

**Macroinvertebrate and Zooplankton Communities  
of the Willard Spur Wetlands:  
Results of 2012 Sampling**

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## 1. Summary

The results of macroinvertebrate and zooplankton sampling in the Willard Spur in 2012 are described. Sampling emphasized the open-water, mid-channel sites that were previously sampled in 2011. Samples collected in 2012 were taken each month between April and November. Unlike the plentiful water supplies present in 2011, 2012 had reduced inflows, resulting in low water conditions at many sites after July. Thus, not all sites could be sampled each month. In addition to low water levels causing stagnant conditions, invertebrate communities were affected by the rapid decline in the condition and abundance of submerged vegetation that occurred in mid-summer.

Macroinvertebrate communities in 2012 had the same taxa present as in 2011, but the relative abundance of major taxa shifted to a greater dominance by midges (Chironomidae) and reduced importance of mayflies and damselflies. Overall abundance of macroinvertebrates was higher due to large numbers of chironomids and corixids. In contrast to communities present in 2011, key metrics, such as the percentage of phytophilous macroinvertebrates and Simpson's Index, declined rapidly in mid-summer 2012, reflecting the loss of submerged vegetation. Stagnant conditions in late summer onwards resulted in a community dominated by taxa adapted to low dissolved oxygen environments.

Life cycles of common macroinvertebrate taxa were examined in greater detail in 2012. Mayflies (*Callibaetis* and *Caenis*), chironomids (*Chironomus* and *Tanytus*), and snails (*Physella* and *Gyraulus*) all appeared to have two generations per year in the Willard Spur with peak abundance occurring in mid- to late summer. Larger Hemiptera, such as *Notonecta* and *Hesperocorixa*, had one generation per year, but the smaller *Corisella* corixids had at least two generations. The amphipod *Hyaella* had a least two generations, while the caddisfly *Ylodes* had one (possibly two) generations per year. Low water levels and stagnant conditions resulted in the loss of the overwintering generations of many macroinvertebrate taxa from the open-water sites.

Stable isotope and gut content analyses were conducted to determine the trophic positions of common macroinvertebrate taxa. For most taxa, <sup>15</sup>N signatures confirmed literature characterizations of trophic position; examples include herbivore-detritivores (mayflies, *Chironomus*, *Hyaella*, *Enochrus* adults, and snails) and predators (odonate larvae and adult *Notonecta*). Late-instar *Notonecta* and *Enochrus* larvae were omnivores. Adult *Corisella* corixids were either predators or omnivores, depending upon the location of collection. *Hesperocorixa*, a corixid characterized as either a predator or piercer-herbivore in the literature, was determined to be a predator in the Willard Spur. *Tanytus*, a chironomid characterized as either a predator or herbivore-detritivore, was determined to be the latter in the Willard Spur.

Zooplankton communities in the Willard Spur were composed of species typical of the impounded wetlands bordering the Great Salt Lake. The most common copepod and rotifer were *Eucyclops* and *Asplanchna*, respectively. Common cladocera included daphnids (*Daphnia* spp., *Simocephalus*, *Scapholeberis*, and *Ceriodaphnia*), chydorids (*Pleuroxus* spp., *Chydorus*, and *Alona*), *Moina*, and *Macrothrix*. Like the macroinvertebrates, the zooplankton responded to the changes in habitat conditions in the Willard Spur between years. Zooplankters associated with submerged vegetation, such as *Simocephalus* and *Scapholeberis*, declined in relative abundance in 2012 compared to 2011, whereas *Moina*, an indicator of stagnant conditions, increased in relative abundance.

## 2. Introduction & General Methods

This report summarizes the results of 2012 sampling of the macroinvertebrate and zooplankton communities present in the Willard Spur wetlands as part of the development of water quality standards pursuant to the operation of the newly-constructed Perry/Willard Regional Wastewater Treatment Plant. In the first section, the status of the macroinvertebrate community is given with a comparison to results of 2011 sampling. The second section presents the results of life cycle studies of selected macroinvertebrates during 2012. The third section summarizes the trophic status of selected macroinvertebrates based on stable isotope analyses. The final section describes the composition of the zooplankton community in 2012 with comparisons to the community present in 2011.

Habitat conditions in the Willard Spur during the 2012 sampling period were very different from conditions in 2011. Spring runoff was reduced in 2012, resulting in rapidly declining water levels and stands of submerged aquatic vegetation by mid-summer. Beginning in July, some sites could not be sampled in subsequent months due to low water depths, particularly in the upper and lower sections of Willard Spur. Water temperatures responded to warmer temperatures in the spring, allowing many macroinvertebrates to begin reproduction earlier than in 2011.

