Effects of anthropogenic alterations to ephemeral and intermittent headwater drainage features on downstream fish communities

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Headwater drainage features (HDFs) in the GTA are commonly subjected to land-use modifications including agricultural uses and urbanization. A temporal study design approach was used to test whether the runoff being exported from previously modified HDFs differed from runoff exported from less disturbed forested channels. Drift nets were deployed in the permanent reaches of streams and in the HDF channels, to give an indication of the quality and quantity of drifting materials. Gastric lavage was used to remove stomach contents from creek chub living downstream from HDFs and these contents were used to determine if invertebrates in HDF runoff could act as food immediately upon reaching fish-bearing sections of stream. Reaches of streams associated with forested HDFs were found to have more fish than either those associated with agricultural or urban HDFs (203, 184 and 145 fish per forested, agricultural and urban site, respectively). Sites associated with forested catchments also had a greater number of salmonids per site. Conditions of high flow in the stream and the HDF coincided with an increased quantity of drifting invertebrates in all site types and land uses, as well as a decrease in the proportion of creek chub with empty stomachs. Overall, aquatic Diptera were the most numerous invertebrates captured in drift nets and in the stomach contents of creek chub. Hymenoptera, terrestrial Oligochaeta and Diplopoda also made major contributions to the diets of creek chub. Results indicate that HDFs in all land uses are exporting both aquatic and terrestrial invertebrates to main streams at times of high flow. Creek chub consume more prey at times of high flow, and this often includes terrestrial invertebrates, which must have been imported from terrestrial sources to the aquatic environment, however the degree to which they are exported by HDFs is still not clear. The series of complex interactions occurring at the HDF/main stream interface requires further study.

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I would also like to thank all of the people I've worked with at the University of Waterloo, these friends provided helpful ideas and suggestions, especially early in the project. I especially thank Odum Idika, who led the headwater study that gave me a strong interest in headwaters.

I wish to extend a special thank you to all my family and friends for your continued love and support, especially to my wonderful partner Greg Dillane.

I would also like to thank my supervisor and mentor, Dave Barton. His experience and advice helped to keep me on track and encourage me through the entire project.

Dedication

This thesis is dedicated to anyone that has ever watched a mighty stream flowing along and wondered where all that water comes from.

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1.0 Introduction

Cumulatively, headwater streams are the longest and most numerous stream type in the world (Nadeau and Rains, 2007). Of these, ephemeral and intermittent streams are components with temporary flow regimes and are estimated to comprise approximately 59% of the total stream length in the USA; this statistic varies regionally, being affected by precipitation and local topography (Nadeau and Rains, 2007). Ephemeral and intermittent streams are highly complex systems (Fritz et. al. 2008), and support a wide variety of aquatic inhabitants, including algae (Robson and Matthews, 2004) and invertebrates (Storey and Quinn, 2007; Wipfli et. al., 2007). There is also evidence that they serve a variety of important functions, both from a physical/chemical perspective (hydrologic connectivity, flood control, water quality improvement, sediment control, ground-water recharge) and from a biological perspective (temperature moderation, detritus/nutrient input, and unique habitat for mussels and terrestrial fauna) (Gomi et. al., 2002; Bernhardt et. al. 2005; Lowe and Likens, 2005; Alexander et. al., 2007; Freeman et. al. 2007; Nadeau and Rains, 2007; TRCA 2007). The term headwater drainage feature (HDF) refers to "ill-defined, non-permanently flowing drainage features that would not qualify as direct fish habitat" (TRCA, 2007). HDFs are classified as ephemeral (no ground water inputs, therefore fed only by antecedent precipitation), intermittent (some seasonal groundwater inputs, but dry for a period of time each year), and perennial (permanently flowing with year-round groundwater inputs). It has been suggested by members of the scientific community (Price et. al., 2003; Wipfli, 2005; Freeman et. al., 2007; Wipfli et. al., 2007) and by members of staff at conservation authorities and government agencies (Del Giudice, 2008; Stanfield, 2008) that HDFs may contribute significantly to downstream fisheries.

In response to increasing awareness of the potential importance of HDFs, a study was undertaken by Idika (2010) in the form of a preliminary investigation into HDFs in the

Toronto region. Idika's findings indicate that substantial quantities of leaf litter and drifting invertebrates (especially oligochaetes and arthropods) of both aquatic and terrestrial origin are exported downstream via HDFs in forested and agricultural areas. Tree canopies are also a source of terrestrial insects to streams, as observed by Mason and Macdonald (1982) and Nakano et. al. (1999); in the study by Mason and Macdonald, several peaks in the input levels were apparently associated with storm events. Mason and Macdonald estimated that terrestrial invertebrate inputs may be equivalent or even greater than autochthonous production of benthic invertebrates in streams, and also that earthworms may be washed from the soil directly into the stream during rainfall. Wipfli (2005) observed that fishless headwater streams in Alaska export substantial quantities of invertebrates and detritus to downstream, fish-bearing reaches. Nadeau and Rains (2007) observed that the fate of this material remains unknown.

It has long been known that stream fishes consume a large quantity of terrestrial invertebrates (Needham, 1928; Garmin, 1991; Wipfli, 1997). Earthworms have been observed to be a potentially important component of fish diets (Mason and Macdonald, 1982), and when available, terrestrial sources can comprise up to 90% of Salmonid diets (Hunt, 1975). McLemore and Meeshan (1988) estimated that 30% of foods eaten by trout in Meadow Creek, Oregon are terrestrial in origin. Nakano et. al. (1999) observed a dramatic cascade effect in a Japanese stream running through deciduous forest. When terrestrial invertebrates were experimentally prevented from entering the water, the fish (mostly Salmonids) shifted their feeding strategy dramatically from mostly terrestrial invertebrates to mostly aquatic invertebrates, the reduction of which resulted in a benthic periphyton bloom. This example emphasizes the multiple levels of linkages that are present in stream and forest systems. Although the presence of terrestrial prey items in the drift and their use as a food item by fish is well known, the precise origin of these prey sources is often only speculated in the literature. McLemore and Meeshan

(1988) proposed that terrestrial invertebrates present in the stream drift or in the stream sediments might have dropped from flight or fallen from vegetation into the stream. Similarly Mason and Macdonald (1982) and Nakano et. al. (1999) assumed that terrestrial invertebrates in steam drift fell from tree canopies directly into the stream below. The study by Wipfli (2005) is the only one that we know of where the quantity of invertebrates and detritus exported from intermittent streams was measured. His findings were extrapolated to calculate that 100-2000 juvenile Salmonids could be supported by drifting invertebrates from HDFs for each kilometre of perennial Salmonid-bearing stream, based on the distribution of temporary streams in the study area.

At the present time, it is a common practise in agricultural and urban areas to alter HDFs for human benefit (TRCA, 2007). Methods of alteration include removal of riparian canopy, and installation of tile drains in agricultural settings, or enclosure (piping), realignment, and feature lowering/deepening in urban settings (TRCA, 2007). These methods provide more efficient drainage which leads to earlier or higher yielding crops in agricultural settings, and allow construction of additional roads and buildings in urban settings. Unfortunately, these land-use alterations are being made before we fully understand the biological and ecological processes naturally occurring in HDFs (Wipfli and Gregovich, 2002; Freeman et. al., 2007; TRCA, 2007). Urbanization in headwater catchments creates a series of problematic changes, including elevated stream flow, nutrient loading, pesticide runoff, and bacterial blooms, among other things (Paul and Meyer, 2001; Pratt and Chang, 2012). Changes in land-use of headwater catchments have also been found to decrease invertebrate quantity and modify invertebrate community composition in these systems (Kawaguchi and Nakano, 2001; Wipfli and Gregovich, 2002; Wipfli, 2005; Smith and Lamp, 2008; Storey et. al. 2011). Not only is the presence of these effects appreciated by the scientific community, they have been legally recognized by the U.S. federal government (Alexander et. al. 2007; Nadeau and Rains, 2007). Because of their small size, ephemeral streams are often overlooked (Storey et. al., 2011); indeed, depending on the scale used, they often do not show up on maps (Nadeau and Rains, 2007). In a recent study of ephemeral streams in New Zealand by Storey et al. (2011), invertebrate communities from different reaches in catchments with different land-uses were compared and it was found that invertebrate density and richness in all headwater reaches, even in the "wet mud" habitat at the upper reach of ephemeral streams was just as great as the taxa diversity in perennial reaches, suggesting that there is no reason to manage ephemeral streams any less strictly than we manage and protect perennial streams.

The aim of this study is to increase our understanding of the relationships between the invertebrates that originate in ephemeral and intermittent streams of different land uses of the greater Toronto area (GTA) and the fish that are living in the main stream adjacent to an HDF. We assume that HDFs in forested catchments represent the least stressed HDF systems, while HDFs in agricultural and urban catchments represent different types and degrees of decline in the health of these systems. Therefore HDFs in forested, agricultural and urban catchments are examined and compared to determine if the impacted areas contain different assemblages of fish and invertebrates (aquatic and terrestrial); and to determine if imported invertebrates from HDFs represent important prey items for fish in permanent reaches downstream.

2.0 Predictions

My study was designed to test the following:

1. Drifting invertebrate assemblages sampled from HDFs will have a higher ratio of terrestrial invertebrate abundance : aquatic invertebrate abundance then drifting invertebrate assemblages in main streams.

2. Urban and Agricultural HDFs will transport fewer invertebrates than forested HDFs.

3. Fish caught in pools located downstream of HDFs will have consumed a higher ratio of terrestrial prey items : aquatic prey items then fish caught in pools not associated with an HDF.

4. Fish captured in pools downstream of HDFs will have more prey items in their stomachs then fish captured in areas not associated with an HDF.

5. Fish captured in pools downstream of forested HDFs will have more prey items in their stomach contents then fish captured in pools downstream of agricultural or urban HDFs.

3.0 Methods

3.1 Study Sites and Sampling

The 24 sites sampled from 17 May to 30 November 2010, were located on 10 streams in the Greater Toronto Area (GTA): Sixteen Mile Creek, Halton Urban Creek Systems, Joshua's Creek, Etobicoke Creek, Don River, Highland Creek, Rouge River, Petticoat Creek, Frenchman's Bay, and Duffins Creek (Table 1, Figure 1, 2). All of these drainage basins include agricultural and urban areas, but the proportions of different land-uses are variable. For example, the Highland and Don Rivers have been urbanized throughout much of their basins, while Duffins Creek is extensively urbanized only at the lower end and mostly agricultural at the upper end with substantial areas of undeveloped conservation lands.

Sites were selected based on proximity to an HDF, and classified according to the dominant current land use of each HDF catchment: forested, agricultural or urban. Land-use was determined on the basis of direct field observations, and confirmed using GIS. All of the urban HDFs used in this study were piped features, and water, once inside the pipe, is not again on the surface until it reaches the main, perennial stream. HDFs that contained storm water management ponds (SWM Ponds), dry ponds, artificial wetlands or other means of urban storm water management, and those that flowed through buffer strips with woody vegetation, were avoided to reduce variability. The numbers of forested, agricultural, and urban sites used in the study were 7, 9 and 8, respectively.

Each sampling site consisted of the point where the HDF entered a perennial fish-bearing stream and two pools (Figure 2). The HDF pool occurred immediately downstream of the confluence between the HDF and the main stream. Generally, a scour pool was present and identified as the HDF pool, except in some cases where channel hardening was in place to prevent the formation of a scour pool, in which case the pools were delineated at approximately 10m long. The control pool was a second pool in the same main stream as the HDF pool, and similar in depth, surface area, and habitat characteristics (substrate type, aquatic and shoreline vegetation, and presence of undercuts). Control pools could not be associated with an HDF (neither the study HDF nor a different one, confirmed by observation on site, to an upstream distance of at least 100m). Preference was for control pools to be located upstream of the HDF pool, to limit any effect that the drift from the HDF could have on the control pool; however, at two sites it was necessary to situate the control pool approximately 250m downstream of the HDF pool, because in these cases the stream channel and riparian characteristics upstream of the HDF were markedly different than the HDF pool (armouring/channelling at FOR 3 and occurrence of macrophytes at FOR 10).

Each pair of pools (HDF pool and control), was sampled during runoff and base flow conditions, i.e. whether or not the HDF was flowing. These conditions were controlled by antecedent rainfall and therefore needed to be sampled on different occasions (days). By sampling during dry and flowing HDF conditions, a pairwise comparison approach could be used to interpret results of the study.

3.2. Drift Nets

On each sampling occasion five nets were arranged along a transect at 90 degrees to the thalweg, equally spaced across the wetted width of the perennial stream at the head of the most upstream pool (control pool in all but two sites). When the HDF was flowing, a sixth net was deployed in the HDF channel itself, at 90 degrees to the thalweg. The drift nets consisted of a 500µm Nitex net bag attached by a drawstring to an aluminum frame 20cm in width, 30cm in height and 7cm in depth. The frame was supported by two rebar posts driven into the stream bed (Figure 3). Drift nets were left for a measured period of time, generally several hours, while fishing occurred. Shorter time periods were occasionally used in autumn when stream drift was exceptionally dense with leaf litter. Samples were placed into a jar and fixed with 10% formalin for at least 24h, then transferred to ethanol within 72h for long term storage.

3.3 Fishing

Each pool was isolated with a blocking net at the upstream end to prevent fish from escaping upstream during electrofishing (Figure 4). Backpack electrofishing (using Smith-Root model 12) was performed by three experienced electrofishers (one shocker and two netters). Each site was approached in a methodical single-pass manner to attempt to capture all of the fish within each pool. Captured fish were identified, weighed to 0.1g on a HIPPO-2000 scale, measured for total length to the nearest mm, and then released. The coefficient of condition was calculated for each fish captured, using the following formula from Williams (2000):

$$K = \frac{100000W}{L^3}$$

Where K= coefficient of condition, W= weight of the fish in grams and L= standard length of the fish in mm. The coefficient of condition is a reflection of the state of sexual maturity and the degree of nourishment of the fish.

3.4 Stomach Contents and Gastric Lavage

Stomach contents were removed from each of the following species: *Semotilus atromaculatus*, *Nocomis biguttatus*, *Notropis rubellus*, *Carassius auratus auratus*, *Cyprinus carpio*, *Micropterus dolomieu*, *Micropterus salmoides*, *Etheostoma flabellare*, *Etheostoma caeruleum*, *Etheostoma nigrum*, *Lepomis gibbosus*, *Ambloplites rupestris*, *Noturus flavus*, *Amelurus melas*, *Cottus bairdii*, *Rhinichthys obtusus*, *Rhinichthys cataractae*, *Catostomus commersonii*, *Hypentelium nigrum*, *Onchorhynchus mykiss*, *Salvelinus fontinalis* and *Salmo salar*. A maximum of ten (randomly drawn from holding buckets) individuals of each species large enough for our apparatus to penetrate their esophagus without injury was sampled from each collection by gastric lavage, a method which is known to result in very few fish injuries or mortalities (Hartleb and Moring, 1995). Stomach contents for each individual fish were preserved in ethanol on site. Gastric lavage could not used for some species (i.e. brook stickleback, fathead minnow and blunt nose minnow) because the mouth was too small, or for common shiner because of mortality in preliminary trials. No other mortalities were observed as a result of gastric lavage. Creek chub were selected for an in-depth gut content analysis as they are known to be opportunistic sight feeders of both aquatic and terrestrial prey items (Scott and Crossman, 1998). This type of non-specialized, opportunistic feeding strategy is ideal for my study, as I am interested in what kinds of drifting prey items are available under different conditions, and it is likely that creek chub will eat whatever is available.

3.5 Sample Processing

Eight of the 87 drift samples were determined to be too large to reasonably justify sorting the entire sample. These were subsampled by dividing the entire sample arbitrarily into equal halves, and choosing one half at random. This was performed 1 to 4 times, yielding subsamples ranging from one half to one sixteenth of the total sample. Drift samples and subsamples were inspected in small portions with a lighted magnifying glass and all invertebrates were separated from other material (algae, sediment, plant litter, etc.). Results from subsampled samples were extrapolated by multiplying. Invertebrates from the drift samples and the stomachs of creek chub were then identified to the level of Order or Family and classified as being of aquatic or terrestrial origin.

Wet volume of each drift sample was determined by measuring displacement of a liquid of all invertebrates that had been removed from the sample.

3.6 Statistical Analysis

Data from the drifting invertebrates and gut content invertebrates were simplified by examining only the 7 most common aquatic invertebrate and the 6 most common terrestrial invertebrate groups, as these represented 83% of drifting invertebrates and 82% of gut contents collected. Histograms were used to visually assess invertebrate assemblages in the drift samples and stomach contents. Chi-square tests and Wilcoxon signed-rank tests were used to test for differences among different land-uses, flow conditions and pools (HDF vs. control). Before conducting chi-square tests, means of each subgroup were calculated and these values were used for the chi-square analysis. Two sample T-tests assuming unequal variances were used to test for differences between coefficients of condition for fish caught at different pools, flow conditions and at different HDF land use designations. Ivlev electivity index was used to assess fish preferences for certain food types.

