A preliminary investigation into the ecological significance of headwater drainage features in Southern Ontario

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

Within Southern Ontario urban development is rapidly devouring headwater systems, and this can have significant repercussions to the health of entire river networks. The ecological contributions of headwaters to downstream aquatic systems are poorly understood. The relationships between exported organic material (invertebrates, organic detritus) and land use were examined from 16 headwater systems (13 ephemeral channels, 3 intermittent channels) located in and around the Toronto Region. Drift traps, precipitation and crest stage gauges were installed at each location to capture exported materials, measure rainfall and estimate peak flow, respectively. Samples were collected during runoff events, snow melt or precipitation from March through November 2008. The amount of snow melt or precipitation necessary to trigger surface runoff was found to be highly dependent on land use and antecedent conditions.

Invertebrates of aquatic and terrestrial origin were collected, with aquatic animals comprising 43% and 87% of the total from ephemeral and intermittent headwaters, respectively. The mean export of organic materials was 963 invertebrates event^{-1} (0.65 g) and 32.0 g of plant matter event^{-1}. The amount of materials transported was highly variable among samples (1 – 13,751 invertebrates event^{-1}).

Within ephemeral channels, Annelida, Insecta and Chironomidae were the most numerous aquatic taxa (representing 40%, 24% and 23% of the total number of invertebrates transported event^{-1}, respectively), while Mollusca, Arachnida and Insecta were the most numerous terrestrial taxa (representing 35%, 21% and 16% of the total number of invertebrates transported event^{-1}, respectively). Earthworms contributed 64% of the total invertebrate volume collected event^{-1}.

Chironomidae, Crustacea and Trichoptera were the most numerous aquatic taxa collected from intermittent channels (representing 55%, 27% and 8% of the total number of invertebrates transported event^{-1}, respectively), whereas Arachnida, Insecta, and Collembola were the most numerous terrestrial taxa (representing 52%, 19% and 13% of the total number of invertebrates transported event^{-1}, respectively). Trichoptera accounted for 59% of the total aquatic invertebrate volume collected event^{-1}.

Preliminary results suggest that the ecological contributions of headwaters to downstream systems are considerable and their importance should not be overlooked.

Acknowledgments

First and foremost I would like to thank my wife and best friend, Andrea Idika for her continual and unconditional love, support and patience throughout my studies, even on the bad days. An equally special thank you to my two children, Tristan and Maya Idika, always ready to welcome me home with a big smile on their faces. I would also like to thank my mother, Jocelyne Larochelle for her support and patience.

I would also like to thank Laura Del Guidice of the Toronto and Regional Conservation Authority for providing the funding to make this project possible. I am grateful for the support of all the field and lab technicians who helped collect and process hundreds of hours of samples. Notably I would like to give thanks to Julie Hennigar and Ante Troglic for all long days in the field and hard work in the lab.

There is no way I can forget to give a very big thank you to everyone in the Barton lab for all their help, support and laughter throughout my studies. It certainly helps to be surrounded with great people that make day to day work enjoyable. Special shout out to Tyrell for countless hours of (often) stimulating philosophical debates, no doubt he will read this thesis through electronic download once he is connected to the one machine.

Last, and certainly not least, I want to thank my supervisor and mentor, David Barton. Under Dave's supervision I have learned a great deal about scientific research and aquatic ecology. Dave's approach to supervision allowed me to find my own path and make my own mistakes, but he was always there to point me back into the right direction. Working in Dave's lab over the past few years has been a very pleasant and rewarding experience of which I will always be truly grateful for.

Dedication

I dedicate this thesis to my son, Tristan Idika, who has taught me that no matter what challenges or obstacles are brought upon us, we should always approach each one with a smile.

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1.0 Introduction

Since 2007, for the first time in history the majority of humans are now living in urban areas (McDonald 2008). Urbanization is a global phenomenon that is transforming our landscapes into densely populated cities at a rate of approximately 230 km^2 a week (McDonald 2008). The Greater Toronto Region (GTA), located in Ontario, Canada, is one of the fastest growing metropolitan areas in North America (Conway and Hackworth, 2007). Such growth comes at the expense of previously unaltered land such as forests and grasslands. Contained within these lands are a series of complex inter-connected ecological pathways which maintain and self regulate ecosystem health. Urbanization is encroaching upon these areas and at particular risk are aquatic ecosystems.

Headwaters, defined as the uppermost area where a stream or river originates and which collect and channel water downgrade, are at high risk of being destroyed by urbanization, due in part to a lack of scientific knowledge pertaining to their ecological functions and significance. In recent years, however, their importance (especially in their potential to subsidize fish-bearing systems) is beginning to be realized and it is gradually becoming clear that altering headwaters has the potential to significantly alter the health of entire river networks (Meyer and Wallace, 2001; Gomi et al., 2002; Wipfli et al., 2007; Meyer et al., 2007).

For example, Wipfli and Gregovish (2002) illustrated that headwaters can transport large amounts of invertebrates to downstream fish habitats. Gomi et al. (2002) estimated that the spatial extent of headwaters within an entire catchment area is between 70%-80%. Because of their spatial extent, and in combination with their ability to supply food (invertebrates) to downstream fish-bearing habitats, headwaters play an important role throughout an entire river ecosystem.

Through what is known as hydrological connectivity, which describes the transport of matter, energy and organisms between systems within the hydrologic cycle (Freeman et al., 2007; Wipfli et al., 2007), headwaters are linked interdependently with downstream waters, facilitating the exchange of important biological supplies such as food, nutrients and, of course, water.

Previous headwater studies (eg. Wipfli and Gregovich, 2002; Alexander et al., 2007) have demonstrated hydrological connectivity; however, the headwaters studied were perennial streams with climate and land uses vastly different than those found in Southern Ontario. With the rapid rate of urbanization in the GTA, continual pressure is being applied on headwaters and the lack of scientific understanding of these systems and their functions has hampered the development of best management practices (TRCA, 2007).

It has been known that urbanization causes a reduction in ground surface permeability which results in an increase in surface runoff and a decrease in groundwater recharge, causing massive alterations to the hydrology of a system (Walsh et al., 2005; Bernhart and Palmer, 2007). These alterations may have significant impacts on downstream fish-bearing systems, including a decrease in invertebrate, nutrient, and allochthonous inputs.

The purpose of my research is to identify and quantify the organic materials and nutrients transported during runoff events from ephemeral and intermittent headwaters. Such research should contribute to developing and implementing better headwater management practices and remediation.

The definition of a headwater varies considerably through the literature (Clarke et al., 2007). For the purpose of this study, a headwater will be considered ephemeral, intermittent or permanent first-order stream. However, in all cases the channel must be a non fish-bearing system. Furthermore, the surrounding area and vegetation are just as important as the headwater channel itself. Therefore, throughout this thesis I will refer to a headwater as a headwater drainage feature (HDF), encompassing both the channel and the surrounding area. Ephemeral channels flow unpredictably after rain and runoff events and dry out quickly following flooding; intermittent channels alternate between wet and dry periods with flooding persisting for months or years (Williams 2006).

2.0 Research objectives

1. Determine the ecological contributions provided by headwaters to downstream fish-bearing systems by examining the transport of invertebrates, nutrients and plant matter.

2. Determine how differences in catchment area, land use and vegetative cover affect the ecological contributions (determined in 1) of HDFs.

3. Quantify any temporal variations in the transport of the ecological contributions.

3.0 Methods

3.1 Study sites

Southern Ontario has a temperate climate (9.2°C mean annual temperature) with warm summers, cold winters and moderate precipitation. Annual rainfall averages 710 mm; average annual snowfall is 133 cm (Environment Canada, 2009). The Oak Ridges Moraine, formed by the melting of the Laurentide ice sheet and stretching for 160 km west to east north of Lake Ontario, is a dominant feature of the Southern Ontario landscape in size and ecological importance (Figure 1). The moraine is approximately 190,000 hectares and varies in width from 3 to 24 km (Whitelaw et al., 2008). Comprising heavy deposits of sand and gravel, the moraine facilitates rapid groundwater recharge which serves as a primary water source for approximately 250,000 people (Gilbert et al., 2009). Half of the moraine is used for agriculture or rural development while approximately 28% of the moraine is covered by deciduous and coniferous forests.

A total of 16 HDFs were selected which extend geographically across the Halton, Peel, York and Durham Region Municipalities (Figure 1), 10 draining forested catchments and 6 draining agricultural fields. HDFs were selected by GIS analysis by the Toronto and Regional Conservation Authority (TRCA). Study sites were categorized by land use (forested or agricultural), channel type (ephemeral or intermittent), vegetation cover, slope and catchment area (Table 1). Surficial soils were predominantly clay and silt. Of the 16 HDFs, 13 were ephemeral and 3 were intermittent.

The widths of the drainage channels were small, varying between approximately 30 cm to 100 cm. The dominant vegetation covering forested HDF was maple, oak and various deciduous trees mixed with some coniferous trees; agricultural HDFs drained corn, wheat, soy bean and hay fields.

3.2 Equipment

Invertebrates, coarse sediments and organic matter were collected by a 500 μm Nitex net bag attached by drawstring to an aluminum frame 20 cm in width, 30 cm in height and 7 cm in depth (Figure 2). Two rebar posts 60 cm in length were driven into the middle of the channel bed to

Table 1 Physical characteristics and locations of the 16 headwater drainage features sampled in 2008.

Site ID	Catchment Area (ha)	Distance to Road (m)	Slope (degrees)	Land Use	Northing	Easting	Channel Definition	Vegetation
Ephemeral channels								
HW_ET 01	25	180	9.66	Forested	4843276.0	597824	Moderate	Deciduous
HW_HUM 1	27	174	7.31	Forested	4863466.2	603975	Well	Deciduous
HW_HUM 3	14	45	7.64	Forested	4863717.0	604311	Poor	Deciduous
HW_HUM 6	8	226	10.22	Forested	4860243.0	598800	Well	Maple
HW_HUM 11	11	237	4.39	Forested	4854215.7	614045	Well	Maple
HW_HUM 12	6	198	4.41	Forested	4854182.8	614010	Well	Maple
HW_OAK 2	6	390	1.92	Forested	4810815.5	598663	Moderate	Deciduous
HW_OAK 3	31	137	2.13	Forested	4811077.6	599695	Well	Deciduous
HW_OAK 4	32	186	2.57	Forested	4811136.8	599681	Well	Deciduous
HW_HUM 4	137	61	3.72	Agricultural	4858987.0	597863	Well	Grass & Clover
HW_HUM 7	137	8	1.62	Agricultural	4854359.0	604484	Well	Soy bean
HW_HUM 8	12	8	1.65	Agricultural	4854596.0	604204	Well	Wheat
HW_ROU 3	27	26	6.48	Agricultural	4869698.0	631725	Well	Corn
Intermittent channels								
HW_DUF 6	88	8	10.55	Forested	4873499.0	652397	Poor	Deciduous
HW_ROU 4	19	10	2.54	Agricultural	4869369.0	631490	Well	Corn
HW_ROU 5	17	15	4.15	Agricultural	4867133.0	631904	Well	Corn

Figure 1 Location of 16 field sites selected in the Halton, Peel, York and Durham Regional Municipalities in Southern Ontario. The Oak Ridges Moraine, covering approximately 190,000 hectares of land, is located to the north and northwest of the Region of Toronto.

Figure 2 Drift trap (20 cm by 30 cm by 7 cm) installation at KET 1 (site not used in this thesis because channel was permanent). Rebar post attached to each side of the aluminum drift trap secure it to the channel bed and support the 100 cm long, clear 2” PVC pipe used to record maximum water level.

anchor each sampler. A 500 µm mesh size was chosen to avoid excess build up of sediment within the drift traps.

A crest stage gauge, consisting of a 2” clear PVC pipe approximately 100 cm in height, was attached vertically to one of the rebar posts and filled with non-hypoallergenic baby powder (non-hypoallergenic baby powder sticks to the PVC readily). Between five and seven 6 mm diameter holes were drilled in the bottom of each pipe to facilitate water entry.

One commercial rain gauge was installed at each site by inserting a plastic holder in an open area (no tree or other high vegetative cover within 15 m) approximately 10 cm into the ground and resting the gauge in the holder. No rain gauge was installed at a site that was within 100 m of another installed rain gauge; this assumes is that precipitation falling in a 100 m^2 geographic area will be uniform, a reasonable assumption given the size of HDFs themselves.

Three 25 mL water samples were collected in plastic PE sample bottles during runoff events and placed on ice. Water samples were analyzed for concentrations of anions, cations and total phosphorus.

3.3 Sampling procedures

All channels were sampled throughout 2008, during snowmelt or rainfall events intense enough to cause overland flow, typically when precipitation exceeded 10 mm. When organic material was present in the drift traps, the bag was removed from the aluminum frame and the contents were transferred to a zip-lock bag and placed in a cooler on ice. A thorough rinse and reversal of the netting was done before replacing it onto the aluminum frame. All samples were then stored in a freezer until processed.

Maximum discharge within the channel was estimated from the mark left by the removal of baby powder as water rose in the pipe. The pipe was cleaned with a wet cloth and reset with the application of new baby powder. Volume of water collected in each rain gauge was recorded and the gauge was emptied and replaced in the holder.

3.4 Sample processing

Drift samples were thawed under cold flowing water and immediately sorted into groups of invertebrates, organic matter and sediment. Invertebrates and organic matter were preserved in a 70% ethanol. Samples requiring over 4 hours of processing time were sub sampled by weight until 300 invertebrates were found. All animals were identified to Family or Order. To estimate invertebrate biomass, animals of each taxonomic order were placed in a 10 mL graduated cylinder (filled with 70% ethanol) and the volumetric displacement was recorded. Selected samples (representing small, medium and large invertebrates) were oven dried at 60°C for 48 hr, then weighed to the nearest 0.0001 g. Dry mass was then used to create a regression plot (Figure 3) to estimate biomass of the remaining samples.

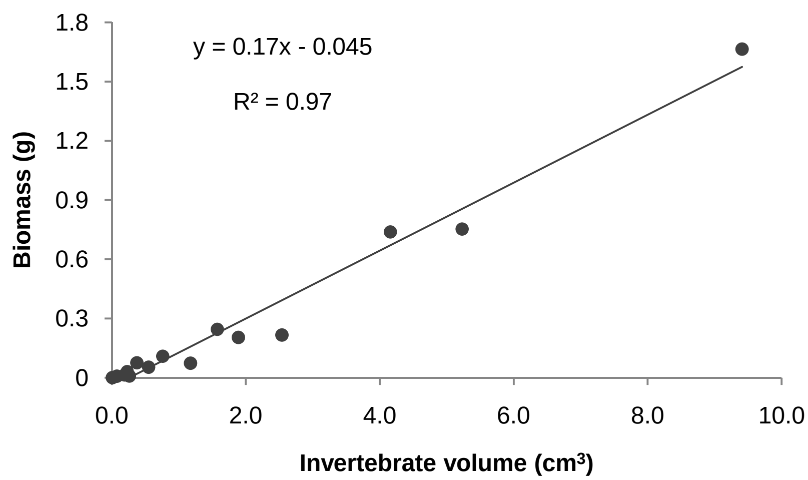

Figure 3 Plot of invertebrate volume (cm^3) against biomass (g). Relationship used to estimate total biomass of all invertebrates collected during the 2008 season.

Organic matter was separated into six categories: deciduous leaves, coniferous needles and cones, crop, herbaceous vegetation, woody material (branches, wood chips, bark) and detritus (empty snail shells, unknown organic matter not assignable to other categories). The separated materials were oven dried at 60°C for 48 hr, then weighed to the nearest 0.1 g.

Anions and cations were analyzed by the Department of Chemical Engineering's analytical services at the University of Waterloo. Total phosphorus was determined in the biology department under the guidelines prepared by the aquatic ecology group analytical laboratory (Wang 2007, personal communication).

3.5 Statistical analysis

Relationships between invertebrates, plant matter, precipitation and maximum water level were examined using Spearman's rank correlation. This non-paramteric test will measure the statistical correlation between two variables (Zar, 2010). To compare independent samples between ephemeral and intermittent channels, as well as between forested and agricultural catchments, the Mann-Whitney test was utilized. This non-parametric test was appropriate because the results are valid regardless of whether or not the sample distributions are normal (Samuels and Witmer, 1999).

4.0 Results

The results will be presented in four different sections. First, I will present the nutrients (water quality) that are being transported by all headwater channels. Second, I will compare precipitation and maximum discharge height data to the amount of materials (invertebrates and plant matter) transported during runoff events. Third, all animals transported from ephemeral and intermittent channels will be analyzed. Lastly, seasonal trends in materials transported will be investigated.

The total number of samples and observations collected from all HDFs are given in table 2.

Table 2 Total number of samples and observations from 16 ephemeral and intermittent channels.

Site ID	Drift Samples Collected	Precipitation Readings	Crest Stage Gauge Readings	Water Samples Collected
Ephemeral forested channels				
HW_ET 01	2	21	7	3
HW_HUM 1	5	22	8	0
HW_HUM 3	1	22	7	0
HW_HUM 6	8	20	26	13
HW_HUM 11	6	18	5	2
HW_HUM 12	7	18	15	3
HW_OAK 2	3	7	14	0
HW_OAK 3	2	18	18	0
HW_OAK 4	1	18	23	0
Ephemeral agricultural channels				
HW_HUM 4	12	21	19	2
HW_HUM 7	3	17	20	11
HW_HUM 8	5	17	17	5
HW_ROU 3	14	21	20	7
Intermittent forested channels				
HW_DUF 6	14	16	23	11
Intermittent agricultural channels				
HW_ROU 4	12	21	29	6
HW_ROU 5	21	21	30	15

4.1 Water quality

Chemical concentrations in water samples collected during runoff events differed significantly between forested and agricultural catchments (Table 3 - See Appendix A for individual sample results). Compared to forested channels, agricultural sites discharged water with significantly higher concentrations of chloride (Mann-Whitney $\alpha = 0.05$, $P < 0.001$), sodium ($P < 0.001$), nitrate ($P < 0.001$) and calcium ($P = 0.017$).