Macroinvertebrate and zooplankton samples were collected from the Willard Spur by Utah Division of Water Quality personnel. Sampling began in April 2012 and continued monthly through November 2012. Samples typically were collected the third week of each month. Macroinvertebrates were collected with a D-net sampler (0.5-mm mesh) according to the DWQ SOP. Zooplankton were collected with a tow net (0.25-mm mesh) according to DWQ SOP. Samples were preserved in the field in ethanol. Processing of samples followed DWQ SOPs. Data collected for macroinvertebrates included counts of individuals by taxon, biomass, and derived community metrics (Simpson's Index and %PMI; Gray 2012). Zooplankton data included counts of individual taxa that were used to determine percentage composition of the community.

Occasional references are made below to results of a DWQ study that examined 53 other impounded wetlands of the Great Salt Lake from June to September 2012. Macroinvertebrate and zooplankton samples from that study were collected and processed using the same DWQ SOPs as the Willard Spur samples.

### 3. Macroinvertebrate Communities

The list of macroinvertebrate taxa collected at all sites in the Willard Spur during 2012 is given in Table 3.1. Although the taxa present were the same as in samples collected in 2011, the macroinvertebrate community showed significant changes in the relative contribution of the various taxa between years. The more rapid decline in the aquatic vegetation and increasingly stagnant conditions as water levels dropped shifted to community towards one dominated by benthic-feeding detritivores and taxa tolerant of low oxygen, such as chironomids and corixids, relative to taxa associated with the aquatic vegetation, such as damselflies and mayflies (Fig. 3.1).

The overall abundance of macroinvertebrates was higher in 2012 than in 2011. Counts per sample were nearly five times greater in 2012 than in 2011 (mean of 854 individuals/sample in 2012 vs. 160 individuals/sample in 2011) with smaller increases in biomass (0.54 g/sample in 2012 vs. 0.45 g/sample in 2011) and total taxa (7.6 taxa/sample in 2012 vs. 7.1 taxa/sample in 2011). Sample counts were similar in both years up until June; thereafter, sample counts were significantly higher in 2012 (Fig. 3.2). These higher sample counts largely were due to much higher numbers of corixids from May through July and chironomids from August through November.

Changes in community metrics reflected the decline in condition and quantity of the submerged vegetation that began in June and became pronounced in July. In 2011, average values of the %PMI and Simpson's Index (SI) metrics at the open-water sites showed gradually increases from spring through mid-summer (Figs. 3.3 & 3.4). %PMI continued to increase through October with the recruitment of overwintering generations of mayflies and damselflies. 2012 values of %PMI showed a similar increase in spring through early summer but decreased rapidly after July. By October, PMI taxa were absent from samples at all sites. The SI metric was less sensitive to the habitat changes in mid-summer, but it also declined to significantly lower values from September through November. In contrast, SI values in 2011 remained relatively high from July through October.

More detailed trends at selected sites in the %PMI metric for both years are given in Figures 3.5 & 3.6 (sites selected were those in which sampling occurred throughout the study period in each year). In 2011, %PMI peaked in August at the upper Spur sites and then declined by October, whereas values increased during the summer at WS-6 (middle Spur) before peaking in October. In 2012, the peak in %PMI occurred earlier at each site. Subsequent declines in values followed a downstream trend with values decreasing progressively later with distance from the outfall confluence/WS-1 sites. SI values in 2011 at the selected sites generally were consistent from August through October, whereas all sites had a general decline from summer through fall (Figs. 3.7 & 3.8).

From August through October, the continued drop water levels resulted in increasingly more severe conditions for macroinvertebrates. At site WS-3, for example, CBOD increased from 0 mg/L in July to 26 mg/L in October. This oxygen stress resulted in a macroinvertebrate community by October that consisted almost entirely of "blood worms" (chironomids with oxygen-binding pigments in the hemolymph, such as *Chironomus* and Tanypodinae) and macroinvertebrates that breathe atmospheric air (e.g., corixids).

At site WS-3, total dissolved solids increased from  $\approx 2.4$  ppt in July to  $\approx 9.3$  ppt in October. This increase in salinity may also have contributed to the decline in populations of chironomids in October (Figs. 4.7 & 4.8). Galat et al. (1988) found that *Chironomus* mortality increased greatly when salinity exceeded 8 ppt over an extended period.

