Fish and Invertebrate Populations of Natural, Dyked and Riprapped banks of the Assiniboine and Red Rivers, Manitoba

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ABSTRACT/ RÉSUMÉ

Watkinson, D.A., W.G. Franzin, and C.L. Podemski. 2004. Fish and invertebrate populations of natural, dyked and riprapped banks of the Assiniboine and Red Rivers, Manitoba. Can. Tech. Rep. Fish. Aquat. Sci. 2524: vii + 46p.

Dyking and armouring stream banks to reduce erosion and provide flood protection for property is common practice in streams and rivers throughout the USA and Canada. To investigate the influences of habitat modifications, fish and benthic invertebrate populations of the Assiniboine and Red rivers, Manitoba, were sampled on natural and modified substrates. Overall fish abundance at riprapped and armoured dyke bank sites of the Assiniboine and Red rivers was significantly higher than at natural, unmodified bank sites. The abundance of certain species of Catostomidae and carp (*Cyprinus carpio*); fish that feed primarily on benthic invertebrates, was higher on riprap. However, we found no significant correlation between invertebrate abundance and fish abundance in either river. Invertebrate and fish diversity and richness did not differ significantly between site-types. Certain invertebrate taxa exhibited significantly higher abundance on the different substrate types. Our study suggests that modifying stream banks potentially may have a profound effect on the fish and invertebrate communities of the Assiniboine and Red rivers.

Keywords: Electrofishing, airlift sampler, fish, invertebrates, Red River, Assiniboine River, riprap, dyke, banks

La pose de digues et d'enrochements pour réduire l'érosion des berges et protéger les propriétés contre les inondations sont des pratiques courantes dans les cours d'eau des États-Unis et du Canada. Pour étudier les répercussions des modifications de l'habitat, on a échantillonné des populations de poissons et d'invertébrés benthiques dans des tronçons naturels et modifiés des rivières Assiniboine et Rouge, au Manitoba. Dans l'ensemble, l'abondance des poissons dans les sites endigués des rivières Assiniboine et Rouge où l'on a posé des perrés et des enrochements était significativement plus élevée que celle observée dans les sites naturels où les berges n'ont pas été modifiées. L'abondance de certaines espèces de Catostomidae et de la carpe (*Cyprinus carpio*), poissons qui se nourrissent principalement d'invertébrés benthiques, était plus forte dans les sites avec enrochements. Toutefois, nous n'avons établi aucune corrélation significative entre l'abondance des invertébrés et l'abondance des poissons dans les deux rivières. La diversité et la richesse des invertébrés et des poissons ne différaient pas significativement d'un type de site à l'autre. Certains taxons d'invertébrés avaient une abondance significativement plus élevée sur les différents types de substrats. Notre étude révèle que la modification des berges peut avoir un effet marqué sur les communautés de poissons et d'invertébrés des rivières Assiniboine et Rouge.

Mots clés : pêche à l'électricité, échantillonneur par injection d'air (airlift), poissons, invertébrés, rivière Rouge, rivière Assiniboine, perré, digue, berges.

INTRODUCTION

Applying large angular rock (riprap) to stream banks or building compacted clay dykes armoured with gravel or riprap is common practice along streams and rivers throughout Canada and the USA to reduce erosion and provide flood protection for property and recreational interests (Schmetterling et al. 2001). These projects are rarely evaluated for their effects on fish and invertebrate productivity (Pennington et al. 1983). Nor is it ascertained which species are favoured or disadvantaged and seldom is consideration given to how habitat modification enhances opportunities for introduced or non-desirable species (Pennington et al. 1983; Jude and DeBoe 1996). Such information is necessary to guide decisions about bank modifications and to predict the response of fish or invertebrate species to the chosen modification (Jude and DeBoe 1996). Changes in fish or invertebrate fauna due to modifications may be deemed positive or negative based on stakeholder values.

Small habitat modifications are often overlooked because of their individual extent and priority when compared to many larger issues that are dealt with by resource management agencies (Panek 1979). A small habitat modification generally results in a minimal change in the structure, stability and/or productivity of an aquatic ecosystem. However, these alterations also are incremental and cumulative (Jennings et al. 1999). Numerous small habitat modifications occurring over time or in a number of places within a watershed often reach levels that result in major biological and ecological change (Panek 1979). It is usually only after the fact that we perceive the cumulative impact of numerous small habitat modifications.

What may constitute a small habitat modification in one ecosystem may represent a substantial modification in another (Panek 1979). The placement of riprap along the Assiniboine and Red rivers may constitute a major habitat modification as riprap results in a homogeneous layer of coarse substrate in a river system that is dominated by fine substrate (Nelson and Franzin 2000). Knowledge of the effects of bank and channel alterations on habitat use by fish and invertebrate communities in Prairie Rivers must assume greater importance.

This study was designed to assess fish and invertebrate populations at natural (unmodified) and modified (riprapped or dyked) banks of the Assiniboine and Red rivers. Our objective was to determine if differences in fish and invertebrate community taxa richness, taxa diversity, catch per unit effort (CPUE) estimates of abundance and estimates of biomass exist between modified and natural (unmodified) substrates.

MATERIALS AND METHODS

ASSINIBOINE RIVER STUDY AREA

Sampling was conducted on the Assiniboine River from 45-134 km upstream of the confluence with the Red River (Figures 1-3). This reach of the river runs through a predominantly cultivated agricultural zone with a minimal forested riparian zone composed of hardwood tree species. The average slope of the reach is 17 cm/km (Andres and Thompson 1995) with a 30 year annual median discharge at Headingley of 35.9 m^3/s (Manitoba Department of Conservation, Water Resources Branch). Fish and invertebrate sampling was conducted July 23-30, 2001 at discharges of approximately 69.3 to 84.9 m^3/s. The 30 year median discharge for this period is 47.7 m^3/s. Forty-nine species of fish have been collected in the Assiniboine River within Manitoba (McCulloch and Franzin 1996).

Assiniboine River sampling was conducted on riprapped banks, Agriculture and Agri-Food Canada Prairie Farm Rehabilitation Administration (PFRA) dykes armoured with gravel and unmodified bank sites. In addition, fish sampling was conducted upstream and downstream of the riprap and dyke sites. All sites were located on an outside bend of the river. There were twelve unmodified bank sites, 133-764 m in length that were assumed to have natural, unmodified substrates. Unmodified bank sites were chosen based on the similarity of radius of arc, arc length and mean channel width measurements with those of the riprap or dyke sites (Table 1). There were five riprap sites 180-380 m in length. At these sites the gradient of the bank had been modified and then armoured, typically with a one-meter thick layer of crushed limestone (5-90 cm diameter). Dykes were 200-470 m in length, built from compacted clay and armoured with gravel. The geographic locations of the upstream and downstream ends of all sites for both the Assiniboine and Red rivers are listed in Tables 1 and 2. To investigate local effects of the riprap and dyke sites, 100 m of bank immediately upstream and downstream of the riprap and dyke sites were sampled for fish abundance and biomass. The upstream and downstream sites were initially assumed to have natural unmodified substrates. However, in the field, we discovered three riprap sites (1, 2 and 5) were built directly on or adjacent to pre-existing dykes that extended beyond the construction of the riprap projects in a downstream direction. In addition, the dyke 5 site (constructed in 1991) had an older dyke adjacent to it on the upstream side.

RED RIVER STUDY AREA

Sampling was conducted on the Red River within the City of Winnipeg, at sites located 11.5 km upstream to 9.2 km downstream of the confluence with the Assiniboine River (Figure 4). The St. Andrews Lock and Dam, at Lockport Manitoba, affects flow and depth of this reach. Median discharge of the Red River at Lockport in last 30 years was 171.4 m^3/s (Manitoba Department of Conservation, Water Resources Branch). Fish sampling was conducted on August 27 and 28, 2001 and invertebrate samples were collected August 29 to September 14, 2001. Discharge varied from approximately 254.7 to 240.6 m^3/s during the fish sampling and 226.4 to 127.4 m^3/s during the invertebrate sampling. The 30 year median discharge for this same period is 83.9 m^3/s. Fifty species of fish have been collected in the Red River, in Manitoba (K.W. Stewart, 291 Dalhousie, Winnipeg, MB, pers. comm.).

Red River sampling included six unmodified bank sites 230-390 m in length that were assumed to have unmodified substrates and five riprap sites 160-310 m in length. These were constructed in a similar fashion to the Assiniboine River riprap sites. All sites were located on outside bends of the river (Table 2). Two unmodified bank sites were chosen based on observed similarities in radius of arc, arc length and mean channel width to the riprap sites. One unmodified bank site was chosen in the field based on similarities of the arc as observed from the boat after the site initially chosen from the digital map was determined inappropriate for the study due to extensive infilling with debris (concrete blocks, bricks, broken glass and crushed rock). The other three unmodified bank sites were locations proposed for riprap placement by the City of Winnipeg in the year 2002. One hundred metres of river upstream and 100 m downstream of the riprap sites also were sampled for fish to investigate local effects. Man-made obstructions such as docks, bridges or proximity to the other riprap sites reduced the number of these sites to two downstream and four upstream. One of the two downstream sites was only 60 m in length and was positioned between two of the riprap sites.

FIELD COLLECTIONS

Fish were sampled using an electroshocking boat equipped with a Smith-Root Type VI-A 5kW electroshocker unit set at 354 volts pulsed DC, 4 amperes, 3 ms pulse width and powered by a 240 volt AC generator. The Assiniboine River electrofishing was performed with the same two netters and boat operator for all sampling. The Red River fish sampling was also performed with two netters, one of which was alternated between sampling days. Fishing was conducted in an upstream to downstream direction approximately 2.5 m from the shore with boat speed maintained slightly faster than the surface water velocity. The duration of electrofishing runs was recorded in seconds. Fish were captured and placed in a holding tub until the end of the sampling run. Individuals were then identified to species, fork length was measured to the nearest millimetre, and fish were returned to the river downstream of the sampling site. Fish identified by sight were not measured but counted as part of the catch. To reduce drift and chasing of fish into adjacent sampling sites the site downstream of the riprap or dykes was fished first, then the riprap or dyke site, and lastly the upstream site (Figure 5). The unmodified bank sites had no adjacent sample sites and were fished in an upstream to downstream direction. All sampling was conducted during daylight hours. Substrate was assessed from within the boat at all sites using a five-meter aluminum pole at each invertebrate sampling location. Substrate was assessed 5 m from the beginning, in the middle and 5 m from the end of each upstream and downstream site.

An airlift sampler modified from the designs of Verollet and Tachet (1978) was used to collect invertebrates (Figure 6). Our sampler's design was also similar to the designs of Pearson et al. (1973) as it was lowered and raised using an aluminum pole, which eliminated the need for a lead weight to hold the sampler on the bottom. Our design differed from both Verollet and Tachet (1978) and Pearson et al. (1973) through the attachment of a 250μm NITEX collection bag directly to the sampling unit. This improved flow considerably, as the water-air emulsion was not constricted through a length of hose prior to reaching the collection bag. The airlift sampled a surface area of 0.032047 m^2 and was capable of sampling quantitatively on a variety of substrates, over a range of depths and produced samples relatively free of substrate. Depth of each Red River invertebrate sampling location was recorded to the nearest 5 cm.

Benthic invertebrate collections were made at the Assiniboine River unmodified bank, riprap and dyke sites and at unmodified bank and riprap sites in the Red River. The upstream and downstream sites in both rivers were not sampled for invertebrates in the Assiniboine or Red rivers. Assiniboine River riprap site 15 was not sampled as the airlift sampler was not able to effectively seal with the large substrate found at that location. Each site was divided into 5 sections of equal length, and a sampling location was chosen randomly within each section (Figure 5). Sampling was performed with the boat approximately 2.5 m from the water's edge with a ten-second burst of 120-psi air. The first sample taken on the inshore side of the boat and a second sample from the offshore side, for a total of 10 samples per site. Samples were washed into plastic bags and 10 % formaldehyde added as a preservative. In the lab the airlift samples were washed through a 250 μm sieve and transferred to 70 % ethanol. Invertebrates were then counted and identified to family with the exception of Oligochaetes, Nematodes, Acari and Ostracoda, which were identified to order. Copepods were identified to suborder. All terrestrial invertebrates collected were omitted from the analyses.

FISH DATA ANALYSIS

Data for the Red and Assiniboine rivers were considered independent of one another in all analyses. For all fish collections, CPUE estimates were calculated for fish observed/min (includes fish identified but not captured and fish captured) and landed fish/min (includes only those fish that were captured and held for length measurements). Length:weight regressions based on data accumulated by Dave Tyson (DFO, Yellowknife), Fisher et al. (1996) and Schaap (1989) on Manitoba fish were used to calculate fish weight so that CPUE (grams/min) could be calculated (Table 3). Boat speed in m/sec was also calculated for all sites as a crude measurement of water velocity based on the time it took to fish a transect of known length.