When ephemeral and intermittent channels were analyzed separately, ephemeral channels yielded significantly higher concentrations of sodium ($P < 0.001$), chloride ($P < 0.001$) and calcium ($P < 0.001$). Similarly, nitrate ($P < 0.001$), sulphate ($P < 0.001$), sodium ($P = 0.025$) and magnesium ($P = 0.02$) concentrations were significantly higher in intermittent agricultural channels than intermittent forested channels.

Analysis of total phosphorus concentrations revealed no statistical difference between land uses and channel types. Phosphorus concentrations were below 0.1 mg/L with the exception of HUM 4, averaging 0.389 mg L^{-1}, an order of magnitude higher than all other sites.

Fluoride ion concentrations were well below 1.0 mg L^{-1} with the exception of ROU 5 and HUM 7 (2.89 mg L^{-1} and 1.94 mg L^{-1} collected on April 8, 2008 and May 2, 2008, respectively).

Concentrations of NO_3^- were below the detection limit (0.57 mg L^{-1}) in most samples from forested channels. In contrast, an average of 10.29 mg L^{-1} of nitrate was present in water draining agricultural catchments.

4.2 Comparison of precipitation and maximum discharge height to predict material transport

There were weak, positive relationships between the amounts of invertebrates (number and volume), plant matter (g) and precipitation since the last sampling event for ephemeral channels (Figure 4, left). Similarly, moderately strong relationships were found between plant matter transported from intermittent channels and precipitation (Figure 4, right). With the exception of 3 statistically significant correlations between plant matter transport and maximum water level ($r = 0.53$, $p = 0.001$; $r = 0.87$, $p < 0.001$; $r = 0.59$, $p < 0.001$ from agricultural ephemeral, forested

Table 3 Mean anion, cation and total phosphorus (TP) concentrations measured in ephemeral and intermittent channels. Li^{+}, Mn^{2+}, NH_4^{+}, F^{-} and HPO_4^{2-} were all below detection limits. All values are in mg/L.

Variable	Ephemeral								Intermittent		
	Forested				Agricultural				Forested	Agricultural	
	ET01	HUM6	HUM11	HUM12	HUM4	HUM7	HUM8	ROU3	DUF6	ROU4	ROU5
TP	0.0361	0.0362	0.0262	0.0158	0.389	0.0418	0.0303	0.0192	0.0221	0.0457	0.0153
Cl^{-}	28.82	2.23	6.47	6.29	87.57	249.54	193.00	66.56	56.23	34.35	104.33
Br^{-}	4.66	8.44	3.87	< 0.65	< 0.65	7.74	1.15	2.67	2.14	2.42	1.21
NO_3^{-}	< 0.57	< 0.57	1.34	0.92	< 0.57	1.38	1.11	4.03	< 0.57	4.15	28.52
SO_4^{2-}	1.32	46.36	22.64	25.10	17.34	18.19	23.55	13.47	2.91	11.52	17.78
Na^{+}	15.16	6.98	3.20	3.85	23.04	115.68	120.35	35.68	21.86	11.77	60.02
NH_4^{+}	< 0.54	< 0.54	< 0.54	< 0.54	< 0.54	< 0.54	< 0.54	< 0.54	< 0.54	< 0.54	< 0.54
K^{+}	1.38	3.69	0.46	< 0.43	< 0.43	0.86	< 0.43	2.03	0.62	0.82	< 0.43
Mg^{2+}	2.06	18.46	7.22	6.45	10.29	7.68	8.66	7.81	5.99	10.58	8.22
Ca^{2+}	19.78	31.89	34.80	47.45	70.66	46.97	63.97	33.17	43.57	47.85	39.89

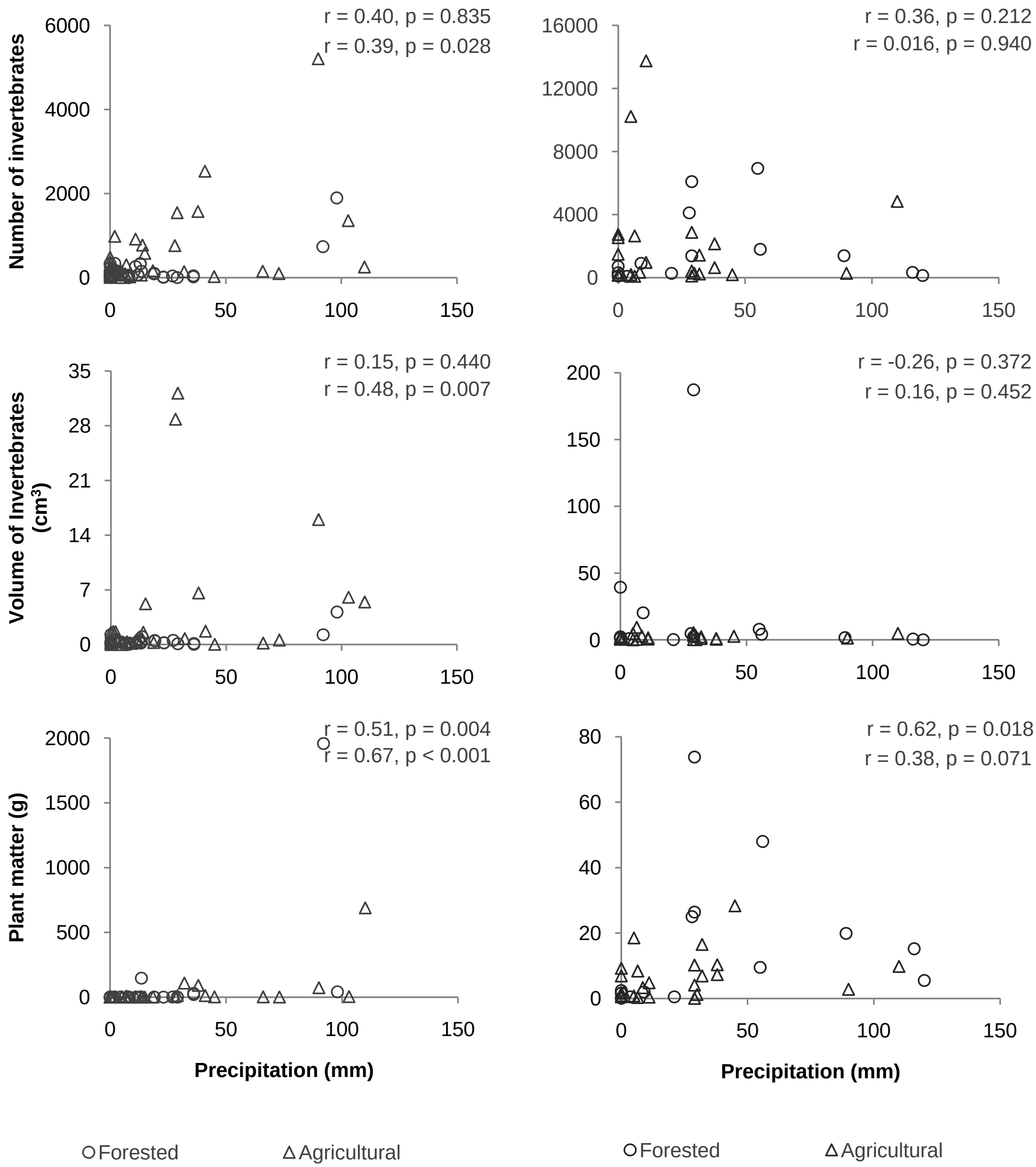

Figure 4 Relationships between the number of invertebrates, volume of invertebrates (cm^3) and plant matter (g) transported event $^{-1}$ and precipitation since the previous sample from ephemeral (left) and intermittent (right) channels. r and associated p values for forested catchments are on top.

intermittent and agricultural intermittent channels, respectively), no other relationships were found.

Overland flow, as estimated from maximum water level, showed no statistically significant relationships to precipitation in forested catchments (Figure 5). In contrast, precipitation and maximum water level from agricultural catchments exhibited moderate to strong correlations for both ephemeral and intermittent channels ($r = 0.45$, $p = 0.012$ and $r = 0.75$, $p < 0.001$, respectively).

4.3 Invertebrate and plant matter transport from ephemeral and intermittent channels

The taxonomic breakdown of all invertebrates collected is given in tables 4 and 5 (see Appendix B for greater taxonomic resolution). The amounts of invertebrates and plant matter transported varied greatly among channel types and land uses (Table 6, 7). Throughout the season, invertebrate transport from ephemeral channels ranged from 1 to 1879 individuals event^{-1} in forested catchments and 5 to 5,708 event^{-1} in agricultural catchments. The average number of animals transported event^{-1} from agricultural catchments (591 individuals event^{-1}) was almost 3-fold greater than that from forested catchments (213 individuals event^{-1}).

Both forested and agricultural intermittent channels transported similar numbers of invertebrates (1,760 and 1,683 individuals transported event^{-1}, respectively). However, catches from agricultural catchments were much more variable, ranging from 23 to 13,751 individuals event^{-1}, versus 81 to 6,932 from forested catchments.

Although both intermittent forested and agricultural channels transported roughly the same number of animals event^{-1}, the volume of invertebrates from forested catchments (17.41 cm^3 event^{-1}) was approximately ten times greater than from agricultural catchments (1.78 cm^3). In contrast, ephemeral agricultural catchments transported an average invertebrate volume of 3.42 cm^3 event^{-1}, almost seven times more than that from ephemeral forested catchments (0.52 cm^3 event^{-1}).

Within ephemeral channels significant differences were found between forested and agricultural catchments for both number ($p = 0.033$) and volume ($p = 0.040$) of invertebrates transported. Quantities of plant matter did not differ significantly between land uses ($p = 0.107$). In contrast,

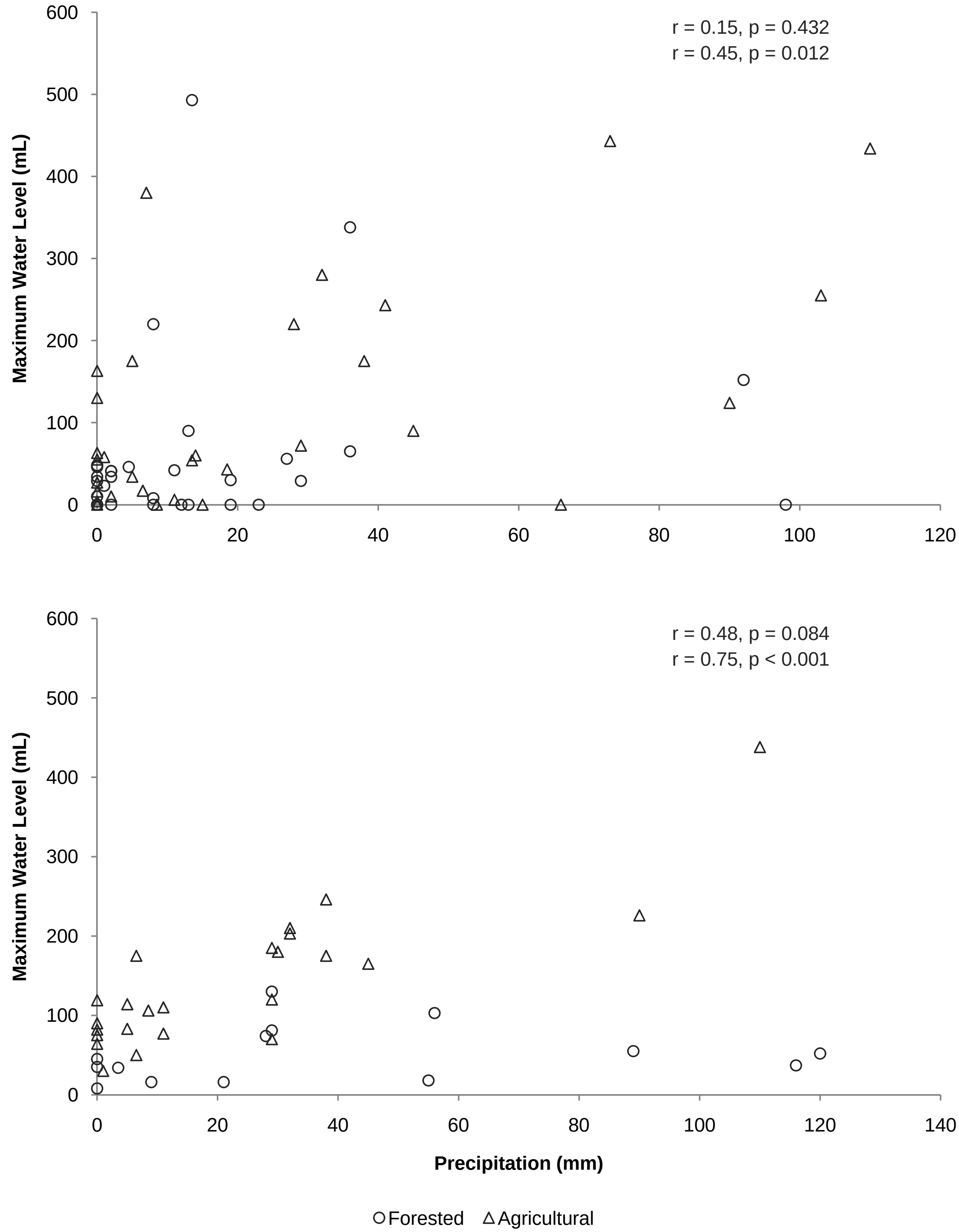

Figure 5 The relationship between precipitation and maximum water level recorded from crest stage gauges from ephemeral (top) and intermittent (bottom) channels draining forested and agricultural catchments. r and associated p values for forested catchments are on top.

Table 4 Mean numbers of aquatic invertebrates transported event^{-1} from ephemeral and intermittent channels. 35 and 34 drift samples were collected from ephemeral forested and agricultural catchments, respectively; 14 and 33 drift samples were collected from intermittent forested and agricultural catchments, respectively.

	Ephemeral Channels		Intermittent Channels	
Taxonomic Group	**Forested**	**Agricultural**	**Forested**	**Agricultural**
Annelida				
Hirudinea	0	0	14.43	0.06
Oligochaeta	0.54	37.21	19.14	5.52
Arthropoda				
Arachnida				
Acariformes	0.09	0.21	20.43	6.91
Crustacea				
Amphipoda				
Gammaridae	0.60	0	1.43	0
Hyalellidae	0	0.21	0	0
Unknown Amphipoda	0.40	0.06	8.64	0
Cladocera				
Daphniidae	0	0	1.71	0
Copepoda	17.91	42.94	450.36	213.91
Decapoda	0	0.32	0	0
Isopoda				
Asellidae	0	0	0	0.09
Ostracoda	7.77	67.85	62.21	129.55
Insecta				
Coleoptera				
Chrysomelidae	0	0	0	1.27
Dryopidae	0.03	0.24	0	0
Dytiscidae	0.11	0.09	28.93	10.06
Elmidae	0	0.03	1.50	0.14
Haliplidae	0	0	8.50	0.06
Hydrophilidae	1.83	5.41	0.93	4.42
Unknown Coleoptera	0.06	0.12	0.29	5.27
Diptera				
Ceratopogonidae	0.09	1.18	3.86	8.91
Chironomidae	29.00	50.62	210.79	1080.94
Culicidae	0.46	0.24	0.14	5.61
Dixidae	0.03	0	0	0
Empididae	0	0	0	0.09
Ephydridae	0.06	0	1.07	0.91
Psychodidae	0	0.97	1.43	1.79
Ptychopteridae	0.06	0	0	0
Sciomyzidae	0	0	1.71	0

Table 4 (*Continued*)

Simuliidae	19.34	0.32	0	13.82
Stratiomyidae	0.207	1.94	4.64	5.91
Tabanidae	0	0.32	0.07	0
Tipulidae	1.77	2.09	9.86	0.24
Unknown Diptera	16.31	28.35	11.79	51.58
Ephemeroptera				
Baetidae	0.03	0	0	0
Caenidae	0	0	0.07	0
Unknown Ephemeroptera	0.31	0.21	0	0.03
Hemiptera				
Corixidae	0	0.03	0	0
Gerridae	0	0	0.07	0
Hebridae	0	0.24	0	0
Mesoveliidae	0	0	0	0.06
Saldidae	0.06	0.15	0	0
Pleidae	0.03	0	10.07	0.03
Unknown Hemiptera	0.06	0.15	0.07	0
Odonata				
Cordulegastridae	0	0	0.21	0
Libellulidae	0	0	0.07	0
Unknown Odonata	0.14	0.15	0.21	0
Plecoptera				
Nemouridae	0	0.06	0	0
Perlodidae	0	0	0	0.03
Unknown Plecoptera	0.06	0	0.14	0
Trichoptera				
Limnephilidae	0	0.15	382.93	1.03
Phryganeidae	0	0	0	0.03
Unknown Trichoptera	0.06	0.26	2.07	1.09
Chordata				
Actinopterygii				
Gasterosteiformes				
Gasterosteidae	0	0	0	0.24
Mollusca				
Gastropoda				
Hydrobiidae	0	0	0	0.03
Lymnaeidae	1.77	2.06	0.21	21.64
Physidae	0	1.53	0	5.12
Planorbidae	0.14	0.12	0	4.70
Unknown Gastropoda	0.03	0	0	5.18

Table 4 (*Continued*)

Bivalvia				
Veneroida				
Sphaeriidae	0.03	0.53	0.79	10.12
Platyhelminthes	0	0.03	0	0
Total taxonomic groups	**31**	**32**	**34**	**36**

Table 5 Mean numbers of terrestrial invertebrates transported event^{-1} from ephemeral and intermittent channels. 35 and 34 drift samples were collected from ephemeral forested and agricultural catchments, respectively; 14 and 33 drift samples were collected from intermittent forested and agricultural catchments, respectively.