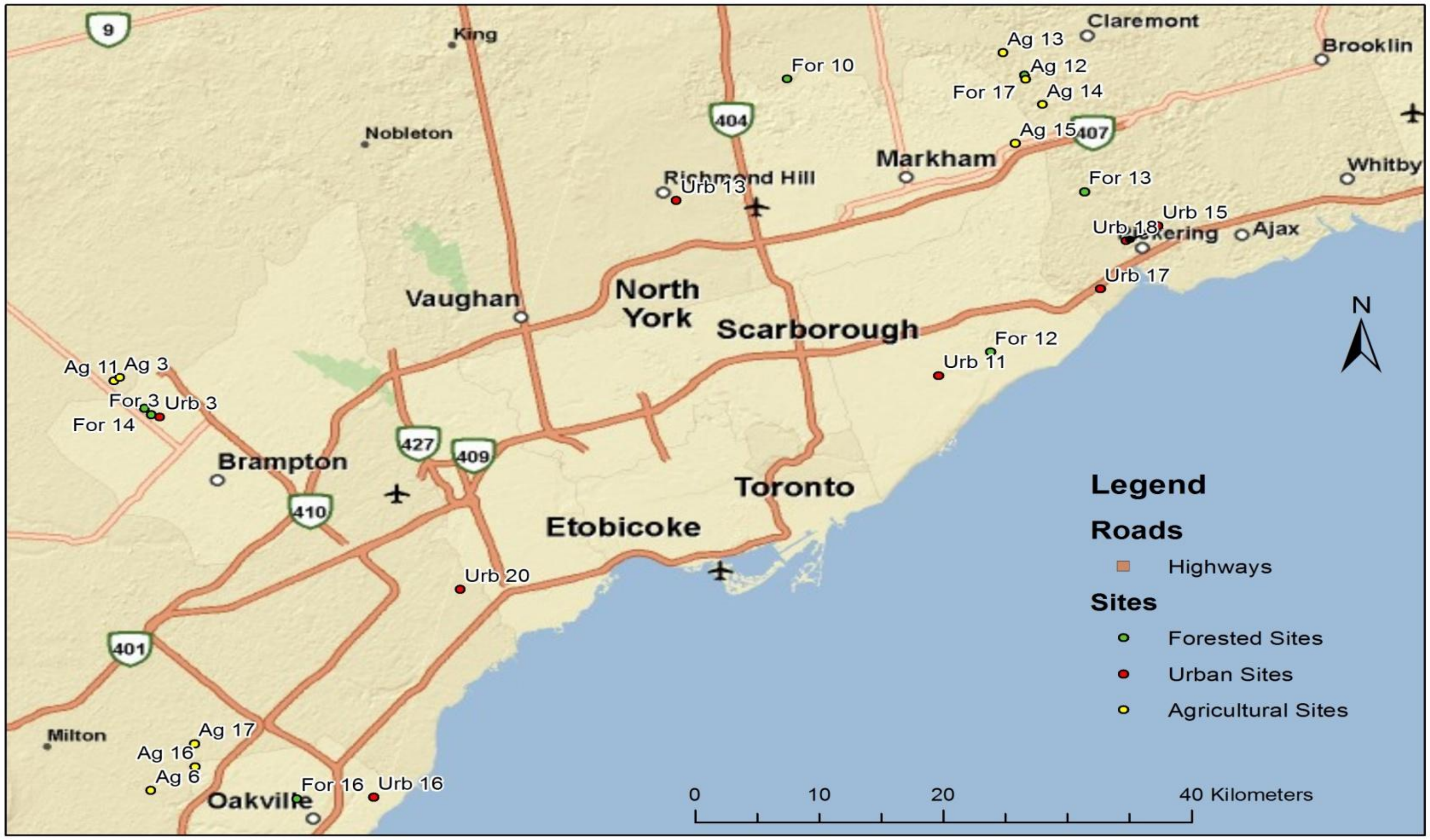

Figure 1. Study area. Location of each site is indicated. Urban sites, agricultural sites and forested sites are represented by red, yellow, and green icons, respectively.

Table 1. Site details

Stream	Site	Flow Condition	Catch-ment Type	Date	Control pool: Length (m)	Control pool: Average Width (m)	Control pool: Electro-fisher seconds (s)	Control pool: Electo-fishing effort (s/m2)	HDF pool: Length (m)	HDF pool: Average width (m)	HDF pool: Electro-fisher seconds (s)	HDF pool: Electro-fishing effort (s/m2)	Drift nets time elapsed (H:MM): Stream nets	Drift nets time elapsed (H:MM): HDF net
Etobicoke	URB 3	Baseflow	Urban	16/07/2010	15.0	6.0	882	9.83	15.3	5.4	1304	15.77	4:45	4:45
Etobicoke	URB 3	Runoff	Urban	04/06/2010	15.3	6.6	668	6.60	14.7	5.8	944	10.99	5:00	5:00
Highland	URB 11	Baseflow	Urban	24/09/2010	10.0	3.9	438	11.18	10.0	5.3	680	12.75	3:55	3:55
Highland	URB 11	Runoff	Urban	22/11/2010	9.0	4.8	561	12.89	10.8	4.2	533	11.83	0:01	2:15
Don	URB 13	Baseflow	Urban	14/09/2010	8.1	3.7	714	24.19	8.2	3.5	705	24.58	5:00	5:00
Don	URB 13	Runoff	Urban	16/09/2010	8.5	4.2	460	12.99	8.2	4.0	460	14.03	1:30	1:30
Duffins	URB 15	Baseflow	Urban	04/10/2010	11.4	4.1	603	12.98	12.0	3.9	589	12.47	3:05	3:05
Duffins	URB 15	Runoff	Urban	30/11/2010	11.4	3.7	430	10.17	12.0	4.1	526	10.61	1:14	5:24
Joshua's	URB 16	Baseflow	Urban	15/09/2010	6.5	3.2	536	25.36	6.6	3.3	609	28.14	7:11	7:11
Joshua's	URB 16	Runoff	Urban	29/09/2010	6.7	3.2	550	25.39	6.7	3.7	584	23.67	2:15	2:15
Petticoat	URB 17	Baseflow	Urban	02/09/2010	10.5	4.7	690	13.95	15.0	4.8	949	13.09	6:15	6:15
Petticoat	URB 17	Runoff	Urban	03/09/2010	10.5	4.7	724	14.70	15.0	4.8	1099	15.15	5:19	5:19
Frenchman’s Bay	URB 18	Baseflow	Urban	10/09/2010	4.4	2.6	198	17.21	3.8	2.8	189	17.54	3:45	3:45
Frenchman’s Bay	URB 18	Runoff	Urban	22/09/2010	4.2	2.7	284	25.17	4.2	2.9	232	19.16	4:35	4:35
Etobicoke	URB 20	Baseflow	Urban	27/08/2010	8.2	7.2	541	9.18	8.7	6.8	549	9.19	4:05	4:05
Etobicoke	URB 20	Runoff	Urban	13/09/2010	8.9	6.6	410	6.92	9.0	6.9	508	8.14	3:55	3:55

					Control pool				HDF pool				Drift nets time elapsed (H:MM)	
Stream	Site	Flow Condition	Catchment Type	Date	Length (m)	Average Width (m)	Electrofisher seconds (s)	Electofishing effort (s/m2)	Length (m)	Average width (m)	Electrofisher seconds (s)	Electrofishing effort (s/m2)	Stream nets	HDF net
Etobicoke	FOR 3	Baseflow	Forested	14/06/2010	6.4	5.1	579	17.45	6.6	4.3	518	18.18	5:06	5:06
Etobicoke	FOR 3	Runoff	Forested	03/06/2010	7.0	5.4	506	7.21	6.9	4.7	498	8.76	5:00	5:00
Rouge	FOR 10	Baseflow	Forested	21/07/2010	6.6	3.3	765	35.45	6.1	2.5	547	35.58	3:30	3:30
Rouge	FOR 10	Runoff	Forested	26/07/2010	5.8	3.2	615	12.73	6.6	2.3	535	16.87	4:29	4:29
Highland	FOR 12	Baseflow	Forested	07/10/2010	12.0	5.8	991	170.80	16.5	3.7	961	128.13	4:45	4:45
Highland	FOR 12	Runoff	Forested	15/10/2010	11.8	5.6	895	9.97	16.0	4.5	757	9.78	5:30	8:00
Duffins	FOR 13	Baseflow	Forested	09/09/2010	15.5	3.3	589	59.10	15.3	3.9	622	39.92	3:40	3:40
Duffins	FOR 13	Runoff	Forested	17/09/2010	16.0	2.8	478	9.57	15.0	3.4	537	8.35	3:55	3:55
Etobicoke	FOR 14	Baseflow	Forested	26/08/2010	9.52	7.6	1036	27.30	8.6	5.7	864	25.42	5:45	5:45
Etobicoke	FOR 14	Runoff	Forested	14/10/2010	7.6	9.3	875	4.71	8.7	4.1	808	9.34	0:05	4:15
16 Mile	FOR 16	Baseflow	Forested	21/09/2010	12.5	2.6	626	33.93	16.2	2.2	510	29.46	4:10	4:10
16 Mile	FOR 16	Runoff	Forested	28/09/2010	12.6	2.9	452	7.03	16.9	3.2	566	7.71	0:22	0:22
Duffins	FOR 17	Baseflow	Forested	19/10/2010	11.3	7.3	1505	22.81	14.5	7.2	1205	16.66	6:43	6:43
Duffins	FOR 17	Runoff	Forested	26/10/2010	11.4	7.1	1234	7.28	14.5	7.2	1315	12.64	0:52	6:51

Table 1 (continued)

					Control pool				HDF pool				Drift nets time elapsed (H:MM)	
Stream	Site	Flow Condition	Catchment Type	Date	Length (m)	Average Width (m)	Electrofisher seconds (s)	Electofishing effort (s/m2)	Length (m)	Average width (m)	Electrofisher seconds (s)	Electrofishing effort (s/m2)	Stream nets	HDF net
Etobicoke	AG 3	Baseflow	Agricultural	15/06/2010	8.5	8.9	1246	16.62	5.6	5.0	887	31.99	7:15	7:15
Etobicoke	AG 3	Runoff	Agricultural	01/06/2010	8.9	8.4	1393	18.72	6.0	4.8	521	18.07	6:35	6:35
Etobicoke	AG 6	Baseflow	Agricultural	22/07/2010	16.4	3.7	559	9.19	16.4	4.5	645	8.72	5:00	5:00
Etobicoke	AG 6	Runoff	Agricultural	29/07/2010	16.5	3.7	423	6.94	16.4	4.5	883	11.94	4.82	8:00
Etobicoke	AG 11	Baseflow	Agricultural	24/08/2010	12.1	6.6	875	10.99	11.1	6.9	1371	17.98	7:30	7:30
Etobicoke	AG 11	Runoff	Agricultural	06/10/2010	12.3	6.0	657	8.92	14.8	4.9	955	13.19	4:35	4:35
Duffins	AG 12	Baseflow	Agricultural	18/10/2010	9.5	6.2	630	10.73	12.0	6.5	763	9.74	3:17	3:17
Duffins	AG 12	Runoff	Agricultural	25/10/2010	10.5	6.4	892	13.21	12.2	6.9	826	9.79	2:45	2:45
Duffins	AG 13	Baseflow	Agricultural	01/11/2010	10.0	4.2	476	11.40	8.5	6.1	675	13.02	3:22	3:22
Duffins	AG 13	Runoff	Agricultural	17/11/2010	9.4	5.0	504	10.75	7.7	8.5	649	9.93	0:35	2:55
Duffins	AG 14	Baseflow	Agricultural	22/10/2010	8.4	1.8	455	30.25	13.2	1.9	561	22.72	4:07	4:07
Duffins	AG 14	Runoff	Agricultural	29/10/2010	8.5	2.0	577	34.11	12.5	2.0	840	33.72	5:01	5:01
Duffins	AG 15	Baseflow	Agricultural	23/09/2010	9.5	4.0	817	21.22	8.7	4.4	929	24.33	6:10	6:10
Duffins	AG 15	Runoff	Agricultural	26/11/2010	8.8	2.2	343	17.92	8.6	2.4	401	19.00	0:40	3:15
16 Mile	AG 16	Baseflow	Agricultural	03/11/2010	7.0	8.1	766	13.48	9.0	8.6	622	8.06	4:25	4:25
16 Mile	AG 16	Runoff	Agricultural	23/11/2010	13.6	8.1	453	4.12	14.0	9.9	1157	8.36	0:17	0:17
16 Mile	AG 17	Baseflow	Agricultural	08/10/2010	10.3	4.1	506	11.94	10.5	4.3	482	10.74	3:19	3:19
16 Mile	AG 17	Runoff	Agricultural	19/11/2010	10.9	3.8	421	10.02	14.0	4.3	727	12.19	2:24	3:59

Table 1 (Continued)

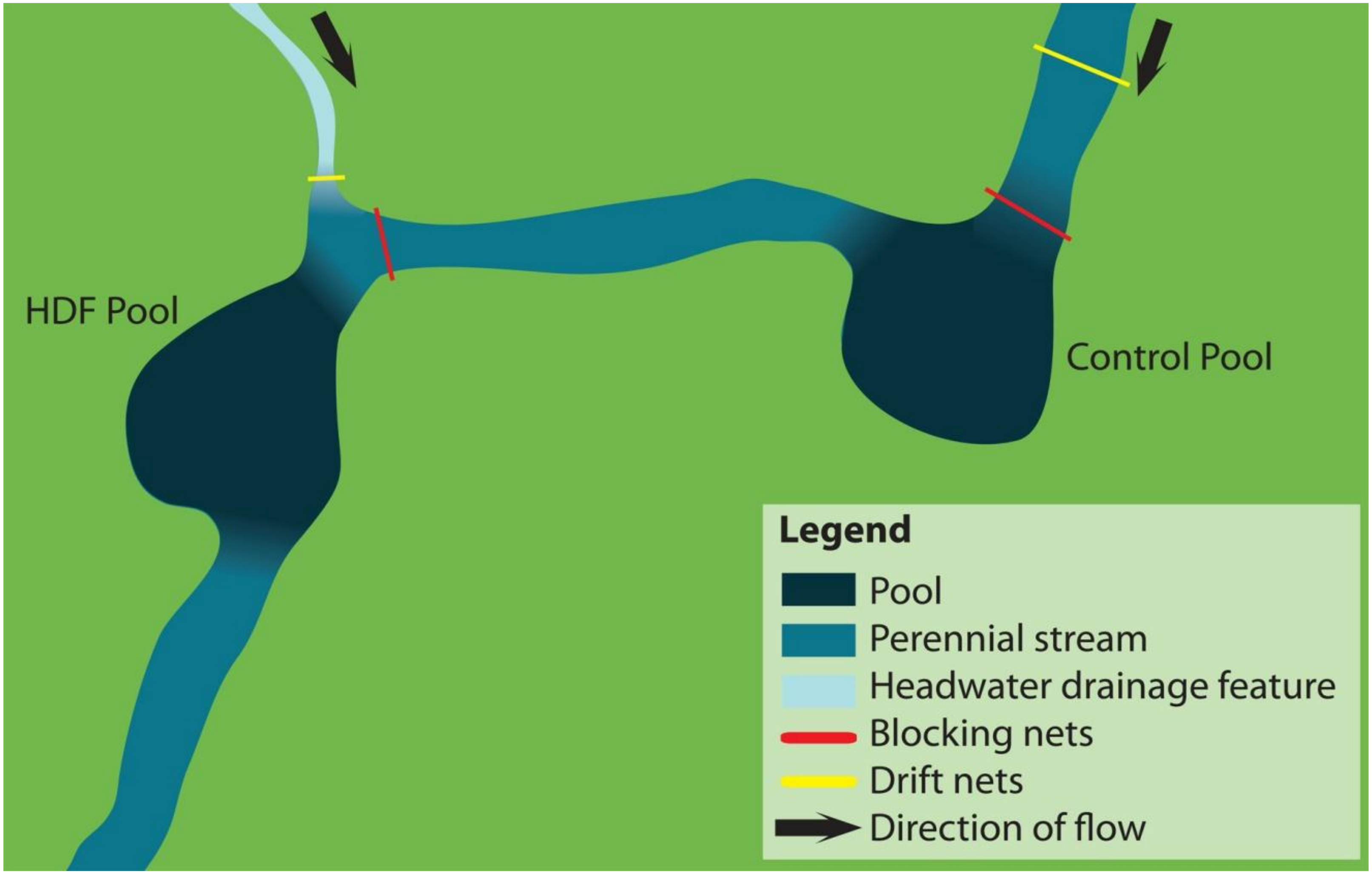

Figure 2. Schematic diagram of a typical confluence between an HDF and a perennial stream. The areas fished are indicated as HDF pool and control pool. During fishing a blocking net was used upstream of both fishing sites, and drift nets were in place to capture drifting invertebrates as indicated. One drift net was deployed in the thalweg of the HDF and 5 drift nets were deployed in the main stream, equally spaced across the wetted width.

Figure 3. Drift nets. Five drift nets were used in the main stream, placed at equally spaced intervals along a transect at 90 degrees to the thalweg.

Figure 4. HDF pool at an urban site. The confluence of the HDF with the perennial stream defined the location of the HDF pool. A blocking net was installed at the upstream end of the pool prior to electrofishing, in an effort to prevent fish from escaping upstream during fishing. The HDF drift net is also visible.

4.0 Results

The study was dependent upon natural precipitation causing runoff in the HDFs, so the timing of data collection was strongly weather-dependent, with only brief windows of suitable time for runoff sampling. In several cases, I was not able to capture the peak time of precipitation at the site and therefore peak runoff from the HDF, so sampling was conducted during the falling limb of the event.

4.1 Fish

A total of 4242 fish was collected during the study (Table 2). Numbers of fish caught per site differed significantly among land uses (forested vs. agricultural vs. urban) (chi-square=9.861, 2 d.f., P=0.007)(Figure 5). Forested sites yielded the largest catches, with a mean of 203 fish captured per site, urban sites the smallest (145 fish per site) and agricultural sites were intermediate (184 fish per site). Fish catches were significantly larger under base flow (56.8 fish per pool) than runoff (32.8) at all land use types (chi-square=6.8, 1 d.f., P=0.009) (Figure 5).

In forested sites, more fish were usually caught in control pools than in HDF pools, both during base flow and runoff conditions, but these differences were not significant. There were no consistent differences in the numbers of fish caught in the control pool compared to the HDF pool, either at base flow conditions or runoff, at agricultural or urban sites (Figure 5).

The most common fish were Creek Chub, Blacknose Dace, and Johnny Darter, with 1064, 776 and 534 individuals, respectively. Creek chub were the most numerous fish caught in both urban and agricultural sites, but black nose dace were the most numerous in forested sites. Minnows, darters, and suckers dominated the catches regardless of land use, and in urban sites these three families comprised 95% of total catch, whereas they comprised 90% and 89% in agricultural and forested sites, respectively (Figure 5). Darters comprised 33% of the total catch in agricultural sites, about twice their relative abundance in forested and urban sites (17% and 14%, respectively). Salmonidae comprised a very small proportion of the catches (0.6%, 0.7% and 1.8% for urban, agricultural, and forested sites, respectively), but were noticeably more numerous in forested sites; the differences between site type and density of Salmonids were not found to be significant (X^2=2.55, 2 d.f., P=0.279).

Mean lengths, weights and coefficient of condition for each fish species caught at each site and pool are presented in Table 3. Neither pool type nor flow condition was found to influence creek chub coefficients of condition at any of the forested, agricultural or urban land use areas. Creek chub at urban sites were found to have a higher coefficient of condition than creek chub at forested sites (t=2.03, 37 d.f., P=0.02).

4.2 Drift nets

Stream drift was collected from the main stream of every site during base flow and runoff conditions, totalling 48 stream drift samples in total. In addition, drift samples were collected from HDFs at times when any flow was present (all sites at runoff, and at base flow from most urban sites, some agricultural sites and one forested site) totalling 38 HDF drift samples. In total, 40628 invertebrates were sorted and identified from drift samples: 30.7% of drifting invertebrates were classified as one of 39 terrestrial groups and 69.3% were identified as one of 51 aquatic groups. The group classifications were taxonomic, however the origin (terrestrial or aquatic) was not, therefore some of the taxonomic groups were represented by both terrestrial and aquatic specimens. The most abundant drifting invertebrates, aquatic Diptera, were represented by 15100 individuals (37.2% of the total catch), and occurred in all samples. Drifting invertebrates are summarized in Table 4.