We were interested in grouping similar habitat types to increase sample sizes and reduce the number of possible pairwise comparisons that could be made. Therefore, Assiniboine River CPUE (fish observed/min, grams/min and landed fish/min) for sites downstream and upstream of the riprap or dykes were tested for significant differences between sites. A Shapiro-Wilk test of normality was applied to all data before any tests of significance between the sites were conducted. The results of these tests on the fish data are displayed in Table 4 for the Assiniboine River and Table 5 for the Red River. The Kruskal-Wallis test was used when the assumptions of normality or equality of covariance were not met for CPUE (grams/min), CPUE (landed fish/min) and boat speed (m/sec). The Mann-Whitney test was used in all comparisons except upstream versus downstream CPUE (fish observed/min) as that comparison met the assumptions of parametric statistics, allowing an independent samples *t*-test to be used. The Red River sites upstream and downstream of the riprap sites were also tested for significant pairwise differences using the Mann-Whitney test. Where no significant differences were found for the pairwise comparisons the similar site types were grouped together in subsequent comparisons.

Analysis of Variance (ANOVA) was used to test the null hypothesis of no difference in fish CPUE (fish observed/min) between site types in the Assiniboine and Red rivers. When a significant difference was found either the independent samples *t*-test or the non-parametric Mann-Whitney test was used to make pairwise comparisons between site types. The significant p-value for $\alpha = 0.05$ was adjusted using a Bonferroni correction for multiple paired tests.

Chi-square tests (Krebs 1989) were used to assess individual fish species distribution patterns among the different site types of the Assiniboine and Red rivers. In the absence of any site preference, we assumed that fish would exhibit random distributions among the sampled sites, with the expected number of fish collected at any site type directly proportional to the total electrofishing time for that site type. A Bonferroni correction was applied to the p-value to maintain a α of 0.05.

Species richness cannot be compared directly among sites with differences in sample sizes (Krebs 1989). To allow for comparisons of species richness among site types rarefaction (Hurlbert 1971) was used to estimate the number of species expected in a random sample of 30 individuals taken from the Assiniboine River collection and 16 individuals from the Red River. Chi-square tests were used to test for significant differences in the calculated rarefaction species abundance estimates. The distribution of fish species was assumed to be random, with the expected number of species collected within a site type being directly proportional to the electrofishing time for that site type.

INVERTEBRATE DATA ANALYSIS

Invertebrate data for the two rivers were considered independent of one another in all analyses. For each sample site (i.e., each replicate) the 10 airlift samples were considered to be subsamples. Invertebrate density, taxonomic richness and Simpson's reciprocal index (1/D) were calculated from the mean of those subsamples.

Before any tests of significance between the site types were conducted, abundance, taxa richness, Simpson's reciprocal index and mean depth for the Assiniboine and Red river sample sites were tested with a Shapiro-Wilk test of normality to ensure they met the assumptions of parametric statistics. The results of these tests on the invertebrate data for both rivers are displayed in Table 6.

A Kruskal-Wallis test was used to test for significant differences in invertebrate abundance, taxa richness and Simpson's reciprocal index of the Assiniboine River unmodified bank, riprap and dyke sites. The Red River unmodified bank and riprap sites were tested for significant differences in density, taxa richness, Simpson's reciprocal index and mean depth (cm) with independent samples *t*-tests.

Chi-square tests were used to test for site-type differences in invertebrate relative abundance. In the absence of any site preference the expected number of taxa members per site-type was calculated as a proportion of the number of samples per site type. A Bonferroni correction was applied to the p-value, maintaining $\alpha = 0.05$.

Pearson's correlation coefficients (Pcc) were calculated between depth, taxa richness, Simpson's reciprocal index, invertebrate abundance and CPUE (fish observed/min) in the Red River. Invertebrate densities in both the Assiniboine and Red rivers, were tested for significant correlations with their respective fish CPUE (observed fish/min).

RESULTS

ASSINIBOINE RIVER FISH COLLECTIONS

Substrates on unmodified banks of the Assiniboine River varied from clay and fine silt to gravel (Table 7). The primary substrate of the unmodified banks was clay and the secondary substrate was silt or sand. The sites downstream of riprap or dykes were dominated by clay with sand as the secondary substrate. Sites upstream from the riprap or dyke sites also were predominately clay with sand as a secondary substrate. The modified bank sites were comprised of coarser substrates, with gravel or crushed limestone riprap dominating (5–80 cm diameter). Gravel was the predominate substrate at all dyke sites. The secondary substrate was variable. Crushed limestone riprap with either sand or clay infill dominated riprapped sites.

Mean boat speed, measured as a surrogate for water velocity, ranged from 0.79 m/sec (± 0.1) at unmodified bank sites to 0.93 m/sec (± 0.34, SD) at dyke sites (Table 7). There was no significant difference in boat speed between sites (Kruskal-Wallis $\chi^2 = 2.511$, P = 0.7673).

During the Assiniboine River sampling, 337 fish representing 17 species were observed or landed (Appendix 1). Sixteen species were observed or caught on natural bank sites (unmodified bank and upstream or downstream of modified sites) and 14 species on the riprap or dyke sites. The catch was dominated by shorthead redhorse (*Moxostoma macrolepidotum*), comprising 36.8% of the total (Table 8). Chi-square tests found nine of the species collected in the Assiniboine River had expected values greater than one (Krebs 1989), this allowed us to test their distribution patterns. Chi-square tests revealed that shorthead redhorse, carp (*Cyprinus carpio*) and burbot (*Lota lota*) showed significant, non-random distribution with a greater occurrence on riprap. Carp and silver redhorse (*Moxostoma anisurum*) were more abundant at dyke sites. Sauger (*Sander canadensis*), goldeye (*Hiodon alosoides*), white sucker (*Catostomus *commersoni*), channel catfish (*Ictalurus punctatus*) and freshwater drum (*Aplodinotus grunniens*) distributions were not significantly different from random.

The mean (± SD) CPUE for fish observed/min varied more than threefold ranging from 1.06 (± 0.98) upstream and downstream (± 0.76) of the riprap or dyke sites to 3.51 (± 1.47) at riprap sites (Table 7). The mean CPUE for grams/min varied more than nine times between site types. The sites upstream of the riprap or dykes had the lowest calculated mean biomass 111.3g (± 174.44). The dyke sites had the highest calculated mean biomass 1031.9g (± 655.38). The CPUE for landed fish/min varied more than five-fold. The sites upstream of the dykes or riprap had the lowest mean CPUE, 0.25 (± 0.3). Riprap had the highest calculated mean CPUE 1.32 (± 0.56).

No statistical differences were found for the pairwise comparisons made between the upstream versus the downstream sites and between the dykes and older dykes adjacent to the riprap or dyke sites (Table 9). The sites upstream and downstream of modified banks were grouped (adjacent sites) for all subsequent comparisons. The dykes and dykes adjacent to the riprap sites or newer dykes were also grouped for all subsequent comparisons.

The unmodified bank sites, adjacent sites, dyke sites and riprap sites differed significantly in CPUE (observed fish/min) (ANOVA F = 10.74, P = <0.0001), CPUE (grams/min) (Kruskal-Wallis χ^2 = 18.29, P = 0.0004) and CPUE (landed fish/min) (Kruskal-Wallis χ^2 = 14.66, P = 0.0021). Pairwise comparisons were made for CPUE (fish observed/min), CPUE (grams/min) and CPUE (landed fish/min). A Bonferroni correction was applied to all Assiniboine River comparisons. The calculated p-value needed to be <0.0125 to be significant with α = 0.05 (Table 10). All of the CPUE (fish observed/min) pairwise comparisons were significant. Both CPUE (grams/min) pairwise comparisons of adjacent sites versus riprap sites and adjacent sites versus dyke sites were significant (Table 10). CPUE (grams/min) unmodified bank sites versus the riprap sites and unmodified bank sites versus dyke sites were not significant. For CPUE (landed fish/min) pairwise comparisons, only the adjacent sites versus riprap sites was significant (Table 10).

There was no difference between the rarefaction species richness values of a random sample of 30 fish for the unmodified bank, adjacent sites, riprap and dyke sample sites (χ^2 = 0.1388, d.f. = 3, P = 0.9840) (Table 11).

ASSINIBOINE RIVER INVERTEBRATE COLLECTIONS

During the Assiniboine River invertebrate sampling, 6764 invertebrates representing 43 taxa were collected (Table 12). Forty-one taxa were sampled on the unmodified bank sites, 31 taxa on the riprap sites and 34 taxa on dyke sites. The catch was dominated by chironomids, comprising 38% of the total catch. The sample sizes were large enough to test individual distribution patterns for 31 of the taxa collected. Chi-square tests revealed that Oligochaetes, Caenidae (Ephemeroptera), Ephemerellidae (Ephemeroptera), Ephemeridae (Ephemeroptera), Ametropodidae (Ephemeroptera) and Hydrophilidae (Tricoptera) had distributions that were significantly different from random with a greater occurrence on unmodified bank sites. Heptageniidae (Ephemeroptera) occurrence was significantly greater on riprap and dyke sites. Hydrobiidis snails (Gastropoda, Hydrobiidae), chironomids (Diptera, Chironomidae) and Ceratopogonids (Diptera, Ceratopogonidae) abundance was higher at dyke and unmodified sites. Baetidae (Ephemeroptera), Oligorneuridae (Ephemeroptera) and cylopoid copepod occurrence was greatest on riprap site types.

The mean density (±SD) of invertebrates ranged from 733.3 (± 276.8) individuals/m^2 at a riprap site to 1079.1 (± 408.6) individuals/m^2 at an unmodified bank site (Table 13). These differences were not significantly different (Kruskal-Wallis χ^2 = 2.679, P = 0.2752).

Invertebrate taxa richness showed no significant differences between sites (Kruskal-Wallis χ^2 = 0.140, P = 0.9384), with means ranging from 20.5 (± 2.4) to 21.6 (± 2.7) at dyke and unmodified bank sites respectively (Table 13).

Simpson's reciprocal index was highest at riprap sites with values of 5.36 (± 2.00) and lowest at dyke sites 4.71 (± 3.08) (Table 13). There was no statistically significant differences in Simpson's reciprocal index (Kruskal-Wallis χ^2 1.294=, P = 0.5482).

The bivariate correlation analysis found no correlation between fish and invertebrate abundance based on the natural log of the density of invertebrates and CPUE (fish observed/min) (Pcc = -0.245, P = 0.2787).

RED RIVER FISH COLLECTIONS

The Red River substrates on unmodified banks varied from clay and fine silt to gravel and man made debris (concrete blocks, bricks, broken glass and crushed rock) (Table 14). The primary substrate at the unmodified bank sites was clay or silt and the secondary substrate was debris. Sites downstream of riprap sites were dominated by clay with gravel as the secondary substrate. Sites upstream from riprap sites had silt and clay substrates. Modified banks were dominated by crushed limestone riprap (5–100 cm diameter), and the secondary substrate was either silt or clay.

Mean boat speed varied from 0.61 m/sec (± 0.04) to 0.63 m/sec (± 0.07). There were no significant differences in boat speed (m/sec) among all sites (Kruskal-Wallis χ^2 = 0.4556, P = 0.9285) (Table 14).

During Red River sampling, 75 fish representing 14 species were observed or landed (Appendix 2). Nine species were observed or landed on the natural bank sites (unmodified bank, upstream and downstream of riprap sites), and 11 species on the riprap sites. Carp dominated the catch, comprising 41.3% of the total catch. The Red River observed fish sample size was large enough to test individual fish species distribution patterns for three of the species collected (Table 15). Chi-square tests indicated carp and emerald shiner (*Notropis atherinoides*) had distributions significantly different from random. Abundance was higher on riprap than would be expected with a random distribution. Since the emerald shiner catch was heavily influenced by one riprap sample site (See Appendix 2), and they are known to be a schooling species, we are not confident in the biological significance of this result. Northern pike (*Esox lucius*) distributions were not significantly different from random.

Mean CPUE (fish observed/min) varied more than fourfold, with the lowest mean calculated for the unmodified bank sites 0.38 (± 0.4) and the highest mean calculated for the riprap sites 1.72 (± 0.94) (Table 14). When converted to biomass (grams/min), the mean CPUE (grams/min) varied more than 12 times between site types. The unmodified bank sites had the lowest calculated mean 59.5 (± 66.1). The sites downstream of riprap sites had the highest calculated mean value 724.3 (± 1024.3). The CPUE (landed fish/min) varied more than six fold between site types. The unmodified bank sites had the lowest mean CPUE (landed fish/min) value of 0.10 (± 0.14). The riprap sites had the highest calculated mean value of 0.64 (± 0.46).