	Ephemeral Channels		**Intermittent Channels**	
Taxonomic Group	**Forested**	**Agricultural**	**Forested**	**Agricultural**
Annelida				
Oligochaeta	15.09	32.85	11.50	0.09
Arthropoda				
Arachnida				
Acariformes	45.40	47.59	337.00	19.48
Araneae	0.89	2.26	3.93	3.67
Chilopoda				
Geophilida	0	0.15	0	0
Lithobiida	0.23	0.12	1.71	0
Collembola	16.51	53.53	28.50	29.15
Crustacea				
Isopoda	1.60	4.82	8.71	2.64
Diplopoda				
Julida	2.69	1.15	2.64	0.30
Insecta				
Coleoptera				
Anthribidae	0	0.12	0	0
Cantharidae	0	0	0	0.03
Carabidae	0	0	0	0.03
Cerambycidae	0	0	0	0.03
Chrysomelidae	0.11	0.21	0	0
Ciidae	0.03	0	0	0
Cleridae	0.09	0	0	0
Cuccinellidae	0	0.15	0	0
Curculionidae	0.06	0.65	1.00	0.24
Lucanidae	0.03	0	0	0
Scarabaeidae	0	0.50	0	0.03
Silphidae	0	0.35	0	0
Staphylinidae	0.26	2.68	0.14	0.42
Unknown Coleoptera	3.51	13.06	29.00	8.03
Dermaptera	0.09	0.09	0	0
Diptera				
Syriphidae	0	0	0.07	0
Unknown Diptera	1.91	12.82	8.21	1.24
Hemiptera				
Aphididae	0	1.82	4.29	8.12
Cercopidae	0.23	0	0	0

Table 5 (*Continued*)

Cicadidae	0.03	0	0	0
Cicadellidae	0.11	0.26	0	0
Lygaeidae	0	0.15	0	0
Thyreocoridae	0	0	0.71	0
Unknown Hemiptera	0.74	3.00	8.14	6.39
Hymenoptera				
Andrenidae	0.03	0	0	0.09
Apoidea	0	0.03	0	0
Chalcidoidea	0.03	0	0	0
Colletidae	0.03	0	0	0
Crabronidae	0.03	0	0	0
Formicidae	0.14	12.88	9.64	5.76
Ichneumonidae	0.03	0	0	0
Unknown Hymenoptera	2.69	5.94	6.64	0.12
Lepidoptera				
Geometridae	0	0.29	0.36	0
Unknown Lepidoptera	0.17	0.18	0.07	0.03
Phthiraptera	0	0	0	0.03
Psocoptera	0	0.09	0.79	0
Orthoptera				
Acrididae	0	0.35	0	0
Unknown Orthoptera	0	0.12	0	0
Thysanoptera	3.60	2.06	3.96	0.27
Mollusca				
Gastropoda	17.03	143.53	28.36	23.52
Unknown invertebrates	0.29	0.62	3.57	4.30
Total taxonomic groups	**31**	**32**	**22**	**23**

Table 6 Mean number and volume (cm^3) of invertebrates collected event^{-1} from 116 drift samples.

Invertebrate Habitat	Ephemeral		Intermittent	
	Forested	Agricultural	Forested	Agricultural
Numbers				
Aquatic	99.40	246.26	1260.79	1596.36
Terrestrial	113.43	343.79	495.29	109.72
Undetermined	0.29	0.62	3.57	4.30
Volume (mL)				
Aquatic	0.18	0.33	15.13	1.58
Terrestrial	0.34	3.08	2.25	0.20
Undetermined	0.00	0.00	0.03	0.00

Table 7 Mean amount (g) of plant matter collected event^{-1} from 116 drift samples.

	Ephemeral		Intermittent	
Plant Matter (g)	Forested	Crop	Forested	Crop
Detritus	11.60	27.86	11.53	2.92
Deciduous	1.06	0.97	2.17	0.26
Coniferous	0.11	0.40	-	-
Crop	-	0.48	-	2.15
Wood	50.42	1.84	2.77	0.14
Grass and Flowers	0.00	0.14	-	0.21

among intermittent channels there were no significant differences between land uses for plant matter ($p = 0.087$), number ($p = 0.163$) or volume ($p = 0.798$) of invertebrates.

Plant matter transported from forested ephemeral channels ranged from 0.0 g to 1,957.9 g event^{-1} (mean = 63.2 g event^{-1}: Table 7). Catches of plant matter from agricultural ephemeral channels were smaller and less variable (0.0 g to 108.8 g event^{-1}, mean = 31.7 g event^{-1}). Intermittent channels transported much less plant matter, on average, than ephemeral channels: forested and agricultural intermittent channels transported an average of 16.5 g and 5.7 g of plant matter event^{-1}, respectively. Transport ranged from 0.0 g to 73.8 g event^{-1} in forested catchments, and 0.1 g and 28.3 g event^{-1} in agricultural catchments.

In total, 108,620 individual animals (a combined volume or mass of 466.52 cm^3 or 75.96 g, respectively) and 3,715.8 g of plant matter were collected from March to October 2008. Overall, 27% of the total number of animals transported event^{-1} from ephemeral channels originated from forested catchments (13% of total volume transported event^{-1}), but for intermittent channels, forested catchments yielded a total of 51% of all animals transported event^{-1} collected (81% of total volume transported event^{-1}) Similarly, 67% and 74% of all plant matter transported event^{-1} from ephemeral and intermittent channels originated from forested catchments, respectively.

4.3.1 Invertebrates from ephemeral channels

Invertebrates of terrestrial origin were slightly more important (58%) in the drift from agricultural sites than from forested sites (53%). The three most numerically abundant aquatic taxa (Crustacea, Insecta and Chironomidae: Figure 6) contributed 87% of the total number of aquatic taxa collected event^{-1} from ephemeral channels. Similarly, Mollusca, Arachnida and Insecta accounted for 72% of the total number of terrestrial animals found in the drift event^{-1} from ephemeral channels. 34 aquatic and 32 terrestrial taxa were collected from agricultural catchments; forested catchments yielded 62 taxa, equally of aquatic and terrestrial origin.

81% of all Copepods and Ostracods, and 99% of aquatic Oligochaeta captured event^{-1} originated from agricultural catchments. Bladder snails (Gastropoda: Physidae) and fingernail clams (Bivalvia: Sphaeriidae) were only collected from agricultural catchments (except 1 sphaeriid collected on May 2, 2008 from HUM 6). 677 black flies (Diptera: Simuliidae) were collected from forested catchments, only 11 from agricultural catchments. Other aquatic Diptera (Ceratopogonidae, Psychodidae, Stratiomyidae and Tabanidae) were almost exclusively collected from agricultural catchments (except 3 Ceratopogonidae collected from OAK 3, HUM 12 and HUM 6 on May 6, May 27 and June 6 of 2008, respectively). Chironomids were captured in large numbers from both forested and agricultural catchments. A large catch of 3905 terrestrial snails from ROU 3 on September 17, 2008, accounted for 80% of all terrestrial gastropods collected from agricultural catchments.

With the exception of Myriapoda, nearly all terrestrial taxa were collected in greater numbers from agricultural catchments. Forested and agricultural catchments yielded approximately equal numbers of arachnids.

In terms of volume, Insecta, Crustacea and Chironomidae accounted for 86% of all aquatic animals collected event^{-1}; Oligochaeta, Mollusca and Insecta contributed 94% of the total

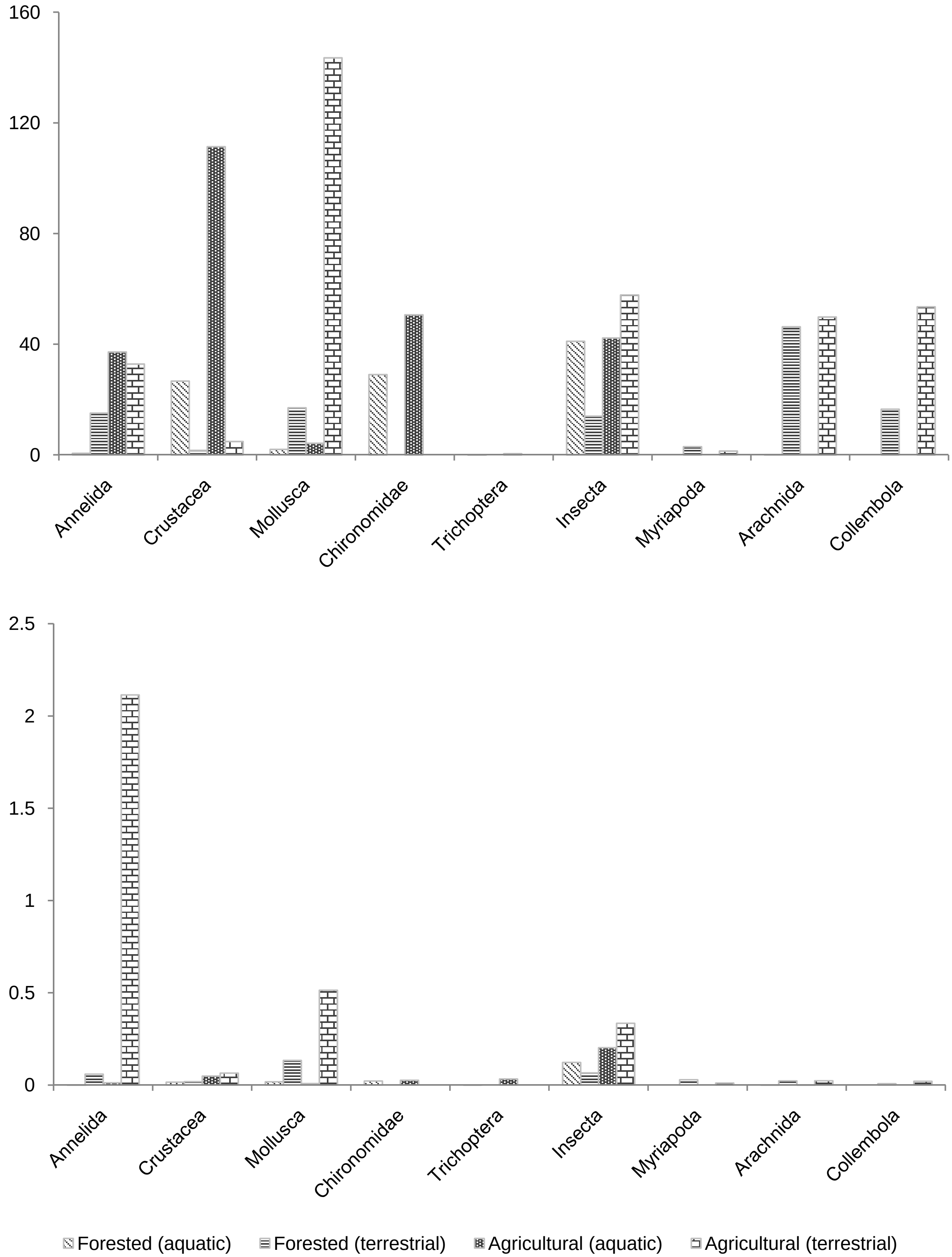

Figure 6 Total numbers (top) and volume (cm^3) (bottom) of aquatic and terrestrial invertebrates collected from ephemeral forested and agricultural channels.

volume of all terrestrial animals collected event^{-1}. Although Ostracoda and Copepoda accounted for 39% of all aquatic animals (by numbers), because of their small size, their volume represented only 10% of the total.

4.3.2 Invertebrates from intermittent channels

In contrast to ephemeral channels, invertebrates of terrestrial origin were less important (6%) in the drift from agricultural sites than forested sites (28%). 33 drift samples were collected from two agricultural catchments, 14 from one forested catchment. Despite collecting more than twice as many samples from agricultural catchments, the total numbers of taxa identified from both forested and agricultural catchments were very similar. Forested and agricultural intermittent channels yielded 34 and 36 different aquatic taxa, and 22 and 23 terrestrial taxa, respectively.

Chironomidae, Crustacea and Trichoptera were the three most numerically common aquatic taxa comprising 89% of the total number of aquatic animals collected event^{-1} (Figure 7). Similarly, the three most abundant terrestrial taxa were Arachnida, Insecta and Collembola, and these accounted for 87% of all terrestrial animals transported event^{-1}.

As in ephemeral channels, Ostracoda and Copepoda were collected in large numbers (Table 3) from intermittent agricultural catchments; however, 6,305 Copepoda were also collected from forested catchments. Leeches (Hirudinea), crawling water beetles (Coleoptera: Haliplidae) and pygmy backswimmers (Hemiptera: *Neoplea*) were collected almost exclusively from forested catchments (2 leeches and 2 crawling water beetles were collected on separate occasions from ROU 5 and 1 pygmy backswimmer was captured from ROU 4 on May 26). Of the 5461 caddisflies (Trichoptera: Limnephilidae) collected from intermittent channels, only 71 came from agricultural catchments; 82% were collected from a single event from DUF 6 on May 5, 2008. Marsh flies (Diptera: Sciomyzidae), amphipods and *Daphnia* were collected exclusively from forested catchments.

Mosquito larvae (Diptera: Culicidae) were found only in agricultural catchments except for 2 individuals captured on separate occasions from DUF 6. Only 16% of chironomids collected event^{-1} originated from forested catchments. In contrast to ephemeral channels, black flies were

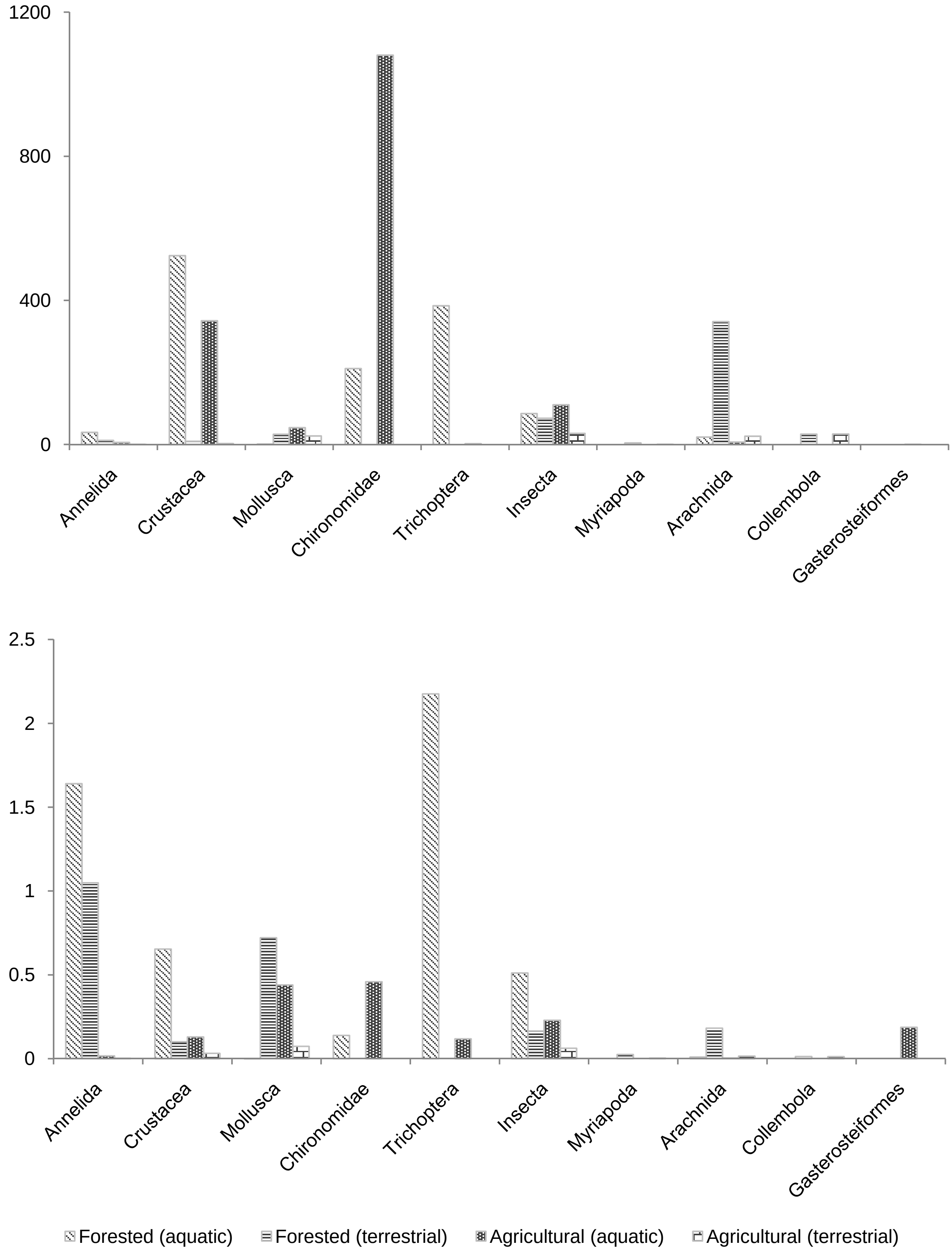

Figure 7 Total numbers (top) and volume (cm^3) (bottom) of aquatic and terrestrial invertebrates collected from intermittent forested and agricultural channels.

exclusively collected from agricultural catchments. Similarily, aquatic molluscs (Bivalvia and Gastropoda) were collected in large numbers only from agricultural catchments, with just 3 Gastropoda (Lymnaeidae) and 11 Bivalvia (Sphaeriidae) being captured from forested catchments.