In forested sites, aquatic Diptera accounted for 52% and 56% of all drifting invertebrates both at base flow and at runoff, respectively. The dominant drifting invertebrates from forested HDFs were aquatic Amphipoda (27%) and terrestrial Hymenoptera (22%), at base flow and runoff, respectively.

In agricultural sites, stream drift was dominated by aquatic invertebrates while HDF drift was dominated by terrestrial invertebrates. In the stream drift, the most numerous invertebrates at base flow were aquatic Diptera (36%) while at runoff the most numerous invertebrates were aquatic Isopoda (50%). In the HDF drift, the most numerous invertebrates at base flow were terrestrial Diptera (14%) while at runoff the most numerous invertebrates were Collembola (16%).

In urban sites, aquatic Diptera were the dominant drifting invertebrates in the stream drift at runoff (24%), however at base flow terrestrial Diptera were most abundant (24%). In the HDF drift, aquatic Diptera was the most numerous group at base flow (37%), while Hymenoptera was the most numerous group at runoff (37%).

Figure 6 shows mean abundances of the commonest drifting invertebrates per hour at each land use type, base flow/runoff conditions and in the HDF and control pools. Abundance in stream drift has been divided by 5 since 5 drift nets were used in its collection, compared to one drift net to collect HDF drift. In most cases, mean number of drifting invertebrates per hour was higher in stream drift than in HDF drift (chi-square>4.1, 1 d.f., $P<0.05$), except urban sites at base flow (chi-square=2.102, 1 d.f., $P=0.147$), and agricultural sites at runoff, where the HDF drift exhibited higher abundance of drifting invertebrates per hour than the stream drift (chi-square=43.948, 1 d.f., $P=3.37 \times 10^{-11}$). Drifting invertebrate abundance was significantly higher at runoff than at base flow in all samples (chi-square>9, 1 d.f., $P<0.003$). At base flow, the main streams of urban sites had almost the same abundances of drifting invertebrates as forested sites, and these were higher than the abundances of drifting invertebrates in agricultural sites, but differences were not significant (chi-square=1.393, 2 d.f., P=0.498). However, the urban HDF drift did have a significantly greater abundance of invertebrates than the forested HDF drift at base flow (chi-square=6.209, 1 d.f., P=0.013). There was not a significant difference between the agricultural HDF drift at base flow and the forested or urban HDF drift at base flow (chi-square<2.973, 1 d.f., P>0.08).

At runoff, the invertebrate abundance in stream drift was highest in forested sites, and lowest in agricultural sites. Both of these were also significantly different from urban sites, which had an intermediate abundance of invertebrate drift (X^2= 349.576, 2 d.f., P=1.23x10^{-76}). In HDF sites at runoff conditions, agricultural HDFs exported the highest abundance of drifting invertebrates, and urban sites exported the lowest. Both of these were also significantly different from forested sites, which exported an intermediate abundance (chi-square=51.312, 2 d.f., P=7.21x10^{-12}).

Drift sample volume varied among samples, from a minimum of 0.5ml to a maximum of 2340ml. Generally, the drift volumes were much greater for stream drift samples than for HDF samples and this meant that in some cases the ratio of drifting invertebrates to volume of drift sample collected at HDFs were higher than the same ratio in the corresponding main stream (Figure 7). When the abundances are viewed relative to the volume of other debris that was flowing with them, it gives a measure of the density of potential prey items of the drifting material. In both urban and agricultural streams, the HDFs were found to contain significantly more prey-item dense drift than the main stream, both during base flow and during runoff (chi-square >4.9, 1 d.f., P<0.026). Conversely, forested main streams contained consistently dense drift, both during runoff and base flow conditions. At runoff, the forested HDFs were found to have significantly lower prey-item density compared to the corresponding main stream (chi-square=4.178, 1 d.f., P=0.041).

4.3 Stomach Contents of Fish

Gut contents were examined from 500 creek chub. Of these, 17.4% had empty stomachs (Figure 8). In most cases, the proportion of creek chub with empty stomachs was higher at base flow than at runoff, and these differences were significant across all land uses and pools. The exceptions were urban HDF pools, which showed no significant difference, and agricultural control pools, which showed a significant increase in the percentage of empty stomachs at runoff conditions. Creek chub in forested streams at runoff had less than half the percentage of empty stomachs than any other conditions, with only 4.2% empty in the control pool and only 1.7% empty in the HDF pool. Differences in percentage of empty stomachs by land use at runoff were significant (chi-square=17.919, 2 d.f., P=0.000129). Though forested sites at base flow appeared to have fish with the lowest percentage of empty stomachs compared to urban and agricultural sites, these differences were not significant (chi-square=1.541, 2 d.f., P=0.463).

Gut contents were identified to the same levels and categories as the drifting invertebrates whenever possible (Table 5). Aquatic Diptera comprised the largest numerical proportion of the creek chub diets, accounting for almost 32.0% of the total prey items which is 3.5 times more than the next most common group. Other important groups were terrestrial Oligochaeta, terrestrial Hymenoptera, aquatic Gastropoda, aquatic Trichoptera, aquatic Isopoda, terrestrial Diplopoda and terrestrial Diptera (9.1 %, 7.5%, 6.5%, 4.7%, 4.4%, 3.4% and 3.4%, respectively). Creek chub from urban sites tended to eat more food items (mean = 3.89 items per fish) than those from forested (2.42 items per fish) or agricultural (2.11 items per fish) sites, however these differences were not significant (chi-square=0.644, 2 d.f., P=0.725).

Differences in abundance of prey items identified from creek chub found in the same pool at base flow versus runoff conditions were not significant in any land use types or in either pool type (chi-square<0.279, 1 d.f., P>0.05). Similarly, the percentage of terrestrial prey items in the creek chub gut contents did not show significant differences at different flow conditions.

There were no significant differences in total abundance of food items for cheek chub between HDF and control pools regardless of land use or flow conditions. Similarly the type of pool appeared not to impact the % terrestrial prey items that were found in creek chub gut contents.

The abundances of the thirteen major groups of prey items eaten by creek chub are summarized in Figure 9. Creek chub with empty stomachs were excluded from this figure. Aquatic Gastropoda contributed to the diets of creek chub in all groups and, although they were found in greater numbers at runoff, especially in forested sites, these differences were not significant ($W=5$, $P>0.2$). Aquatic Isopoda did not make major contributions to creek chub diets in forested sites, either at base flow or runoff, but were important during runoff in both agricultural HDF pools and all urban pools. Differences in isopod proportions in the creek chub stomach contents across the different land uses, pool types and flow conditions were not found to be significant ($P>0.2$). Aquatic Amphipoda contributed to the diets of creek chub at all sites, except in control pools of forested sites at runoff, and did not show significant differences among treatments. Aquatic Ephemeroptera contributed to the diets of creek chub at most sites, except forested HDF pools during runoff, and in agricultural HDF pools both at runoff and base flow; they did not show significant differences among treatments($P>0.2$). Aquatic Trichoptera contributed to the diets of creek chub in all sites with no exceptions, and comprised an especially high proportion in forested sites during runoff conditions, although these differences were not found to be significant($P>0.2$). Aquatic Coleoptera contributed to the diets of creek chub in all sites, except in agricultural control pools at base flow, and did not show significant differences among treatments($P>0.2$). Aquatic Diptera were major contributors to creek chub diets in all treatments sampled. Most were Chironomidae (82.5% of identified Diptera). Culicidae and Tipuliidae were also present in many cheek chub stomachs. All aquatic Diptera accounted for between 44% and 85% of the food items in creek chub stomachs. Urban HDF pools at base flow and urban control pools at runoff had the highest quantities of aquatic food items, with 2.64 and 2.80 items per stomach, respectively. Creek chub in agricultural sites at runoff ate the highest proportions of aquatic food items: 85% of prey items were of aquatic origin in both in the HDF and control pools.

Terrestrial Oligochaeta contributed to the diets of creek chub in all groups, and were the third most numerous prey items found in creek chub stomach contents. They were most abundant from fish collected during runoff conditions, especially in urban HDF pools (mean = 1.23 worms/fish). Terrestrial Diplopoda contributed to the diets of creek chub in all groups except HDF pools of forested sites at base flow, and control pools of agricultural sites at both base flow and runoff; and tended to be more numerous at urban sites than at either forested or agricultural sites. Homoptera were only eaten in large numbers in the control pools of agricultural sites at base flow, but were present in most other land uses and conditions in very low proportions. Terrestrial Coleoptera only appeared in large numbers in urban HDF pools at runoff, but were present in most other land uses and conditions in very low proportions. Hymenoptera contributed to the diets of creek chub in all groups except control pools of agricultural sites at runoff and were the second most numerous prey item found in creek chub stomach contents overall (approximately 8% of prey items were Hymenoptera). Except in agricultural sites at runoff, Hymenoptera represented a major contribution to creek chub stomach contents. Terrestrial Diptera were present in all conditions except forested HDF pools during runoff; they were especially numerous in urban control and HDF pools during base flow.

Figure 10 is derived from the same counts of invertebrates as figure 9, except that each group has been weighted to account for differences in size and therefore caloric content of each of the groups of food organisms. These weightings place emphasis on large food items such as earthworms and millipedes, and at the same time de-emphasize the contributions from numerous strikes on small items, such as Chironomidae larvae or aphids. The contribution of Oligochaeta and sometimes diplopods to the diets of creek chub during runoff conditions is highly apparent. Figure 10 also shows that aquatic prey is more important in base flow conditions while terrestrial contributions are greater during runoff conditions.

4.4 Selectivity for Prey Items

The IVLEV electivity index was used to assess the appeal of different prey items to creek chub in the study. This index takes into account the availability of the prey source (in the drift) as well as the frequency that fish eat that prey item. Earthworms were positively selected for under all conditions by creek chub (Ivlev's index = -0.704 to -1, $P<0.05$). No other prey type was consistently selected for or against.

Table 2. Fish sampled over the course of the study. Since different numbers of each type of site were sampled, mean catch of each type of fish per site is shown to normalize abundance of fish captured. Totals for each family are also shown (shaded).

	Urban (8 sites)		Agricultural (9 sites)		Forested (7 sites)		Total
Fish Species	Total	Mean per site	Total	Mean per site	Total	Mean per site	for all sites
Unidentified Cyprinidae	21	2.7	7	0.8	1	0.1	27
Semotilus atromaculatus	347	43.4	377	41.9	340	48.6	1064
Rhinichthys obtusus	222	27.8	143	15.9	411	58.7	776
Rhinichthys cataractae	48	6	52	5.8	208	29.7	308
Pimephales notatus	58	7.3	131	14.6	12	1.7	201
Pimephales promelas	136	17	4	0.4	3	0.4	143
Luxilus cornutus	22	2.8	90	10	13	1.9	125
Notropis rubellus	0	0	45	5	0	0	45
Nocomis biguttatus	1	0.3	13	1.4	0	0	14
Total Cyprinidae	857	107.2	862	95.8	988	141.1	2705
Etheostoma flabellare	22	2.8	152	16.9	50	7.1	224
Etheostoma caeruleum	45	5.6	105	11.7	40	5.7	190
Etheostoma nigrum	97	12.1	282	31.3	155	22.1	534
Total Etheostoma	164	20.5	539	59.9	245	35	948
Catostomus commersonii	91	11.4	67	7.4	33	4.7	191
Hypentelium nigricans	0	0	26	2.9	0	0	26
Total Catostomidae	91	11.4	93	10.3	33	4.7	217
Lepomis *spp.*	17	2.1	2	0.2	2	0.3	21
Lepomis gibbosus	5	0.6	12	1.3	12	1.7	29
Ambloplites rupestris	24	3	59	6.6	59	8.4	142
Micropterus salmoides	0	0	0	0	2	0.3	2
Micropterus dolomieu	0	0	3	0.3	0	0	3
Total Centrarchidae	46	5.8	76	8.4	75	10.7	197
Noturus flavus	0	0	5	0.6	0	0	5
Amelurus melas	0	0	1	0.1	0	0	1
Total Ictaluridae	0	0	6	0.7	0	0.0	6
Onchorhynchus mykiss	4	0.5	2	0.2	9	1.3	15
Salvelinus fontinalis	0	0	5	0.6	15	2.1	20
Salmo salar	2	0.3	5	0.6	2	0.3	9
Total Salmonidae	6	0.8	12	1.3	26	3.7	44
Cottus bairdii	0	0	64	7.1	54	7.7	118
Culaea inconstans	0	0	6	0.7	1	0.1	7
Totals	1162	145.3	1658	184.2	1422	203.1	4242

Table 3. Details of each fish species caught at each site, pool and flow condition. Details include mean length, weight and condition factor (coefficient of condition), as well as standard deviations (s.d.) for each.

		Baseflow																Runoff															
		Control								HDF								Control								HDF							
Site Code	Species	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.
AG 3	*Ambloplites rupestris*	8.0	8.0	91.5	35.7	20.1	20.7	1.8	0.2	1.0	1.0	54.0	-	3.0	-	1.9	-	16.0	10.0	64.9	21.1	6.6	6.3	1.9	0.2	2.0	2.0	84.0	50.9	16.0	19.8	1.8	0.1
	Catostomus commersonii	5.0	5.0	104.0	6.6	11.5	1.9	1.0	0.1	0.0	0.0							1.0	1.0	85.0	-	6.0	-	1.0	-	0.0	0.0						
	Etheostoma flabellare	5.0	5.0	52.4	6.9	1.4	0.4	1.0	0.3	18.0	10.0	52.9	14.0	1.6	1.1	1.0	0.3	12.0	10.0	56.2	13.0	2.0	0.8	1.2	0.4	32.0	10.0	53.1	4.9	1.6	0.4	1.1	0.3
	Etheostoma nigrum	13.0	13.0			1.8				9.0	9.0			1.3				41.0	41.0			1.4				6.0	6.0			1.3			
	Lepomis gibbosus	3.0	3.0	78.7	7.8	7.2	1.9	1.4	0.1	0.0	0.0							0.0	0.0							0.0	0.0						
	Luxilus cornutus	1.0	1.0	85.0	-	6.5	-	1.1	-	4.0	4.0			5.5				5.0	5.0			6.4				0.0	0.0						
	Pimephales notatus	18.0	18.0			2.3				33.0	33.0			1.3				30.0	30.0			2.9				7.0	7.0			3.3			
	Pimephales promelas	0.0	0.0							1.0	1.0	55.0	-	2.5	-	1.5	-	1.0	1.0	74.0	-	3.0	-	0.7	-	1.0	1.0	51.0	-	1.5	-	1.1	-
	Rhinichthys obtusus	1.0	1.0	57.0	-	1.0	-	0.5	-	11.0	10.0	64.4	10.0	2.8	1.3	1.0	0.2	1.0	1.0	80.0	-	5.5	-	1.1	-	6.0	6.0	63.7	12.5	3.2	1.4	1.5	1.3
	Semotilus atromaculatus	7.0	7.0	104.3	26.9	13.6	10.1	1.1	0.2	21.0	12.0	99.8	24.1	24.0	30.8	2.3	3.0	12.0	10.0	95.2	16.4	9.9	3.8	1.1	0.2	7.0	7.0	73.1	19.5	4.5	3.0	1.1	0.2
AG 6	*Ambloplites rupestris*	0.0	0.0							2.0	2.0	130.5	7.8	42.0	7.1	1.9	0.0	0.0	0.0							0.0	0.0						
	Amelurus melas	0.0	0.0							1.0	1.0	152.0	-	51.5	-	1.5	-	0.0	0.0							0.0	0.0						
	Catostomus commersonii	0.0	0.0							6.0	6.0	72.8	41.1	7.4	13.5	1.0	0.1	0.0	0.0							13.0	10.0	149.3	38.6	37.4	18.9	1.0	0.1
	Etheostoma caeruleum	0.0	0.0							0.0	0.0							1.0	1.0	60.0	-	3.0	-	1.4	-	0.0	0.0						
	Etheostoma nigrum	0.0	0.0							9.0	7.0	59.0	4.0	1.9	0.9	0.9	0.3	0.0	0.0							4.0	1.0	66.0	-	2.0	-	0.7	-
	Hypentelium nigricans	0.0	0.0							0.0	0.0							0.0	0.0							4.0	4.0	153.8	33.7	43.1	29.7	1.0	0.1
	Lepomis sp.	0.0	0.0							2.0	2.0			0.5				0.0	0.0							0.0	0.0						
	Luxilus cornutus	3.0	3.0			9.5				0.0	0.0							1.0	1.0	111.0	-	15.0	-	1.1	-	4.0				11.5			
	Micropterus dolomieu	0.0	0.0							0.0	0.0							0.0	0.0							1.0	1.0	95.0	-	8.0	-	0.9	-
	Nocomis biguttatus	5.0	5.0	104.4	49.4	18.7	22.0	1.1	0.2	0.0	0.0							7.0	7.0	104.9	17.1	13.6	7.2	1.1	0.1	1.0	1.0	127.0	-	25.0	-	1.2	-
	Noturus flavus	3.0	3.0	145.0	36.1	30.3	19.5	0.9	0.1	1.0	1.0	181.0	-	49.0	-	0.8	-	0.0	0.0							0.0	0.0						
	Onchorhynchus mykiss	1.0	1.0	46.0	-	1.0	-	1.0	-	0.0	0.0							1.0	1.0	59.0	-	4.0	-	2.0	-	0.0	0.0						
	Rhinichthys cataractae	10.0	10.0	88.5	11.1	6.4	2.6	0.9	0.1	0.0	0.0							10.0	10.0	93.5	12.6	7.1	2.8	0.9	0.2	0.0	0.0						
	Semotilus atromaculatus	0.0	0.0							3.0	3.0	139.3	24.5	27.2	14.9	0.9	0.1	0.0	0.0							3.0	3.0	140.0	34.1	32.0	26.2	1.0	0.1

Table 3 (continued)