No statistical differences existed for any of the pairwise comparisons made between the downstream versus the upstream sites for CPUE (fish observed/min, grams/min and fish landed/min) (Table 9). The upstream and downstream sites were grouped together for all subsequent comparisons (adjacent sites).

The unmodified banks, adjacent and riprap sites differed significantly in CPUE (observed fish/min) (ANOVA F = 6.89, P = 0.0082), but not in CPUE (grams/min) (Kruskal-Wallis χ^2 = 2.02, P = 0.3624) or CPUE (landed fish/min) (Kruskal-Wallis χ^2 = 5.83, P = 0.0542). Therefore, pairwise comparisons were only made for CPUE (fish observed/min). A Bonferroni correction was applied to all these comparisons so that the calculated p-value needed to be <0.025 to be significant with α = 0.05 (Table 10). The difference between adjacent sites versus riprap sites was not significant. The unmodified bank sites versus riprap sites comparison was significant (*t*-test *t* = -3.1972, P = 0.0109).

No significant difference was found between the calculated rarefaction species richness for unmodified bank and riprap sites based on a random sample of 16 fish (χ^2 = 0.0004, d.f. = 1, P = 0.9868) (Table 11).

RED RIVER INVERTEBRATE COLLECTIONS

During the Red River invertebrate sampling, 4651 invertebrates representing 32 taxa were captured (Table 16). Twenty-seven taxa were collected on the unmodified bank sites and 30 taxa on the riprap sites. The catch was dominated by Oligochaetes, which comprised 46% of the total catch. Chi-square tests were used to test distribution patterns of 22 of the taxa collected. Oligochaeta, Sphaeriidae (Pelecypoda), Acari, Ostracoda and Ephemeridae (Ephemeroptera) were distributed significantly differently from random with a greater occurrence on unmodified bank sites. Ceratopogonidae (Diptera), Cyclopoida (Copepoda) and Cladocera (Copepoda) distributions also were significantly nonrandom with a greater occurrence on riprap sites.

The mean (± SD) density of invertebrates was 1447.9 (± 808.6) individuals/m^2 at unmodified bank sites and 1165.2 (± 570.4) individuals/m^2 at riprap sites (Table 13). The mean invertebrate taxa richness was 15.2 (± 2.9) at riprap sites and 14.8 (± 2.6) at unmodified bank sites (Table 13). There was no significant difference in the density of invertebrates (*t*-test *t* = 0.655, P = 0.5288) or taxa richness (*t*-test *t* = -0.221, P = 0.8301). There was also no significant difference in Simpson's reciprocal index between unmodified bank and riprap sites (*t* test, assuming unequal variance, *t* = 1.310, P = 0.2383).

The mean depth (cm ±SD) at the airlift sampling sites was significantly greater at unmodified bank sites 119.7 (± 30.8) than riprap sites 80.2 (± 11.4) (*t*-test *t* = 2.700, P = 0.0244; Table 13). Bivariate correlation analyses was conducted on mean depths of samples versus the natural log of invertebrate density, natural log of taxa richness and square root of Simpson's reciprocal index to determine if any significant correlations existed. A significant correlation may indicate that any observed difference between riprap and unmodified bank sites are due to depth differences rather than substrate modification. None of the bivariate comparisons (mean sample depths versus natural log of invertebrate density Pcc = -0.021, P = 0.950, mean sample depths versus natural log of taxa richness Pcc = 0.159, P = 0.641 and mean sample depths versus square root of Simpson's reciprocal diversity index Pcc = 0.433, P = 0.184), were significantly correlated with one another, indicating that sample depth was of no consequence among these samples.

The correlations derived from a bivariate correlation analysis on the natural log of invertebrate density versus CPUE (fish observed/min) and mean depth versus CPUE (fish observed/min) were not significant (Pcc = -0.196, P = 0.564; Pcc = -0.593, P = 0.057).

DISCUSSION

The modification of riverbanks by placement of crushed limestone riprap or building of dykes armoured with gravel had a significant effect on fish abundance within the Assiniboine and Red rivers. Modified banks appear to attract certain fish species. Carp, an introduced species, was the only species whose abundance was significantly greater on riprap and dyke sites in the Assiniboine River and on riprap in the Red River. Carp were also found to be more abundant on revetted bank habitat of the lower Mississippi River (Pennington et al. 1983;) and on riprap in the upper Mississippi River (Madejczyk et al. 1998). The attraction of riprap or armoured dykes in the Assiniboine River to carp appeared to be especially strong. No carp were found on any upstream or downstream sites adjacent to the riprap or dykes. These adjacent sites also had significantly lower CPUE (grams/min) and CPUE (landed fish/min) when compared to riprap and dyke sites. Wolter (2001) found artificial structures only benefited eurytopic species. The only piscivorous fish that was more abundant on riprap in the Assiniboine River was burbot, and these fish were usually juveniles. This attraction may be a result of increased shelter offered by the modified habitat, increased food supply, or attraction to structural complexity, resulting in the establishment of a small microcosm atypical of the surrounding area (Dorr and Miller 1975). Pennington et al. (1983) and MacDonnell (1999) found fish abundance also was higher on revetted or riprapped banks. These results contradict Wolter (2001) who found fish species abundance was negatively correlated with artificial embankments (riprap and sheet pile walls) in German waterways. Madejczyk et al. (1998) found no significant difference in fish community abundance between the wing dykes, woody snags and bare shore in the upper Mississippi River.

Invertebrate and fish community composition in the Assiniboine and Red rivers responded similarly to bank stabilization. Invertebrate taxa diversity, richness and fish species richness of the collections were not significantly different between site types, although the relative abundance of certain invertebrate taxa and fish species were significantly affected by site type. Similarly, studies by Allan (1975), Madejczyk et al. (1998) and Jennings et al. (1999) reported that complex artificial substrates had little effect on overall fish or invertebrate community diversity, but the fish and invertebrate community composition differed. Pennington et al. (1983), Knudsen and Dilley (1987), Madejczyk et al. (1998) and Wolter (2001) found some fish species and invertebrate taxa (Seegert et al. 1984) had higher abundance on revetted or riprapped banks while other taxa abundances were higher on natural banks. None of the Assiniboine or Red rivers fish species showed a significantly lower abundance on riprap or dyke sites.

Although the placement of riprap was found to favour certain Catostomid (sucker) species and carp, which feed primarily on benthic invertebrates, we found no significant correlation between invertebrate density and fish abundance in either river sampled. This was possibly a result of substrate bias of the airlift sampler. It was noted in the field that the sampler did not seal effectively with the coarse riprap and therefore may have under sampled benthos on those sites. Diver observation in an unrelated study confirmed the airlift sampler was ineffective in completely sampling the invertebrate communities located on coarse substrate. Air-lift samplers have been reported to function quite effectively on substrates ranging from mud to 3 cm gravel (Pearson et al. 1973). We may have exceeded the effective range of particle sizes at which airlift samplers can function. Any coarse rock substrate, such as riprap is difficult to sample quantitatively by standard sampling techniques. Researchers have generally resorted to the use of either artificial substrate (Wise and Molles 1979; Khalaf and Tachet 1980; Clifford et al. 1989; Clifford et al. 1992; Way et al. 1995; Tockner 1996; Schmude et al. 1998) or air-lift samplers (Drake 1983; Pohofer 1998) to sample stony bottoms. Artificial substrates have the disadvantage of requiring two sampling trips, one for deployment and one for retrieval. They often require the use of SCUBA divers for retrieval, and need to be left for a sufficient period of approximately five weeks to allow colonization. Both rivers are too large and turbid for anyone but professional divers to operate, which was cost prohibitive in this study. In addition, the short-term nature of this exploratory survey negated the use of artificial substrate samples.

The Assiniboine River fish community is made up of habitat generalists that make use of a variety of habitat types and habitat specialist species that show a predictable relationship between habitat structure and fish community structure (Nelson and Franzin 2000). The difference in species specific fish abundance we observed on riprap and at dyke sites could potentially affect fish species composition and abundance at the community level. The Assiniboine River was highly modified at the time this study was conducted with 13 of 40 outside bends within the study area riprapped or dyked by 17 projects. Many of these alterations have been present for nearly two decades. If modification of the riverbank influences the fish community then likely there has already been a shift from the historic Assiniboine River fish community. However, detection of community shifts using site-specific change in fish composition is neither practical nor biologically meaningful (Jennings et al. 1999). The appropriate temporal and spatial scales must be defined to measure the effects of habitat modification.

The substratum is the medium upon which aquatic insects move, rest, find shelter and seek food. If riprap placement is found necessary, the median size of the rock placed should be considered carefully. Uniformly sized substrates have been reported to support fewer insects than substrates of mixed particle size (Allan 1975), and the highest invertebrate abundances have been reported from small gravel (mean 25 mm) (Williams and Mundie 1978; Wise and Molles 1979, Khalaf and Tachet 1980). The increased surface area of smaller particles is believed to be the main factor responsible as it affords the invertebrate more substrate on which to live. Placing riprap with a median size of 15 cm to 30 cm may not be optimal for higher invertebrate abundance. Our study was not comprehensive enough to test for significance differences in fish or invertebrate abundance on different sizes of crushed limestone. When comparing riprap and dykes, two artificial substrates with a large difference in substrate size, we observed significantly higher invertebrate density on dykes as compared to riprap. However, fish abundance was not significantly different among these site types. This is possibly an artifact of invertebrate sampling inefficiency.

Fish abundance is not influenced solely by invertebrate abundance as fish may feed selectively. This study described invertebrate presence and abundance on the different substrates of the Red and Assiniboine rivers, but to assess the importance of the different site types to the fish community, fish stomach content analysis should be conducted in conjunction with the benthic invertebrate study. If possible, a study should investigate which species are important fish foods on a seasonal and relative abundance or biomass basis. For example Oligochaetes are a major component of the catch at Red River unmodified bank sites, but are not considered important fish food (Seegert et al. 1984). On the other hand cyclopoid copepods were abundant on riprap and are an important component of the diet of many of the Red River fish species (P.A. Nelson, 318 Wildwood Park, Winnipeg, MB, pers. comm.). Additionally, this study identified invertebrates only to family, potentially masking important species specific differences in habitat use. Early spring or late fall sampling when invertebrate communities are composed of more mature individuals would allow for more precise identifications.

Few studies examine the long-term response of biota to natural or man-made disturbances to habitat (Carlisle and Hawkins 1998). However, these studies are necessary to obtain a better understanding of the effects of bank and channel modifications on fish and invertebrate communities. A sampling program should be considered that encompasses the different seasons and flow conditions that exist for the Assiniboine and Red rivers. Habitat quality, substrate composition, habitat requirements of fish and invertebrate taxa and the community structure of fish and invertebrates may change seasonally or with variation in flows (Platts 1979; Seegert et al. 1984; Schlosser 1987). Fish (Pennington et al. 1983) and invertebrate (Beckett et al. 1983; Seegert et al. 1984) abundance, biomass and species composition varies seasonally. Modified bank sites in particular were reported to have large temporal changes in fish populations (Pennington et al. 1983) and invertebrate biotic composition (Beckett et al. 1983). These temporal changes were correlated with changes in river stage and resultant alterations in current and substrate. The presence of large amounts of silt and sand coincided with a reduction in the species richness and abundance of stream insects (Chutter 1969).

The gravel and crushed rock substrate of dyke and riprap sites may provide spawning habitat for fish species that, outside of their spawning seasons, show no significant attraction to the modified sites. These substrates may increase fish spawning success. If riprap were selected as spawning habitat it would be important to understand what portion of the bank the fish utilize, as it is atypical to have rock substrate on the gradient of the bank. If fish spawn near the top of the bank at bank full flow and the eggs do not hatch before the flow drops below the level at which they were deposited or decreasing current results in smothering deposition, the riprap may be a sink for a spawning population.

SAMPLING CONSIDERATIONS

Large fish are more likely to be captured with electrofishing gear as effectiveness is greatest with fish that have a higher electrical potential created from head to tail, a function of fish length (Vibert 1967). The fish observed but not landed by the netters were also potentially biased towards larger fish and/or species that are distinct and easily identified by sight. This bias may be corrected if different sampling methods such as backpack electrofishing, beach seines or minnow traps are used, in addition to boat electrofishing as these methods are more effective for capturing smaller individuals. Seegert et al. (1984) found fish abundance differed significantly for some gear types and not for others.

The trend in all CPUE measurements was for increased fish abundance and fish biomass on riprap or dyke sites of the Assiniboine and Red rivers. The CPUE measures of (grams/min) and (landed fish/min) were significantly different among all sites, but failed to show a significant difference in many of the pairwise comparisons. This was possibly a result of inadequate sample sizes. Based on the significance of the CPUE (fish observed/min) comparisons we are confident that increased sampling would have resulted in similar significant results for CPUE (landed fish/min). Alternatively, the small sample size ($N = 2$) of the downstream sites in the Red River made it very difficult to detect a statistical difference if one existed.