Caddisflies (with case) accounted for 34% of the total aquatic invertebrate volume collected $event^{-1}$ from intermittent channels. Chironomidae only accounted for 9% of the total volume transported $event^{-1}$ despite being numerically dominant. In contrast, Hirudinea were not collected in large numbers (204 individuals) but totaled 25% of the total aquatic invertebrate volume transported $event^{-1}$.

Earthworms were collected almost solely from forested catchments and contributed a total of 42% of the terrestrial animal volume transported $event^{-1}$. Although collected in similar numbers $event^{-1}$ in forested and agricultural catchments, 91% of all terrestrial Mollusca volume transported $event^{-1}$ originated from forested catchments. Terrestrial mites and thrips (Thysanoptera) were primarily transported from forested catchments. Conversely, aphids (Hemiptera: Aphididae) were collected in larger numbers $event^{-1}$ from agricultural catchments.

4.3.3 Plant matter from ephemeral and intermittent channels

Although ephemeral forested channels transported approximately twice as much plant matter $event^{-1}$ as did agricultural channels (as reported in section 4.3), caution is warranted because a few very large samples bias these data. For example, HUM 6 transported 231.6 g of detritus and 1,725.3 g of woody materials on September 17, 2008. This accounts for 57% of all detritus and 98% of all wood collected from forested ephemeral channels in 2008. Similarly, ROU 3 transported 687.6 g of detritus on July 24, 2008, equaling 73% of the total detritus collected from agricultural ephemeral channels.

The amount of plant matter transported was moderately correlated with the number of invertebrates transported, with the exception of plant materials transported from forested ephemeral channels ($r = 0.25$, $p = 0.140$) (Figure 8).

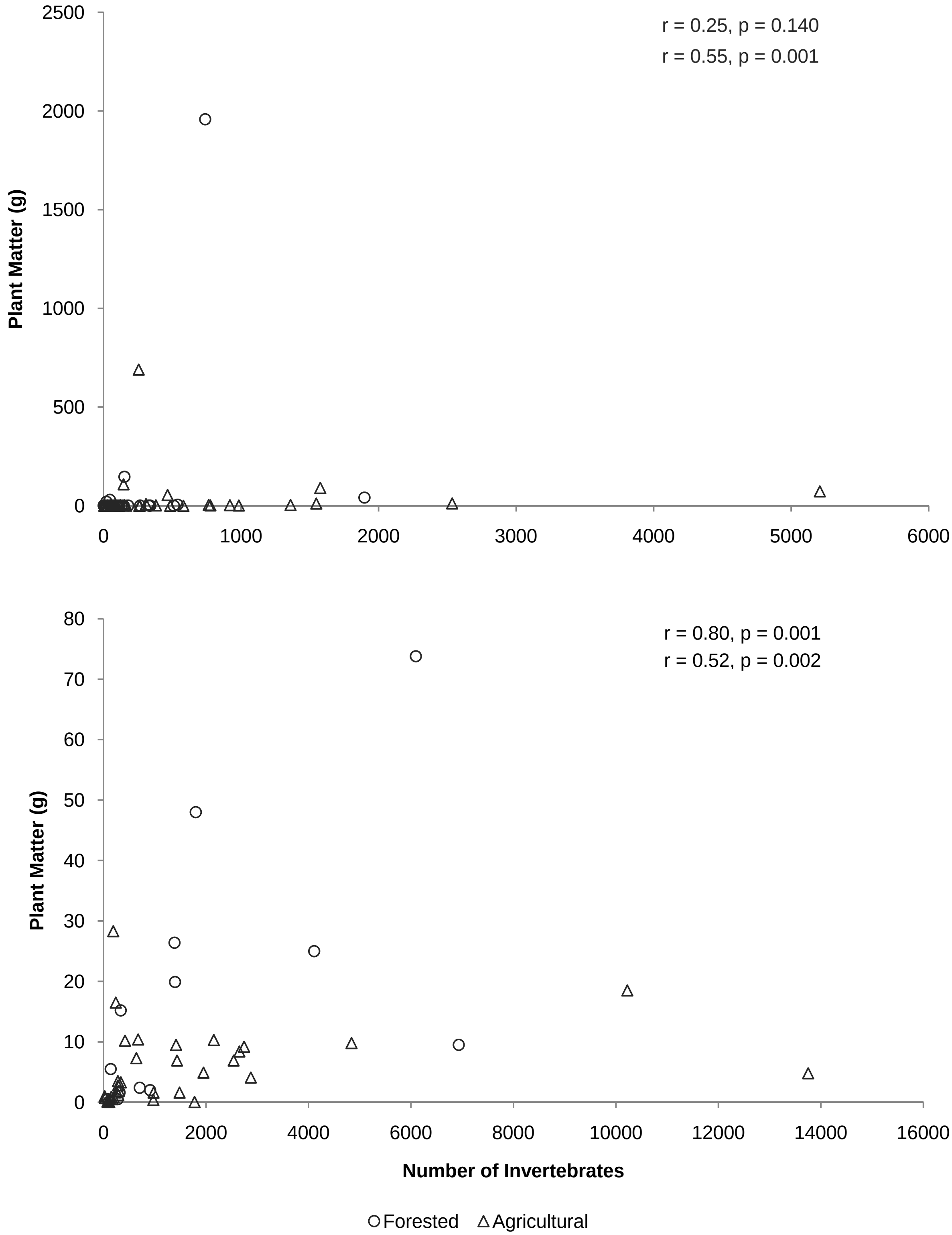

Figure 8 The relationship between the number of invertebrates and plant matter from ephemeral (top) and intermittent (bottom) channels draining forested and agricultural catchments. r and associated p values for forested catchments are on top.

4.4 Seasonality

There was no seasonal pattern in the total amounts of invertebrates or plant matter exported from either ephemeral or intermittent channels (Figure 9). However, the dominant taxonomic group transported from both ephemeral and intermittent channels changed throughout the season (Figure 10 - 17).

Table 8 illustrates the number of drift samples collected throughout the 2008 study season. 93 samples were collected from March through June, while the remaining 23 samples were collected from July through October.

4.4.1 Seasonal changes in invertebrate community composition from ephemeral channels

In forested and agricultural ephemeral channels, crustaceans were more abundant early, terrestrial molluscs and annelids later in the season. Mites were caught from agricultural catchments throughout the sampling period, but in forested catchments were very abundant only from July through September. Within agricultural catchments chironomids were transported in high numbers (108 individuals event^{-1}) all season except in June and July (0.8 individuals event^{-1}). Overall, within forested catchments more invertebrates were collected event^{-1} during July, August and September than earlier in the season. Surprisingly, this coincides with a significant decrease in overland flow (as recorded by the crest stage gauge) and a large influx of Myriapoda (millipedes), Arachnida (mites), Annelida (earth worms) and Mollusca (terrestrial snails).

4.4.2 Seasonal changes in invertebrate community composition from intermittent channels

Trichoptera, Myriapoda, and Collembola were primarily collected early in the season from forested catchments; Crustacea were mainly transported early from agricultural catchments. Molluscs, both aquatic and terrestrial, were collected in larger numbers from July onward within agricultural catchments.

In contrast to ephemeral channels, intermittent channels had more instances of very large catches of various taxonomic groups. For example, 7 samples collected from intermittent channels yielded > 1000 individual Insecta; no samples collected from ephemeral channels yielded > 1000 Insecta (Figure 15).

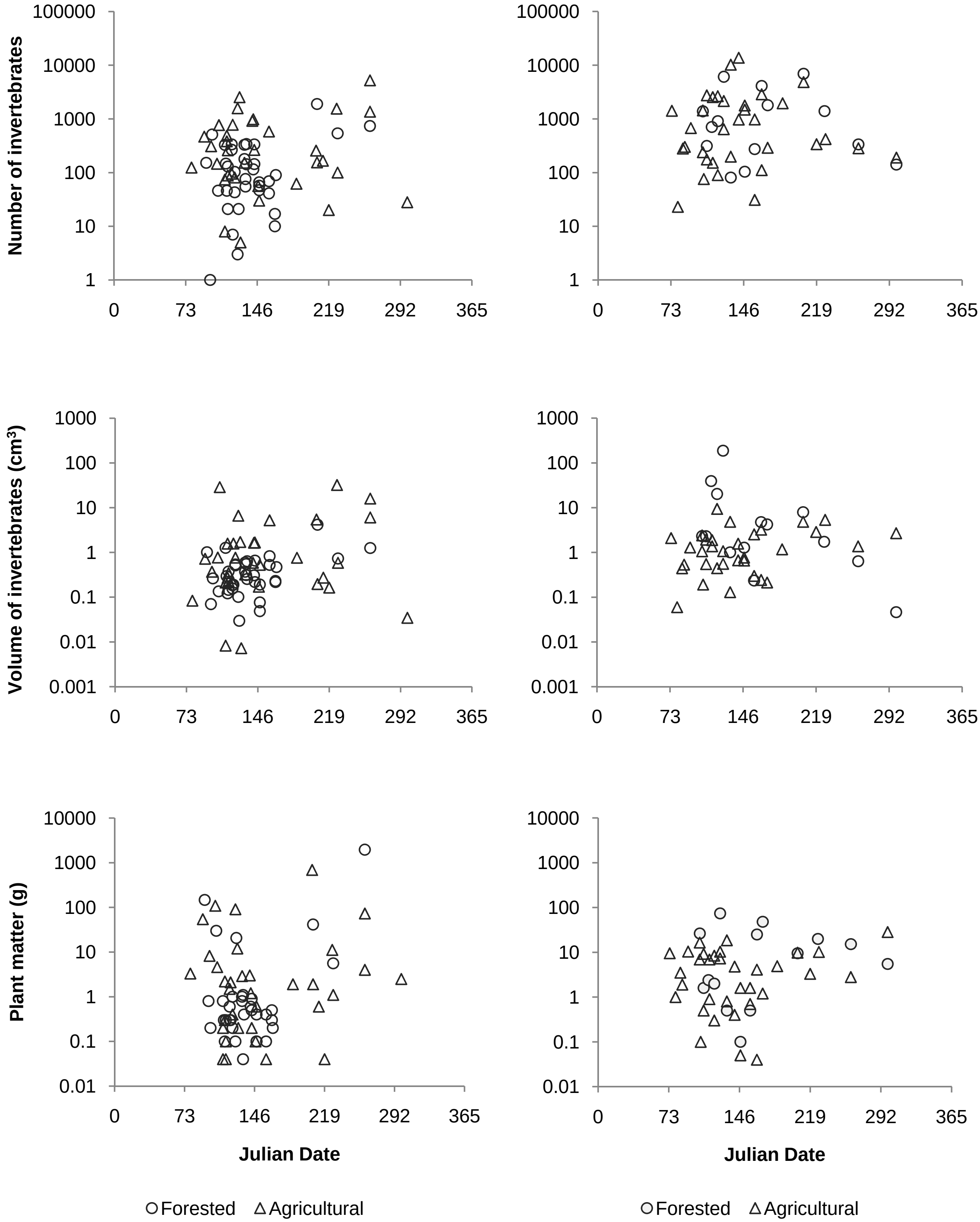

Figure 9 Seasonal distribution of the transport of organic materials from ephemeral (left) and intermittent (right) channels throughout the 2008 field season.

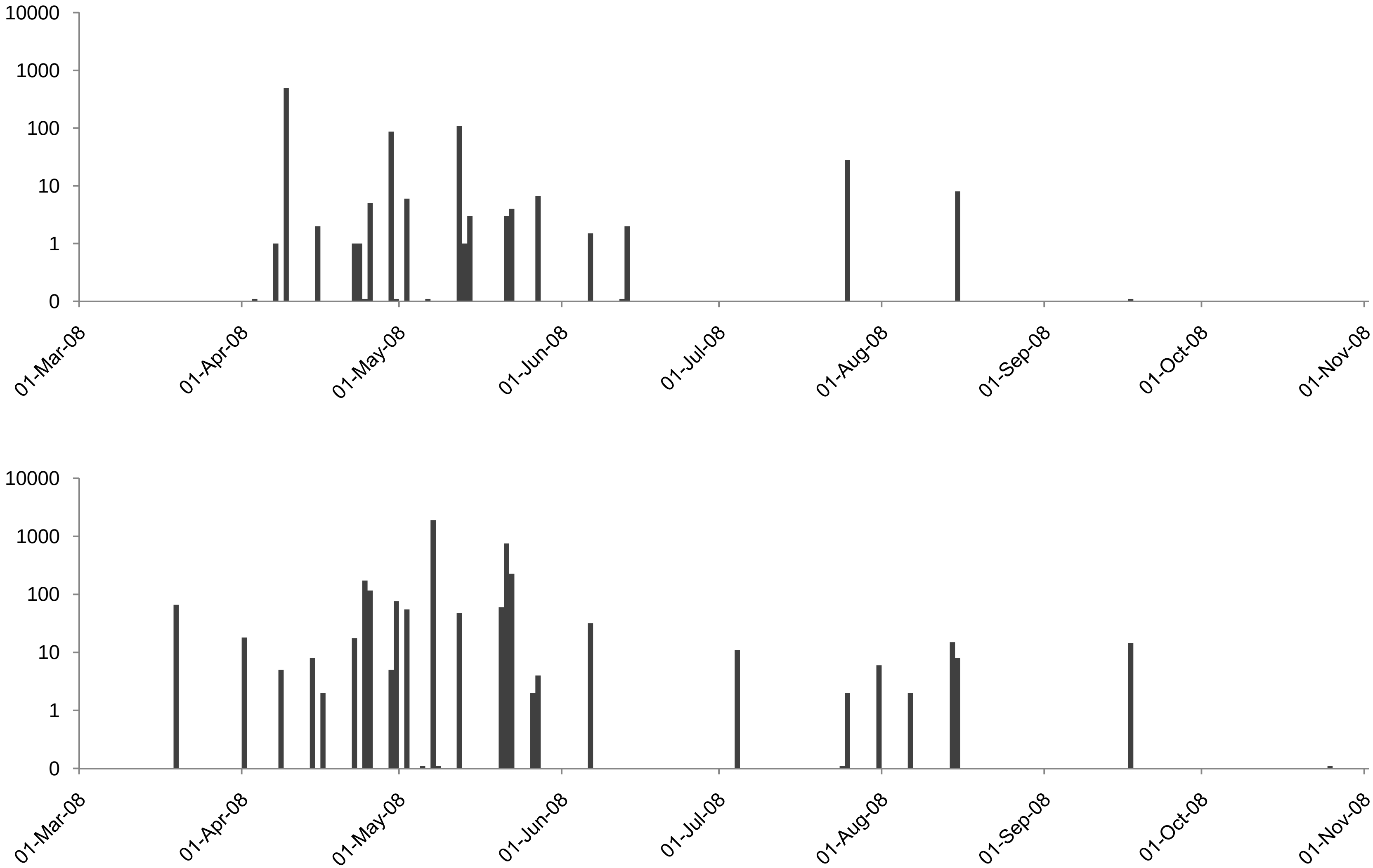

Figure 10 Total number of Crustacea collected from each runoff event from ephemeral forested (top) and agricultural (bottom) catchments.