Snails were absent after August despite the presence of numerous egg masses in August samples (Fig. 4.10). Although adult pulmonate snails can use atmospheric air as necessary, some dissolved oxygen is needed for eggs to develop and hatch (Harman 1974). Early-instar *Ischnura* were abundant in September, but few survived to October (Fig. 4.3); likewise, *Callibaetis* and *Caenis* mayflies were absent after September (Fig. 4.1 & 4.2). The loss of the overwintering generations of the main PMI taxa means that recovery of these populations in the Willard Spur in 2013 initially will depend upon immigration of individuals from other wetlands.

Macroinvertebrates were sampled regularly at several other sites not included in the "open-water" category. These sites included the tailrace from Willard Bay leading into Willard Spur and the site within Willard Spur adjacent to the outflow from the Harold Crane Wildlife Management Area drainage ditch.

The inflow tailrace site was sampled every month from April to November. Few macroinvertebrates were present. Only five taxa were found at the site, and sample counts varied from 4 to 120 individuals per sample. The fauna consisted entirely of chironomids (4 taxa and 99% of total individuals) and oligochaetes.

At the outflow tailrace site, the fauna was more varied in terms of taxa when it was sampled from April to June (6 to 12 taxa per sample), but most individuals were either *Corisella* corixids (32%) or chironomids (47%). PMI taxa comprised less than 2% of individuals present.

The Harold Crane site was sampled from April to June and again in October-November. Total taxa varied from 5 to 10 per sample. There was little change in composition of the fauna between seasons; dominant taxa were chironomids (60% of total individuals), *Corisella* corixids (22%), and oligochaetes (10%). PMI taxa were less than 1% of total individuals.

## 4. Life Cycles of Wetlands macroinvertebrates

### 4.1 Introduction

The life cycles of common macroinvertebrates in the Willard Spur were examined during the 2012 sampling in order to better understand natural fluctuations in populations. Unlike other groups of organisms, macroinvertebrate numbers can be affected significantly by emergence of adult insects, semelparity (adults die after reproducing), and variation in the length of life stages (e.g., length of time required for eggs to hatch). These factors can affect the interpretation of external impacts on the wetlands.

For this study of life cycles, individuals were examined primarily from the sweep samples used in the primary sampling program. This methodology imposed several limitations on the examination of life cycles, including:

1. numbers of individuals of a particular taxon may be insufficient for size class analysis from single site samples, thus requiring the use of multiple samples from several sites to obtain enough individuals;
2. the 0.5-mm mesh size of the sweep nets allows early instars of many taxa to pass through and thus be underrepresented in samples;
2. no emergence traps were used, so no information is available directly on emergence periods for some taxa (e.g., odonates, mayflies, chironomids);
3. the Willard Spur is not an isolated wetland, thus recruitment likely occurred from adults immigrating from nearby wetlands in addition to *in situ* populations;
4. only mid-channel (thalweg) sites were sampled during the study period, and not all of these sites were sampled in each sampling period due to declines in water level; and
5. multiple species are possible within some taxa (e.g., chironomids, damselflies); however, there is no current way to tell different species apart as immatures.

Individuals were assigned into size (age) classes for histogram construction. For the mayflies, damselflies, and amphipods, body length (as correlated with head capsule width in the insects) was used to assign individuals into size classes. Head capsule width was used to determine chironomids instars. Instars of the hemipterans (corixids, notonectids) were determined from wing pad development.

Comparisons to life cycles in other GSL wetlands are based on observations from previous studies (Gray, 2009-2011). Table 4.1 presents water temperature and degree-days by month for 2012 based on data collected from May 2 through September 19/20 by monitoring probes at sites WS-2 and WS-6. Table 4.2 gives an overall summary of number of generations per year and period of peak abundance for each taxon.

## 4.2 Mayflies (*Callibaetis* and *Caenis*)

*Callibaetis* is common throughout the GSL wetlands. It is unusual compared to other mayflies in that adults are relatively long-lived (females can live up to 2 weeks) and ovoviviparous (eggs are retained by the female for several days and hatch immediately upon contact with water; Edmunds et al. 1976). Edmunds et al. (1976) state that “certain species” have a larval development time of 6 weeks (presumably during the summer). In a detailed study of *C. fluctuans* in a West Virginia marsh, Johnson et al. (2000) found 3 generations per year. Their data indicate that the June generation required only 35 days for larval development (ca. 900 degree-days), whereas the subsequent late summer generation required 107 days for development and approximately 2000 degree-days. Larval development time of the overwintering generation was 227 days. In Florida, *C. floridanus* required 1 month for larval development at 28-32°C (approx. 800 degree-days) during summer and 60-75 days for development at 18-20°C (approx. 1200-1400 degree-days) in November (Trost & Berner 1963).