ECOSYSTEM EFFECTS

By riprapping banks large woody debris recruitment is eliminated because lateral migration is stopped and fewer large trees and plants become established (Christensen et al. 1996; Dykaar and Wigington 2000). This loss of riparian vegetation can lead to simplified aquatic habitat (Ralph et al. 1994). Riparian vegetation ensures cooler summer water temperatures by shading the water, stabilizes stream banks, inputs nutrients into the system, provides direct inputs of terrestrial invertebrates that are available as fish food, and provides fish cover (Platts and Rinne 1985; Weshe et al. 1987; Jennings et al. 1999; Schmetterling et al. 2001).

Stream bank modifications may not immediately affect biotic communities, rather, they may result in long-term alterations. By changing stream reach sediment transport capacity and introducing large angular rock, the bedload size and particle distributions can be moved outside of the natural range of sediment sizes for a particular stream reach (Beschta and Platts 1986). Fine-grained stream reaches in the Assiniboine and Red rivers can start to incise (adjust downwards rather than laterally) when lateral adjustments are prevented. This may lead to a series of morphological changes. These changes include floodplain abandonment, bank steepening and erosion, lowering of the water table, changes in stream bank vegetation and changes in stream substrate (Heede 1986; Schmetterling et al. 2001). These morphological adjustments often migrate upstream and downstream from the bank alteration site (Beschta and Platts 1986; Heede 1996).

In most areas, allowing channel migration within the floodplain is important for the integrity of physical and biological stream components (Schmetterling et al. 2001). Resource managers must work to meet the often divergent goals of both maintaining natural fluvial processes, while protecting public infrastructure and private property from these same processes (Jennings et al. 1999; Schmetterling et al. 2001). Reducing floodplain development through public education and government regulations will reduce the need for further bank stabilization (Schmetterling et al. 2001).

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Table 1. Assiniboine River sample sites; radius of arc (m), arc length (m), top, middle and bottom widths (m). The upstream and downstream ends of the sample sites are also indicated in UTM, zone 14 North, NAD 1983 (Canada).

Sample site	Radius of Arc (m)	Arc Length (m)	Arc river width			Upstream		Downstream	
			downstream end (m)	middle (m)	upstream end (m)	Northing	Easting	Northing	Easting
Unmodified 1	62.6	133.4	45.5	54.0	67.4	5526988.9	606998.0	5526906.3	607115.5
Unmodified 2	227.8	308.5	66.5	68.2	55.3	5532083.8	600362.8	5531877.4	600590.0
Unmodified 3	594.4	391.1	71.7	61.6	59.5	5532810.2	600900.4	5532416.7	600965.0
Unmodified 4	194.0	292.0	58.8	61.1	62.9	5532931.3	600577.0	5532861.1	600869.7
Unmodified 5	105.6	194.9	48.5	49.5	54.6	5533793.7	599307.3	5533726.8	599114.4
Unmodified 6	635.4	492.1	59.3	69.0	59.2	5534198.5	597800.0	5534325.3	598097.0
Unmodified 7	76.2	134.6	36.7	49.2	56.8	5535847.5	596191.4	5535927.1	596309.2
Unmodified 8	1328.0	764.6	81.1	89.9	73.9	5539650.2	592348.4	5539246.4	592993.8
Unmodified 9	330.9	421.7	59.7	55.9	61.8	5543601.4	583420.7	5543800.8	583797.2
Unmodified 10	790.9	666.5	75.0	70.3	50.4	5543695.8	581166.8	5544230.4	581575.6
Unmodified 11	387.9	238.3	63.5	67.0	61.1	5542754.2	572818.5	5542936.5	572963.4
Unmodified 12	1201.4	545.9	76.4	78.8	66.6	5542913.9	568812.7	5542605.2	569280.1
Dyke 1	192.7	317.2	51.6	61.7	53.1	5537423.2	564901.6	5537621.2	564877.5
Dyke 2	745.9	669.7	61.9	66.5	90.7	5544723.8	579129.2	5544646.2	579276.1
Dyke 3	59.1	160.9	44.6	55.7	60.6	5540932.8	585395.8	5540787.4	585421.5
Dyke 4	78.8	242.3	44.7	50.8	66.5	5539775.1	587769.8	5540034.7	587585.2
Dyke 5	627.2	435.0	54.8	60.0	47.0	5539245.7	586179.3	5539245.0	586415.4
Riprap 1	323.0	435.9	50.6	45.6	55.0	5540758.1	586098.4	5540829.7	586345.8
Riprap 2	603.2	671.9	68.8	67.1	80.5	5541431.5	584356.9	5541293.2	584563.9
Riprap 3	1286.0	1114.0	65.4	79.7	63.7	5543271.1	574072.7	5543165.4	574305.0
Riprap 4	95.2	234.7	41.4	69.9	68.6	5537117.3	564810.5	5537262.5	564798.3
Riprap 5	419.0	300.3	60.0	53.4	41.8	5540756.2	587317.7	5540632.5	587659.7

Table 2. Red River sample sites; upstream and downstream ends. UTM, zone 14 North, NAD 1983 (Canada).

Site	Upstream		Downstream	
	Northing	Easting	Northing	Easting
Unmodified 1	5522688.0	633842.6	5522937.9	634035.4
Unmodified 2	5525832.1	635630.9	5526006.1	635417.8
Unmodified 3	5533597.9	636223.4	5533714.1	636456.3
Unmodified 4	5523766.6	633730.3	5523898.9	633919.0
Unmodified 5	5524059.3	633771.5	5524098.4	634033.7
Unmodified 6	5528817.7	634129.9	5529204.7	634339.7
Riprap 1	5529396.5	635847.7	5529643.8	635880.7
Riprap 2	5525883.7	633919.2	5526152.8	633778.8
Riprap 3	5526251.2	633754.7	5526446.9	633772.0
Riprap 4	5527768.2	634709.4	5527956.4	634701.8
Riprap 5	5528029.1	634688.2	5528167.3	634615.6

Table 3. Length weight equations used to calcualte biomass for the fish species captured during the Assiniboine and Red rivers electrofishing (y = weight and x = length). Burbot equation (Fisher et al. 1996). Emerald shiner equation (Schaap 1989). All other equations are unpublished data courtesy of Dave Tyson (DFO, Yellowknife).

Species	Common name	Length weight equation
Moxostoma anisurum	Silver redhorse	$\ln(y) = 2.7652\ln(x) - 9.5837$
Moxostoma erythrurum	Golden redhorse	$\ln(y) = 3.256\ln(x) - 12.442$
Moxostoma macrolepidotum	Shorthead redhorse	$\ln(y) = 3.1567\ln(x) - 11.984$
Catostomus commersoni	White sucker	$\ln(y) = 3.1426\ln(x) - 11.903$
Carpiodes cyprinus	Quillback	$\ln(y) = 3.074\ln(x) - 11.276$
Hiodon alosoides	Goldeye	$\ln(y) = 3.0773\ln(x) - 11.859$
Hiodon tergisus	Mooneye	$\ln(y) = 3.8169\ln(x) - 15.545$
Esox lucius	Northern pike	$\ln(y) = 2.968\ln(x) - 11.433$
Cyprinus carpio	Common carp	$\ln(y) = 2.8051\ln(x) - 9.673$
Notropis atherinoides	Emerald shiner	$\ln(y) = 3.114\ln(x) - 5.377$
Sander canadensis	Sauger	$\ln(y) = 3.2515\ln(x) - 12.912$
Ictalurus punctatus	Channel catfish	$\ln(y) = 3.3714\ln(x) - 13.47$
Lota lota	Burbot	$\log_{10}(y) = 2.898\log_{10}(x) – 4.868$
Aplodinotus grunniens	Freshwater drum	$\ln(y) = 3.2858\ln(x) - 12.866$

Table 4. Shapiro-Wilk tests of normality for Assiniboine River electrofishing data. The data was considered to have a distribution significantly different from normal if the p-value was less than 0.05.

Site Types		Shapiro-Wilk		
		Statistic	df	p-value
CPUE (fish/min)	Unmodified banks	0.9508	12	0.6034
	Downstream	0.9034	7	0.3905
	Riprap	0.9839	5	0.9347
	Upstream	0.8822	9	0.2221
	Adjacent	0.9051	16	0.0977
	Dykes	0.8809	9	0.2150
Boat Speed (m/sec)	Unmodified banks	0.9291	12	0.4075
	Downstream	0.9398	7	0.6071
	Riprap	0.8510	5	0.2489
	Upstream	0.9524	9	0.6885
	Adjacent	0.9756	16	0.8928
	Dykes	0.8876	9	0.2505
CPUE (grams/min)	Unmodified banks	0.9176	12	0.3309
	Downstream	0.7985	7	0.0469
	Riprap	0.8062	5	0.1008
	Upstream	0.7199	9	0.0100
	Adjacent	0.7507	16	0.0100
	Dykes	0.9391	9	0.5444
CPUE (fish landed/min)	Unmodified banks	0.9437	12	0.5100
	Downstream	0.9150	7	0.4421
	Riprap	0.9617	5	0.7669
	Upstream	0.7127	9	0.0100
	Adjacent	0.8320	16	0.0100
	Dykes	0.9063	9	0.3491

Table 5. Shapiro-Wilk tests of normality for Red River electrofishing data. The data was considered to have a distribution significantly different from normal if the p-value was less than 0.05.

		Shapiro-Wilk		
	Site Types	Statistic	df	p-value
CPUE (fish observed/min)	Unmodified banks	0.8218	6	0.0945
	Downstream		2	
	Riprap	0.9030	5	0.4205
	Upstream		4	
	Adjacent sites	0.8428	6	0.1664
Boat Speed (m/sec)	Unmodified banks	0.9736	6	0.8965
	downstream		2	
	Riprap	0.9112	5	0.4479
	Upstream		4	
	Adjacent			
CPUE (grams/min)	Unmodified banks	0.7279	6	0.0150
	downstream		2	
	Riprap	0.7690	5	0.0580
	Upstream		4	
	Adjacent	0.6563	6	0.0100
CPUE (Fish landed/min)	Unmodified banks	0.7644	6	0.0343
	downstream		2	
	Riprap	0.8681	5	0.3052
	Upstream		4	
	Adjacent	0.6685	6	0.0100

Table 6. The Shapiro-Wilk tests of normality for Assiniboine and Red rivers invertebrate collection data. The data was considered to have a distribution significantly different from normal if the p-value was less than 0.05.

River	Measurement	Shapiro-Wilk			
		Site type	Statistic	d.f.	p-value
Assiniboine	Density (invertebrates/m^2)	Unmodified bank	0.986	12	0.998
		Dykes	0.905	5	0.436
		Riprap		4	
	Taxa richness	Unmodified bank	0.894	12	0.132
		Dykes	0.845	5	0.180
		Riprap		4	
	Simpson's reciprocal index (1/D)	Unmodified bank	0.992	12	1.000
		Dykes	0.858	5	0.220
		Riprap		4	
Red	Density (invertebrates/m^2)	Unmodified bank	0.854	6	0.168
		Riprap	0.880	5	0.309
	Taxa richness	Unmodified bank	0.847	6	0.148
		Riprap	0.942	5	0.680
	Simpson's reciprocal index (1/D)	Unmodified bank	0.882	6	0.276
		Riprap	0.971	5	0.884
	Depth (m)	Unmodified bank	0.942	6	0.630
		Riprap	0.898	5	0.404

Table 7. Summary of Assiniboine River site data and electrofishing catches. Sample sites are separated into types: unmodified bank sites, downstream of riprap or dykes, dykes, dykes adjacent to riprap or dykes, riprap and upstream of riprap or dykes. The sample site length (m), electrofishing effort (sec), boat speed (m/sec), primary substrate, secondary substrate, CPUE (fish observed/min), CPUE (grams/min) and CPUE (fish landed/min) are included.