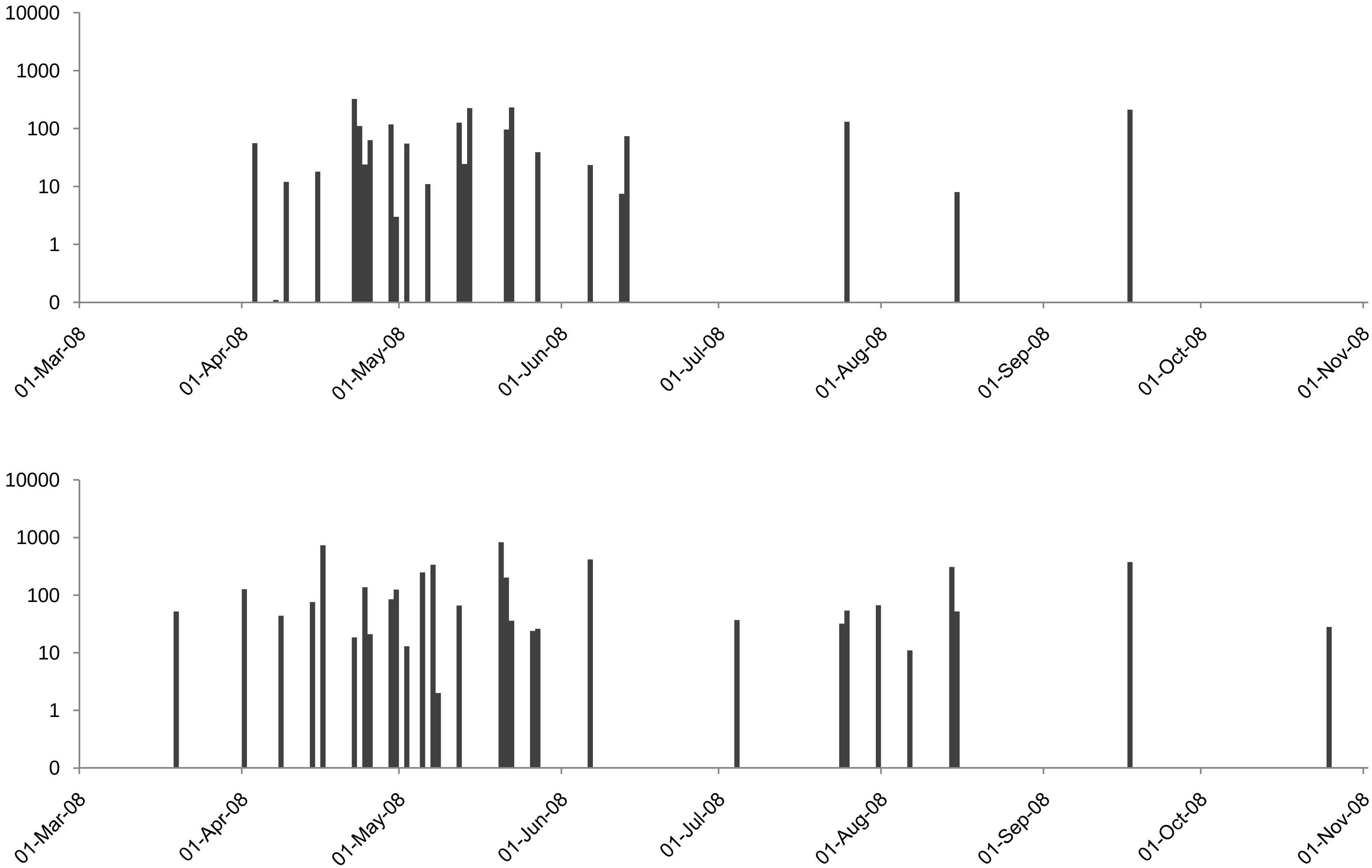

Figure 11 Total number of Insecta collected from each runoff event from ephemeral forested (top) and agricultural (bottom) catchments.

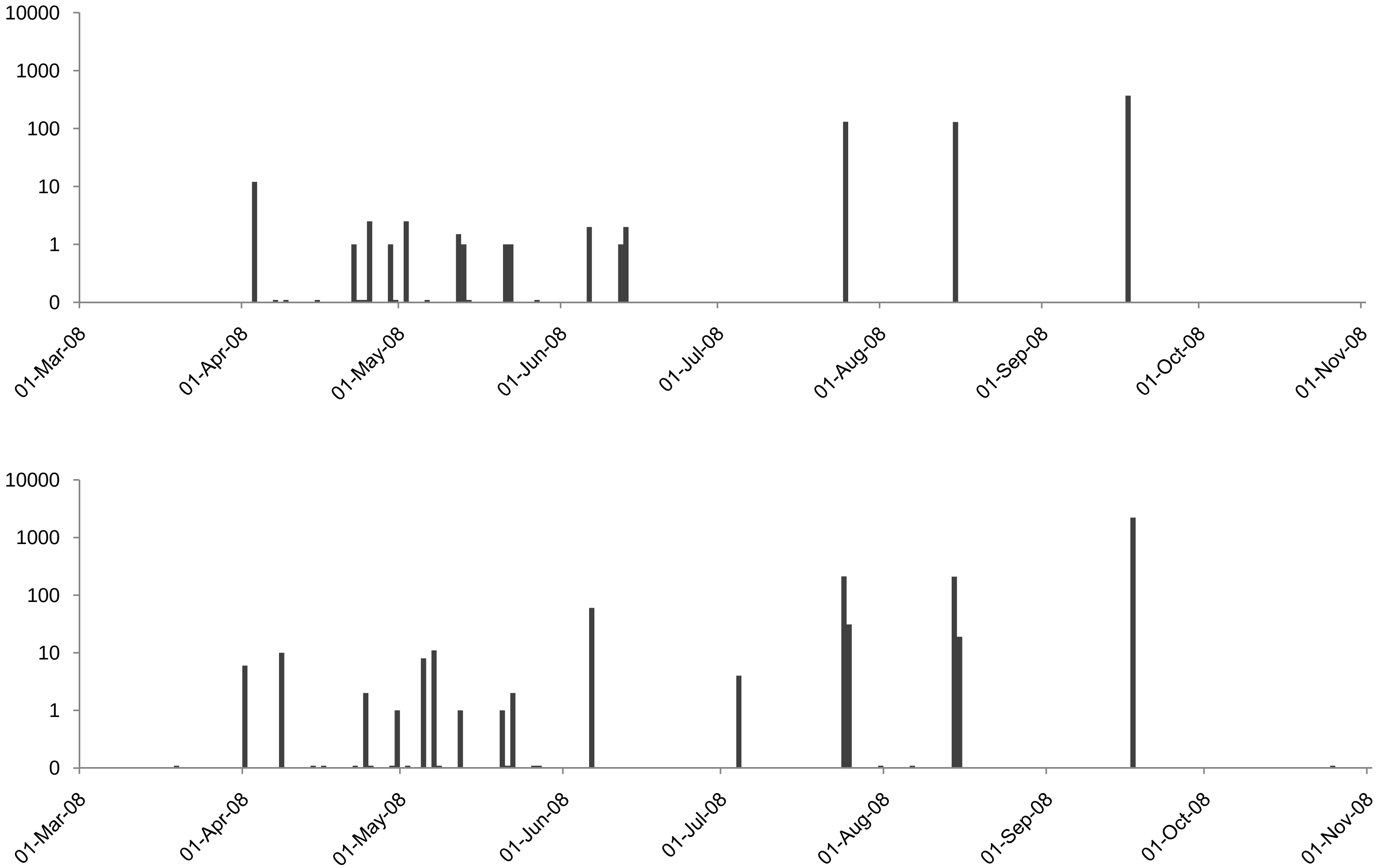

Figure 12 Total number of Mollusca collected from each runoff event from ephemeral forested (top) and agricultural (bottom) catchments.

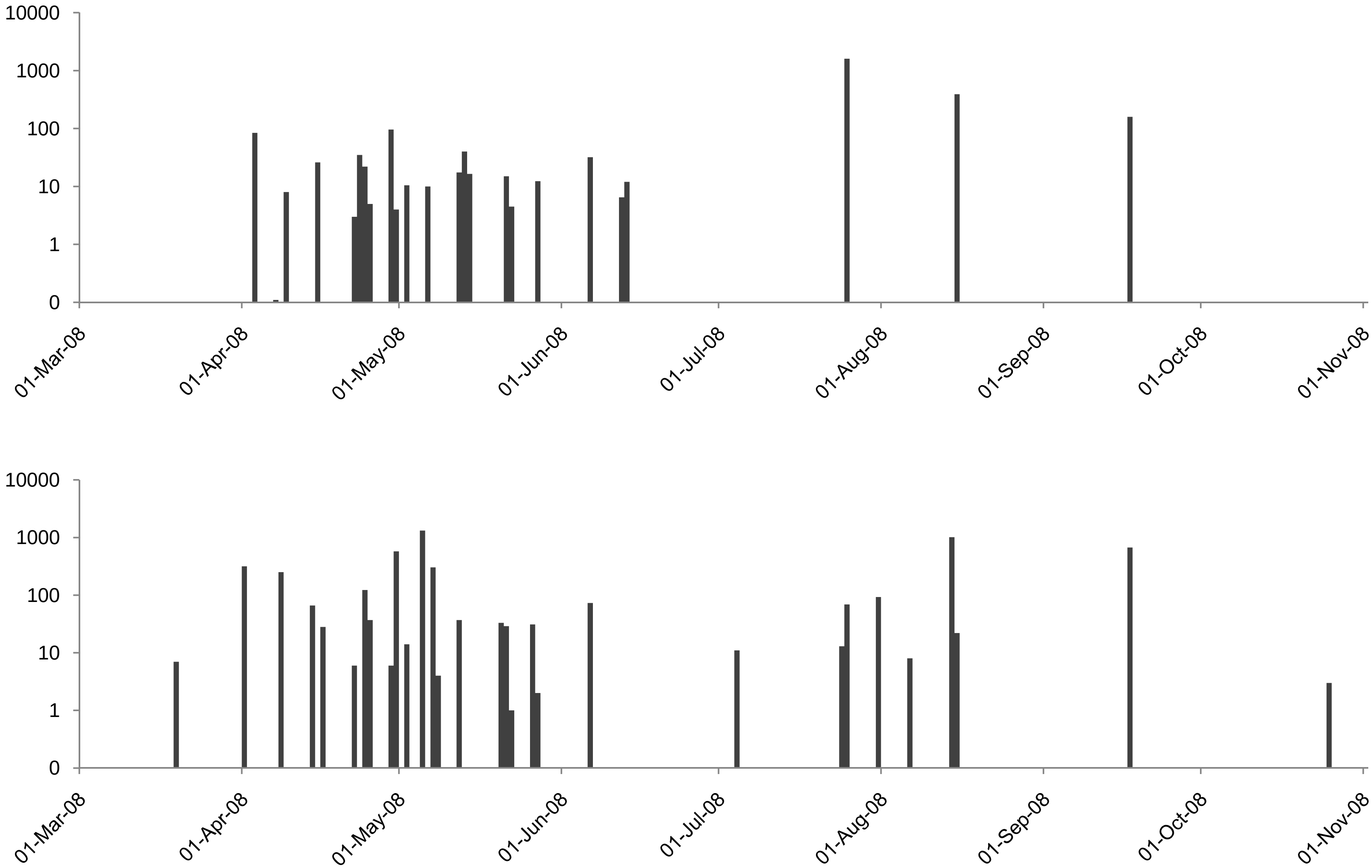

Figure 13 Total number of Annelida, Collembola, Myriapoda, Arachnida and unknowns collected from each runoff event from ephemeral forested (top) and agricultural (bottom) catchments.

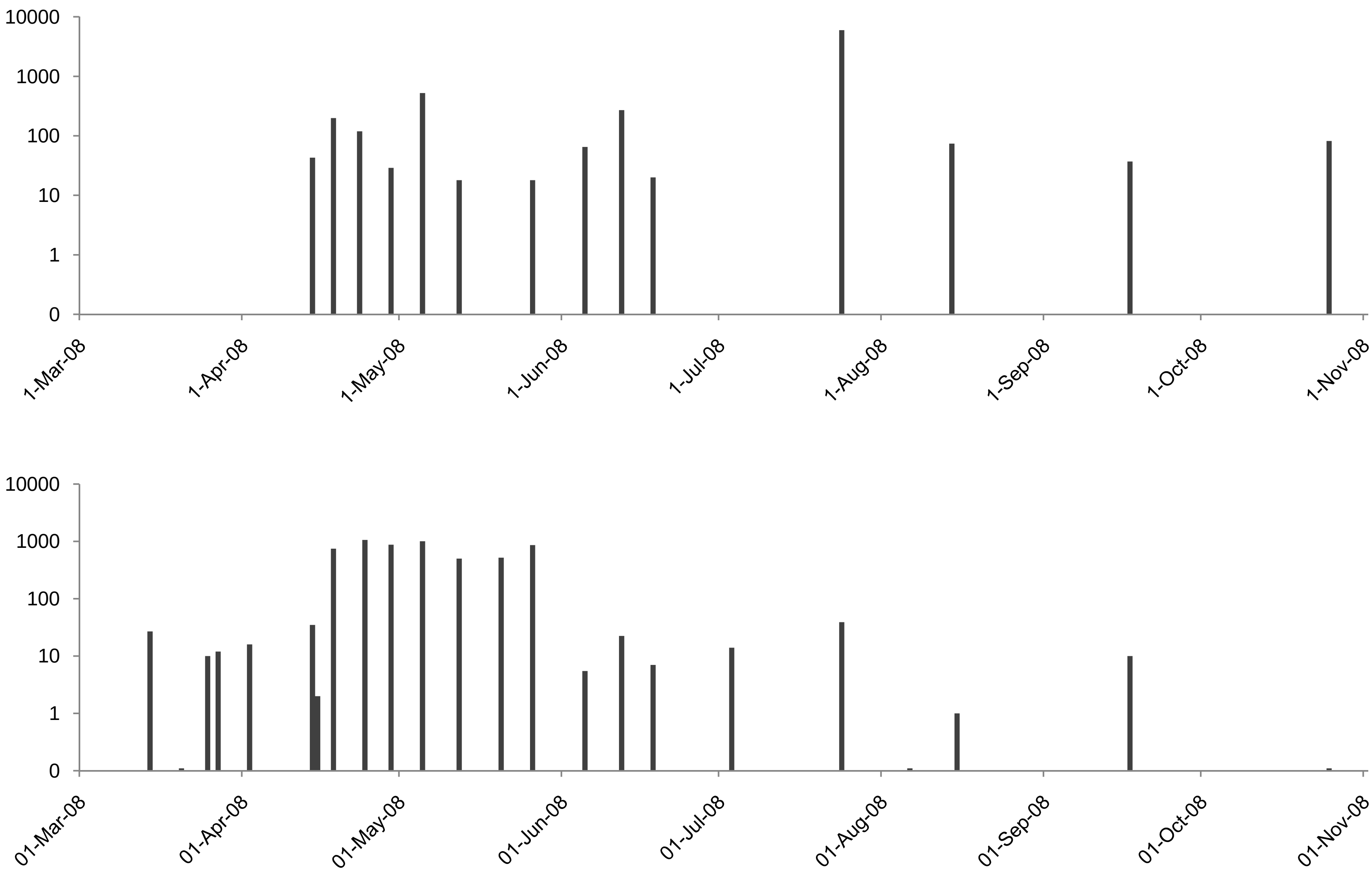

Figure 14 Total number of Crustacea collected from each runoff event from intermittent forested (top) and agricultural (bottom) catchments.

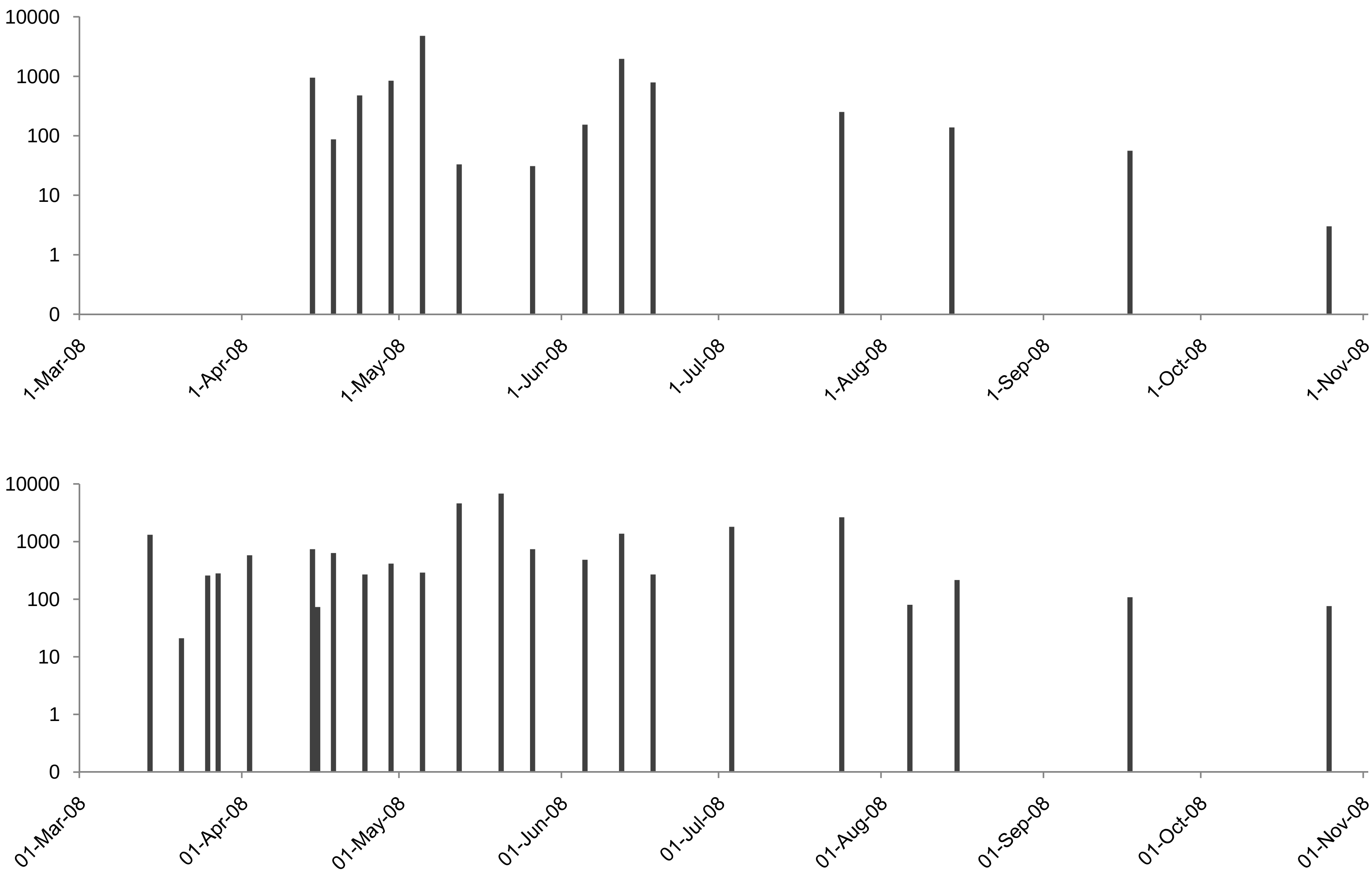

Figure 15 Total number of Insecta collected from each runoff event from intermittent forested (top) and agricultural (bottom) catchments.