In the Willard Spur in 2012, early instars first appeared in June from reproduction by the overwintering generation. Later instars dominated in July and August (Fig. 4.1), suggesting a second generation that would give rise to the overwintering generation in fall. The period from late July to late September had sufficient degree-days (ca. 1200) for development of another generation; however, this could not be confirmed due to the lack of *Callibaetis* in samples after August. In previous sampling in other GSL wetlands, early instars were common in October-November samples (Gray 2010, 2011). Thus, *Callibaetis* likely has 2, and possibly 3, generations per year in the Willard Spur.

*Caenis amica* is the other species of mayfly present in the Willard Spur. Edmunds et al. (1976) considered it to be bivoltine but with extended adult emergence during summer and fall. Taylor & Kennedy (2006) found 5 overlapping generations per year for *C. latipennis* in Oklahoma; summer generations required 70-77 days (1711-1730 degree-days) to complete larval development. In addition, they found that this species did not emerge as adults if the water temperature was below 14 °C.

In the Willard Spur, early instars dominated in April, while late instars (presumably emerging adults as well) were present in May and June (Fig. 4.2). Early instars were common again in July and August. No larvae were collected after August, but a mix of instars are commonly found in fall samples from other GSL wetlands (Gray 2010, 2011). Temperature data from the Willard Spur indicated a sufficient number of degree-days (ca. 1900) from early May through July for a summer generation to develop. Thus, it appears that *Caenis* has 2 generations per year, an overwintering generation that emerges in spring and a summer generation with extended emergence through fall.

### 4.3 Damselflies (*Ischnura*)

The discussion of odonate life cycles emphasizes the life cycle of *Ischnura*, the most common damselfly in the Willard Spur. Other damselflies (e.g., *Archilestes*) and dragonflies were collected in insufficient numbers for life cycle determination.

Coenagrionid damselflies typically have one generation per year, although some *Ischnura* are bivoltine (Corbet 1999, Pennak 1978). Corbet (1999) noted that voltinism decreased with increasing latitude and that the limit on bivoltinism in *Ischnura* was 42° N latitude. Baker et al. (1992) found *I. verticalis* in southern Ontario had 1 generation per year with a 97-day emergence period in summer. A laboratory study of *I. evansi* found that total developmental time from egg to adult required 278 days at 25°C, or nearly 7000 degree-days (Marzoq et al. 2004).

In the Willard Spur, April samples had a mix of early, middle, and late instars that had overwintered (Fig. 4.3). Late instars then dominated the population through July. August and September samples were mostly early instars. Overall, it is likely that *Ischnura* is univoltine in the Willard Spur with extended emergence of overwintering larvae in spring and early summer followed by an extended reproductive period from August into fall. The abundance of early instars in 2012 peaked about one month earlier than in 2011 and likely is related to the warmer water temperatures in spring and early summer 2012 compared to 2011.

### 4.4 Water boatmen (*Corisella* and *Hesperocorixa*) and Backswimmers (*Notonecta*)

Corixids have relatively rapid larval development. For temperate corixids in general, Lauck (1979) states that reproduction occurs during the warmer months; eggs hatch in 1-2 weeks with each of the 5 instars lasting 7-10 days (or 42-64 days total for development from egg to adult). Sweeney & Schnack (1977) found that *Sigara alternata* in Pennsylvania required 52 days (900 degree-days) for larval development. Two corixid species in a Mexican lake required 5-6 weeks (ca. 630-760 degree days) for development (Peters & Spurgeon 1973).

*Corisella decolor* was the most common species of corixid in the Willard Spur in 2012 and the one emphasized for life cycle study. The relatively warm water temperatures in spring allowed an early start to reproduction by overwintering adults in May and June (Fig. 4.4). This summer generation became adults by late July and started another generation in August. Given the number of degree-days, it is possible that another generation, smaller in number than the other two generations, was present between June and August. Alternatively, age structure may have been affected by adults immigrating from other wetlands during this time.

In previous sampling of other GSL wetlands in years with cooler spring temperatures, reproduction of the overwintering adults does not begin until mid-June. Subsequently, reproduction from the summer generation does not begin until September. Thus peaks in early instars occurred one month earlier than usual for both the spring and late summer generations.