Site Type	Sample sites	Length (m)	Effort (sec)	Boat speed (m/sec)	Primary substrate	Secondary substrate	CPUE (fish observed/min)	CPUE (grams/min)	CPUE (fish landed/min)
Unmodified banks	Unmodified 1	133.4	207	0.64	silt	clay	0.58	0.0	0.00
	Unmodified 2	308.5	385	0.80	clay	gravel	2.81	1441.8	1.56
	Unmodified 3	391.1	503	0.78	silt	clay	0.12	63.9	0.12
	Unmodified 4	292.0	356	0.82	clay	silt	1.35	659.5	0.67
	Unmodified 5	194.9	326	0.60	clay	silt	1.47	974.4	0.74
	Unmodified 6	320.0	342	0.94	sand	sand	1.93	223.2	0.88
	Unmodified 7	134.6	187	0.72	silt	sand	1.28	22.1	0.32
	Unmodified 8	764.6	948	0.81	gravel	sand	1.58	657.0	0.76
	Unmodified 9	421.7	482	0.87	clay	silt	1.12	621.3	0.62
	Unmodified 10	666.5	804	0.83	sand	clay	0.97	752.8	0.52
	Unmodified 11	238.3	294	0.81	sand	silt	1.43	743.6	0.61
	Unmodified 12	545.9	627	0.87	clay	sand	2.68	1391.6	0.96
	Mean	367.6	455.1	0.79			1.44	629.3	0.65
	S.D.	202.1	233.7	0.10			0.77	489.9	0.41
Downstream of riprap and dykes	Dyke 1d	100.0	109	0.92	clay	sand	0.00	0.0	0.00
	Dyke 2d	100.0	145	0.69	clay		0.41	57.6	0.41
	Dyke 3d	100.0	123	0.81	clay	sand	1.95	385.4	0.98
	Dyke 4d	100.0	122	0.82	clay	sand	0.49	0.0	0.00
	Dyke 5d	100.0	142	0.70	clay	silt	1.69	427.5	0.85
	Riprap 3d	100.0	96	1.04	clay	sand	1.25	2.5	0.63
	Riprap 4d	100.0	109	0.92	silt	sand	1.65	193.6	0.55
	Mean	100.0	120.8	0.84			1.06	152.3	0.49
	S.D.	0.0	17.9	0.13			0.76	186.9	0.38

Table 7. Continued.

Site Type	Sample sites		Length (m)	Effort (sec)	Boat speed (m/sec)	Primary substrate	Secondary substrate	CPUE (fish observed/min)	CPUE (grams/min)	CPUE (fish landed/min)
Upstream of riprap and dykes	Dyke 1u		100.0	86	1.16	silt	sand	1.40	0.0	0.00
	Dyke 2u		100.0	109	0.92	clay	silt	0.55	0.0	0.00
	Dyke 3u		100.0	169	0.59	sand		0.36	0.0	0.00
	Dyke 4u		100.0	188	0.53	clay	sand	0.32	0.0	0.00
	Riprap 1u		100.0	118	0.85	sand	silt	0.51	41.2	0.51
	Riprap 2u		100.0	104	0.96	silt	clay	1.73	468.8	0.58
	Riprap 3u		100.0	112	0.89	clay	sand	1.61	167.3	0.54
	Riprap 4u		100.0	123	0.81	silt		0.00	0.0	0.00
	Riprap 5u		100.0	97	1.03	clay	gravel	3.09	325.0	0.62
		Mean	100.0	122.8	0.86			1.06	111.3	0.25
		S.D.	0.0	33.7	0.20			0.98	174.4	0.30
Adjacent sites		Mean	100.0	122.0	0.85			1.06	129.3	0.35
		S.D.	0.0	27.1	0.17			0.86	175.0	0.35
Dykes	Dyke 1		200.0	345	0.58	gravel	clay	1.57	362.4	0.52
	Dyke 2		270.0	169	1.60	gravel	sand	2.13	952.8	1.07
	Dyke 3		260.0	196	1.33	gravel	clay	3.98	1546.7	1.53
	Dyke 4		470.0	449	1.05	silt	sand	1.87	452.0	0.53
	Dyke 5		240.0	343	0.70	gravel	clay	3.67	1845.7	1.40
	Riprap 1d		100.0	116	0.86	gravel	cobble	2.07	1288.6	1.03
	Riprap 2d		100.0	107	0.93	gravel	sand	3.93	900.8	0.56
	Riprap 5d		100.0	147	0.68	sand	gravel	2.45	180.4	0.82
	Dyke 5d		100.0	146	0.68	gravel	silt	1.23	481.5	0.41
		Mean	204.4	224.2	0.93			2.54	890.1	0.87
		S.D.	123.9	122.7	0.34			1.05	575.3	0.41

Table 7. Continued

Site Type	Sample sites		Length (m)	Effort (sec)	Boat speed (m/sec)	Primary substrate	Secondary substrate	CPUE (fish observed/min)	CPUE (grams/min)	CPUE (fish landed/min)
Riprap	Riprap 1		250.0	340	0.74	riprap	sand	4.24	905.2	1.59
	Riprap 2		230.0	301	0.76	riprap	sand	3.59	749.0	1.00
	Riprap 3		265.0	254	1.04	riprap	sand	5.43	2362.4	2.13
	Riprap 4		180.0	198	0.91	riprap	clay	2.73	287.7	1.21
	Riprap 5		380.0	539	0.71	riprap	clay	1.56	281.2	0.67
		Mean	261.0	326.4	0.83			3.51	917.1	1.32
		S.D.	73.8	130.1	0.14			1.47	854.1	0.56

Table 8. Total numbers of each fish species observed and electrofishing effort at each site type in the Assiniboine River. Results of chi-square distribution tests are included. A Bonferroni corrected significant p-value was calculated as 0.05/8 = 0.0063 for $\alpha = 0.05$. NT = not tested.

		Unmodified banks	Adjacent	Dykes	Riprap	Total	Chi-square p-value
Moxostoma anisurum	Silver redhorse	13	2	19	7	41	<0.001
Moxostoma erythrurum	Golden redhorse	0	1	1	3	5	NT
Moxostoma macrolepidotum	Shorthead redhorse	45	12	27	40	124	<0.001
Catostomus commersoni	White sucker	7	0	0	5	12	0.015
Carpiodes cyprinus	Quillback	1	0	0	0	1	NT
Ictiobus cyprinellus	Bigmouth buffalo	1	0	1	0	2	NT
Hiodon alosoides	Goldeye	16	3	6	5	30	0.749
Hiodon tergisus	Mooneye	0	1	0	0	1	NT
Esox lucius	Northern pike	0	1	1	1	3	NT
Cyprinus carpio	Carp	18	0	13	11	42	0.002
Hybopsis storeriana	Silver chub	3	1	0	0	4	NT
Sander canadensis	Sauger	14	5	4	1	24	0.496
Sander vitreus	Walleye	1	0	1	0	2	NT
Ictalurus punctatus	Channel catfish	6	1	1	1	9	NT
Noturus flavus	Stonecat	0	0	0	2	2	NT
Lota lota	Burbot	2	0	2	9	13	<0.001
Aplodinotus grunniens	Freshwater drum	7	5	7	3	22	0.268
	Total	134	32	83	88	337	
	Effort (sec)	5461	1952	2018	1632	11063	

Table 9. Multiple pairwise comparisons of similar Assiniboine and Red rivers sample types for CPUE (fish observed/min, grams/min and landed fish/min). An independent samples *t* test was used if the data met the assumptions of parametric statistics. Alternatively, a Mann-Whitney U test was used to test for significant differences between the pairs.

River	Calculated variable	First site type	N	Second site type	N	Statistical test	t or z statistic	Calculated p-value
Assiniboine	CPUE (fish observed/min)	Upstream of dykes or riprap	9	Downstream of dykes or riprap	7	*t* test	-0.0043	0.9967
	CPUE (grams/min)	Upstream of dykes or riprap	9	Downstream of dykes or riprap	7	Mann-Whitney	-0.8287	0.4698
	CPUE (landed fish/min)	Upstream of dykes or riprap	9	Downstream of dykes or riprap	7	Mann-Whitney	-1.3812	0.2105
Red	CPUE (fish observed/min)	Upstream of riprap	4	Downstream of riprap	2	Mann-Whitney	-0.2348	0.8000
	CPUE (grams/min)	Upstream of riprap	4	Downstream of riprap	2	Mann-Whitney	-0.8216	0.5333
	CPUE (landed fish/min)	Upstream of riprap	4	Downstream of riprap	2	Mann-Whitney	-0.2739	0.8000

Table 10. Multiple pairwise comparisons of different Assiniboine and Red rivers sample site types for CPUE (fish observed/min, grams/min and landed fish/min). An independent samples *t* test was used if the data meet the assumptions of parametric statistics. Alternatively, a Mann-Whitney U test was used to test for statistical significance between the pairs. A Bonferroni corrected significant p-value as 0.05/4 = 0.0125 for the Assiniboine River and 0.05/2 = 0.025 for the Red River. Asterisks indicate significance.

River	Calculated variable	Bonferroni corrected significant p-value	First site type	N	Second site type	N	Statistical test	t or z statistic	Calculated p-value
Assiniboine	CPUE (fish observed/min)	0.0125	Adjacent sites	16	Riprap	5	*t* test	-4.6733	0.0002*
					Dykes	9	*t* test	-3.8164	0.0009*
			Unmodified banks	12	Riprap	5	*t* test	-3.8601	0.0015*
					Dykes	9	*t* test	-2.7832	0.0118*
	CPUE (grams/min)	0.0125	Adjacent sites	16	Riprap	5	Mann-Whitney	-2.6917	0.0059*
					Dykes	9	Mann-Whitney	-3.6057	0.0001*
			Unmodified banks	12	Riprap	5	*t* test	-0.8884	0.3883
					Dykes	9	*t* test	-1.1220	0.2758
	CPUE (landed fish/min)	0.0125	Adjacent sites	16	Riprap	5	Mann-Whitney	-3.1964	0.0004*
					Dykes	9	Mann-Whitney	-2.4038	0.0165
			Unmodified banks	12	Riprap	5	*t* test	-2.7820	0.0140
					Dykes	9	*t* test	-1.2719	0.2188
Red	CPUE (fish observed/min)	0.025	Adjacent sites	6	Riprap	5	*t* test	-2.6241	0.0276
			Unmodified banks	6	Riprap	5	*t* test	-3.1972	0.0109*

Table 11. Assiniboine River calculated rarefaction species richness values for a random sample of 30 sampled fish for the unmodified bank, adjacent, riprap and dyke sites. Red River calculated rarefaction species richness values for a random sample of 16 sampled fish for the unmodified bank and riprap sites. Chi-square goodness of fit test results are included. Expected values were calculated as the mean species richness for the sample sites.

River	Site Type		Calculated rarefaction species richness	Expected
Assiniboine	Unmodified banks		8.99	8.89
	Adjacent sites		9.68	8.89
	Riprap		8.72	8.89
	Dykes		8.14	8.89
		Chi-square p-value	0.9868	
Red	Unmodified banks		6.63	6.60
	Riprap		6.56	6.60
		Chi-square p-value	0.9840	

Table 12. Total numbers of invertebrates sampled and number of samples from each site type in the Assiniboine River. Results of chi-square distribution tests are included. Expected numbers within a site type were directly proportional to the total number of samples. A Bonferroni corrected significant p-value was calculated as 0.05/35 = 0.00143 for α = 0.05. NT = not tested.

Order	Family name/Sub Order	Dykes	Riprap	Unmodified banks	Total	Chi-square p-value
Oligochaeta	Unidentified	42	48	359	449	<0.0001
Coelenterata	Hydridae	1	4	13	18	0.1824
Nematoda	Unidentified	3	3	18	24	0.1914
Pelecypoda	Sphaeriidae	2	5	25	32	0.0300
	Unionidae	0	0	1	1	NT
Gastropoda	Planorbidae	2	0	1	3	0.2086
	Lymnaeidae	1	1	0	2	NT
	Hydrobiidae	37	1	53	91	<0.0001
Acari	Unidentified	2	2	1	5	0.2416
Amphipoda	Talitridae	0	0	1	1	NT
Ostracoda	Unidentified	22	6	55	83	0.0207
Ephemeroptera	Caenidae	257	167	766	1190	<0.0001
	Baetidae	6	28	43	77	<0.0001
	Heptageniidae	153	143	266	562	<0.0001
	Ephemerellidae	0	0	22	22	0.0002
	Siphlonuridae	2	0	6	8	NT
	Ephemeridae	79	15	431	525	<0.0001
	Ametropodidae	2	0	29	31	0.0002
	Leptophlebiidae	0	3	2	5	NT
	Tricorythidae	38	21	75	134	0.3797
	Polymitarcidae	10	2	6	18	0.0075
	Isonychiidae	8	22	49	79	0.0074
	Oligorneuridae	0	6	1	7	NT
	Metretopodidae	1	0	4	5	NT
Plecoptera	Perliidae	6	1	3	10	0.0290
	Perlodiidae	1	0	4	5	NT
	Nemouridae	0	2	6	8	0.2819
Trichoptera	Limnephilidae	0	0	3	3	NT
	Leptoceridae	33	20	75	128	0.5754
	Hydroptilidae	4	3	41	48	0.0003
	Hydropsychidae	33	23	103	159	0.1104

Continued

Table 12. Continued

Order	Family name/Sub Order	Dykes	Riprap	Unmodified banks	Total	Chi-square p-value
Odonata-Anisoptera	Gomphidae	36	17	95	148	0.0480
Coleoptera	Elmidae	12	9	53	74	0.0351
Hemiptera	Corixidae	3	2	6	11	0.9688
Diptera	Chironomidae	804	316	1429	2549	<0.0001
	Ceratopogonidae	36	5	37	78	<0.0001
	Tipulidae	0	0	2	2	NT
	Simuliidae	7	7	13	27	0.6005
	Empididae	2	3	1	6	0.0877
Copepoda (Crustacea)	Cyclopoida	10	42	45	97	<0.0001
	Calanoidia	0	0	1	1	NT
	Cladocera	8	13	16	37	0.0463
Bryozoa	Plumatellina	1	0	0	1	NT
	Total	1664	940	4160	6764	
	Effort (number of samples)	50	40	118	208	

Table 13. Number of invertebrate samples collected at each site, density of invertebrates, taxa richness and Simpson's reciprocal index for the Assiniboine and Red rivers. Mean depths of the Red River sample sites are also included.