Site Code	Species	Baseflow																Runoff															
		Control								HDF								Control								HDF							
		# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.
AG 11	*Ambloplites rupestris*	9.0	9.0	80.6	15.0	8.7	5.8	1.5	0.3	10.0	10.0	64.9	10.4	4.0	1.8	1.4	0.4	3.0	3.0	87.0	28.0	11.5	10.9	1.4	0.0	3.0	3.0	76.0	9.5	7.3	2.3	1.6	0.1
	Catostomus commersonii	2.0	2.0	124.0	9.9	18.0	5.7	0.9	0.1	3.0	3.0	70.0	3.6	2.8	0.8	0.8	0.3	3.0	3.0	202.7	26.6	75.4	30.3	0.9	0.1	2.0	2.0	110.5	34.6	10.5	6.4	0.8	0.2
	Culaea inconstans	0.0	0.0							0.0	0.0							0.0	0.0							1.0	1.0	52.0	-	2.0	-	1.4	-
	Cyprinidae	0.0	0.0							1.0	1.0	44.0	-	0.7	-	0.8	-	0.0	0.0							2.0	2.0	44.0	2.8	0.7	0.0	0.8	0.2
	Etheostoma flabellare	13.0	10.0	59.5	5.3	2.2	0.7	1.0	0.3	44.0	10.0	60.6	4.6	1.8	0.4	0.8	0.1	5.0	5.0	54.0	6.5	1.5	0.7	0.9	0.3	6.0	6.0	59.3	6.9	2.0	0.6	0.9	0.1
	Etheostoma nigrum	13.0	13.0			1.0				34.0	10.0	60.2	5.6	1.9	0.5	0.8	0.1	4.0	4.0	56.8	2.4	1.2	0.2	0.6	0.0	12.0	10.0	53.6	3.2	1.3	0.4	0.9	0.2
	Lepomis gibbosus	1.0	1.0	108.0	-	24.0	-	1.9	-	1.0	1.0	109.0	-	22.0	-	1.7	-	0.0	0.0							6.0	6.0	56.0	19.7	2.8	3.6	1.2	0.2
	Luxilus cornutus	1.0	1.0	103.0	-	8.4	-	0.8	-	1.0	1.0	92.0	-	7.2	-	0.9	-	2.0	2.0	132.5	10.6	30.5	21.9	1.2	0.6	0.0	0.0						
	Pimephales notatus	4.0	4.0			2.0				8.0	8.0			0.5				2.0	2.0	83.5	12.0	10.5	4.9	1.7	0.1	24.0	3.0	36.3	4.0	0.5	0.1	1.1	0.2
	Pimephales promelas	0.0	0.0							5.0	1.0	67.0	-	3.0	-	1.0	-	0.0	0.0							0.0	0.0						
	Rhinichthys obtusus	3.0	3.0	72.3	2.5	3.8	0.3	1.0	0.1	0.0	0.0							1.0	1.0	83.0	-	4.5	-	0.8	-	0.0	0.0						
	Semotilus atromaculatus	30.0	10.0	120.1	55.0	25.3	28.8	1.0	0.2	20.0	10.0	99.4	26.6	10.1	7.9	0.9	0.1	4.0	4.0	96.5	35.9	9.8	8.4	0.9	0.1	10.0	10.0	118.6	68.8	28.9	37.2	1.1	0.3
AG 12	*Catostomus commersonii*	0.0	0.0							5.0	5.0	84.2	53.6	13.2	24.5	1.0	0.2	1.0	1.0	62.0	-	1.5	-	0.6	-	3.0	3.0	79.7	27.3	5.1	5.0	0.8	0.0
	Cottus bairdii	6.0	6.0	51.2	5.8	1.2	0.5	0.9	0.3	7.0	7.0	58.0	15.7	2.5	2.0	1.1	0.5	6.0	6.0	66.8	25.6	4.0	4.6	0.9	0.2	5.0	5.0	80.8	25.9	7.4	5.0	1.2	0.2
	Etheostoma caeruleum	1.0	1.0	65.0	-	3.2	-	1.2	-	0.0	0.0							0.0	0.0							0.0	0.0						
	Etheostoma nigrum	5.0	2.0	65.5	0.7	2.0	0.4	0.7	0.1	11.0	11.0	57.6	7.1	1.5	0.5	0.8	0.1	1.0	1.0	62.0	-	2.3	-	1.0	-	6.0	6.0	63.2	4.3	2.9	0.5	1.1	0.1
	Luxilus cornutus	1.0	1.0	67.0	-	1.7	-	0.6	-	0.0	0.0							2.0	2.0	43.5	3.5	0.5	0.1	0.6	0.0	0.0	0.0						
	Rhinichthys obtusus	14.0	10.0	56.7	7.0	1.8	0.7	0.9	0.3	7.0	4.0	75.3	9.7	3.8	1.5	0.8	0.1	9.0	3.0	60.0	15.4	2.2	1.6	0.9	0.1	3.0	3.0	51.3	30.5	2.4	2.5	1.2	0.2
	Salmo salar	1.0	1.0	99.0	-	8.0	-	0.8	-	0.0	0.0							0.0	0.0							0.0	0.0						
	Salvelinus fontinalis	0.0	0.0							1.0	1.0	189.0	-	60.0	-	0.9	-	1.0	1.0	274.0	-	201.0	-	1.0	-	0.0	0.0						
	Semotilus atromaculatus	5.0	1.0	105.0	-	10.2	-	0.9	-	9.0	9.0	91.6	48.3	11.4	16.5	0.7	0.1	6.0	6.0	52.7	11.6	1.5	1.5	0.8	0.2	7.0	7.0	81.3	38.3	8.9	11.9	1.2	0.2
AG 13	*Rhinichthys cataractae*	4.0	4.0	65.0	10.8	2.6	1.1	0.9	0.1	1.0	1.0	90.0	-	5.0	-	0.7	-	1.0	1.0	87.0	-	6.0	-	0.9	-	2.0	2.0	57.5	17.7	1.8	0.4	1.1	0.8
	Rhinichthys obtusus	14.0	10.0	69.0	13.1	3.5	2.0	1.0	0.2	13.0	7.0	69.3	12.1	3.5	2.3	0.9	0.3	3.0	3.0	59.3	17.0	2.2	1.8	0.8	0.1	2.0	2.0	33.0	2.8	0.8	0.4	2.0	0.5
	Salmo salar	1.0	1.0	115.0	-	10.0	-	0.7	-	1.0	1.0	115.0	-	10.8	-	0.7	-	0.0	0.0							0.0	0.0						
	Salvelinus fontinalis	1.0	1.0	105.0	-	7.4	-	0.6	-	1.0	1.0	105.0	-	9.7	-	0.8	-	0.0	0.0							0.0	0.0						
	Semotilus atromaculatus	2.0	2.0	120.0	99.0	32.1	43.7	0.9	0.0	6.0	6.0	43.3	5.3	1.2	0.3	1.5	0.5	0.0	0.0							1.0	1.0	42.0	-	1.0	-	1.4	-
AG 14	*Catostomus commersonii*	0.0	0.0							0.0	0.0							0.0	0.0							2.0	2.0	95.5	13.4	8.5	3.5	0.9	0.0
	Cottus bairdii	0.0	0.0							6.0	6.0	64.2	14.2	3.7	1.9	1.3	0.3	0.0	0.0							3.0	3.0	78.7	10.1	5.9	1.9	1.2	0.1
	Culaea inconstans	0.0	0.0							3.0	3.0			0.7				2.0	2.0			0.9				0.0	0.0						
	Etheostoma caeruleum	0.0	0.0							1.0	1.0	53.0	-	2.0	-	1.3	-	0.0	0.0							2.0	2.0	51.0	8.5	1.9	0.8	1.4	0.1
	Etheostoma nigrum	24.0	10.0	57.3	4.2	1.9	0.6	1.0	0.2	10.0	10.0	58.6	2.8	1.8	0.8	0.9	0.3	20.0	10.0	56.8	4.7	1.7	0.5	0.9	0.2	17.0	10.0	59.5	2.1	2.1	0.7	1.0	0.3
	Luxilus cornutus	19.0	19.0			0.3				17.0	17.0			1.2				4.0	4.0			0.5				8.0	8.0			0.1			
	Pimephales notatus	1.0	1.0	35.0	-	0.5	-	1.2	-	0.0	0.0							0.0	0.0							0.0	0.0						
	Rhinichthys obtusus	16.0	7.0	62.7	6.0	2.2	0.8	0.9	0.3	9.0	4.0	57.3	12.7	1.6	0.9	0.9	0.3	3.0	3.0	55.3	14.5	1.9	1.2	1.0	0.4	16.0	10.0	60.9	10.8	2.2	1.2	0.9	0.2
	Salvelinus fontinalis	0.0	0.0							0.0	0.0							0.0	0.0							1.0	1.0	157.0	-	31.0	-	0.8	-
	Semotilus atromaculatus	62.0	6.0	63.2	10.1	2.1	1.3	0.8	0.3	21.0	5.0	48.4	5.3	1.1	0.2	1.0	0.2	24.0	10.0	58.7	16.1	1.9	1.2	0.9	0.2	50.0	10.0	64.5	14.7	2.5	2.8	0.8	0.3

Table 3 (continued)

		Baseflow																Runoff															
		Control								HDF								Control								HDF							
Site Code	Species	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.
AG 15	*Catostomus commersonii*	9.0	9.0	60.6	7.0	2.1	0.5	0.9	0.2	0.0	0.0							0.0	0.0							1.0	1.0	53.0	-	1.0	-	0.7	-
	Cottus bairdii	9.0	9.0	48.1	5.0	1.3	0.4	1.2	0.2	19.0	10.0	53.4	10.3	1.9	1.3	1.1	0.1	2.0	2.0	59.5	2.1	2.0	0.0	1.0	0.1	1.0	1.0	55.0	-	2.0	-	1.2	-
	Etheostoma caeruleum	14.0	10.0	56.4	6.4	2.0	0.6	1.1	0.2	23.0	10.0	59.7	2.5	2.4	0.4	1.1	0.1	3.0	3.0	60.3	2.5	2.7	0.6	1.2	0.2	4.0	4.0	48.0	11.3	1.6	1.2	1.2	0.3
	Etheostoma nigrum	19.0	10.0	57.4	8.2	1.9	0.8	1.0	0.2	4.0	4.0	50.8	4.2	1.2	0.2	0.9	0.1	0.0	0.0							0.0	0.0						
	Luxilus cornutus	1.0	1.0	86.0	-	5.0	-	0.8	-	2.0	2.0	63.5	34.6	2.3	2.5	0.7	0.2	0.0	0.0							3.0	3.0			12.0			
	Rhinichthys cataractae	1.0	1.0	99.0	-	8.5	-	0.9	-	0.0	0.0							0.0	0.0							0.0	0.0						
	Rhinichthys obtusus	3.0	3.0	47.3	9.7	1.3	0.6	1.2	0.2	1.0	1.0	45.0	-	1.0	-	1.1	-	1.0	1.0	36.0	-	0.5	-	1.1	-	6.0	1.0	60.0	-	2.0	-	0.9	-
	Salmo salar	1.0	1.0	80.0	-	6.0	-	1.2	-	1.0	1.0	75.0	-	2.4	-	0.6	-	0.0	0.0							0.0	0.0						
	Semotilus atromaculatus	23.0	10.0	88.6	15.4	5.0	2.3	0.7	0.1	19.0	10.0	55.2	11.9	1.9	1.4	0.9	0.2	4.0	4.0	84.5	37.3	9.5	13.8	0.9	0.2	20.0	10.0	85.4	26.0	6.9	6.6	0.8	0.2
AG 16	*Catostomus commersonii*	0.0	0.0							0.0	0.0							0.0	0.0							5.0	5.0	165.4	23.0	43.6	27.1	0.8	0.4
	Etheostoma caeruleum	24.0	10.0	56.7	8.4	2.3	1.2	1.1	0.3	2.0	2.0	58.5	9.2	2.5	0.7	1.3	0.2	11.0	11.0	48.5	4.8	1.3	0.6	1.1	0.2	2.0	2.0	43.5	7.8	1.5	0.7	1.8	0.1
	Etheostoma flabellare	7.0	7.0	64.0	12.1	2.9	1.1	1.1	0.3	0.0	0.0							9.0	9.0	58.2	12.1	2.3	1.5	1.0	0.2	0.0	0.0						
	Etheostoma nigrum	0.0	0.0							5.0	5.0	54.0	7.9	1.2	0.5	0.7	0.1	1.0	1.0	55.0	-	0.7	-	0.4	-	4.0	4.0	61.8	10.7	1.9	0.9	0.7	0.1
	Hypentelium nigricans	4.0	4.0	165.0	10.8	46.2	9.5	1.0	0.0	1.0	1.0	154.0	-	39.1	-	1.1	-	4.0	4.0	165.5	17.2	48.8	16.1	1.0	0.1	2.0	2.0	207.0	39.6	107.5	72.8	1.1	0.2
	Luxilus cornutus	0.0	0.0							0.0	0.0							0.0	0.0							1.0	1.0	109.0	-	12.2	-	0.9	-
	Micropterus dolomieu	0.0	0.0							0.0	0.0							0.0	0.0							1.0	1.0	150.0	-	39.0	-	1.1	-
	Notropis rubellus	0.0	0.0							0.0	0.0							0.0	0.0							10.0	10.0	93.4	21.5	6.3	4.2	0.7	0.1
	Pimephales notatus	0.0	0.0							0.0	0.0							0.0	0.0							2.0	2.0			5.0			
	Rhinichthys cataractae	14.0	10.0	90.9	15.2	8.4	3.6	1.1	0.1	2.0	2.0	92.5	7.8	5.5	0.7	0.7	0.3	5.0	5.0	81.2	20.1	5.0	4.2	0.8	0.1	1.0	1.0	96.0	-	9.0	-	1.0	-
	Semotilus atromaculatus	1.0	1.0	98.0	-	7.0	-	0.7	-	0.0	0.0							0.0	0.0							1.0	1.0	147.0	-	29.0	-	0.9	-
AG 17	*Ambloplites rupestris*	5.0	5.0	88.4	25.4	43.1	65.1	5.0	7.5	0.0	0.0							0.0	0.0							0.0	0.0						
	Catostomus commersonii	3.0	3.0	110.3	17.2	13.2	6.9	0.9	0.0	0.0	0.0							1.0	1.0	133.0	-	20.1	-	0.9	-	2.0	2.0	122.0	5.7	17.6	2.9	1.0	0.0
	Etheostoma caeruleum	3.0	3.0	52.3	10.0	1.7	1.0	1.1	0.2	8.0	8.0	43.4	6.6	1.0	0.5	1.2	0.2	1.0	1.0	41.0	-	0.5	-	0.7	-	5.0	5.0	45.4	5.9	1.3	0.7	1.3	0.5
	Etheostoma flabellare	1.0	1.0	50.0	-	0.7	-	0.6	-	0.0	0.0							0.0	0.0							0.0	0.0						
	Etheostoma nigrum	0.0	0.0							2.0	2.0	57.5	9.2	1.3	0.1	0.7	0.3	1.0	1.0	38.0	-	0.1	-	0.2	-	2.0	2.0	46.0	2.8	0.8	0.1	0.8	0.1
	Hypentelium nigricans	2.0	2.0	117.5	41.7	15.6	20.4	0.6	0.5	5.0	5.0	117.8	39.9	22.6	20.8	1.1	0.1	2.0	2.0	92.5	7.8	7.3	1.8	0.9	0.0	2.0	2.0	131.0	65.1	31.8	37.1	1.0	0.1
	Lepomis gibbosus	1.0	1.0	83.0	-	83.0	-	1.9	-	0.0	0.0							0.0	0.0							0.0	0.0						
	Luxilus cornutus	0.0	0.0							0.0	0.0							9.0	9.0			23.2				1.0	1.0	96.0	-	7.5	-	0.9	-
	Micropterus dolomieu	0.0	0.0							1.0	1.0	96.0	-	12.0	-	1.4	-	0.0	0.0							0.0	0.0						
	Notropis rubellus	1.0	1.0	99.0	-	10.0	-	1.0	-	1.0	1.0	75.0	-	3.2	-	0.8	-	30.0	10.0	113.9	12.2	8.1	2.9	0.5	0.1	3.0	3.0	89.0	22.5	4.5	3.5	0.6	0.0
	Noturus flavus	0.0	0.0							1.0	1.0	78.0	-	4.7	-	1.0	-	0.0	0.0							0.0	0.0						
	Pimephales notatus	0.0	0.0							0.0	0.0							0.0	0.0							3.0	3.0			5.0			

Table3 (continued)

