	0	0
Coleoptera indet	0	0	0	0	0	0	0	0	0	0	0	0	0
Hemiptera													
Ainsops	0	0	0	0	0	0	0	0	0	0	0	0	0
Mesoveliidae	0	0	0	0	0	0	0	0	0	0	0	0	0
Sigara	0	0	0	0	0	0	0	2	2	0	0	0	2
Diptera													
?Thaumaleidae	0	2	2	0	0	0	0	0	0	1	3	4	6
Austrosimulium	0	0	0	1	0	1	5	2	7	0	0	0	8
Empididae	4	0	4	0	1	1	0	0	0	6	0	6	11
Eropterini	0	0	0	0	0	0	0	0	0	0	0	0	0
Harrisius	1	0	1	4	0	4	12	2	14	2	0	2	21
Limonia nigrescens	0	0	0	0	0	0	0	0	0	0	1	1	1
Mischoderus	0	0	0	0	0	0	0	0	0	0	0	0	0
Molophilus	0	0	0	0	0	0	0	0	0	0	0	0	0
Muscidae	0	0	0	0	0	0	0	0	0	3	0	3	3
Orthocladiinae	43	125	168	265	370	635	76	80	156	441	71	512	1471
Parachironomus	1	0	1	2	0	2	1	0	1	10	2	12	16
Polypedilum	4	0	4	0	0	0	8	0	8	0	0	0	12
Psychodidae	0	1	1	1	1	2	0	0	0	0	0	0	3
Sciomyzidae	0	0	0	0	0	0	0	0	0	0	0	0	0
Tanitarsini	119	58	177	122	99	221	135	46	181	382	41	423	1002
Tanypodinae	0	0	0	0	0	0	0	0	0	0	0	0	0
Tipulidae	0	0	0	0	0	0	0	0	0	0	0	0	0
Tipulinae	0	0	0	0	0	0	0	0	0	0	0	0	0
Zelandotipula	0	0	0	0	0	0	0	0	0	2	0	2	2
?Diptera	0	0	0	0	0	0	0	0	0	0	0	0	0
Crustacea													
Amarinus lacustris	0	0	0	0	5	5	0	0	0	0	0	0	5
Cladocera	1	0	1	0	0	0	0	2	2	0	0	0	3
Paracalliope	328	1080	1408	1047	491	1538	3071	1246	4317	1801	750	2551	9814
Paratya curvirostris	0	0	0	0	0	0	4	0	4	0	1	1	5
Pheatogammarus	0	6	6	5	3	8	12	2	14	12	0	12	40
Tanais stanfordi	13	276	289	77	261	338	1	0	1	326	7	333	961
Mollusca													
Ferrissia	0	1	1	0	0	0	2	1	3	6	0	6	10
Gyraulus spp.	0	16	16	2	9	11	6	37	43	0	105	105	175
Musculium novaezealandiae	0	3	3	0	0	0	0	0	0	0	0	0	3
Physa acuta	0	2	2	0	0	0	18	3	21	4	8	12	35
Potamopyrgus antipodarum	74	12	86	37	66	103	46	7	53	50	26	76	318
Oligochaeta													
?Branchiura	0	0	0	0	0	0	0	0	0	0	0	0	0
Oligochaeta sp. A	3	16	19	20	1	21	0	0	0	4	2	6	46
Oligochaeta sp. B	3	119	122	23	36	59	4	3	7	39	13	52	240
Oligocheta sp. C	0	5	5	4	27	31	0	1	1	4	2	6	43
Oligocheta sp. D	0	0	0	0	0	0	0	0	0	0	0	0	0
Oligocheta sp. E	0	0	0	0	0	0	0	0	0	0	0	0	0
Oligochaeta other	0	0	0	9	0	9	0	3	3	14	0	14	26
Nematoda	0	0	0	0	0	0	0	0	0	0	0	0	0
Nemertea													
Nemertea indet.	0	0	0	0	0	0	0	0	0	0	0	0	0
Prostoma sp.	0	0	0	1	0	1	2	0	2	0	0	0	3
Hirudinea	2	4	6	2	1	3	6	1	7	8	4	12	28
Acari	0	0	0	0	0	0	0	0	0	0	0	0	0