River	Site Type	Sample sites	Number of samples	Density of individuals (individuals/m^2)	Taxa richness	Simpson's reciprocal index (1/D)	Depth (cm)
Assiniboine	Unmodified banks	Unmodified 1	10	1397.9	21	5.51	
		Unmodified 2	10	349.5	18	4.89	
		Unmodified 3	10	1469.7	22	6.00	
		Unmodified 4	10	1394.8	27	5.29	
		Unmodified 5	9	1026.3	21	4.52	
		Unmodified 6	10	1198.2	22	3.30	
		Unmodified 7	10	752.0	19	2.47	
		Unmodified 8	10	1800.5	26	5.92	
		Unmodified 9	9	565.1	19	7.16	
		Unmodified 10	10	1085.9	22	5.05	
		Unmodified 11	10	1029.7	20	4.02	
		Unmodified 12	10	880.0	22	3.88	
		Mean		1079.1	21.6	4.83	
		S.D.		408.6	2.7	1.29	
	Dykes	Dyke 1	10	555.4	22	9.86	
		Dyke 2	10	608.5	20	4.22	
		Dyke 3	10	1073.4	16	1.77	
		Dyke 4	10	1572.7	23	3.18	
		Dyke 5	10	1382.3	22	4.50	
		Mean		1038.4	20.6	4.71	
		S.D.		453.6	2.8	3.08	
	Riprap	Riprap 1	10	808.2	22	2.77	
		Riprap 2	10	817.5	21	4.92	
		Riprap 3	10	973.6	22	6.35	
		Riprap 4	10	333.9	17	7.38	
		Mean		733.3	20.5	5.36	
		S.D.		276.8	2.4	2.00	
Red	Unmodified banks	Unmodified 1	10	783.2	17	6.17	126.0
		Unmodified 2	10	876.8	15	3.30	67.4
		Unmodified 3	10	1866.0	10	1.41	103.9
		Unmodified 4	10	536.7	17	7.27	156.0
		Unmodified 5	10	2277.9	14	3.05	126.5
		Unmodified 6	10	2346.6	16	1.46	138.5
		Mean		1447.9	14.8	3.8	119.7
		S.D.		808.6	2.6	2.4	30.8
	Riprap	Riprap 1	10	808.2	16	2.21	98.0
		Riprap 2	10	2093.8	19	3.44	71.5
		Riprap 3	10	964.2	11	1.55	79.0
		Riprap 4	10	661.5	15	2.71	83.0
		Riprap 5	10	1298.1	15	2.13	69.5
		Mean		1165.2	15.2	2.4	80.2
		S.D.		570.4	2.9	0.7	11.4

Table 14. Summary of electrofishing catches at Red River sites. Sample sites are separated into types: unmodified bank, downstream of riprap, riprap and upstream of riprap. The sample site length (m), electrofishing effort (sec), boat speed (m/sec), primary substrate, secondary substrate, CPUE (fish observed/min), CPUE (grams/min) and CPUE (fish landed/min) are included.

Site Type	Sample sites	Length (m)	Effort (sec)	Boat speed (m/sec)	Primary substrate	Secondary substrate	CPUE (fish observed/min)	CPUE (grams/min)	CPUE (fish landed/min)
Unmodified bank	Unmodified 1	310	488	0.64	silt	sand	0.86	122.1	0.37
	Unmodified 2	265	442	0.60	silt	clay	0.81	0.0	0.00
	Unmodified 3	256	388	0.66	clay	debris	0.00	0.0	0.00
	Unmodified 4	230	394	0.58	silt	clay	0.00	0.0	0.00
	Unmodified 5	270	485	0.56	debris	silt	0.12	126.5	0.12
	Unmodified 6	390	647	0.60	clay	silt	0.46	99.2	0.09
	mean	286.8	474.0	0.61			0.38	59.5	0.10
	S.D.	56.7	94.9	0.04			0.40	66.1	0.14
Downstream of riprap	Riprap 1d	100	170	0.59	clay	gravel	0.00	0.0	0.00
	Riprap 3d	60	96	0.63	clay	gravel	1.25	1448.6	0.63
	mean	80.0	133.0	0.61			0.63	724.3	0.31
	S.D.	28.1	52.3	0.03			0.88	1024.3	0.44
Upstream of riprap	Riprap 1u	100	132	0.76	silt	clay	0.45	0.0	0.00
	Riprap 2u	100	173	0.58	clay	silt	0.35	0.0	0.00
	Riprap 3u	100	158	0.63	clay	silt	1.14	1269.9	0.76
	Riprap 4u	100	166	0.60	silt	clay	0.00	0.0	0.00
	mean	100.0	157.2	0.64			0.49	317.5	0.19
	S.D.	0.0	17.9	0.08			0.48	634.9	0.38
Adjacent sites	mean	93.3	149.1	0.63			0.53	453.1	0.23
	S.D.	16.2	29.9	0.07			0.55	704.2	0.36

Table 14 Continued

Site Type	Sample sites		Length (m)	Effort (sec)	Boat speed (m/sec)	Primary substrate	Secondary substrate	CPUE (fish observed/min)	CPUE (grams/min)	CPUE (fish landed/min)
Riprap	Riprap 1		255	400	0.64	riprap	silt	1.95	860.2	0.60
	Riprap 2		160	263	0.61	clay	silt	0.91	0.3	0.23
	Riprap 3		185	317	0.58	riprap	silt	3.03	102.3	1.32
	Riprap 4		195	295	0.66	riprap	clay	2.03	1354.0	0.81
	Riprap 5		310	520	0.60	riprap	clay	0.69	4.0	0.23
		mean	221.0	359.0	0.62			1.72	464.1	0.64
		S.D.	60.7	103.2	0.03			0.94	613.7	0.46

Table 15. Total number of each fish species observed and electrofishing effort at each site type in the Red River. Results of chi-square distribution tests are included. Expected numbers within a site type calculated as directly proportional to the total electrofishing effort for the different site types. A Bonferroni corrected significant p-value was calculated as 0.05/3 = 0.017 for $\alpha = 0.05$. NT = not tested.

Species	Common name	Unmodified banks	Adjacent sites	Riprap	Total	Chi-square p-value
Moxostoma anisurum	Silver redhorse	0	2	0	2	NT
Moxostoma macrolepidotum	Shorthead redhorse	0	1	1	2	NT
Catostomus commersoni	White sucker	2	0	0	2	NT
Carpiodes cyprinus	Quillback	0	0	4	4	NT
Ictiobus cyprinellus	Bigmouth buffalo	0	0	1	1	NT
Hiodon alosoides	Goldeye	2	1	1	4	NT
Esox lucius	Northern pike	3	0	5	8	0.148
Cyprinus carpio	Carp	8	3	20	31	<0.001
Hybopsis storeriana	Silver chub	0	0	1	1	NT
Notropis atherinoides	Emerald shiner	0	0	10	10	<0.001
Sander canadensis	Sauger	2	0	3	5	NT
Ictalurus punctatus	Channel catfish	1	0	0	1	NT
Lota lota	Burbot	1	0	1	2	NT
Aplodinotus grunniens	Freshwater drum	0	0	2	2	NT
	Total	19	7	49	75	
	Effort (sec)	2844	895	1795	5534	

Table 16. Total numbers of invertebrates sampled and number of samples at each site type in the Red River. Results of chi-square distribution tests are included. Calculated expected numbers within a site type were directly proportional to the total number of samples for that site type compared to the total number of samples. A Bonferroni corrected significant p-value was calculated as 0.05/22 = 0.0023 for α = 0.05. NT = not tested.

Order	Family name/Sub Order	Riprap	Unmodified banks	Total	Chi-square p-value
Oligochaeta	Unidentified	513	1632	2145	<0.0001
Coelenterata	Hydridae	1	4	5	0.2530
Nematoda	Unidentified	3	15	18	0.0142
Pelecypoda	Sphaeriidae	4	30	34	<0.0001
Gastropoda	Hydrobiidae	1	0	1	NT
Acari	Unidentified	5	73	78	<0.0001
Amphipoda	Talitridae	0	1	1	NT
Ostracoda	Unidentified	74	440	514	<0.0001
Ephemeroptera	Caenidae	4	5	9	0.9515
	Baetidae	1	2	3	0.6733
	Heptageniidae	48	60	108	0.8330
	Ephemeridae	44	129	173	<0.0001
	Leptophlebiidae	8	10	18	0.9314
	Tricorythidae	11	5	16	0.0613
	Polymitarcidae	4	12	16	0.1003
Trichoptera	Leptoceridae	2	6	8	0.2453
	Polycentropodidae	1	1	2	NT
	Hydroptilidae	2	0	2	NT
	Hydropsychidae	4	5	9	0.9515
Odonata-Anisoptera	Gomphidae	0	1	1	NT
Coleoptera	Dytiscidae	1	0	1	NT
	Elmidae	1	6	7	0.0977
Hemiptera	Corixidae	4	4	8	0.7963
Megaloptera	Sialidae	1	1	2	NT
Diptera	Chironomidae	124	197	321	0.0141
	Ceratopogonidae	40	17	57	0.0002
	Simuliidae	1	0	1	NT
	Empididae	3	1	4	NT

Continued

Table 16. Continued

Order	Family name/Sub Order	Riprap	Unmodified banks	Total	Chi-square p-value
Copepoda (Crustacea)	Cyclopoida	935	122	1057	<0.0001
	Calanoidia	3	2	5	0.5136
	Cladocera	23	3	26	<0.0001
Bryozoa	Plumatellina	1	0	1	NT
	Total	1867	2784	4651	
	Effort (number of samples)	50	60	110	

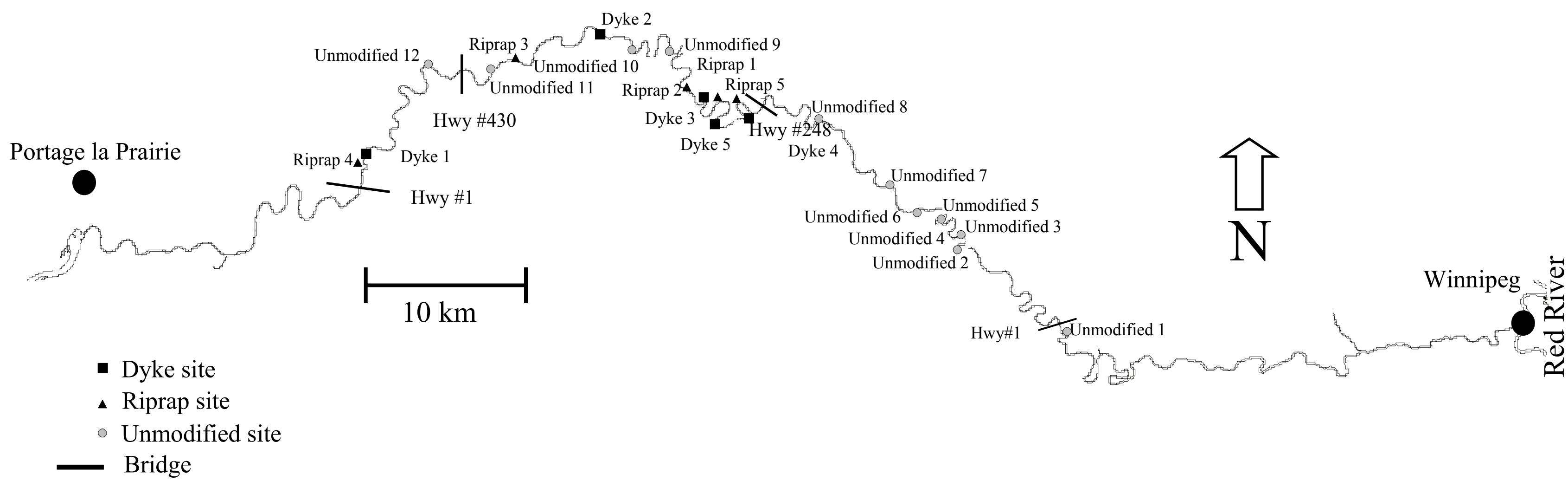

Figure 1. Overview map of Assiniboine River unmodified bank, riprap and dyke sample site locations.