		Baseflow																Runoff															
		Control								HDF								Control								HDF							
Site Code	Species	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.
URB 3	*Ambloplites rupestris*	3.0	3.0	118.3	22.5	33.7	18.6	1.9	0.2	17.0	10.0	100.8	32.3	23.6	18.6	1.8	0.1	2.0	2.0	84.5	13.4	13.1	7.1	2.0	0.2	2.0	2.0	59.0	28.3	4.8	4.7	2.1	0.6
	Catostomus commersonii	8.0	8.0	166.0	27.1	46.5	26.5	0.9	0.1	0.0	0.0							5.0	5.0	198.4	44.2	87.4	57.6	1.0	0.1	3.0	3.0	185.0	40.9	67.3	39.5	1.0	0.0
	Etheostoma flabellare	9.0	9.0	58.7	10.0	2.1	1.0	1.0	0.3	9.0	9.0	68.7	6.5	2.7	0.5	0.8	0.2	3.0	3.0	55.0	1.7	1.5	0.3	0.9	0.1	1.0	1.0	74.0	-	2.5	-	0.6	-
	Etheostoma nigrum	5.0	5.0			2.0				41.0	41.0			0.5				2.0	2.0	44.5	0.7	1.1	0.1	1.2	0.0	7.0	7.0			0.9			
	Lepomis sp.	0.0	0.0							5.0	5.0			0.7				0.0	0.0							0.0	0.0						
	Luxilus cornutus	0.0	0.0							1.0	1.0	120.0	-	16.0	-	0.9	-	1.0	1.0	126.0	-	21.6	-	1.1	-	3.0	3.0	66.0	6.1	3.0	0.3	1.1	0.3
	Pimephales notatus	0.0	0.0							2.0	2.0			4.5				1.0	1.0	60.0	-	2.3	-	1.1	-	0.0	0.0						
	Rhinichthys obtusus	1.0	1.0	83.0	-	6.0	-	1.1	-	2.0	2.0	56.0	42.4	3.1	4.1	1.0	0.1	0.0	0.0							1.0	1.0	77.0	-	4.3	-	0.9	-
	Semotilus atromaculatus	9.0	9.0	150.8	39.2	38.0	33.4	1.0	0.3	5.0	5.0	146.8	54.9	47.4	52.3	1.1	0.1	5.0	5.0	92.6	15.3	10.0	5.1	1.2	0.1	2.0	2.0	63.5	3.5	2.9	0.6	1.1	0.1
URB 11	*Carassius auratus*	1.0	1.0	112.0	-	9.5	-	0.7	-	0.0	0.0							0.0	0.0							0.0	0.0						
	Catostomus commersonii	1.0	1.0	87.0	-	5.0	-	0.8	-	0.0	0.0							0.0	0.0							4.0	4.0	74.3	40.1	6.1	9.0	0.9	0.1
	Pimephales promelas	0.0	0.0							11.0	11.0			1.9				4.0	4.0			1.6				3.0	3.0			2.1			
	Rhinichthys cataractae	1.0	1.0	68.0	-	3.3	-	1.1	-	6.0	6.0	71.0	12.3	3.6	1.8	0.9	0.1	1.0	1.0	55.0	-	1.5	-	0.9	-	5.0	5.0	68.0	8.0	2.7	1.1	0.8	0.2
	Rhinichthys obtusus	16.0	10.0	65.9	16.4	3.2	1.6	1.1	0.3	30.0	10.0	68.7	9.9	3.3	1.3	0.9	0.1	4.0	4.0	47.3	20.6	1.4	1.5	1.2	0.5	33.0	10.0	68.1	9.6	3.3	2.0	0.9	0.2
	Semotilus atromaculatus	0.0	0.0							4.0	4.0	72.8	21.5	4.1	3.3	1.1	0.6	0.0	0.0							0.0	0.0						
URB 13	*Lepomis sp.*	6.0	6.0	33.3	5.0	0.7	0.3	1.8	0.6	5.0	5.0	28.0	5.6	0.5	0.4	2.0	0.8	1.0	1.0	31.0	-	0.4	-	1.3	-	0.0	0.0						
	Pimephales notatus	0.0	0.0							1.0	1.0	27.0	-	0.3	-	1.5	-	0.0	0.0							0.0	0.0						
	Pimephales promelas	53.0	10.0	61.9	5.1	2.2	1.0	0.9	0.3	14.0	4.0	62.0	7.1	2.7	0.8	1.1	0.1	0.0	0.0							0.0	0.0						
	Pimephales promelas	0.0	0.0							0.0	0.0							6.0	1.0	61.0	-	2.2	-	1.0	-	3.0	7.0	64.1	4.7	4.2	1.3	1.5	0.3
	Rhinichthys obtusus	5.0	3.0	47.3	6.8	1.0	0.5	1.1	0.8	0.0	0.0							1.0	1.0	49.0	-	1.4	-	1.2	-	1.0	1.0	54.0	-	1.8	-	1.1	-
	Semotilus atromaculatus	44.0	10.0	79.9	17.7	6.0	3.9	1.1	0.2	13.0	10.0	49.8	7.1	1.4	0.5	1.2	0.7	11.0	11.0	68.3	28.1	5.1	8.6	1.0	0.2	16.0	10.0	89.5	23.6	8.3	6.8	0.9	0.1
URB 15	*Catostomus commersonii*	9.0	9.0	100.1	44.0	15.8	31.2	0.9	0.1	0.0	0.0							0.0	0.0							0.0	0.0						
	Etheostoma caeruleum	25.0	10.0	54.3	4.2	1.7	0.5	1.0	0.2	18.0	10.0	54.6	4.1	2.2	0.6	1.3	0.3	0.0	0.0							1.0	1.0	45.0	-	1.1	-	1.2	-
	Etheostoma nigrum	13.0	10.0	62.4	4.1	2.3	0.6	0.9	0.2	1.0	1.0	62.0	-	2.0	-	0.8	-	1.0	1.0	70.0	-	3.0	-	0.9	-	1.0	1.0	55.0	-	2.5	-	1.5	-
	Lepomis gibbosus	1.0	1.0	49.0	-	1.7	-	1.4	-	2.0	2.0	47.0	7.1	2.4	0.9	2.2	0.1	0.0	0.0							2.0	2.0	60.0	21.2	4.5	3.5	1.9	0.4
	Luxilus cornutus	0.0	0.0							0.0	0.0							1.0	1.0	100.0	-	9.1	-	0.9	-	0.0	0.0						
	Pimephales promelas	0.0	0.0							0.0	0.0							0.0	0.0							1.0	1.0	47.5	3.5	1.8	0.4	1.6	0.0
	Rhinichthys cataractae	0.0	0.0							6.0	6.0	49.7	13.1	1.8	1.3	1.4	0.5	1.0	1.0	38.0	-	0.5	-	0.9	-	12.0	10.0	64.4	13.7	2.7	1.2	1.0	0.2
	Rhinichthys obtusus	1.0	1.0	52.0	-	2.0	-	1.4	-	0.0	0.0							0.0	0.0							7.0	1.0	50.0	-	1.8	-	1.4	-
	Rhinichthys obtusus	1.0	1.0	76.0	-	5.0	-	1.1	-	2.0	2.0	44.0	4.2	1.3	0.4	1.5	0.1	1.0	1.0	52.0	-	2.5	-	1.8	-	1.0	1.0	55.0	-	1.6	-	1.0	-
	Salmo salar	0.0	0.0							0.0	0.0							2.0	2.0	167.5	3.5	38.8	1.1	0.8	0.0	0.0	0.0						
	Semotilus atromaculatus	7.0	7.0	125.6	34.9	26.2	29.3	1.0	0.2	0.0	0.0							3.0	3.0	119.3	46.9	24.2	21.2	1.1	0.1	72.0	10.0	84.3	15.7	6.4	3.1	1.0	0.3

Table 3 (continued)

		Baseflow																Runoff															
		Control								HDF								Control								HDF							
Site Code	Species	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.
URB 16	*Catostomus commersonii*	21.0	10.0	147.4	46.8	34.0	36.9	0.8	0.1	19.0	10.0	107.3	14.5	10.5	3.5	0.8	0.2	5.0	5.0	123.2	54.3	23.7	29.2	0.9	0.0	0.0	0.0						
	Cyprinus carpio	1.0	1.0	100.0	-	15.0	-	1.5	-	0.0	0.0							0.0	0.0							0.0	0.0						
	Etheostoma nigrum	2.0	2.0	62.0	5.7	2.0	0.7	0.8	0.1	12.0	12.0	56.1	5.2	1.3	0.5	0.7	0.1	3.0	3.0	57.7	7.1	1.7	0.8	0.8	0.1	4.0	4.0	47.5	1.7	1.0	0.3	0.9	0.2
	Luxilus cornutus	9.0	9.0			10.8				7.0	7.0			2.0				3.0	3.0	99.3	22.6	4.8	3.5	0.7	0.5	0.0	0.0						
	Nocomis biguttatus	1.0	1.0	95.0	-	8.5	-	1.0	-	0.0	0.0							0.0	0.0							0.0	0.0						
	Onchorhynchus mykiss	0.0	0.0							1.0	1.0	66.0	-	2.9	-	1.0	-	1.0	1.0	150.0	-	26.0	-	0.8	-	0.0	0.0						
	Pimephales notatus	19.0	19.0			2.6				18.0	18.0			1.5				7.0	7.0			1.3				7.0	7.0			1.4			
	Pimephales promelas	6.0	6.0	64.7	5.7	2.6	0.6	1.0	0.1	1.0	1.0	71.0	-	4.0	-	1.1	-	1.0	1.0	45.0	-	1.0	-	1.1	-	1.0	1.0	74.0	-	3.8	-	0.9	-
	Rhinichthys cataractae	0.0	0.0							10.0	10.0	61.5	12.0	2.4	1.2	1.0	0.3	0.0	0.0							3.0	3.0	52.3	2.5	1.1	0.1	0.7	0.0
	Rhinichthys obtusus	9.0	9.0	71.6	11.2	3.1	1.1	0.8	0.2	15.0	10.0	68.3	14.3	2.9	1.3	0.9	0.1	0.0	0.0							8.0	8.0	66.3	14.3	3.0	1.7	0.9	0.1
	Semotilus atromaculatus	26.0	10.0	142.3	39.2	28.8	21.5	0.8	0.1	24.0	10.0	109.4	26.0	13.1	10.5	0.8	0.2	7.0	7.0	136.0	24.2	21.5	8.7	0.8	0.1	9.0	9.0	106.3	27.8	14.5	12.2	1.0	0.1
URB 17	*Rhinichthys obtusus*	2.0	2.0	83.0	17.0	5.8	3.1	1.0	0.1	12.0	12.0	36.8	13.9	0.9	0.8	1.4	0.6	1.0	1.0	72.0	-	4.1	-	1.1	-	1.0	1.0	41.0	-	5.5	-		-
	Semotilus atromaculatus	16.0	10.0	102.0	30.9	12.9	12.8	0.9	0.1	3.0	3.0	90.0	28.2	8.9	7.6	1.0	0.0	2.0	2.0	89.5	3.5	7.3	0.4	1.0	0.1	2.0	2.0	74.0	39.6	6.2	7.3	1.0	0.0
URB 18	*Catostomus commersonii*	2.0	2.0	134.0	62.2	26.9	31.3	0.8	0.1	9.0	9.0	134.6	30.2	25.6	15.1	0.9	0.1	4.0	4.0	124.5	43.4	24.9	29.4	0.9	0.1	1.0	1.0	90.0	-	5.0	-	0.7	-
	Cyprinidae	2.0	2.0	56.8	23.7	5.8	6.7	1.2	0.5	6.0	6.0	56.2	19.5	2.5	3.2	1.1	0.1	4.0	4.0			14.5				7.0	1.0	106.0	-	14.0	-	1.2	-
	Etheostoma caeruleum	0.0	0.0							1.0	1.0	65.0	-	3.6	-	1.3	-	0.0	0.0							0.0	0.0						
	Etheostoma nigrum	0.0	0.0							3.0	3.0	56.0	5.2	1.6	0.2	1.6	0.2	1.0	1.0	68.0	-	3.3	-	1.1	-	1.0	1.0	69.0	-	3.4	-	1.0	-
	Onchorhynchus mykiss	1.0	1.0	130.0	-	18.5	-	0.8	-	0.0	0.0							1.0	1.0	198.0	-	73.8	-	1.0	-	0.0	0.0						
	Pimephales promelas	2.0	2.0	60.5	0.7	2.3	0.3	1.0	0.1	0.0	0.0							6.0	6.0			1.6				16.0	1.0			1.5			
	Rhinichthys cataractae	1.0	1.0	88.0	-	5.0	-	0.7	-	1.0	1.0	88.0	-	7.0	-	1.0	-	1.0	1.0	72.0	-	3.5	-	0.9	-	0.0	0.0						
	Rhinichthys obtusus	17.0	10.0	71.3	2.6	3.5	0.5	1.0	0.1	7.0	7.0	64.4	14.2	2.8	1.4	1.0	0.1	18.0	10.0	73.8	6.5	3.7	1.4	0.9	0.2	15.0	7.0	71.7	4.6	3.4	0.7	0.9	0.1
	Semotilus atromaculatus	5.0	5.0	110.4	44.5	20.2	24.1	1.0	0.2	27.0	10.0	106.7	41.9	23.8	27.5	1.7	2.5	19.0	10.0	107.2	35.3	14.0	12.7	0.9	0.3	15.0	10.0	122.0	45.7	22.5	19.0	0.9	0.2
URB 20	*Rhinichthys obtusus*	4.0	4.0	60.0	24.6	1.5	2.1	0.7	0.4	5.0	5.0	53.6	22.9	2.9	2.8	1.4	0.2	0.0	0.0							1.0	1.0	48.0	1.0	1.7	1.0	1.5	1.0

Table 3 (continued)

Site Code	Species	Baseflow																Runoff															
		Control								HDF								Control								HDF							
		# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.
FOR 03	*Ambloplites rupestris*	10.0	10.0	88.1	37.4	21.6	32.3	1.8	0.3	10.0	10.0	74.1	21.9	8.6	8.9	1.4	0.4	6.0	6.0	121.7	17.1	39.3	16.9	2.1	0.1	3.0	3.0	60.0	13.9	3.9	1.7	1.9	0.7
	Catostomus commersonii	1.0	1.0	103.0	-	11.0	-	1.0	-	0.0	0.0							0.0	0.0							0.0	0.0						
	Etheostoma caeruleum	1.0	1.0	55.0	-	1.0	-	0.6	-	1.0	1.0	61.0	-	2.0	-	0.9	-	0.0	0.0							0.0	0.0						
	Etheostoma flabellare	3.0	3.0	55.3	13.1	1.8	1.0	1.0	0.1	5.0	5.0	57.0	10.0	1.7	1.0	0.8	0.2	9.0	9.0	51.1	11.3	1.2	1.2	0.7	0.2	1.0	1.0	63.0	-	3.0	-	1.2	-
	Etheostoma nigrum	7.0	7.0			1.7				5.0	5.0			2.0				1.0	1.0	45.0	-	1.0	-	1.1	-	0.0	0.0						
	Luxilus cornutus	0.0	0.0							0.0	0.0							0.0	0.0							1.0	1.0	106.0	-	12.5	-	1.1	-
	Pimephales notatus	0.0	0.0							1.0	1.0	90.0	-	9.0	-	1.2	-	1.0	1.0	57.0	-	2.0	-	1.1	-	2.0	2.0	70.0	0.0	4.8	0.4	1.4	0.1
	Rhinichthys obtusus	0.0	0.0							0.0	0.0							3.0	3.0	76.7	0.6	4.3	0.6	1.0	0.1	2.0	2.0	82.5	6.4	6.5	2.1	1.1	0.1
	Semotilus atromaculatus	9.0	9.0	108.1	11.8	13.8	3.6	1.1	0.1	2.0	2.0	91.0	38.2	9.0	8.5	1.0	0.2	4.0	4.0	115.5	18.2	19.4	8.6	1.2	0.1	3.0	2.0	123.0	51.6	28.2	31.1	1.2	0.2
FOR 10	*Catostomus commersonii*	0.0	0.0							1.0	1.0			0.5				0.0	0.0							0.0	0.0						
	Cottus bairdii	0.0	0.0							0.0	0.0							0.0	0.0							1.0	1.0	82.0	-	7.0	-	1.3	-
	Culaea inconstans	0.0	0.0							0.0	0.0							0.0	0.0							1.0	1.0	37.0	-	0.5	-	1.0	-
	Etheostoma nigrum	3.0	10.0	66.2	5.4	3.1	1.0	1.0	0.1	5.0	5.0	67.2	4.9	3.0	1.2	1.0	0.2	5.0	4.0	65.8	3.8	3.1	0.9	1.1	0.2	5.0	5.0	59.8	15.7	2.1	1.0	1.0	0.3
	Micropterus salmoides	0.0	0.0							1.0	1.0	59.0	-	3.0	-	1.5	-	0.0	0.0							1.0	1.0	66.0	-	3.0	-	1.0	-
	Onchorhynchus mykiss	0.0	0.0							2.0	2.0	312.5	53.0	363.5	164.8	1.2	0.0	0.0	0.0							0.0	0.0						
	Rhinichthys obtusus	1.0	1.0	77.0	-	5.5	-	1.2	-	2.0	2.0	73.5	4.9	3.5	0.7	0.9	0.0	1.0	1.0	73.0	-	4.5	-	1.2	-	6.0	6.0	64.7	17.1	3.6	2.1	1.2	0.2
	Salvelinus fontinalis	0.0	0.0							1.0	1.0	172.0	-	62.0	-	1.2	-	0.0	0.0							0.0	0.0						
	Semotilus atromaculatus	15.0	10.0	114.4	46.8	16.9	17.6	0.8	0.3	8.0	7.0	123.3	37.9	16.4	8.7	1.1	0.5	7.0	4.0	143.8	51.2	22.1	11.7	0.8	0.4	13.0	10.0	138.3	40.9	23.0	21.3	0.8	0.4
FOR 12	*Luxilus cornutus*	0.0	0.0							1.0	1.0	158.0	-	38.0	-	1.0	-	0.0	0.0							0.0	0.0						
	Pimephales promelas	0.0	0.0							0.0	0.0							1.0	1.0	52.0	-	2.0	-	1.4	-	0.0	0.0						
	Rhinichthys cataractae	84.0	10.0	70.1	12.1	3.0	1.8	0.8	0.1	53.0	10.0	71.5	11.1	3.4	2.6	0.8	0.2	45.0	10.0	69.5	10.4	3.5	1.3	1.0	0.2	22.0	10.0	75.5	6.8	4.3	1.6	0.9	0.2
	Rhinichthys obtusus	37.0	10.0	67.7	9.3	3.0	1.1	0.9	0.2	69.0	10.0	70.4	9.9	3.2	1.2	0.9	0.1	13.0	10.0	66.4	5.1	3.4	0.8	1.2	0.2	20.0	10.0	70.0	4.5	3.4	0.8	1.0	0.1
	Semotilus atromaculatus	4.0	4.0	95.5	9.1	7.9	2.1	0.9	0.0	1.0	1.0	95.0	-	8.0	-	0.9	-	1.0	1.0	102.0	-	10.0	-	0.9	-	2.0	2.0	120.5	34.6	18.5	13.4	1.0	0.1
FOR 13	*catostomus commersonii*	0.0	0.0							2.0	2.0	159.0	128.7	74.0	100.4	0.9	0.0	0.0	0.0							1.0	1.0	103.0	-	9.3	-	0.9	-
	Cottus bairdii	0.0	0.0							1.0	1.0	48.0	-	1.0	-	0.9	-	0.0	0.0							0.0	0.0						
	Etheostoma caeruleum	2.0	2.0	58.5	2.1	2.7	0.4	1.3	0.1	2.0	2.0	58.0	2.8	2.2	0.3	1.1	0.0	1.0	1.0	63.0	-	3.6	-	1.4	-	1.0	1.0	55.0	-	2.0	-	1.2	-
	Etheostoma nigrum	0.0	0.0							2.0	2.0	63.0	18.4	2.7	1.8	1.0	0.1	0.0	0.0							3.0	3.0	63.0	5.2	2.6	0.7	1.0	0.3
	Onchorhynchus mykiss	2.0	2.0	100.0	32.5	10.9	9.4	0.9	0.0	0.0	0.0							4.0	4.0	91.0	26.2	7.3	5.4	0.9	0.2	1.0	1.0	65.0	-	3.0	-	1.1	-
	Rhinichthys cataractae	8.0	8.0	66.4	15.3	2.6	1.9	0.8	0.2	0.0	0.0							13.0	10.0	78.8	12.7	5.2	2.3	1.2	1.0	1.0	1.0	50.0	-	1.1	-	0.9	-
	Rhinichthys obtusus	2.0	2.0	66.5	23.3	2.5	2.5	0.7	0.1	0.0	0.0							4.0	4.0	68.5	19.1	4.0	2.0	1.2	0.3	2.0	2.0	83.5	2.1	5.6	0.8	1.0	0.1
	Salmo Salar	0.0	0.0							0.0	0.0							1.0	1.0	130.0	-	12.2	-	0.6	-	0.0	0.0						
	Semotilus atromaculatus	0.0	0.0							4.0	4.0	68.5	7.8	3.8	1.2	1.2	0.3	1.0	1.0	183.0	-	56.8	-	0.9	-	5.0	5.0	89.8	35.7	8.6	9.6	0.9	0.3

Table 3 (continued)