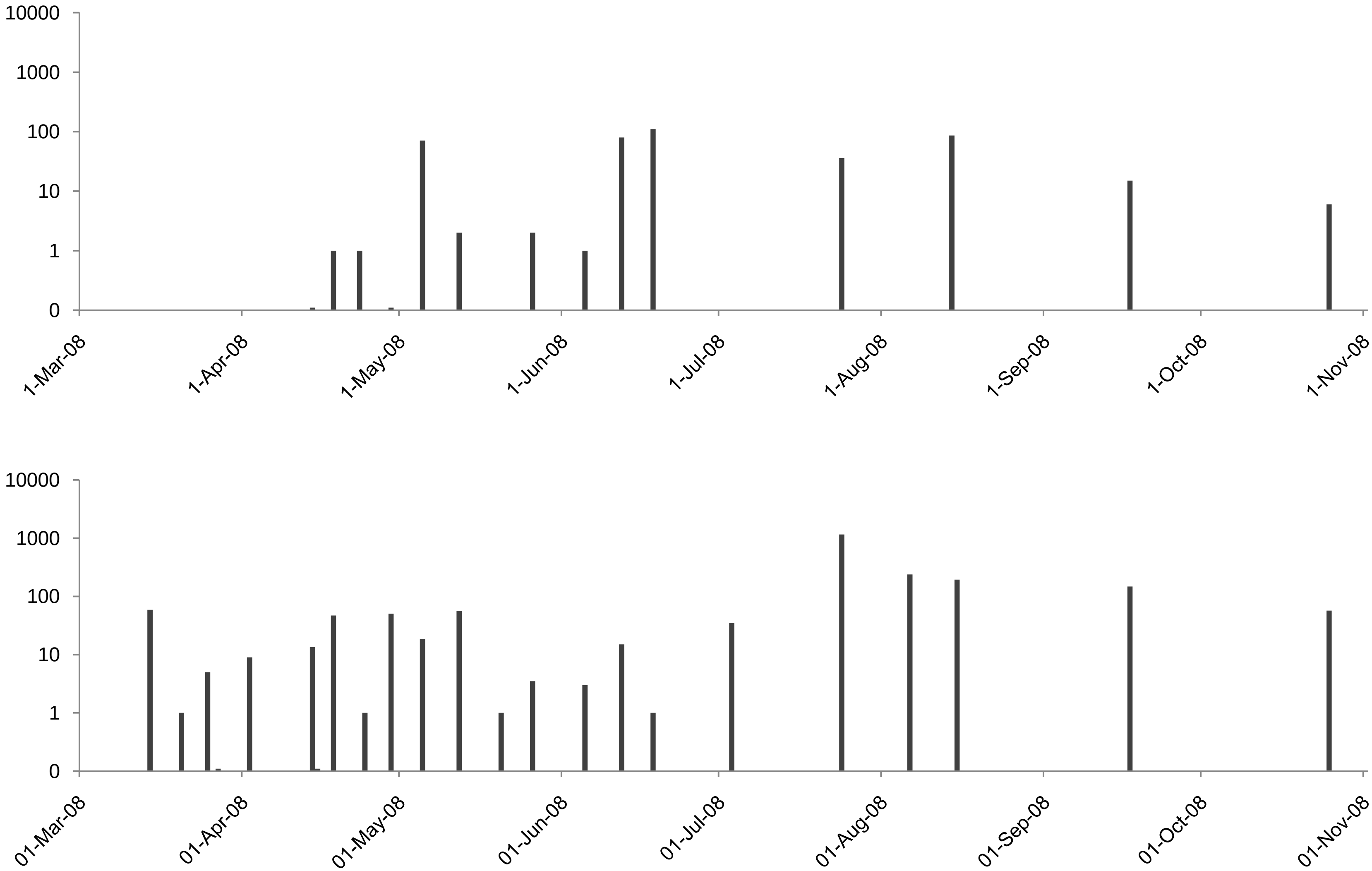

Figure 16 Total number of Mollusca collected from each runoff event from intermittent forested (top) and agricultural (bottom) catchments.

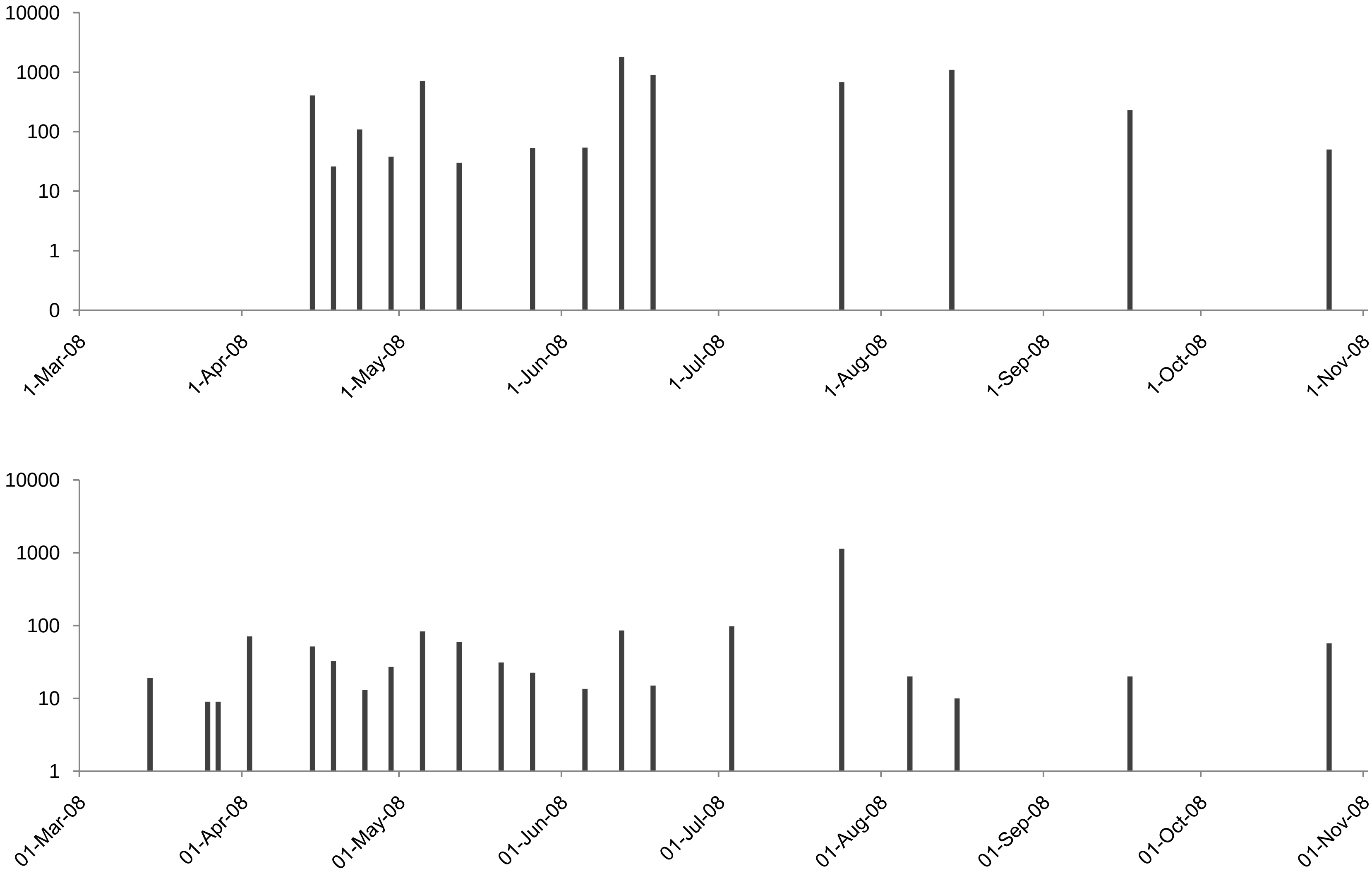

Figure 17 Total number of Annelida, Collembola, Myriapoda, Arachnida and unknowns collected from each runoff event from intermittent forested (top) and agricultural (bottom) catchments.

Table 8 Temporal distribution of drift samples collected by land use and channel type throughout the 2008 study season.

Channel Type	March	April	May	June	July	August	September	October
Ephemeral								
Forested	0	12	15	5	1	1	1	0
Agricultural	1	12	10	1	4	3	2	1
Intermittent								
Forested	0	4	3	3	1	1	1	1
Agricultural	4	10	8	5	2	2	1	1

4.5 Catchment area

Figure 18 illustrates the quantities of invertebrates and plant matter transported from all channels and it is clear that there were no overall relationships between material exported and catchment area.

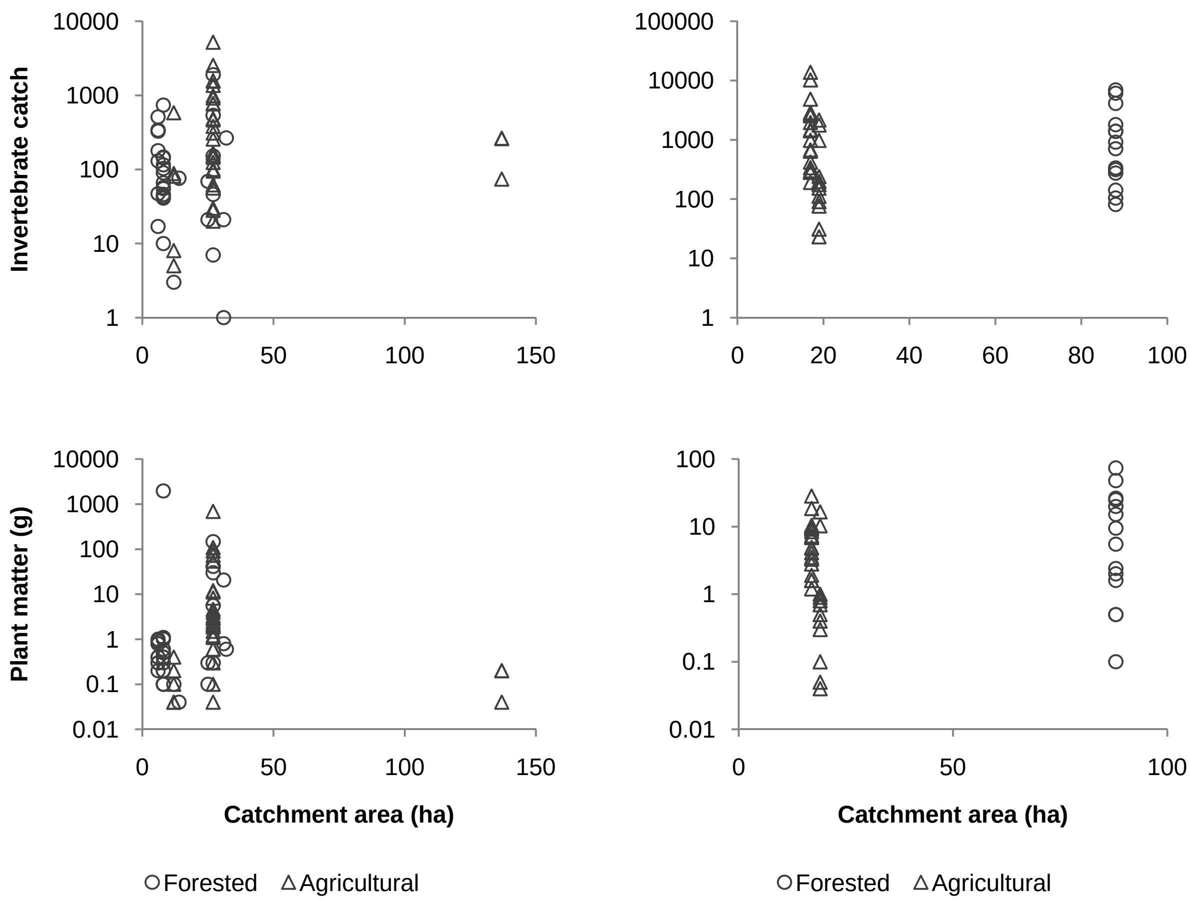

Figure 18 Relationship between the number of invertebrates and the amount of plant material transported and the catchment area of ephemeral (left) and intermittent (right) channels.

5.0 Discussion

5.1 Water quality

The results of the water quality analysis illustrate that land-use practices have a clear effect on the quality of water draining forested and agricultural catchments in Southern Ontario. These differences are primarily elevated levels of salt and nitrates from agricultural catchments.

The application of salts (primarily sodium chloride) on roads and highways is a common practice in snow-belt regions across Canada, the United States and Europe. Although de-icing agents such as sodium chloride decrease snow and ice related traffic accidents in the winter by 88% (Taylor-Vaisey 2010), our surface and groundwater drinking supplies are contaminated or at risk of being contaminated with elevated concentrations of these compounds. In the GTA over 100,000 tonnes of road salt are applied on roads each year (Howard & Beck 1993); annually, only 45% is removed from the catchment while the remaining ions infiltrate to temporary storage in the subsurface (Howard and Haynes 1993). In other words, Na^+ and Cl^- ions accumulate close to the point source (roadsides). Therefore, although concentrations of Na^+ and Cl^- ions are higher from agricultural catchments, this difference is attributed to the proximity of the channels to a road (Table 1) and not from a specific land-use factor such as vegetative cover or agricultural practices.

Unlike Na^+ and Cl^- ion concentrations, differences in nitrate concentrations between forested and agricultural catchments are associated with land-use practices. The application of nitrogen-based fertilizers to maximize crop yield is a common practice in Southern Ontario. Excess nitrates that are not assimilated by crops are easily dissolved and transported through overland flow, and groundwater.

Best management practices (BMPs), methods used to control and minimize pollution from agricultural practices, are gaining in popularity in Southern Ontario but are still not commonplace. Without proper management and implementation of BMPs we will continue to see elevated levels of nitrates in our HDFs draining from agricultural fields.

5.2 Predictor of organic material transport: precipitation or maximum discharge height

Overland flow resulting from rainfall or snowmelt is determined by a series of interlinked environmental variables, including antecedent physical conditions. The infiltration capacity of a soil, defined as its maximum ability to absorb rainfall at a given condition (Horton, 1933), will vary depending on moisture content, soil type and vegetative cover. For example, periods of rainfall will facilitate overland flow by increasing the soil's saturation and reducing infiltration capacity. Figure 19 illustrates the processes that contribute to channel flow within ephemeral and intermittent channels. Regardless of whether a channel is ephemeral or intermittent, precipitation that results in channel flow (or an increase in channel flow) occurs rapidly and is often distinct from event to event (Ward, 1984).

In comparison to forested soils, cultivated surfaces tend to have hardened, less permeable soils due to continual cultivation, erosion and exposure to sun. Furthermore, the lack of roots and root pores created by vegetative cover may limit the presence of macropores which significantly increase the infiltration capacity of soils (Cey et al. 2009). Therefore, as expected, moderate and strong correlations between the amount of rainfall and corresponding maximum discharge height were observed in ephemeral and intermittent agricultural catchments. The slopes of these correlations indicated a gradual rise in maximum water level with increasing precipitation. In forested channels, the absence of correlation between precipitation and maximum discharge height from both ephemeral and intermittent channels suggests that surface runoff and channel flow is more dependent on antecedent conditions than the volume of precipitation in any single event.

Increasing precipitation did result in a gradual increase in the transport of organic materials within ephemeral catchments, and large increases in maximum water level caused a slight increase in plant matter transport in agricultural catchments. On the other hand, small increases in maximum water level greatly increase the transport of plant matter from intermittent forested catchments.