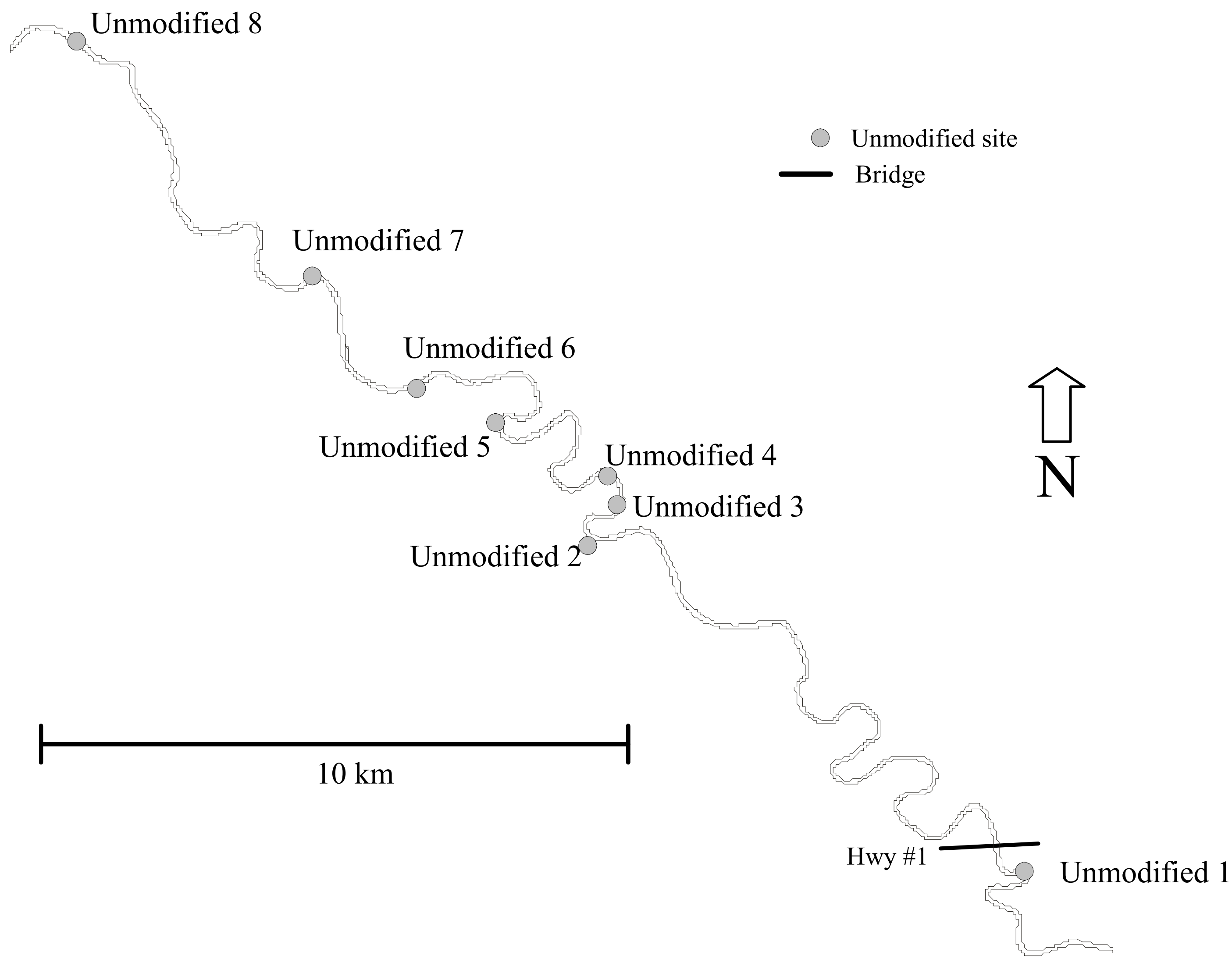

Figure 2. Eastern half of the Assiniboine River sampling reach.

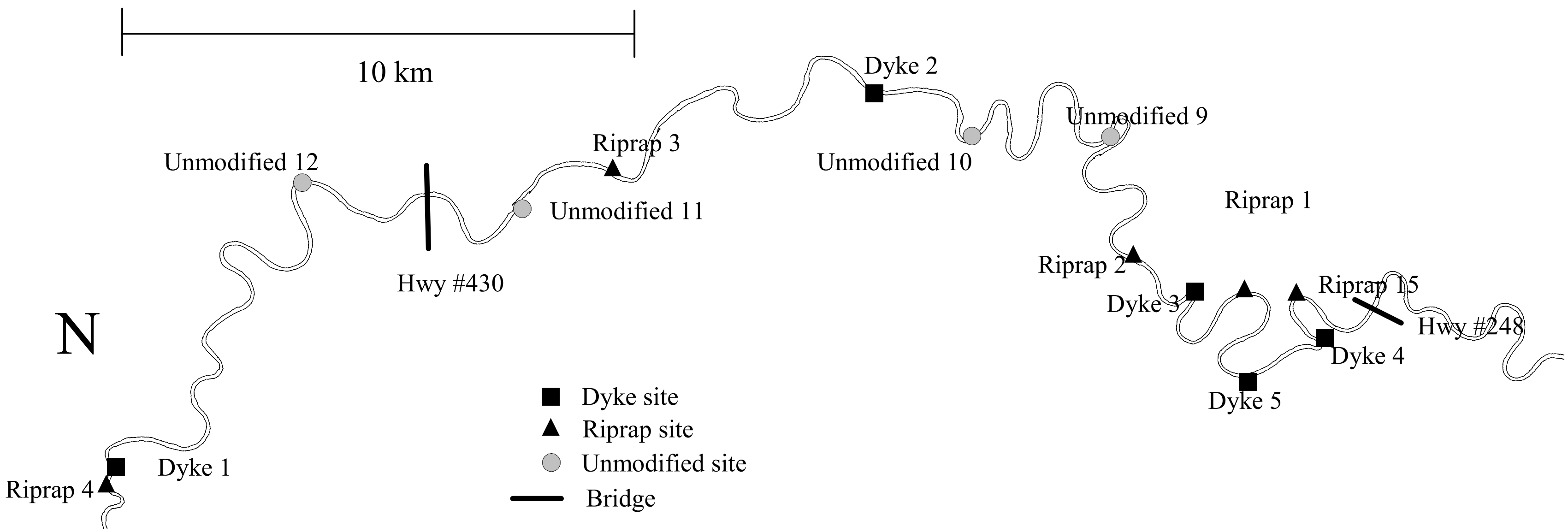

Figure 3. Western half the Assiniboine River study reach.

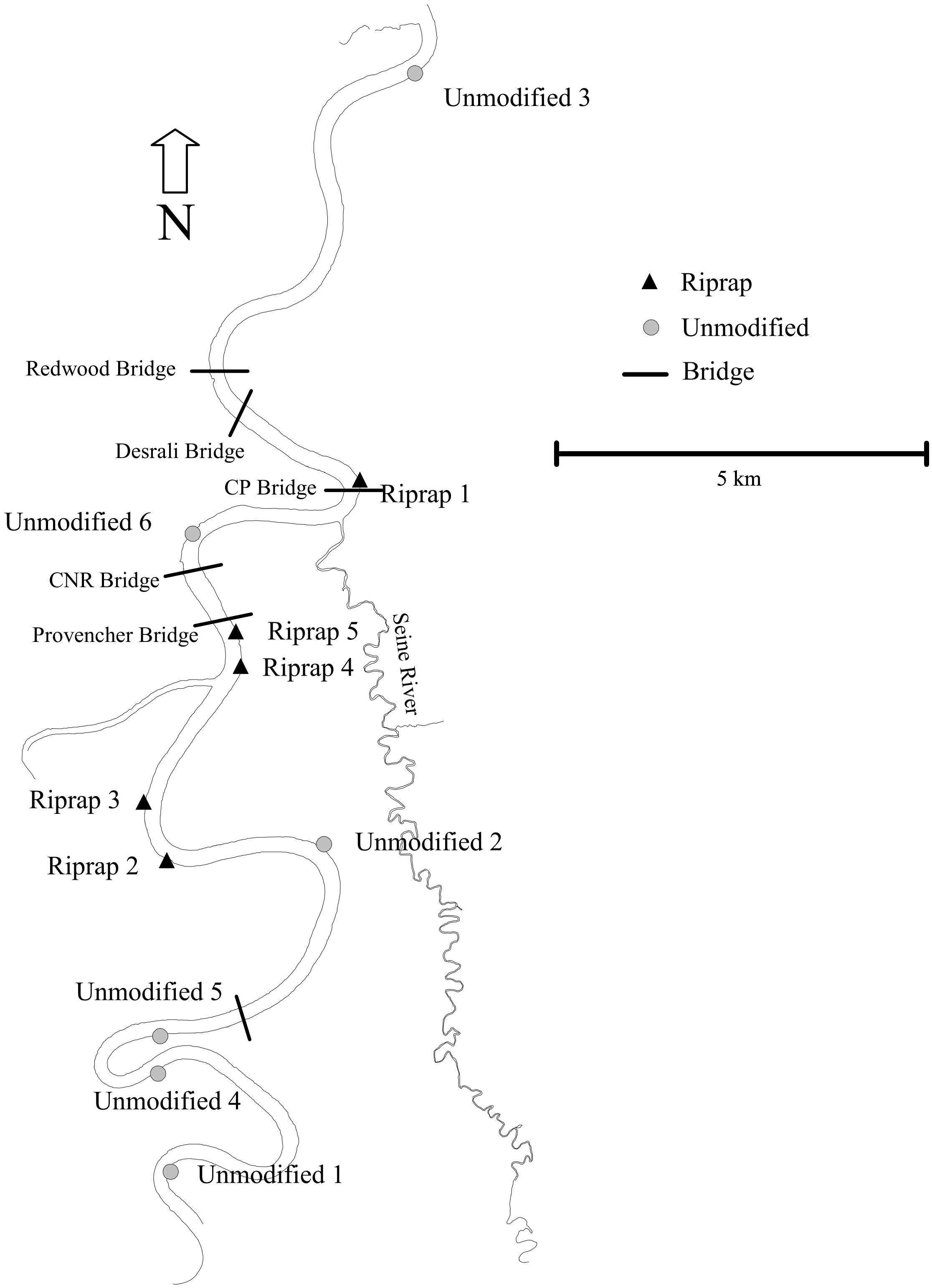

Figure 4. Red River sample site locations.