		Baseflow																Runoff															
		Control								HDF								Control								HDF							
Site Code	Species	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.	# fish	n	mean length (mm)	length s.d.	mean weight (g)	weight s.d.	mean condition factor	Condition factor s.d.
FOR 14	*Ambloplites rupestris*	9.0	9.0	92.3	40.5	20.8	19.0	2.0	0.9	14.0	10.0	69.2	37.4	10.3	12.6	1.7	0.6	0.0	0.0							7.0	7.0	41.9	11.8	1.6	1.3	1.9	0.5
	Catostomus commersonii	12.0	10.0	123.8	38.0	20.8	18.4	0.9	0.1	2.0	2.0	210.5	64.3	89.3	75.4	0.8	0.0	3.0	3.0	122.3	32.2	18.3	11.0	0.9	0.1	2.0	2.0	206.0	1.4	73.9	0.1	0.8	0.0
	Cyprinidae	0.0	0.0							0.0	0.0							0.0	0.0							1.0	1.0	25.0	-	0.1	-	0.6	-
	Etheostoma caeruleum	6.0	6.0	53.8	5.6	2.5	1.3	1.6	1.1	5.0	5.0	55.8	4.8	2.4	0.8	1.4	0.5	3.0	3.0	50.3	4.7	1.3	0.4	1.0	0.2	3.0	3.0	58.7	2.5	2.0	0.1	1.0	0.1
	Etheostoma flabellare	10.0	10.0	53.5	8.8	1.4	0.6	0.9	0.1	16.0	10.0	64.7	6.5	2.0	0.7	0.7	0.1	4.0	4.0	47.3	13.1	1.0	1.0	0.7	0.3	2.0	2.0	64.0	5.7	2.0	0.0	0.8	0.2
	Etheostoma nigrum	14.0	14.0			0.9				13.0	13.0			1.0				1.0	1.0	51.0	-	1.0	-	0.8	-	3.0	3.0	47.3	7.6	1.1	0.3	1.0	0.3
	Lepomis gibbosus	0.0	0.0							10.0	10.0	44.2	2.1	1.4	0.2	1.7	0.3	0.0	0.0							2.0	2.0	51.0	0.0	2.0	0.0	1.5	0.0
	Luxilus cornutus	2.0	2.0			0.7				1.0	1.0	45.0	-	45.0	-	0.7	-	3.0	3.0			11.0				0.0	0.0						
	Pimephales notatus	2.0	2.0			0.8				4.0	4.0			0.9				2.0	2.0	53.5	29.0	2.2	3.0	0.7	0.6	0.0	0.0						
	Rhinichthys obtusus	1.0	1.0	81.0	-	4.2	-	0.8	-	0.0	0.0							1.0	1.0	34.0	-	0.3	-	0.8	-	0.0	0.0						
	Semotilus atromaculatus	19.0	10.0	120.6	61.2	30.7	44.8	1.0	0.2	13.0	10.0	116.8	35.0	19.5	24.4	0.9	0.1	8.0	8.0	78.0	21.0	4.1	3.1	0.7	0.1	2.0	2.0	112.0	2.8	12.5	0.7	0.9	0.0
FOR 16	*Lepomis sp.*	1.0	1.0	36.0	-	0.4	-	0.9	-	0.0	0.0							0.0	0.0							1.0	1.0	46.0	-	1.2	-	1.2	-
	Pimephales promelas	2.0	2.0			1.5				0.0	0.0							0.0	0.0							0.0	0.0						
	Rhinichthys obtusus	84.0	10.0	64.1	7.9	2.3	0.9	0.8	0.1	42.0	10.0	61.1	7.2	2.0	0.7	0.9	0.2	10.0	10.0	66.4	6.3	2.5	0.6	0.9	0.1	21.0	4.0	64.5	7.3	2.5	0.5	0.9	0.2
	Semotilus atromaculatus	54.0	10.0	81.2	20.4	5.6	4.0	0.9	0.2	51.0	10.0	97.2	44.7	13.4	15.1	0.9	0.2	10.0	10.0	90.5	18.7	7.9	5.6	0.9	0.2	17.0	8.0	111.5	22.2	14.9	8.6	1.0	0.1
FOR 17	*Catostomus commersonii*	3.0	3.0	64.7	1.5	2.5	0.4	0.9	0.1	0.0	0.0							6.0	6.0	71.2	18.3	3.5	3.2	0.8	0.0	0.0	0.0						
	Cottus bairdii	19.0	10.0	55.1	13.1	2.3	1.9	1.2	0.2	13.0	10.0	68.9	14.7	4.4	2.7	1.2	0.3	9.0	9.0	54.8	17.1	2.3	3.3	1.0	0.1	11.0	11.0	62.2	19.7	3.7	4.6	1.1	0.1
	Etheostoma caeruleum	7.0	7.0	48.0	10.8	1.6	1.3	1.1	0.4	5.0	5.0	52.0	14.9	3.5	3.3	3.1	4.5	1.0	1.0	61.0	-	2.5	-	1.1	-	2.0	2.0	55.0	9.9	2.5	0.7	1.5	0.4
	Etheostoma nigrum	36.0	10.0	60.8	8.0	1.8	1.2	0.7	0.4	2.0	2.0	57.0	15.6	2.0	1.4	1.0	0.1	38.0	10.0	52.9	8.3	1.3	0.7	0.8	0.2	3.0	3.0	65.7	5.1	2.6	0.7	0.9	0.1
	Luxilus cornutus	3.0	3.0			1.3				2.0	2.0	89.5	57.3	10.1	12.1	1.1	0.3	0.0	0.0							0.0	0.0						
	Rhinichthys obtusus	32.0	10.0	61.1	12.9	2.7	1.6	1.1	0.1	39.0	10.0	69.6	11.3	3.9	1.2	1.2	0.3	10.0	8.0	74.8	11.7	4.1	1.5	1.0	0.1	9.0	6.0	71.2	14.8	3.6	2.0	0.9	0.1
	Salmo Salar	0.0	0.0							0.0	0.0							0.0	0.0							1.0	1.0	136.0	-	18.0	-	0.7	-
	Salvelinus fontinalis	1.0	1.0	97.0	-	7.3	-	0.8	-	7.0	7.0	142.7	43.0	28.9	22.5	0.8	0.1	2.0	2.0	97.0	4.2	7.0	1.4	0.8	0.1	4.0	4.0	111.8	37.9	14.5	15.9	0.8	0.1
	Semotilus atromaculatus	34.0	10.0	83.0	11.5	4.4	1.7	0.7	0.1	22.0	10.0	89.0	33.7	7.9	9.6	0.8	0.2	6.0	6.0	66.3	16.7	2.7	1.5	0.9	0.2	7.0	7.0	74.1	28.1	4.9	5.5	0.8	0.1

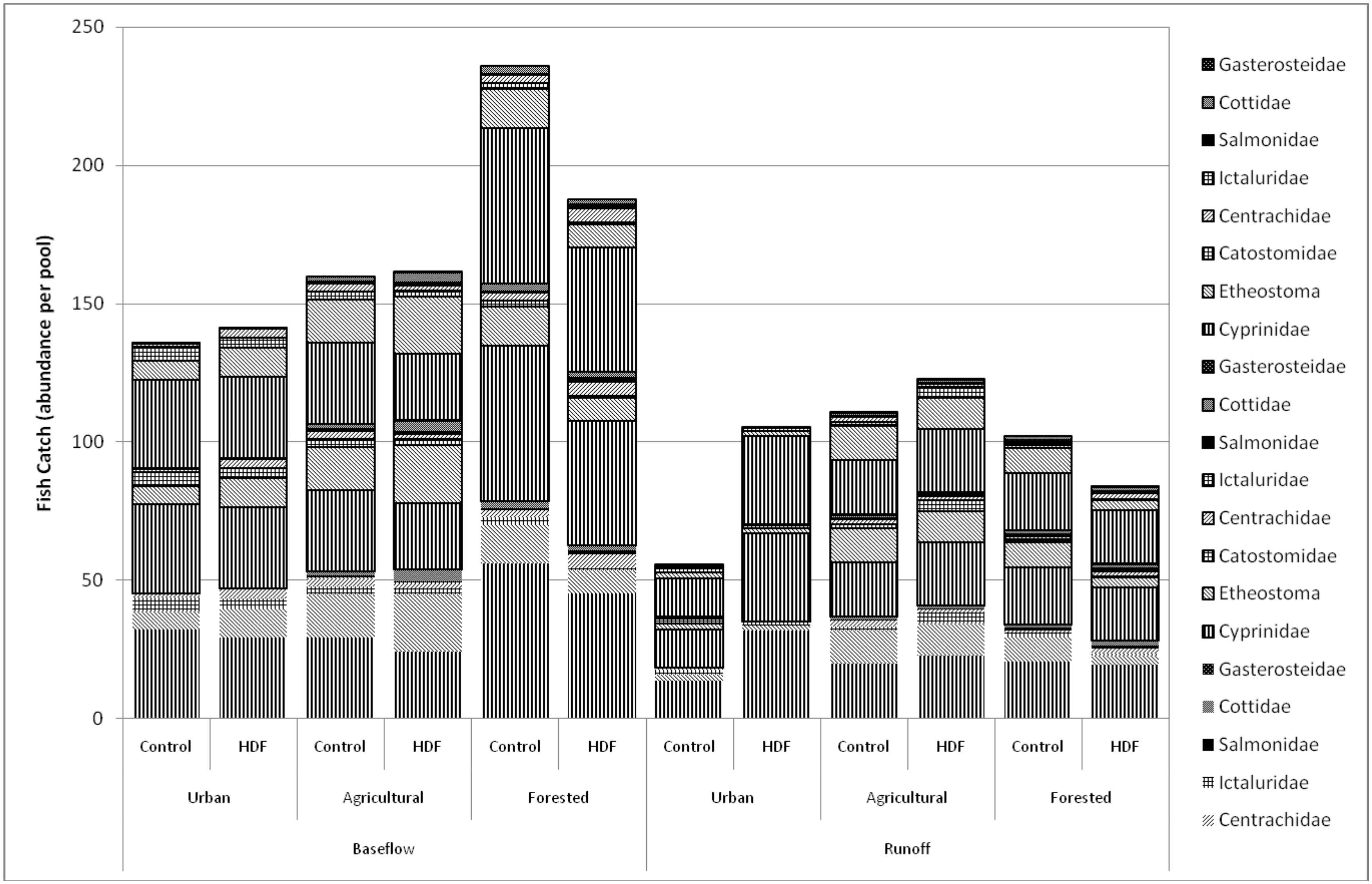

Figure 5. Mean abundance of each fish family caught at each flow condition, land use type and pool type.

Table 4. Drifting invertebrates sampled over the course of the study. Since different numbers of each type of site were sampled, mean catch of each type of invertebrate per site is shown to normalize abundances. Totals are indicated by shading.

		Forested				Agricultural				Urban				
		BF		RO		BF		RO		BF		RO		
		Stream	HDF	Stream	HDF	Stream	HDF	Stream	HDF	Stream	HDF	Stream	HDF	Totals
Aquatic	Nematoda	0.0	0.0	0.1	0.0	0.6	0.0	0.0	0.4	0.1	0.0	2.9	0.0	4.1
	Oligochaeta	0.0	0.0	80.9	1.0	0.2	0.0	7.8	4.0	2.5	0.0	18.0	1.5	115.9
	Gastropoda	2.1	0.0	23.1	1.3	1.4	0.2	1.7	3.1	2.3	0.4	4.1	2.4	42.2
	Copepoda	0.0	1.0	26.9	0.0	0.2	3.0	16.3	1.6	0.0	0.0	1.1	0.1	50.2
	Isopoda	4.0	0.0	64.6	3.3	80.9	0.6	316.4	20.9	2.4	0.7	30.9	3.6	528.3
	Amphipoda	0.6	3.0	5.7	1.0	2.4	0.2	9.4	0.4	3.4	0.0	5.1	3.8	35.1
	Decapoda	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Hydracarina	5.1	0.0	7.1	1.1	3.3	0.6	6.7	3.3	4.4	0.1	3.9	1.6	37.4
	Odonata	0.7	0.0	5.6	0.1	1.4	0.0	3.2	0.0	3.1	0.1	1.1	0.0	15.5
	Plecoptera	13.7	0.0	1.7	0.0	4.9	0.0	71.9	14.2	0.5	0.0	5.6	0.1	112.6
	Ephemeroptera	8.1	0.0	221.3	0.0	20.3	0.0	19.9	0.2	86.9	0.9	37.6	0.5	395.7
	Trichoptera	17.0	0.0	38.3	0.9	25.2	0.4	15.1	1.0	12.6	0.3	17.6	0.6	129.0
	Hemiptera	2.9	1.0	16.7	1.4	3.1	0.8	26.9	13.3	1.9	0.9	1.6	1.0	71.4
	Coleoptera	2.0	0.0	32.9	0.7	3.2	3.4	10.3	4.0	5.0	0.4	5.3	0.6	67.9
	Lepidoptera	0.6	0.0	9.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.7	0.0	11.2
	Diptera	285.7	2.0	1269.7	9.9	143.6	2.6	69.0	9.0	92.3	22.9	141.4	30.8	2078.7
	Egg	0.1	0.0	0.6	3.1	0.0	0.0	0.0	1.7	0.0	0.0	4.4	0.0	10.0
	Other	0.0	0.0	1.1	0.0	0.8	0.4	4.2	0.1	0.1	0.1	0.3	0.0	7.2
	Unknown	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.3	0.0	2.3
Total Aquatic		344.7	7.0	1805.7	23.9	294.9	12.2	580.7	77.7	217.8	27.3	285.9	47.9	3725.5

Table 4 (Continued)

		Forested				Agricultural				Urban				
		BF		RO		BF		RO		BF		RO		
		Stream	HDF	Stream	HDF	Stream	HDF	Stream	HDF	Stream	HDF	Stream	HDF	Totals
Terrestrial	Oligochaeta	0.0	0.0	18.3	1.4	0.0	0.0	0.2	2.7	0.6	0.0	0.4	0.0	23.7
	Gastropoda	0.9	0.0	0.1	0.0	0.0	0.0	0.9	10.0	0.3	0.3	0.3	0.0	12.7
	Isopoda	0.0	0.0	2.4	0.1	0.0	0.2	0.0	3.1	0.0	3.7	0.9	0.4	10.8
	Diplopoda	0.1	0.0	0.3	4.6	0.0	0.4	0.6	1.0	0.8	0.7	2.0	0.6	11.0
	Chilopoda	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.0	0.3	0.4	1.2
	Arachnida	5.9	1.0	51.0	3.0	8.8	1.4	6.8	4.8	8.1	5.5	14.0	9.3	119.4
	Collembola	3.9	1.0	25.6	1.0	2.2	3.8	2.1	22.4	9.8	2.1	7.1	16.8	97.8
	Psocoptera	14.1	0.0	13.9	0.9	5.1	0.2	2.0	1.7	15.4	1.4	9.1	3.5	67.3
	Hemiptera	10.4	0.0	7.0	0.6	7.1	0.2	0.8	0.4	6.9	1.1	13.6	0.5	48.6
	Homoptera	6.0	0.0	51.1	1.1	10.7	3.0	10.4	4.9	27.3	0.7	28.1	16.6	160.0
	Coleoptera	7.9	0.0	9.3	1.0	3.1	0.4	3.4	2.2	6.6	0.0	5.9	3.9	43.7
	Lepidoptera	1.7	0.0	0.7	0.4	1.4	0.0	0.1	0.1	1.1	0.0	7.7	1.0	14.4
	Hymenoptera	87.9	1.0	205.5	11.4	32.3	4.2	7.2	4.3	78.1	10.3	111.7	74.5	628.5
	Thysanoptera	1.1	0.0	0.0	0.0	0.2	0.0	0.0	0.1	1.4	0.7	1.1	0.3	5.0
	Diptera	54.4	1.0	61.3	2.0	24.6	4.2	11.6	8.1	117.3	7.7	85.7	25.8	403.6
	Other	6.4	0.0	4.9	0.0	2.0	0.0	0.0	0.6	0.6	0.0	1.9	0.3	16.6
	Unknown	0.0	0.0	1.1	0.1	0.1	0.4	0.1	0.1	0.0	0.1	0.3	0.4	2.8
Total Terrestrial		200.9	4.0	452.4	27.7	97.7	18.4	46.6	66.7	274.0	34.4	290.1	154.0	1666.9
Total Terrestrial + Aquatic		545.6	11.0	2258.1	51.6	392.6	30.6	627.2	144.3	491.8	61.7	576.0	201.9	5392.3
Percentage Terrestrial		37%	36%	20%	54%	25%	60%	7%	46%	56%	56%	50%	76%	31%

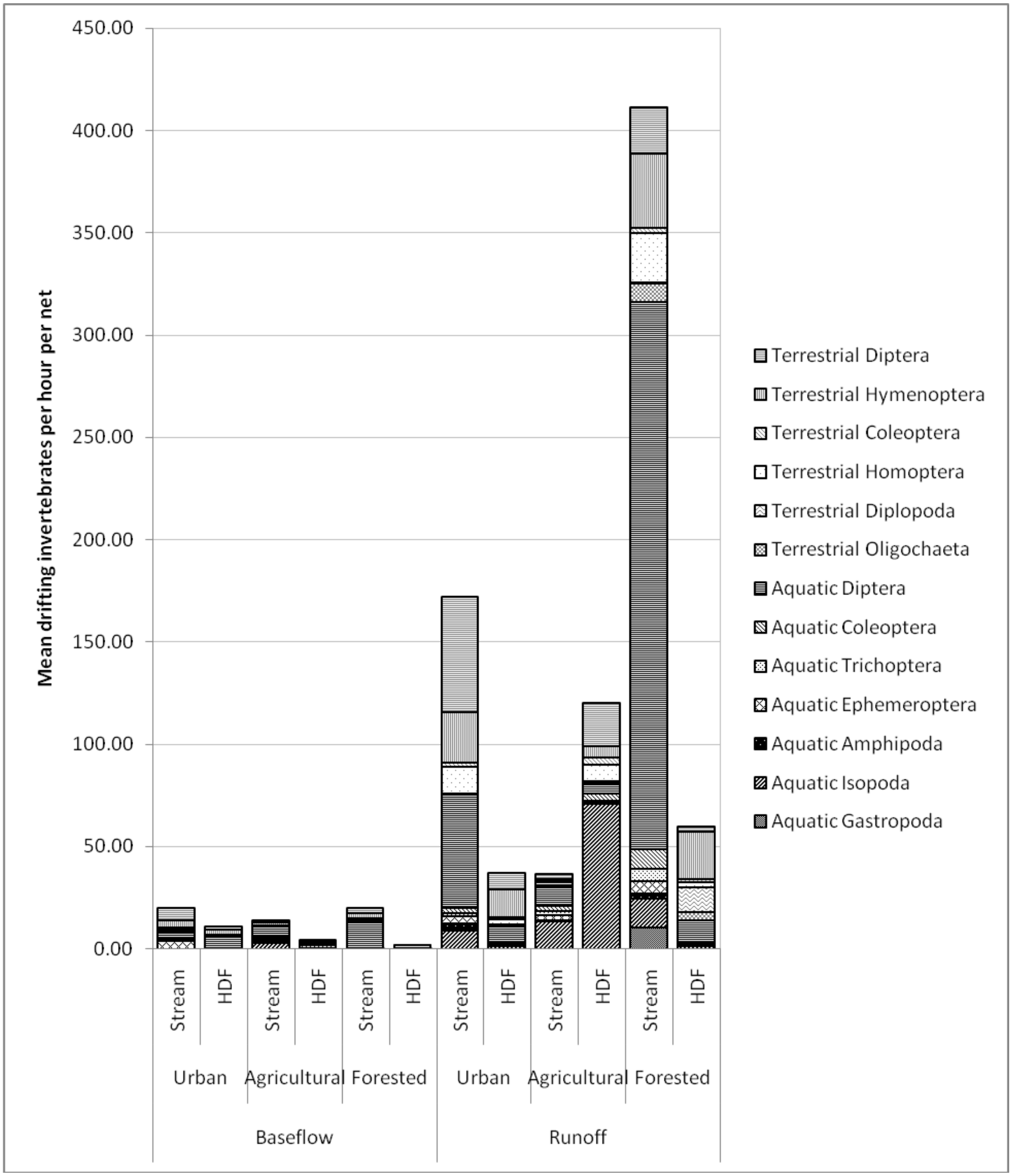

Figure 6. Selected mean drifting invertebrates per hour. Drifting invertebrates in stream have been divided by five to account for the additional nets that were used during collection compared to the invertebrates drifting in the HDF.