For the most part, there was no relationship between organic matter transport and maximum water level, suggesting that precipitation appears to be a better indicator of organic matter transport than maximum discharge height measured from crest stage gauges. However, it must

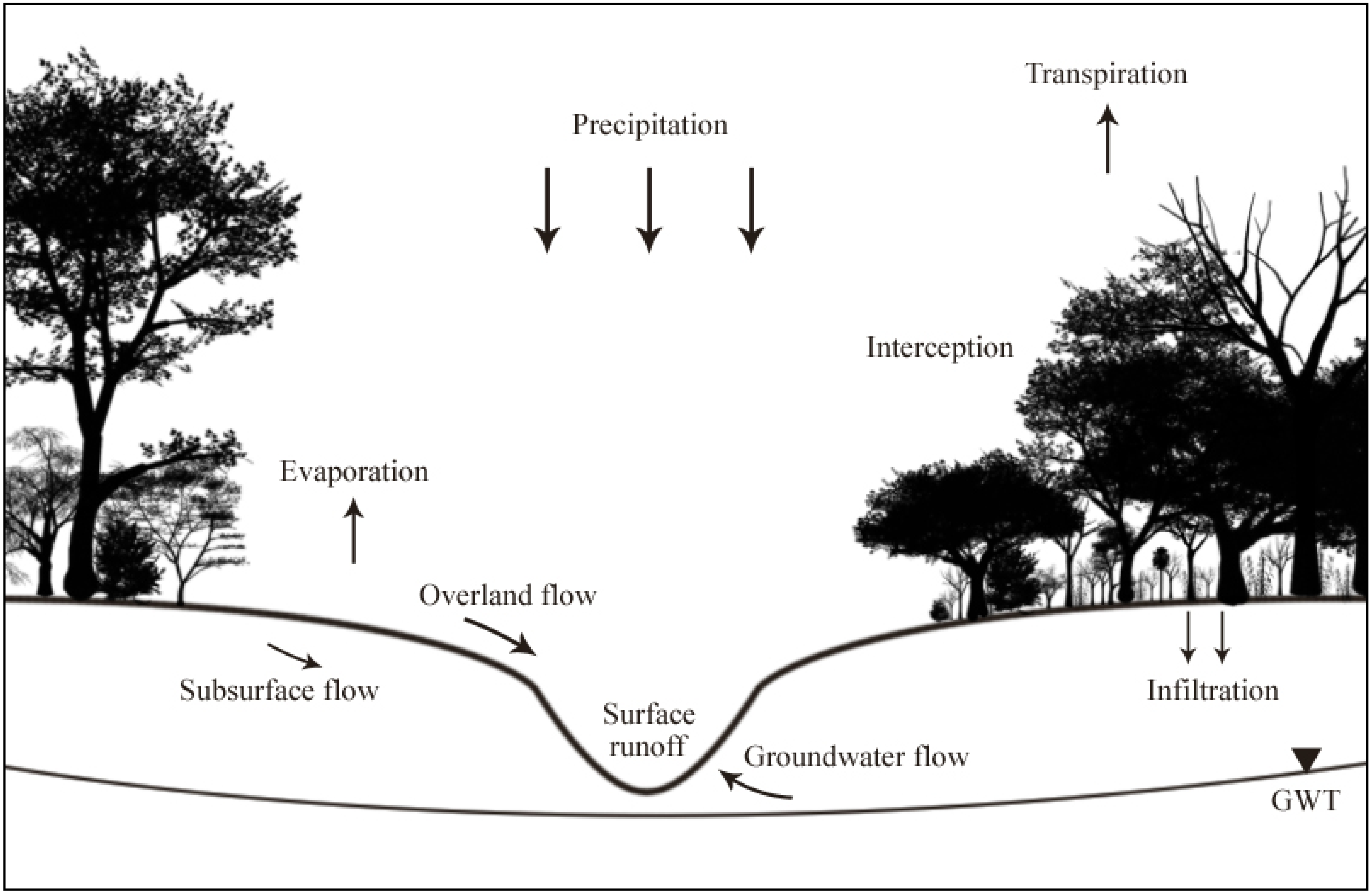

Figure 19 Conceptual diagram illustrating the basic components contributing to surface runoff within an ephemeral or intermittent channel.

be noted that I experienced difficulties throughout the field season with the crest stage gauges. Field evidence – no response of the crest stage gauge despite large catches of sediment in drift traps and patterns of overland flow carved into the channel – suggests that direct exposure to sunlight may 'bake' the baby powder onto the PVC tube, resulting in no dissolution of baby power during overland flow.

5.3 Invertebrate composition

5.3.1 Aquatic invertebrates

A surprising result from this study was the large proportion of aquatic animals; aquatic invertebrates comprised 43% and 87% of the total number of invertebrates collected in drift nets from ephemeral and intermittent channels, respectively. This is very likely a reflection of the heavy precipitation received during the spring and summer of 2008. During the 2008 field season, the GTA received 169 mm more rainfall and 78.7 cm more snow than average (Table 9). As a result, the intermittent channels were seldom dry, so supported invertebrate communities more typical of permanent flowing waters. For example, when compared to ephemeral channels, intermittent channels transported significantly more leeches, mites, diving bettles (Dytiscidae), crawling water beetles, pigmy backswimmers and caddisflies. Furthermore, because of the predominately wet conditions in the intermittent channels, Ostracoda, Copepoda and Chironomidae were collected in large numbers throughout the season. *Daphnia* and Amphipoda, strictly aquatic organisms, were also only found in drift nets from intermittent channels. The catch of eight sticklebacks from ROU 5 illustrates that if the conditions are appropriate HDFs have the capability, albeit temporarily, of being direct fish habitat.

In contrast, ephemeral channels flow only after moderate to heavy rainfall events or during the spring freshet, offering challenging environments for aquatic or terrestrial organisms as they continually cycle through wet and dry periods, with abrupt changes in temperature and nutrient composition (when water is present). Therefore, aquatic animals inhabiting ephemeral channels must be well adapted to rapidly changing physical characteristics.

The aquatic invertebrates that were collected from ephemeral channels were typical of what we would expect to find living in such variable physical conditions (Williams, 2006). For example, ephemeral channels were primarily wet during the spring, providing suitable habitats for aquatic crustaceans (Ostracoda and Copepoda); during the warmer, dryer summer months, the drift composition shifted to predominantly animals more suited to a dry environment (mites, millipeds, earthworms and terrestrial snails).

Table 9 Mean monthly total precipitation at Pearson International Airport, Toronto, Ontario for the years 1971-2000 and 2007-2008, recorded by Environment Canada weather station. One mm of rainfall is approximately equivalent to one cm of snowfall.

	2007-08			Historical data (1971-2000)		
Month	Rainfall (mm)	Snowfall (cm)	Total precipitation	Rainfall (mm)	Snowfall (cm)	Total precipitation
November	73.6	11	84.6	62	7.6	69.6
December	49.2	44.4	93.6	34.7	29.2	63.9
January	35.6	22.8	58.4	24.9	31.1	56
February	30.6	76.8	107.4	22.3	22.1	44.4
March	23.2	38	61.2	36.7	19	55.7
April	53.6	1	54.6	62.4	5.7	68.1
May	68.8	0	68.8	72.4	0.1	72.5
June	110.4	0	110.4	74.2	0	74.2
July	193.2	0	193.2	74.4	0	74.4
August	92.6	0	92.6	79.6	0	79.6
September	83.4	0	83.4	77.5	0	77.5
October	39.6	0	39.6	63.4	0.5	63.9

Furthermore, black flies, common daytime swarming and biting flies in Southern Ontario, typically lay their eggs in moving water and their larvae rely on free flowing water for filter-feeding and respiration. Therefore, much like microcrustaceans, black flies were only found early in the season in ephemeral channels, coinciding with wet conditions.

Chironomidae, the largest group of Dipterans, were collected from ephemeral channels early and late in the season; Very few chironomids were captured in June and July. Some Chironomidae are known to burrow into the shallow subsurface and seek refuge during periods of drought (Stanley et al., 1994), while some species posses the ability to survive months of drought and even extreme desiccation (Hinton, 1951).

It may seem that this explanation of Chironomidae abundance is in contradiction to earlier claims of the GTA receiving above average precipitation, especially in June and July (Table 9). However, it has been shown that precipitation within Southern Ontario is variable and extremely patchy (Stanfield, 2009). It is not uncommon for one area to receive a quick, intense precipitation event and another area a few hundred meters away to be left completely dry. Thus it is not surprising that many of our ephemeral channels remained dry despite large amount of precipitation recorded by the region. This patchiness may also have contributed to the weakness of the relationship between precipitation and export of organic matter.

Furthermore, the patchiness of precipitation is likely responsible for the almost complete absence of Ephemeroptera, Plecoptera and Trichoptera (EPT) from ephemeral channels. The variability in the intensity, duration and interval between rainfall events effectively limits the habitat to animals that are capable of responding quickly to sudden wet conditions and surviving extended dry periods. Many EPT species require more stable environmental conditions than those available in ephemeral channels.

Water quality may also explain the distribution of Ostracoda within ephemeral channels. These animals use Ca^{2+} and CO_3^{2-} ions to calcify their carapaces, so the distribution and abundance of most species of Ostracoda are limited by calcium (Meeren et al., 2010). Not surprisingly, HUM 4 was the site with the highest concentration of calcium (70.66 mg L^{-1}) and the only site of this subset to yield substantial numbers of ostracods. However, within intermittent channels ostracods were collected in large numbers from all channels with much lower Ca^{2+} ion concentrations, suggesting that these particular ostracods may be more limited by the availability of surface water than high levels of Ca^{2+} ions within ephemeral channels.

5.3.2 Terrestrial invertebrates

The terrestrial invertebrates caught in the traps included many of the common animals that we would expect to find in Southern Ontario (Marshall 2006), and more taxa were collected from ephemeral channels than from intermittent channels. As previously discussed, intermittent channels were wet throughout the 2008 season, inhibiting terrestrial animals from colonizing the channel bed. The common terrestrial animals, such as spiders (Arachnida), aphids, ants, beetles, snails, pill bugs (Isopoda) and springtails (Collembola) - comprising 89% of the total number of terrestrial animals caught from intermittent channels - tend to be active forms so were likely to have fallen or blown into the flowing channel.

Within ephemeral channels, the abundance of ants and snails from agricultural catchments is somewhat peculiar. Much like Ostracoda, snails use calcium from their environment to build their shells; the significantly elevated levels of calcium observed from agricultural catchments may explain the predominance of snails in agricultural fields. It is well known, especially to casual backyard gardeners, that snails enjoy feeding on a variety of vegetables, thus an agricultural field may present an ideal habitat.

It is unclear why ants were almost exclusively collected from agricultural catchments. Compared to agricultural catchments, vegetative cover (such as grass, flowers and small shrubs) is much more prominent on forested catchments. Therefore, during rainfall and overland flow it is likely that ants seek refuge by climbing up into the nearby vegetation thereby avoiding being transported by surface runoff.

5.4 Plant materials

The composition of plant detritus clearly reflected land-use upslope. Deciduous leaves and woody materials were trapped from forested catchments, crop residues from agricultural catchments. Plant matter deposited in headwaters is well known to be an important source of energy for food webs (Vannote et al., 1980). For example, the accumulation of materials on the stream bed can form suitable habitats for various invertebrates (Hynes, 1975); heterotrophic production releases energy stored within organic matter, making it available for other organisms and it also becomes a major source of energy production when opportunities for photosynthesis are reduced (Allan, 1995).

5.5 Seasonality

The sites were sampled during the same runoff events throughout the season because we expected that there may be important seasonal influences on the invertebrate composition collected in the drift. Although it was illustrated there were differences in the types of taxa that were collected throughout the season, it appears that changes in the total contribution of invertebrate drift are not dependent on the season. Therefore, subsequent studies need not be constrained by the timing of sampling and collection of drift.

5.6 Catchment area

It is interesting to note that the data indicate that catchment area had little effect on the quantity of materials being transported. This suggests that the area in close proximately to the HDF channel is the area most important in the determining the amount of materials a particular channel will transport. Therefore, in order to manage HDFs affectively it is likely that creating vegetative buffer strips along the channel may be an efficient and inexpensive way of maintaining their ecological functions.

However, a caveat must be discussed. The drift nets only collected materials flowing across a 20 cm width of a single channel within a catchment. It is unlikely that the catches represented a complete picture of the total amount of materials transported $event^{-1}$ for the entire catchment, especially from the larger catchments. Therefore, it would be premature to dismiss the importance of the catchment area draining an HDF.

5.7 Conclusions

Because of the unusually large amount of precipitation received by the Toronto Region in 2008, it is likely that this study has underestimated the quantity of materials transported during runoff events. Large flows within the HDF channels were common and often greatly exceeded the 20 cm width of the drift traps, resulting in an undersampling of invertebrate and plant drift.

Rather expectedly, the community composition of invertebrates clearly reflected the physical characteristic of the channels. Drift from intermittent HDFs, being wet for longer periods than ephemeral HDFs, was predominantly of aquatic origin. The longer a channel remains dry the greater the percentage of terrestrial animals in the drift. However, the data do not conclusively suggest that either forested or agricultural HDFs will transport a greater number (or mass) of invertebrates or plant materials. Forested HDFs may transport somewhat larger invertebrates than do HDFs on agricultural lands.

This study illustrates that the transport of invertebrates and plant materials by HDFs is substantial. The data suggests that each 20 cm wide segment of an ephemeral or intermittent channel contributes an average of 963 invertebrates (0.65 g) and 32.0 g of plant matter during each runoff event. Given the vast spatial extent and the potential for hundreds of thousands of headwaters to subsidize one downstream system (Freeman et al., 2007), it becomes clear that the contributions cannot be dismissed as inconsequential. Although it is not clear how far downstream the materials transported by HDFs will extend once they enter permanently flowing reaches, the River Continuum Concept and ecosystem linkage suggest that materials (invertebrates, plant matter and nutrients) are exchanged across ecosystem boundaries (particularly upstream subsidizing downstream reaches) and those exchanges have significant implications in community composition and ecosystem health (Hynes 1975; Vannote et al. 1980; Freeman et al. 2007; Meyer et al., 2007). Therefore, it is likely that the majority of the materials transported from HDFs will be available for consumption downstream and the importance and ecological contributions of HDFs to downstream fish-bearing communities are significant but, as current regulations in Southern Ontario illustrate, have historically been overlooked.

I recommend that resource managers consider the importance of HDFs in maintaining the health of downstream systems. Managing HDFs to ensure their ecological contributions remain intact will become very important as the Region of Toronto continues to develop and encroach upon this habitat. At a minimum, the application of vegetative buffer strips along the channel is recommended in order to maintain some of the ecological contributions to downstream fish habitats.

5.8 Recommendations for future study

The fate of the drift that was collected for this thesis is unknown. Although it is reasonably safe to assume that the majority of the materials captured in drift nets would be available for downstream consumption, it is unclear how long it will take for these materials to reach a permanent system downstream, or how far they will reach. Therefore, to better understand the ecological linkages between HDFs and permanent fish bearing systems it is critical to study the drift from various locations within an HDF, particularly where an HDF discharges its materials into a permanent waterway.

It also would be advantageous to compare materials transported from forested and agricultural channels to heavily modified urban channels. Such data could potential strengthen the results of this thesis in order to quantify, in absolute values, the ecological functions that are lost through urban development of HDFs.

It should be considered that yearly fluctuations in precipitation will have varying effects on the quantity of the drift. For example, during drought years drift is less likely to be underrepresented because of reduced channel flow, increasing the percentage of overland flow coursing through the drift traps.

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Appendix

Appendix A Water quality analysis of anions, cations and total phosphorus (TP). Li+ and HPO4 2- levels were below detection for all samples (0.10 and 1.66 mg/L, respectively).

Site_ID	Date	Variable (mg/L)										
		TP	F-	Cl-	Br -	NO3 -	SO4 2-	Na+	NH4+	K+	Mg 2+	Ca+
Ephemeral forested catchments												
HW_ET01	22-May-08	0.0246	< 0.30	32.70	6.06	< 0.57	2.03	19.63	< 0.54	1.80	2.98	25.61
HW_ET01	15-Aug-08	0.0395	< 0.30	38.64	< 0.65	< 0.57	1.53	17.54	< 0.54	< 0.43	< 0.26	24.24
HW_ET01	17-Sep-08	0.0441	< 0.30	15.11	3.25	< 0.57	0.39	8.31	< 0.54	0.96	1.15	9.49
HW_HUM6	02-May-08	0.0116	< 0.30	3.05	< 0.65	< 0.57	113.78	8.06	< 0.54	< 0.43	22.72	30.89
HW_HUM6	21-May-08	0.0189	< 0.30	2.31	< 0.65	< 0.57	94.76	7.62	< 0.54	< 0.43	24.93	37.15
HW_HUM6	06-Jun-08	0.0150	< 0.30	5.02	< 0.65	< 0.57	65.38	8.94	< 0.54	1.21	18.80	44.85
HW_HUM6	13-Jun-08	0.0456	< 0.30	1.89	10.08	0.82	55.89	7.49	< 0.54	8.66	1.36	25.39
HW_HUM6	19-Jun-08	0.0222	< 0.30	3.15	< 0.65	< 0.57	< 0.80	6.53	< 0.54	< 0.43	20.00	37.51
HW_HUM6	27-Jun-08	0.0531	< 0.30	0.75	< 0.65	< 0.57	24.66	8.88	< 0.54	< 0.43	28.22	25.51
HW_HUM6	04-Jul-08	-	< 0.30	1.20	< 0.65	< 0.57	40.74	7.40	< 0.54	< 0.43	< 0.26	-
HW_HUM6	10-Jul-08	0.0162	< 0.30	1.21	< 0.65	< 0.57	19.28	4.63	< 0.54	< 0.43	14.08	21.13
HW_HUM6	25-Jul-08	0.0468	< 0.30	1.25	< 0.65	< 0.57	30.82	7.95	< 0.54	< 0.43	24.66	30.27
HW_HUM6	07-Aug-08	0.0407	< 0.30	2.19	< 0.65	< 0.57	17.03	7.29	< 0.54	< 0.43	23.37	-
HW_HUM6	15-Aug-08	0.0571	< 0.30	1.43	< 0.65	< 0.57	29.62	5.19	< 0.54	< 0.43	14.91	27.67
HW_HUM6	21-Aug-08	0.0549	< 0.30	2.71	< 0.65	< 0.57	< 0.80	7.60	< 0.54	< 0.43	20.54	41.08
HW_HUM6	17-Sep-08	0.0525	< 0.30	2.87	6.80	1.48	17.99	3.17	< 0.54	1.20	7.93	29.28
HW_HUM11	02-May-08	0.0319	< 0.30	6.40	< 0.65	2.68	25.11	3.32	< 0.54	< 0.43	7.01	38.63
HW_HUM11	22-May-08	0.0204	< 0.30	6.54	7.75	< 0.57	20.17	3.08	< 0.54	0.92	7.43	30.96
HW_HUM12	02-May-08	0.00710	< 0.30	8.17	< 0.65	1.83	30.40	4.73	< 0.54	< 0.43	7.42	57.41
HW_HUM12	22-May-08	0.0264	< 0.30	5.65	< 0.65	0.94	21.23	2.79	< 0.54	0.55	5.74	34.86
HW_HUM12	25-Jul-08	0.0140	< 0.30	5.04	< 0.65	< 0.57	23.67	4.02	< 0.54	< 0.43	6.20	50.08