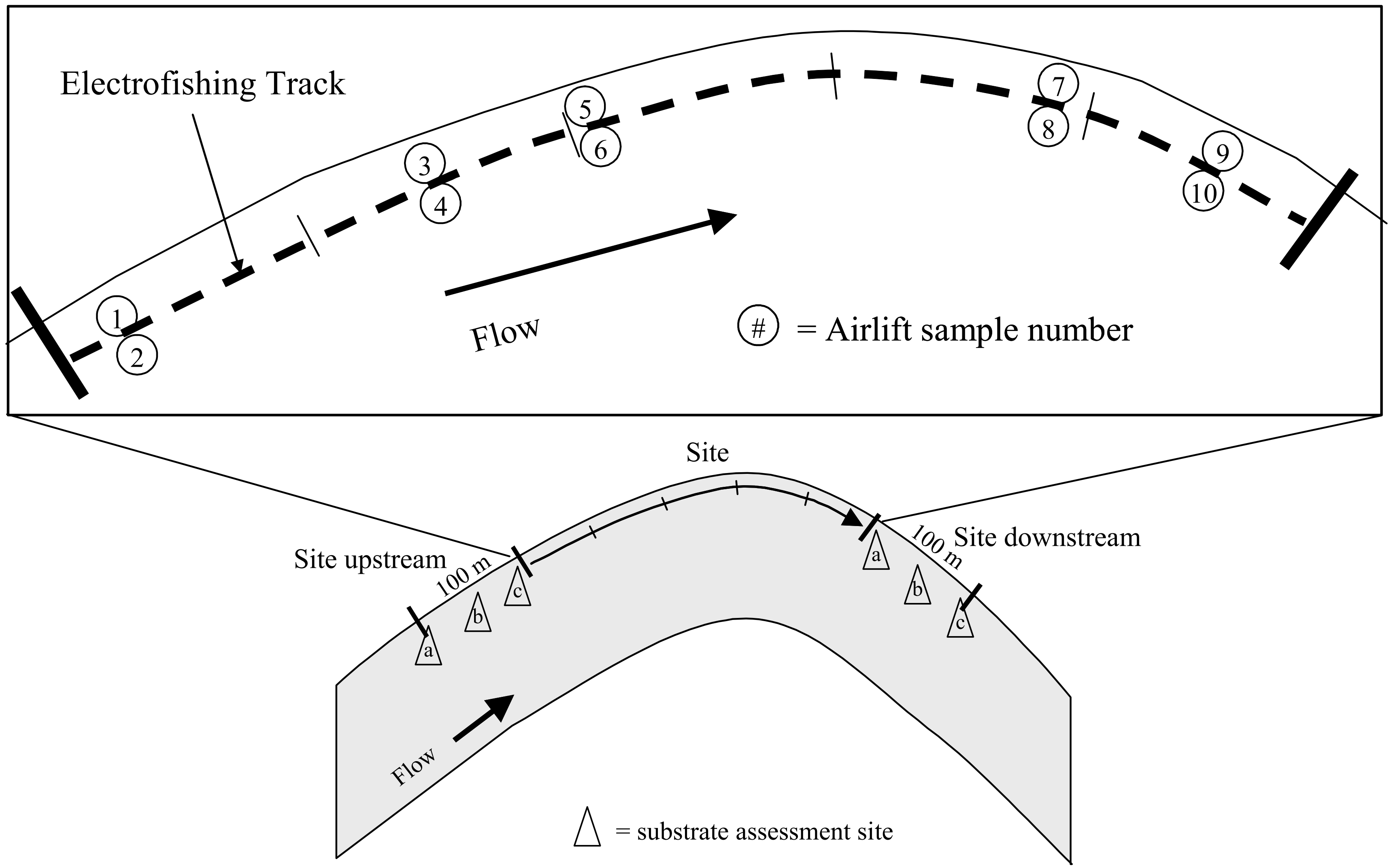

Figure 5. Electrofishing and airlift sampling protocol used on the Assiniboine and Red rivers for the collection of fish and benthic invertebrate occurrence data. Each site's invertebrate sampling locations were chosen randomly within the 5 equal sampling blocks. Substrate was assessed at each invertebrate sampling location and 5 m from the beginning, in the middle and 5 m from the end of each upstream and downstream site.

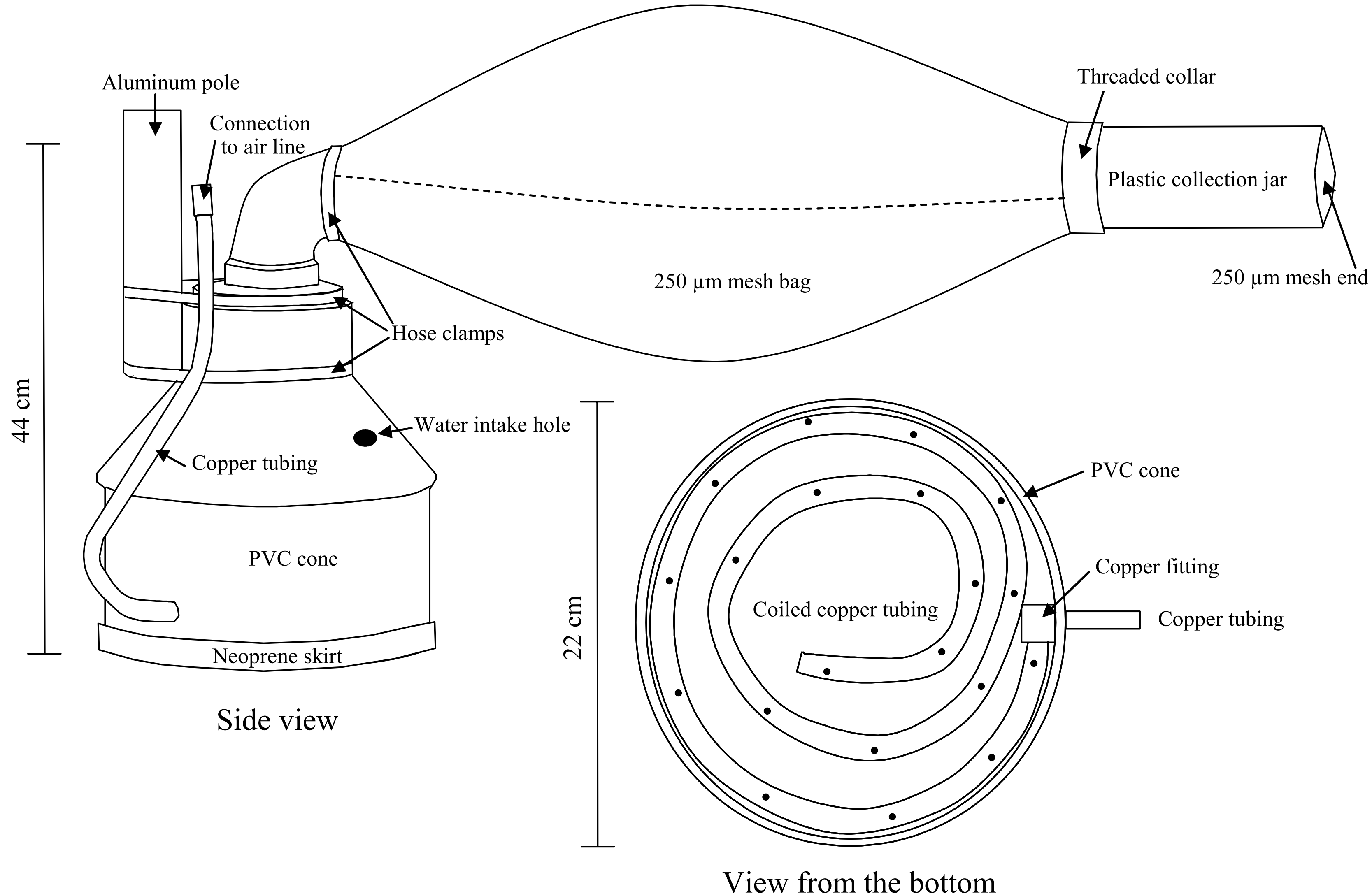

Figure 6. Airlift sampler side and bottom views.

Appendix 1– Assiniboine River observed fish and number of fish landed. Species abbreviations are as follows: silver redhorse (SR) (*Moxostoma anisurum*), golden redhorse (GR) (*Moxostoma erythrurum*), shorthead redhorse (SHR) (*Moxostoma macrolepidotum*), white sucker (WS) (*Catostomus commersoni*), quillback (QB) (*Carpiodes cyprinus*), bigmouth buffalo (BB) (*Ictiobus cyprinellus*), goldeye (GE) (*Hiodon alosoides*), mooneye (ME) (*Hiodon tergisus*), northern pike (NP) (*Esox lucius*), carp (CARP) (*Cyprinus carpio*), silver chub (SC) (*Hybopsis storeriana*), sauger (SAUG) (*Sander canadensis*), walleye (WALL) (*Sander vitreus*), channel catfish (CC) (*Ictalurus punctatus*), stonecat (SCAT) (*Noturus flavus*), burbot (LOTA) (*Lota lota*) and freshwater drum (FWD) (*Aplodinotus grunniens*).

Site Type	Sample sites	Total number of fish observed	Number of fish landed	SR	GR	SHR	WS	QB	BB	GE	ME	NP	CARP	SC	SAUG	WALL	CC	SCAT	LOTA	FWD
Unmodified bank	Unmodified 1	2	0			2														
	Unmodified 2	18	10	1		6	1			4			2		1				1	2
	Unmodified 3	1	1			1														
	Unmodified 4	8	4			2				4			2							
	Unmodified 5	8	4			2				1			1	1	2		1			
	Unmodified 6	11	5	1		1	1			5					2					1
	Unmodified 7	4	1			1									3					
	Unmodified 8	25	12	1		5	2		1	1			5		3		3		1	3
	Unmodified 9	9	5			4	1	1					2		1					
	Unmodified 10	13	7	4		3	2						1		1		2			
	Unmodified 11	7	3			3							2	1	1					
	Unmodified 12	28	10	6		15				1			3	1		1				1
	Total	134	62	13	0	45	7	1	1	16	0	0	18	3	14	1	6	0	2	7
Downstream of Riprap and Dykes	Dyke 1d	0	0																	
	Dyke 2d	1	1												1					
	Dyke 3d	4	2			3				1										
	Dyke 4d	1	0																	1
	Dyke 5d	4	2																	4
	Riprap 3d	2	1	1							1									
	Riprap 4d	3	1	1	1	1														
	Total	15	7	2	1	4	0	0	0	1	1	0	0	0	1	0	0	0	0	5

ADDPENDIX 1 – Continued

Site Type	Sample sites	Total number of fish observed	Number of fish landed	SR	GR	SHR	WS	QB	BB	GE	ME	NP	CARP	SC	SAUG	WALL	CC	SCAT	LOTA	FWD
Dykes	Dyke 1	9	3	1		4									2					2
	Dyke 2	6	3	5																1
	Dyke 3	13	5	2		5				1			2			1	1			1
	Dyke 4	14	4	3		4				2		1	2						1	1
	Dyke 5	21	8	5		10							3		1					2
	Riprap 1d	4	2	1		2							1							
	Riprap 2d	7	1			2							5							
	Riprap 5d	6	2						1	3					1				1	
	Dyke 5u	3	1	2	1															
	Total	83	29	19	1	27	0	0	1	6	0	1	13	0	4	1	1	0	2	7
Riprap	Riprap 1	24	9	1	2	12	3			1		1	3						1	
	Riprap 2	18	5	3		10	1						2				1		1	
	Riprap 3	23	9	3	1	12	1			1			3					1	1	
	Riprap 4	9	4			2				2			1		1				3	
	Riprap 5	14	6			4				1			2					1	3	3
	Total	88	33	7	3	40	5	0	0	5	0	1	11	0	1	0	1	2	9	3
Upstream of Riprap and Dykes	Dyke 1u	2	0											1	1					
	Dyke 2u	1	0												1					
	Dyke 3u	1	0												1					
	Dyke 4u	1	0									1								
	Riprap 1u	1	1												1					
	Riprap 2u	3	1			3														
	Riprap 3u	3	1			1				2										
	Riprap 4u	0	0																	
	Riprap 5u	5	1			4											1			
	Total	17	4	0	0	8	0	0	0	2	0	1	0	1	4	0	1	0	0	0

Appendix 2 – Red River observed fish and number of fish landed. Species abbreviations are as follows: silver redhorse (SR) (*Moxostoma anisurum*), shorthead redhorse (SHR) (*Moxostoma macrolepidotum*), white sucker (WS) (*Catostomus commersoni*), quillback (QB) (*Carpiodes cyprinus*), bigmouth buffalo (BB) (*Ictiobus cyprinellus*), goldeye (GE) (*Hiodon alosoides*), northern pike (NP) (*Esox lucius*), carp (CARP) (*Cyprinus carpio*), silver chub (SC) (*Hybopsis storeriana*), emerald shiner (ES) (*Notropis atherinoides*), sauger (SAUG) (*Sander canadensis*), channel catfish (CC) (*Ictalurus punctatus*), burbot (LOTA) (*Lota lota*) and freshwater drum (FWD) (*Aplodinotus grunniens*).

Site Type	Sample sites	Total number of fish observed	Number of fish landed	SR	SHR	WS	QB	BB	GE	NP	CARP	SC	ES	SAUG	CC	LOTA	FWD
Unmodified banks	Unmodified 1	7	3						1		4			1			1
	Unmodified 2	6	0							3	3						
	Unmodified 3	0	0														
	Unmodified 4	0	0														
	Unmodified 5	1	1								1						
	Unmodified 6	5	1			2			1					1	1		
	Total	19	5	0	0	2	0	0	2	3	8	0	0	2	1	0	1
Downstream of Riprap	Riprap 1d	0	0														
	Riprap 3d	2	1	2													
	Total	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Upstream of Riprap	Riprap 1u	1	0								1						
	Riprap 2u	1	0						1								
	Riprap 3u	3	2		1						2						
	Riprap 4u	0	0														
	Total	5	2	0	1	0	0	0	1	0	3	0	0	0	0	0	0
Riprap	Riprap 1	13	4							1	11					1	
	Riprap 2	6	2							1	1		3			1	
	Riprap 3	10	4				2		1		6						1
	Riprap 4	4	1									1	1	2			
	Riprap 5	16	7		1		2	1		3	2		6	1			
	Total	49	18	0	1	0	4	1	1	5	20	1	10	3	0	2	1