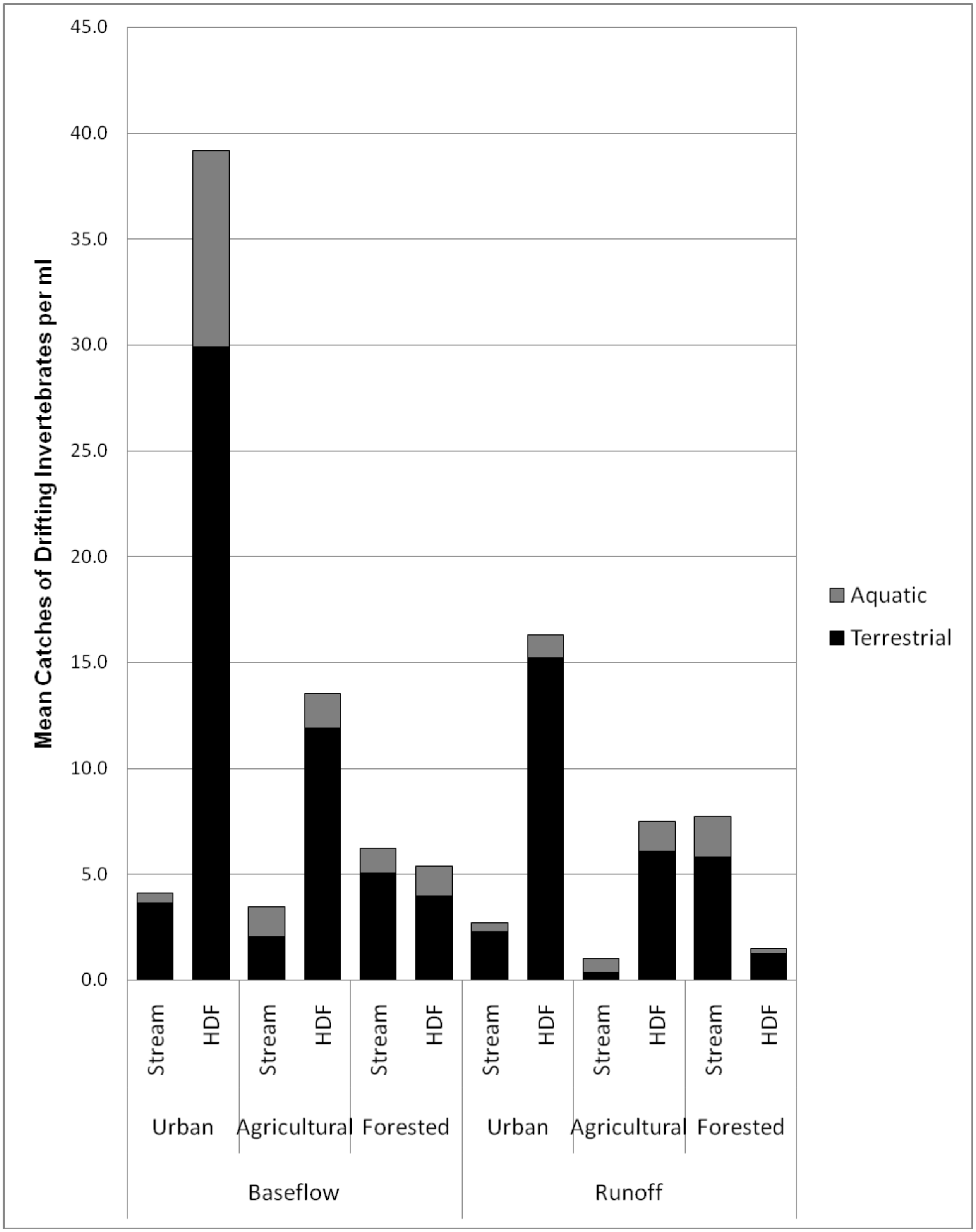

Figure 7. Mean drifting invertebrates per ml of drift material.

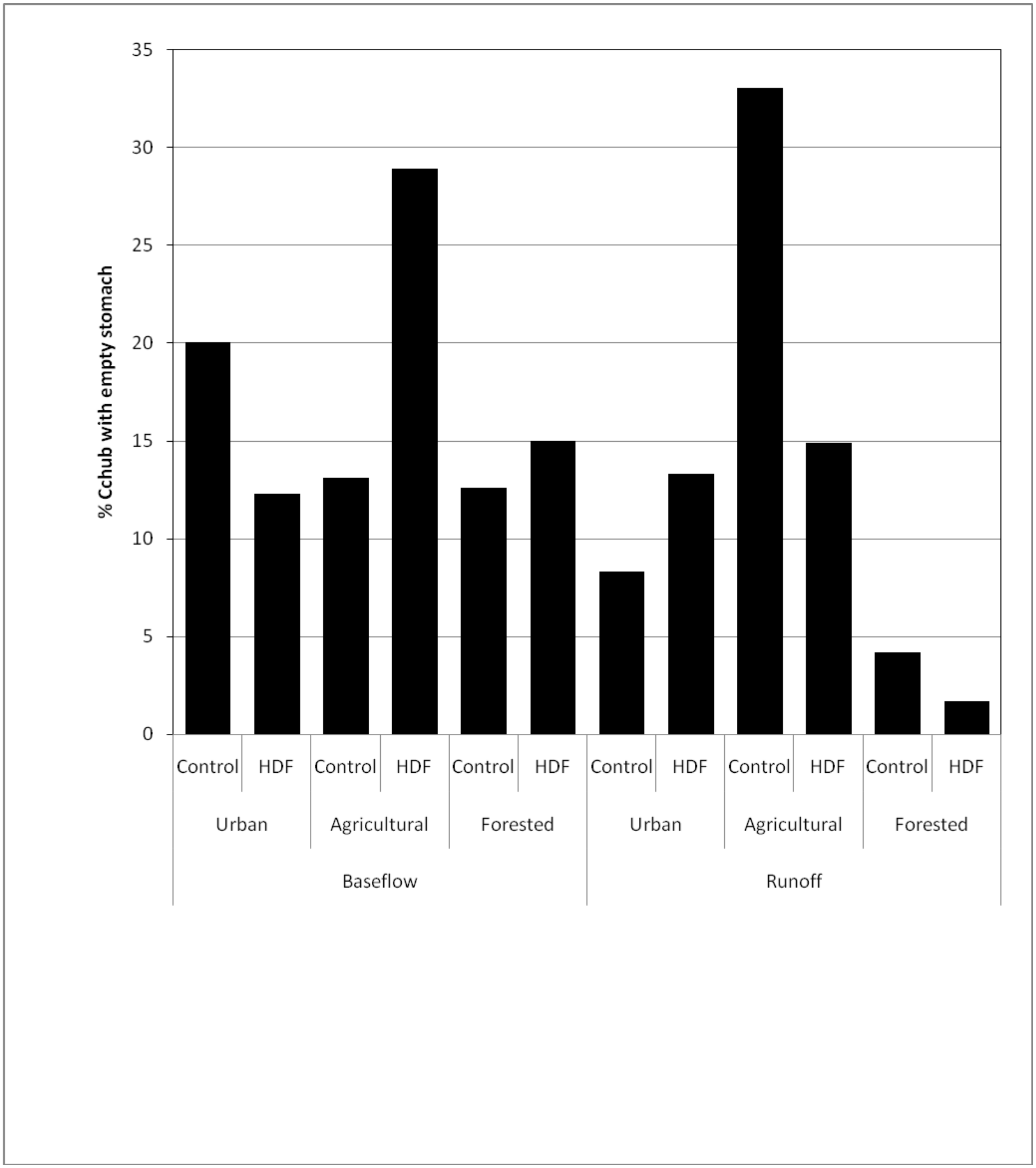

Figure 8. Percentages of creek chub with empty stomachs

Table 5. Mean numbers of each food item from creek chub stomachs. Amounts are expressed in items per fish stomach.

		Forested				Agricultural				Urban					
		BF		RO		BF		RO		BF		RO			
		CTL	HDF	CTL	HDF	CTL	HDF	CTL	HDF	CTL	HDF	CTL	HDF	Total	Percent
Aquatic	Nematoda		0.02			0.03								0.05	0.14%
	Oligochaeta	0.05	0.09	0.09	0.32			0.03		0.02	0.05	0.05	0.02	0.72	2.13%
	Gastropoda	0.12	0.22	0.12	0.22	0.27	0.18	0.12	0.20	0.12	0.12	0.24	0.33	2.25	6.60%
	Copepoda							0.03						0.03	0.09%
	Isopoda		0.07	0.06	0.05	0.03			0.33	0.27	0.10	0.42	0.16	1.49	4.37%
	Amphipoda	0.05	0.07		0.14	0.03	0.16	0.03	0.12	0.16	0.10	0.08	0.09	1.02	2.99%
	Decapoda	0.02	0.02		0.05	0.08	0.04			0.06	0.02	0.05	0.02	0.37	1.08%
	Hydracarina	0.02		0.03	0.03	0.03								0.10	0.29%
	Odonata						0.04						0.02	0.06	0.18%
	Plecoptera	0.10			0.03		0.02		0.14				0.02	0.31	0.91%
	Ephemeroptera	0.05	0.02	0.03		0.03		0.03		0.10	0.21	0.05	0.07	0.59	1.74%
	Trichoptera	0.18	0.04	0.62	0.24	0.11	0.07	0.06	0.08	0.02	0.12	0.08	0.09	1.72	5.06%
	Hemiptera	0.02	0.11	0.24	0.03	0.05	0.02	0.09	0.04	0.04		0.03		0.66	1.93%
	Coleoptera	0.15	0.02	0.06	0.03		0.11	0.03	0.06	0.02	0.02	0.39	0.12	1.01	2.97%
	Lepidoptera	0.03							0.02	0.04				0.09	0.27%
	Diptera	0.47	0.84	0.41	0.57	0.54	0.33	1.06	0.86	1.12	3.64	0.76	0.44	11.04	32.44%
	Unknown	0.22	0.11	0.15	0.16	0.14	0.22	0.24	0.18	0.27	0.14	0.26	0.26	2.35	6.89%
Total Aquatic		1.47	1.64	1.79	1.86	1.32	1.18	1.71	2.04	2.24	4.52	2.42	1.65	23.85	70.10%

Table 5 (Continued)

		Forested				Agricultural				Urban					
		BF		RO		BF		RO		BF		RO			
		CTL	HDF	CTL	HDF	CTL	HDF	CTL	HDF	CTL	HDF	CTL	HDF	Total	Percent
Terrestrial	Oligochaeta	0.08	0.02	0.47	0.41	0.03	0.02	0.15	0.29	0.08	0.14	0.37	1.23	3.28	9.64%
	Gastropoda			0.03	0.05				0.02				0.05	0.15	0.44%
	Isopoda												0.02	0.02	0.07%
	Diplopoda	0.07		0.15	0.03		0.04		0.02	0.02	0.21	0.37	0.33	1.23	3.60%
	Chilopoda			0.03			0.02	0.03						0.08	0.23%
	Arachnida	0.03	0.04	0.06		0.03	0.04	0.03		0.04	0.12	0.06		0.44	1.31%
	Collembola	0.02					0.02							0.03	0.10%
	Psocoptera											0.03		0.03	0.08%
	Hemiptera			0.03										0.03	0.09%
	Homoptera		0.02			0.27		0.03	0.04	0.02	0.02		0.05	0.45	1.33%
	Coleoptera	0.03	0.04	0.03	0.03		0.07				0.07	0.11	0.05	0.43	1.26%
	Lepidoptera					0.14			0.02					0.16	0.47%
	Hymenoptera	0.55	0.18	0.09	0.16	0.43	0.07		0.02	0.18	0.12	0.18	0.35	2.33	6.85%
	Thysanoptera									0.02				0.02	0.06%
	Diptera	0.03	0.09	0.09		0.22	0.02	0.06	0.02	0.33	0.14	0.03	0.12	1.14	3.36%
	Unknown		0.02	0.03		0.03		0.03	0.02	0.04	0.10	0.08		0.34	1.00%
Total Terrestrial		0.82	0.42	1.00	0.68	1.14	0.29	0.32	0.45	0.73	0.93	1.22	2.19	10.17	29.90%
Total Aquatic + Terr.		2.28	2.06	2.79	2.54	2.46	1.47	2.03	2.49	2.96	5.45	3.64	3.84	34.03	
Percent Terrestrial		36%	20%	36%	27%	46%	20%	16%	18%	25%	17%	33%	57%	29%	

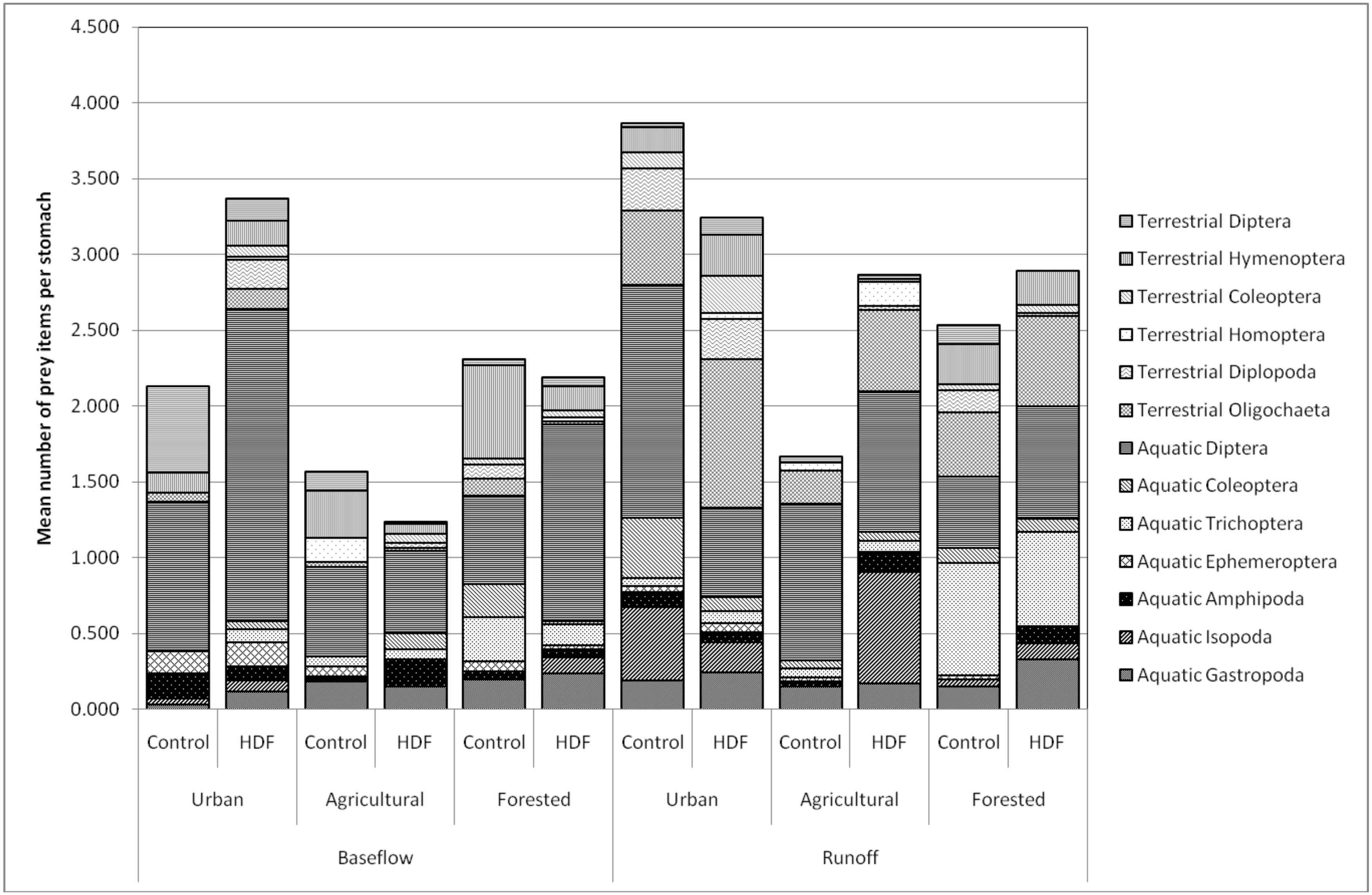

Figure 9. Mean gut contents of creek chub (empty stomachs excluded)

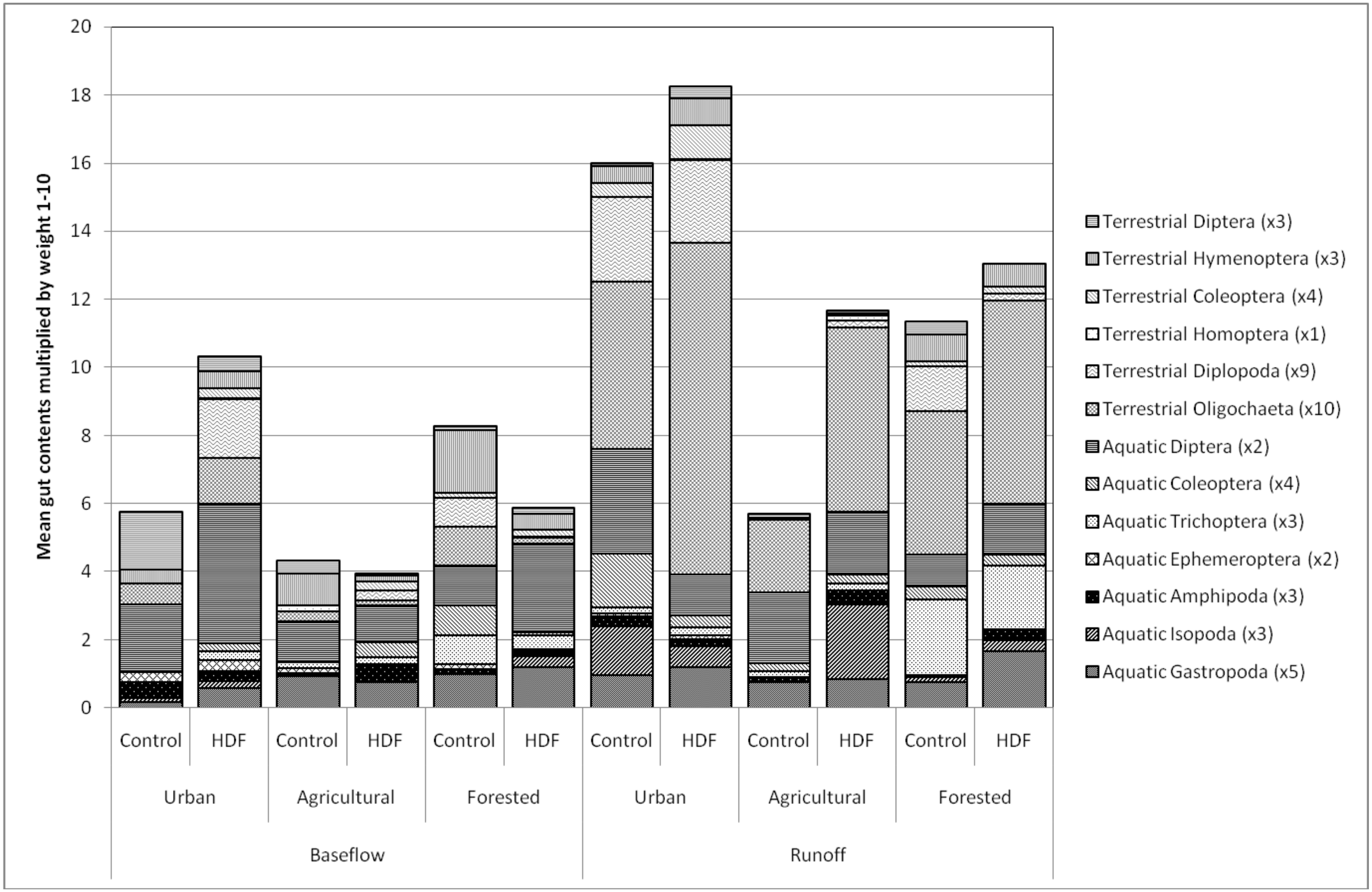

Figure 10. Estimated volumes of gut contents of creek chub. Volumes were based primarily on the relative sizes of prey items, as shown in the legend.