Appendix A (*continued*)

Ephemeral agricultural catchments

HW_HUM4	30-Apr-08	0.646	< 0.30	165.93	< 0.65	< 0.57	26.04	37.36	< 0.54	< 0.43	13.36	102.88
HW_HUM4	21-May-08	0.132	< 0.30	9.22	< 0.65	< 0.57	8.64	8.72	< 0.54	< 0.43	7.22	38.43
HW_HUM7	02-May-08	0.0634	1.94	504.58	< 0.65	< 0.57	48.82	> 220	< 0.54	< 0.43	12.78	69.78
HW_HUM7	22-May-08	0.0532	< 0.30	259.64	7.26	< 0.57	19.93	136.93	< 0.54	2.46	10.72	51.26
HW_HUM7	06-Jun-08	0.0637	< 0.30	307.17	< 0.65	< 0.57	24.13	167.61	< 0.54	3.11	9.15	59.49
HW_HUM7	13-Jun-08	0.0472	< 0.30	336.86	8.65	< 0.57	16.21	185.80	< 0.54	2.54	9.37	61.55
HW_HUM7	19-Jun-08	0.0356	< 0.30	397.84	< 0.65	< 0.57	19.18	172.20	< 0.54	< 0.43	7.61	50.82
HW_HUM7	27-Jun-08	0.0383	< 0.30	450.57	< 0.65	< 0.57	23.33	> 220	< 0.54	< 0.43	10.48	51.58
HW_HUM7	25-Jul-08	0.0419	< 0.30	188.76	< 0.65	< 0.57	23.06	127.74	< 0.54	< 0.43	6.86	46.46
HW_HUM7	31-Jul-08	0.0371	< 0.30	77.21	< 0.65	< 0.57	7.47	94.35	< 0.54	< 0.43	4.83	33.84
HW_HUM7	07-Aug-08	0.0313	< 0.30	67.62	< 0.65	< 0.57	4.85	66.88	< 0.54	< 0.43	4.30	29.77
HW_HUM7	15-Aug-08	0.0198	< 0.30	108.04	< 0.65	1.38	4.34	62.22	< 0.54	< 0.43	4.85	32.40
HW_HUM7	17-Sep-08	0.0277	< 0.30	46.71	7.32	< 0.57	8.80	27.45	< 0.54	1.36	3.58	29.69
HW_HUM8	02-May-08	0.0555	0.39	> 522	< 0.65	< 0.57	39.61	> 220	< 0.54	< 0.43	13.82	79.02
HW_HUM8	27-Jun-08	0.00950	< 0.30	103.95	< 0.65	0.65	7.77	75.18	< 0.54	< 0.43	7.62	65.07
HW_HUM8	25-Jul-08	0.0540	< 0.30	234.19	< 0.65	4.00	23.85	109.24	< 0.54	< 0.43	6.57	60.61
HW_HUM8	31-Jul-08	0.00650	< 0.30	227.21	< 0.65	< 0.57	29.23	99.29	< 0.54	< 0.43	6.38	69.85
HW_HUM8	17-Sep-08	0.0260	< 0.30	206.64	5.73	0.89	17.30	98.06	< 0.54	1.57	8.91	45.32
HW_ROU3	29-Apr-08	0.0246	< 0.30	67.87	< 0.65	3.86	23.67	34.92	< 0.54	< 0.43	10.62	43.60
HW_ROU3	20-May-08	-	< 0.30	52.04	< 0.65	2.50	< 0.80	28.01	< 0.54	< 0.43	6.38	45.53
HW_ROU3	24-Jul-08	0.0109	< 0.30	96.96	10.09	12.00	11.35	56.65	< 0.54	2.75	7.44	38.34
HW_ROU3	01-Aug-08	0.0392	< 0.30	56.32	< 0.65	3.85	11.32	29.02	< 0.54	< 0.43	7.89	23.89
HW_ROU3	06-Aug-08	0.0156	< 0.30	77.72	< 0.65	1.85	12.09	43.59	< 0.54	< 0.43	8.48	32.12
HW_ROU3	14-Aug-08	0.0216	< 0.30	65.25	< 0.65	2.30	< 0.80	28.00	< 0.54	< 0.43	7.19	20.51
HW_ROU3	17-Sep-08	0.00310	< 0.30	49.74	8.58	1.84	8.88	29.59	< 0.54	1.31	6.69	28.22

Appendix A (*continued*)

Intermittent forested catchments

HW_DUF6	29-Apr-08	0.00467	< 0.30	71.77	< 0.65	< 0.57	10.41	29.17	< 0.54	< 0.43	5.45	-
HW_DUF6	20-May-08	0.0177	< 0.30	38.63	< 0.65	< 0.57	3.96	13.97	< 0.54	< 0.43	< 0.26	35.64
HW_DUF6	05-Jun-08	0.0213	0.58	75.56	8.32	< 0.57	3.02	26.73	< 0.54	0.68	7.29	45.44
HW_DUF6	12-Jun-08	0.0292	< 0.30	75.46	8.62	< 0.57	2.55	25.81	< 0.54	0.85	8.43	45.14
HW_DUF6	18-Jun-08	0.0216	< 0.30	70.86	< 0.65	< 0.57	1.45	24.26	< 0.54	< 0.43	6.87	41.79
HW_DUF6	26-Jun-08	0.0183	< 0.30	61.27	< 0.65	< 0.57	1.07	21.95	< 0.54	< 0.43	5.12	38.36
HW_DUF6	03-Jul-08	0.0180	< 0.30	55.10	< 0.65	< 0.57	0.95	20.03	< 0.54	< 0.43	4.87	46.60
HW_DUF6	01-Aug-08	0.0413	< 0.30	59.54	< 0.65	< 0.57	3.48	25.30	< 0.54	< 0.43	6.84	55.78
HW_DUF6	06-Aug-08	0.0243	< 0.30	29.85	< 0.65	< 0.57	1.31	23.48	< 0.54	< 0.43	6.07	49.10
HW_DUF6	14-Aug-08	0.0237	< 0.30	63.07	< 0.65	< 0.57	1.85	21.80	< 0.54	< 0.43	5.89	48.81
HW_DUF6	17-Sep-08	0.0228	< 0.30	17.40	6.63	< 0.57	1.96	7.94	< 0.54	0.32	3.04	29.07

Intermittent agricultural catchments

HW_ROU4	29-Apr-08	0.00740	< 0.30	50.87	< 0.65	< 0.57	20.96	16.64	< 0.54	< 0.43	12.31	43.42
HW_ROU4	20-May-08	0.0213	< 0.30	45.56	< 0.65	< 0.57	14.98	15.18	< 0.54	< 0.43	12.64	45.09
HW_ROU4	12-Jun-08	0.0183	< 0.30	23.55	< 0.65	< 0.57	6.44	10.79	< 0.54	0.28	8.78	33.67
HW_ROU4	24-Jul-08	0.132	< 0.30	22.01	12.09	19.15	9.83	6.20	< 0.54	4.61	8.60	66.52
HW_ROU4	01-Aug-08	0.0246	< 0.30	21.69	< 0.65	1.62	7.35	7.74	< 0.54	< 0.43	9.40	38.41
HW_ROU4	06-Aug-08	0.0710	< 0.30	42.42	< 0.65	< 0.57	9.59	14.05	< 0.54	< 0.43	11.75	59.97
HW_ROU5	29-Apr-08	0.00190	2.89	179.48	< 0.65	29.22	28.36	104.47	< 0.54	< 0.43	12.49	56.15
HW_ROU5	05-May-08	-	< 0.30	181.52	< 0.65	32.83	27.56	115.78	< 0.54	< 0.43	< 0.26	50.32
HW_ROU5	20-May-08	0.0156	< 0.30	120.66	< 0.65	21.35	21.58	67.33	< 0.54	< 0.43	8.11	39.41
HW_ROU5	05-Jun-08	0.00860	0.68	83.87	< 0.65	17.58	19.50	49.78	< 0.54	0.46	7.53	35.58
HW_ROU5	12-Jun-08	0.0275	< 0.30	66.53	7.54	20.25	16.97	38.32	< 0.54	0.53	7.58	42.85
HW_ROU5	18-Jun-08	0.0083	< 0.30	90.75	< 0.65	37.50	19.59	36.49	< 0.54	< 0.43	5.22	34.37
HW_ROU5	26-Jun-08	0.0113	< 0.30	89.68	< 0.65	26.57	20.10	51.74	< 0.54	< 0.43	6.77	40.89
HW_ROU5	03-Jul-08	-	< 0.30	114.02	< 0.65	43.54	19.86	64.68	< 0.54	< 0.43	10.43	43.37
HW_ROU5	09-Jul-08	0.00590	< 0.30	122.92	< 0.65	30.95	19.39	74.07	< 0.54	< 0.43	9.02	39.14
HW_ROU5	24-Jul-08	0.0601	< 0.30	49.42	< 0.65	52.33	14.24	32.36	< 0.54	1.59	9.66	47.46

HW_ROU5	01-Aug-08	0.0168	< 0.30	64.16	< 0.65	23.94	< 0.80	31.92	< 0.54	< 0.43	5.36	27.41
HW_ROU5	06-Aug-08	0.00980	< 0.30	136.20	< 0.65	30.28	18.62	83.40	< 0.54	< 0.43	10.59	40.37
HW_ROU5	14-Aug-08	0.00980	< 0.30	91.72	< 0.65	22.07	14.04	56.49	< 0.54	< 0.43	7.58	36.93
HW_ROU5	20-Aug-08	0.00440	< 0.30	117.65	< 0.65	21.63	15.20	59.11	< 0.54	< 0.43	6.98	31.01
HW_ROU5	17-Sep-08	0.0183	0.58	56.32	8.15	17.76	11.69	34.43	< 0.54	0.75	7.76	33.14

Appendix B1 Full taxonomic resolution of all aquatic invertebrates transported from ephemeral and intermittent channels.

	Ephemeral Channels		Intermittent Channels	
Taxonomic Group	**Forested**	**Agricultural**	**Forested**	**Agricultural**
Annelida				
Hirudinea	0	0	202	2
Oligochaeta	19	1265	268	182
Arthropoda				
Arachnida				
Acariformes	3	7	286	228
Crustacea				
Amphipoda				
Gameridae	21	0	20	0
Hyalellidae				
Hyalella	0	7	0	0
Unknown Amphipoda	14	2	121	0
Cladocera				
Daphniidae				
Daphnia	0	0	24	0
Copepoda	627	1460	6305	7059
Decapoda	0	11	0	0
Isopoda				
Asellidae	0	0	0	3
Ostracoda	272	2307	871	4275
Insecta				
Coleoptera				
Chrysomelidae				
Donacia	0	0	0	42
Dryopidae				
Helichus	1	0	0	0
unknown	0	8	0	0
Dytiscidae				
Agabus	1	0	0	46
Celina	0	0	0	1
Hydroporous	3	0	0	16
unknown	0	3	405	269
Elmidae				
Optioservus	0	0	0	1
unknown	0	1	21	3
Haliplidae				
Haliplus	0	0	0	1
Peltodytes	0	0	119	1

Appendix B1 (*Continued*)

Hydrophilidae				
Berosus	0	7	0	1
Crenitis	5	29	1	44
Helocombus	5	4	0	0
Helophorus	12	92	0	33
Hydrobius	2	1	0	3
Hydrochus	0	0	2	0
Laccobius	8	0	0	0
Paracymus	0	11	0	10
Tropisternus	1	1	0	0
unknown	31	39	10	55
Unknown Coleoptera	2	4	4	174
Diptera				
Ceratopogonidae				
Stilobezzia	1	0	0	0
Probezzia	0	0	0	3
Leptoconops	0	0	0	22
unknown	2	40	54	269
Chironomidae				
Limnophyes	0	0	11	0
Krenopsectra	0	0	1	0
Orthocladiinae	0	83	0	0
Smitta	2	0	0	0
Tanypodinae	2	0	0	0
unknown	1011	1638	2939	35671
Culicidae	16	8	2	185
Dixidae				
Dixa	1	0	0	0
Empididae				
Hemerodromia	0	0	0	3
Ephydridae				
Paracoenia	0	0	0	11
unknown	2	0	15	19
Psychodidae				
Pericoma	0	26	20	59
unknown	0	7	0	0
Ptychopteridae				
Ptychoptera	2	0	0	0
Sciomyzidae	0	0	24	0
Simuliidae	677	11	0	456

Appendix B1 (*Continued*)

Stratiomyidae				
Allognasta	0	0	10	0
Oxycera	0	0	0	3
Stratiomys	0	36	2	51
unknown	7	30	53	141
Tabanidae	0	11	1	0
Tipulidae				
Holorosia	4	0	0	0
Limophila	0	1	0	0
Megistocera	1	0	0	0
Tipula	31	20	11	1
unknown	26	50	127	7
Unknown Diptera	571	964	165	1702
Ephemeroptera				
Baetidae	1	0	0	0
Caenidae				
Caenis	0	0	1	0
Unknown Ephermeroptera	11	7	0	1
Hemiptera				
Corixidae				
Hesperocorixa	0	1	0	0
Gerridae	0	0	1	0
Hebridae	0	8	0	0
Mesoveliidae				
Mesoelia	0	0	0	2
Saldidae	2	5	0	0
Pleidae				
Neoplea	1	0	141	1
Unknown Hemiptera	2	5	1	0
Odonata				
Cordulegastridae				
Cordulegaster	0	0	3	0
Libellulidae				
Ladona	0	0	1	0
Unknown Odonata	5	5	3	0
Plecoptera				
Nemouridae	0	2	0	0
Perlodidae	0	0	0	1
Unknown Plecoptera	2	0	2	0

Appendix B1 (*Continued*)

Trichoptera				
Limnephilidae	0	5	5361	34
Phryganeidae	0	0	0	1
Unknown Trichoptera	2	9	29	36
Chordata				
Actinopterygii				
Gasterosteiformes				
Gasterosteidae				
Culaea inconstans	0	0	0	8
Mollusca				
Gastropoda				
Hydrobiidae	0	0	0	1
Lymnaeidae				
Fossaria	4	69	0	694
unknown	58	1	3	20
Physidae				
Physella	0	0	0	129
Physinae	0	52	0	0
unknown	0	0	0	40
Planorbidae				
Gyraulus	0	0	0	137
Planorbella trivolvis	0	0	0	2
unknown	5	4	0	16
Unknown Gastropoda	1	0	0	171
Bivalvia				
Veneroida				
Sphaeriidae				
Musculium	0	0	0	10
unknown	1	17	11	324
Platyhelminthes	0	1	0	0

Appendix B2 Full taxonomic resolution of all terrestrial invertebrates transported from ephemeral and terrestrial channels.

	Ephemeral Channels		Intermittent Channels	
Taxonomic Group	**Forested**	**Agricultural**	**Forested**	**Agricultural**
Annelida				
Oligochaeta	528	1117	161	3
Arthropoda				
Arachnida		0		0
Acariformes	1589	1618	4718	643
Araneae	31	77	55	121
Chilopoda				
Geophilida	0	5	0	0
Lithobiida	8	4	24	0
Collembola	578	1820	399	962
Crustacea				
Isopoda	56	164	122	87
Diplopoda				
Julida	94	39	37	10
Insecta				
Coleoptera				
Anthribidae	0	4	0	0
Cantharidae	0	0	0	1
Carabidae	0	0	0	1
Cerambycidae	0	0	0	1
Chrysomelidae				
Calligrapha	0	4	0	0
unknown	4	3	0	0
Ciidae	1	0	0	0
Cleridae	3	0	0	0
Cuccinellidae	0	5	0	0
Curculionidae	2	22	14	8
Lucanidae	1	0	0	0
Scarabaeidae	0	17	0	1
Silphidae				
Nicrophorus	0	12	0	0
Staphylinidae	9	91	2	14
Unknown Coleoptera	123	444	406	265
Dermaptera	3	3	0	0
Diptera				
Syriphidae	0	0	1	0
Unknown Diptera	67	436	115	41

Appendix B2 (*Continued*)

Hemiptera				
Aphididae	0	62	60	268
Cercopidae	8	0	0	0
Cicadidae	1	0	0	0
Cicadellidae	4	9	0	0
Lygaeidae	0	5	0	0
Thyreocoridae				
Corimelaena	0	0	10	0
Unknown Hemiptera	26	102	114	211
Hymenoptera				
Andrenidae	1	0	0	3
Apoidea	0	1	0	0
Chalcidoidea	1	0	0	0
Colletidae	1	0	0	0
Crabronidae	1	0	0	0
Formicidae	5	438	135	190
Ichneumonidae	1	0	0	0
Unknown Hymenoptera	94	202	93	4
Lepidoptera				
Geometridae	0	10	5	0
Unknown Lepidoptera	6	6	1	1
Phthiraptera	0	0	0	1
Psocoptera	0	3	11	0
Orthoptera				
Acrididae	0	12	0	0
Unknown Orthoptera	0	4	0	0
Thysanoptera	126	70	54	9
Mollusca				
Gastropoda	596	4880	397	776
Unknown Invertebrates	10	21	50	142