For *Hesperocorixa*, early instars were present only in late June (Fig. 4.5). Only adults were present from July through September, indicating a single generation. This

life cycle pattern is similar to that present in other GSL wetlands, although reproduction may occur at other sites until early August.

*Notonecta* was similar in life cycle to *Hesperocorixa* (Fig. 4.6). Reproduction was greatest in July and August with only adults present afterward.

#### 4.5 Midges (Chironomidae: *Chironomus* and *Tanypus*)

The life cycle of *Chironomus frommeri* in Utah Lake was studied in detail by Shiozawa and Barnes (1977). They found that larvae overwintered as late instars that emerged over an extended period from May through late June. Onset of the summer generation peaked in early July with emergence occurring late July through August. Reproduction from the summer generation formed the overwintering population. Thus *C. frommeri* had 2 main generations (overwintering and summer), although some emergence of adults and reproduction occurred throughout the warmer months.

In the Willard Spur, *Chironomus* followed a similar life cycle (Fig. 4.7). Heavy emergence in spring from overwintering late-instar larvae led to an extended period of recruitment through June. From July through October, there was continuous recruitment and emergence. Numbers of larvae greatly increased in September compared to July and August; in Utah Lake, this peak in larval numbers occurred in August. The delay in the peak numbers in the Willard Spur may be the result of relatively high water temperatures in July and August. Frouz et al. (2002) found that high temperatures can inhibit larval growth in *Chironomus*. In previous sampling in the GSL wetlands, *Chironomus* numbers typically were lowest in August.

Shiozawa and Barnes (1977) found that *Tanypus stellatus* was bivoltine in Utah Lake. The peak emergence of the overwintering generation occurred in July and was followed by emergence of the resulting summer generation in August-September. They found that the summer generation completed development in ca. 6 weeks and was smaller in number than the overwintering generation. In the Willard Spur, late instars of *Tanypus* dominated the larval population through August, but recruitment was evident as early as mid-June (Fig. 4.8). Emergence and recruitment was continuous from August through October. In contrast to the Utah Lake study, larval densities greatly increased in the late summer-fall compared to spring-early summer.

#### 4.6 Amphipoda (*Hyalella*)

*Hyalella* overwintered mainly as adults in the Willard Spur and had peaks in reproduction in July and September (Fig. 4.9). A similar pattern occurred in 2011. During the warmer months, *Hyalella* females are capable of producing multiple broods (Pennak 1978), and reproduction can be continuous when water temperatures are above 12°C (Strong 1972).

#### **4.7 Snails (*Physella* and *Gyraulus*)**

The population trends for these snails in the Willard Spur from March 2011 to October 2012 is given in Figure 4.10. Both species began to increase in June from reproduction by overwintering adults and reached peak densities in July. An abundance of egg masses was present in August of both years. Densities then remained steady through October in 2011, but populations declined in 2012 to the point where no snails were collected in mid-channel samples after August.

The pattern of reproduction in early summer from the overwintering generation with a second period of reproduction in late summer is typical of the pattern found in other GSL wetlands and fits the “Type C” bivoltine life cycle of pulmonate snails (Dillon 2000). The warmer spring and early summer temperatures in 2012 compared to 2011 allowed reproduction to begin earlier and produce higher densities in July. Samples collected from peripheral sites in shallower water indicated that snail reproduction occurred earlier at these sites than at the mid-channel sites, thus the large increase in densities in July 2012 in the mid-channel may be partly due to an influx of snails from peripheral sites.

#### **4.8 Caddisflies (*Ylodes* (*Triaenodes*))**

In samples taken from various sites throughout the GSL wetlands since 2007, cases of these caddisflies were commonly found attached to *Stuckenia* during summer but lacking larvae. Larvae were typically present in very small numbers, primarily in late fall.

During 2012, however, *Ylodes* was more abundant throughout the GSL wetlands, including the Willard Spur, and larvae were collected throughout the study period. Early instars were present in May and again in September, suggesting there may have been a summer generation in addition to an overwintering generation. Ross (1944) noted that *Triaenodes tarda* in Illinois lakes had an extended emergence period through the summer, indicating more than one generation.

## 5. Stable Isotope Analyses

### 5.1 Introduction

One of the primary research areas regarding the biota of Willard Spur is the characterization of food webs and feeding relationships among consumer organisms. This characterization includes not only the role of macroinvertebrates within the wetlands food web in general, but also the food web within the macroinvertebrate community. A research activity during the 2012 sampling was to further elucidate the feeding roles of common macroinvertebrates using stable isotopes ( $^{15}\text{N}$  and  $^{13}\text{C}$ ).