5.0 Discussion

5.1 Fish

As expected, fish abundance was highest in forested sites and lowest in urban sites. Stair et. al. (1984) found that fish population density in disturbed streams was only one-third that of undisturbed streams. This is likely due in large part to a lack of suitable habitat, as urban sites tended to be hardened with lower quality riparian zones. Smiley et. al. (2011) found that suitable habitat conditions are potentially the most important factor in determining whether a species of fish will live in a stream. In addition to habitat requirements, it is also probable that urban sites had relatively poorer water quality than the agricultural or forested sites because of pollutants originating from roads and built areas (Walsh et. al. 2005). Agricultural catchments might likewise have poor water quality, due to nutrient loading from nearby active farms and possible contamination from herbicides and insecticides; these effects are particularly harmful to aquatic invertebrates (Kattwinkel et.al. 2011), but are also harmful to fish (Turner, 2003). Forested sites used in my study were not situated in pristine forested catchments, but the magnitude of road runoff and other land-use impacts should have been much less severe than in the urban and agricultural catchments.

More fish were caught in both types of pool (HDF and control) during base flow than runoff conditions. This is probably almost entirely an effect of turbidity on sampling – at runoff conditions the stream was much more turbid, making seeing and netting fish more challenging. Every effort was made to catch as many fish as possible every time a pool was fished, however with the method of single-pass electro-fishing in turbid waters, it is reasonable to expect that more fish would be missed than when the water is clear.

Fish have been known to migrate in response to seasonal availability of food sources (Anglemeiser and Karr, 1983); therefore it was hypothesized that if food input from HDFs to the main stream were substantial, a temporary migration of fish into the HDF pools might result. This was not found to occur in our study as there were no significant differences in catches between the control pool and the HDF pool at base flow or runoff conditions. It is possible that dominant fish set up territories in these areas, preventing other fish from using them. Additionally, it is possible that, since HDFs are common in these basins, close proximity to a particular HDF for access to food is unnecessary during runoff conditions, as a surfeit of prey is continuously available throughout the stream during runoff events. A tagging study might resolve these questions.

Cyprinidae are very abundant in the greater Toronto area so were expected to be, and were, the commonest fish caught. Urbanization leads to lower diversity of fish, reduced abundance of sensitive species, and numerical dominance of disturbance-tolerant species (Walsh et. al., 2005). The diversity of fish in my samples was also greatest from forested sites, intermediate in agricultural sites and lowest in urban sites. As expected, salmonids were most numerous in forested sites, least in urban sites. It was not expected that *Etheostoma spp.* would be so much more abundant in agricultural sites but this is probably a result of stream substrate: agricultural sites tended to have pebbled substrates while forested sites tended to have rock covered bottoms and urban sites were often hardened. *Semotilus atromaculatus* caught in areas with urban HDFs were found to have a greater coefficient of condition then those caught in areas with forested HDFs. This could be a result of less competition for food resources, as more sensitive fish species are excluded due to other factors such as a lack of suitable habitat or chemical pollutants in the water originating from nearby urban areas.

5.2 Invertebrates in the Stream Drift

Drift in the main streams and the HDFs at runoff contained large quantities of both aquatic and terrestrial invertebrates. Previous studies have reported great numbers of drifting terrestrial invertebrates in perennial headwaters (Cloe and Garmin, 1996; Wipfli, 2007) and HDFs (Wipfli and Gregovich, 2002; Idika, 2010). Terrestrial invertebrates are also commonly found drifting in main streams, and follow predictable seasonal trends in abundance (Cloe and Garmin, 1996; Angermeiser and Karr, 1983).

The numerically dominant groups of drifting invertebrates observed in HDFs were Amphipoda (aquatic) and Hymenoptera (terrestrial), Diptera (terrestrial and aquatic) and Collembola (terrestrial). Similar assemblages have previously been described in HDFs in the study area by Idika (2010). Invertebrates found drifting in main streams were also typical of the study region (Mackie, 1999).

In addition to large quantities of drifting invertebrates, HDFs supply substantial amounts of largely allochthonous detritus (leaves, woody material, etc.) to main streams. Wallace et. al. (1997) found that these detrital inputs are important for aquatic invertebrates living in the main stream: when riparian leaf litter was experimentally prevented from entering streams, the local aquatic invertebrate community was changed, suggesting that even seemingly small changes in nutrient availability can make noticeable changes to stream communities. Similarly, Smith and Lamp (2008) observed dramatic reductions in diversity and taxonomic richness of the benthic communities of perennial streams subjected to urbanization. It doesn't appear that any particular invertebrate groups have been excluded from streams with altered catchments in my study, as all groups were found in proximity to all site types, and in both the HDF and the main stream. However, invertebrates were identified only to the level of Order or Family.

In all cases, the numbers of invertebrates drifting per hour were higher during runoff than at base flow. This was expected not only because of the greater volumes of water, but also because the increased water velocity will cause more aquatic invertebrates to be dislodged from the stream bed and the rainfall and flow through HDFs will wash terrestrial invertebrates into the drift. In most cases, the stream drift transported a greater number of invertebrates than the HDF drift per hour but this may reflect the larger volume of water that was flowing in streams compared to HDFs. Unfortunately water volume was not measured in this study, because conditions were found to be extremely transient in the HDFs: occasionally a turbulent rush of water reduced to a mere trickle in a matter of minutes, and vice versa. In consequence, it was impossible to make enough measurements to estimate total discharges.

Drift densities were similar in all stream types during base flow in the main streams, but the drift in the HDFs at base flow was lower at forested sites than at urban sites. This is likely due to the greater velocity and greater water volume in most urban HDFs at base flow. All but one forested HDF was dry at base flow. The one forested site that was flowing at base flow exported 0.27 ml/hr of material. The average volume transported by agricultural sites at base flow conditions was only slightly higher, at 0.29 ml/hr and the average volume transported by urban sites at base flow conditions was 0.50ml/hr, almost double the volume transported by the forested HDF.

During runoff conditions, forested main streams transported the largest numbers of invertebrates per hour. Aquatic Diptera made up most of the drifting invertebrates at these sites, dominated by Chironomidae but including a diverse assemblage of other orders. The abundance of aquatic invertebrates in forested streams is typical, and the diverse assemblage indicates, as expected, that the conditions in these streams support a wide variety of life forms. Agricultural main streams at runoff yielded the fewest drifting invertebrates, and this could be due in part to the use of pesticides on farmland, which are known to be detrimental to both aquatic and terrestrial arthropods (Kattwinkel et. al., 2011). Urban main streams contained more invertebrates than agricultural main streams, but fewer than forested main streams. This intermediate position is probably caused by having less pressure from insecticides in the stream than the agricultural sites, while having less suitable and varied habitat conditions for invertebrates than the forested sites, due to the effects of channel hardening and stream alterations that were common at urban sites.

Agricultural HDFs exported the most invertebrates during runoff conditions and urban sites the fewest. Most of the invertebrates transported by agricultural HDFs at runoff were aquatic Isopoda, an Order which was present in much smaller numbers in both the urban and the forested HDFs. It is unclear why Isopoda were so abundant in agricultural HDFs at runoff, but this group may thrive in isolated pools during dry weather. The most prevalent invertebrates in forested HDF drift at runoff were Hymenoptera, most of which were Formicidae (ants). This result was expected as ants are very common in forests of the study area, and commonly inhabit valleys and HDF channels. Formicidae are also common in urban areas, and urban HDFs at runoff exported mostly aquatic Diptera and Formicidae; the presence of aquatic Diptera indicates that the channels in this study remain wet between runoff events.

Drift densities in water flowing from urban and agricultural HDFs were greater than stream drift sampled at the same time. This was especially apparent at base flow, when a very small volume of water was slowly flowing from the HDF, but contained relatively more invertebrates than the stream drift. This is probably due in part to the fact that the HDFs were fishless, so any invertebrates in the drift were not eaten until they entered the main stream. Conversely, forested HDFs exported drift that was equally or less rich than the main stream, but drift in the forested main streams was consistently richer in species than main streams in either of the other catchment types.

The runoff from urban sites is generally flashy with higher velocity and more turbulent flow (Walsh et. al., 2005), while the runoff from forested sites generally has slower velocity. More invertebrates would be expected to be knocked off of vegetation or otherwise swept downstream at higher flow velocities. In forested sites, with less flashy responses to rain events, invertebrates may be able to resist being swept away by the current in the HDF. It would appear that drift from forested HDFs is actually contributing comparatively fewer invertebrates to the main stream than the other catchment types, and this suggests that impacted HDFs may actually play a larger role in the importation of invertebrates to main streams than unimpacted HDFs.

5.3 Creek Chub Stomach Contents

More creek chub in forested and urban streams appeared to be actively feeding during runoff events, as evidenced by the lower proportions of empty stomachs. This is probably due to the large quantity of available prey in the drift, as discussed in the previous section. Creek chub in forested sites at runoff had very few empty stomachs when more invertebrates were drifting. It is unknown why more creek chub in agricultural control pools had empty stomachs during runoff conditions. Stair et. al. (1984) also found that fish from disturbed areas have a greater proportion of empty stomachs than fish from undisturbed areas.

Aquatic Diptera were the prey most commonly consumed by creek chub in the study, consistent with their relative availability in the main stream drift. In contrast, creek chub appeared to have a strong preference for terrestrial Oligochaeta (earthworms) which were not abundant in the stream or the HDF drift. The same applies to Diplopoda (millipedes). These two food choices may indicate that creek chub preferentially consume food items that are long and worm-like, or at least very large. Other commonly consumed prey items (Hymenoptera, Gastropoda, Trichoptera, Isopoda, and terrestrial Diptera) were all found to be common in the stream drift therefore it was not surprising to find them in the stomach contents as creek chub are known to be generalists, allowing them to switch prey items readily to eat whatever is available (Magnan and Fitzgerald, 1984; Garman and Moring, 1993).

The ratio of terrestrial : aquatic invertebrates consumed by creek chub did not change with different flow conditions or pool type (associated with an HDF vs. control). Therefore, even though in some cases more terrestrial invertebrates are imported during runoff, creek chub do not preferentially consume them. This is contrary to the findings of Stair et. al. (1984), who found that fish from disturbed areas have a greater dependence on terrestrial food sources.

It is interesting to note that aquatic Isopoda were not eaten by fish in the agricultural control pools during runoff, but made a large contribution to the diet of fish in HDF pools. This reflects availability, as isopods were very abundant in the HDF drift but almost absent from the main stream drift at the time that these fish were captured. This is an indication that fish in the HDF pool have access to food during times of runoff which is not necessarily available to the fish in other areas of the stream.

When prey items consumed are weighted to account for their relative sizes, the selection for larger prey items becomes more apparent. Creek chub seem to select for large earthworms and millipedes when available (during runoff). This selection is probably instinctual, as these larger prey items offer more nutrition per feeding strike (Cummins and Wuycheck, 1971). Larger prey could also be easier for the creek chub to see.

Garmin and Moring (1993) examined the effects of changes in prey availability after clear-cut logging adjacent to rivers in Maine. After logging, the annual production of the comparatively specialist blacknose dace significantly declined and the annual production of the more generalist creek chub significantly increased. The authors suggest that these changes were a direct result of a reduction in benthic invertebrate abundance (the preferred prey of blacknose dace), with a simultaneous increase in the amount of terrestrial arthropod prey items (which became the predominant prey choice of creek chub). For generalist feeders, such as creek chub, changes in prey type do not seem to negatively affect their population; on the contrary, the effects of urbanization might actually benefit creek chub populations by limiting other, more specialized stream fishes. This could help to explain why creek chub were abundant in all site types in our study, but also why more sensitive fish, such as salmonids, were not often found in urban sites, and the specialist feeders, such as darters, were mainly found only in agricultural sites.

Our study did not examine seasonal shifts in drifting prey availability, however several other studies (Cloe and Garmin, 1996; Nakano and Murakami, 2001; Kawaguchi and Nakano, 2001) have shown that seasonality is an important aspect dictating the terrestrial and aquatic components of stream drift. Cloe and Garmin (1996) found that large numbers of terrestrial invertebrates are transported by headwater streams (and riparian corridors). They found that inputs were greatest in the summer months, which is also the time at which there is typically low aquatic invertebrate availability to stream fish. This was reflected when they examined the stomach contents of *Lepomis auritus* and *Lepomis macrochirus*, which had higher proportions of terrestrial prey items in their stomach contents in the summer, compared to other seasons. These findings indicate that terrestrial and aquatic arthropods may be equally important to fish. Kawaguchi and Nakano (2001) examined seasonality of prey in relation to consumption by resident salmonids. They found that terrestrial prey items contributed 68-77% to diets in the summer, contrasting with only 1% in winter. These consumption rates correlated with the availability of terrestrial invertebrates drifting in the stream.

Kawaguchi and Nakano (2001) also observed that terrestrial invertebrates tend to enter the drift during the daytime, when fish are actively foraging. This contrasts with aquatic prey items, more of which drift at night, outside the normal foraging time for many fishes. The interdependence and interconnectivity of landscape scale processes was further demonstrated by Nakano and Murakami (2001) in Japanese streams. They found that subsidies to the ecosystem go both ways: aquatic to terrestrial and terrestrial to aquatic. Inputs of terrestrial invertebrates to streams were greater in the summertime when aquatic invertebrates are at their lowest densities. These terrestrially derived food sources were eaten by fishes and accounted for 44% of their annual energy budget. Alternatively, when densities of terrestrial invertebrates were low and aquatic invertebrates were high (spring), birds consumed more aquatic invertebrates. Urbanization and other alterations to stream channels might well alter these reciprocal subsidies: Kawaguchi et. al. (2003) found that the experimental exclusion of terrestrial invertebrates from forested streams resulted in a local decrease in salmonid density and a decrease in individual sizes of fishes.

5.4 Recommendations for Future Study

As a result of the nature of the study, the sampling schedule was largely reliant on antecedent precipitation, and likewise on antecedent dry periods. The limitations imposed by relying on natural precipitation; i.e. sampling order, time between sampling at runoff vs. base flow, missing the precise time of peak runoff, etc. introduced a series of variables that could not have been predicted or adequately measured. Ideally, the sampling conditions could be controlled experimentally by adding water to HDFs. However, this preliminary field study has value in describing the conditions and qualities of HDF features. Once the types and quantities of drifting invertebrates from different land-uses in HDFs become more well known from this and other studies, it will be possible to better assess the contribution of different HDF types to stream fish diets.

Our study used a comparative approach between existing catchment types. To strengthen the study, a BACI design could be used, where the same stream is examined before and after disturbance (a land-use change). In order to detect causal linkages between urbanization in headwaters and fish community assemblages, the same stream would need to be monitored before and after urbanization; which would entail a more long-term study of forested streams which are then urbanized, to ascertain the effects that take place and to determine potential causality.

It is apparent that in a pristine, healthy condition removal or alteration of a single headwater drainage feature may not cause any appreciable damage to the downstream ecosystem as the landscape is made up of almost innumerable additional catchments and HDFs. However, if we impose no restrictions on HDF modifications, and they are all altered, it is certain that the main stream will lose biological diversity and hydrological connectivity, and stream and landscape-level health will suffer. By extension, then, there must be a critical density of functional, healthy HDFs feeding into a stream; below which we will see a decline in stream health. The cumulative effects of alterations to HDFs must be evaluated (Gomi et. al., 2002).

5.5 Conclusions

HDFs in all land uses studied were found to transport substantial amounts of allochthonous material to main, fish-bearing streams, including numerous invertebrates which are a potential prey for fish. These inputs are greater during runoff events. Fish in streams representing all land-use types consume prey items that might have originated in HDFs. Piped urban streams in this study usually did not stop flowing completely between runoff events; therefore they continuously exported material to main streams. Urban HDFs are flashier than forested or agricultural HDFs, and this probably explains why they export more terrestrial invertebrates to main streams than forested or agricultural HDFs. Fish in urban streams may have a greater dependence on the inputs from HDFs than fish in forested streams, because the benthic macroinvertebrate community is impaired and supports fewer autochthonous food sources than more productive streams in forested areas.

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