Stable isotopes have become increasingly common as a means of determining the trophic position of invertebrates in a variety of aquatic and terrestrial habitats (IAEA 2009). Although gut analysis can be useful for determining specific items ingested during feeding, it does not necessarily reflect differential digestion and assimilation of the various food items. In aquatic environments, detritus and algae, for example, vary widely in nutritional value and are often ingested indiscriminately as a result of the feeding method used. In addition, some animals feed in a manner that does not result in identifiable remains in the gut. For example, most hemiptera have piercing mouthparts and ingest only fluids from their food. Isotopic analysis can provide valuable additional information, because animal tissues reflect the isotopic composition of the foods ingested, or, as commonly stated, “you are what you eat.” Although the mechanisms behind changes in isotopic concentrations with trophic level are poorly understood, there are consistent, ubiquitous trends in changes in isotopic concentrations regardless of habitat or trophic level (AEIA 2009, Gladyshev 2009, Mulholland et al. 2000, Vander Zanden & Rasmussen 2001).

Stable isotope data are presented as the relative difference between ratios of heavy-to-light stable isotopes of a sample and a standard. A differential notation known as the delta ( $\delta$ ) notation is used express these relative differences:

$$\delta R (\text{‰}) = [R_{\text{sample}}/R_{\text{standard}} - 1] \times 10^3$$

where  $R = {}^{13}\text{C}/{}^{12}\text{C}$  or  ${}^{15}\text{N}/{}^{14}\text{N}$ ;  $\delta R = \delta^{13}\text{C}$  or  $\delta^{15}\text{N}$  as parts per thousand (‰).

$\delta^{15}\text{N}$  is the most commonly used metric to measure the trophic position of a particular animal. Changes in  $\delta$  values (or “signatures”) follow the trend of an increase of 1-3 ‰ with each increase in trophic position, i.e., secondary consumers (predators) will concentrate  $^{15}\text{N}$  to a greater extent than primary consumers (herbivores and detritivores). A similar trend may occur in  $\delta^{13}\text{C}$ , although it is more variable and changes between trophic levels are much less than that for  $\delta^{15}\text{N}$ .  $\delta^{13}\text{C}$  has been more useful as a means of distinguishing plant and detritus sources as food items. This discrimination occurs as a result of large  $\delta^{13}\text{C}$  differences between plants with the typical C3 photosynthetic pathway versus plants with the C4 photosynthetic pathway.

## 5.2 Methods

Macroinvertebrates for stable isotope analysis were collected on 25 July 2012 at sites WS-2 and WS-6 using a standard sweep net. Samples were placed on ice after collection. Animals were separated from debris and sorted into taxa and size/age classes. Animals that were still alive were kept in clean water overnight to allow gut clearance. Dead animals, especially midge (Chironomidae) larvae, had gut contents dissected out as the residual gut flora can cause anomalous  $\delta^{15}\text{N}$  values (Goedkoop et al. 2006). Specimens were then dried in a drying oven, ground to a fine powder, and placed in labeled vials. Isotopic analyses were conducted by the Archaeological Center Research Facility at the University of Utah. Each sample was analyzed in triplicate if sufficient material was available. The standard deviation of a  $\delta^{15}\text{N}$  or  $\delta^{13}\text{C}$  value for an individual specimen was typically 0.1 to 0.2‰.

Trophic position is defined as a value that represents the energy-weighted number of energy transfers leading to the particular consumer. Because of the enrichment in  $^{15}\text{N}$  that accompanies each energy transfer, the trophic position of a species can be calculated using the following formula (Gladyshev 2009):

$$\text{TP}_x = (\delta^{15}\text{N}_x - \delta^{15}\text{N}_{\text{base}}) / \Delta\delta^{15}\text{N} + \text{TP}_{\text{base}}$$

where:

$\text{TP}_x$  = the Trophic Position of the species;

$\delta^{15}\text{N}_x$  = the  $^{15}\text{N}$  “signature” of the species;

$\delta^{15}\text{N}_{\text{base}}$  = the  $^{15}\text{N}$  “signature” of the baseline species;

$\Delta\delta^{15}\text{N}$  = the trophic enrichment constant (i.e., average change in  $^{15}\text{N}$  signature between trophic levels); and

$\text{TP}_{\text{base}}$  = trophic position of the baseline species.

The snail *Gyraulus* was chosen as the baseline species due to its well-known feeding habits as a grazer (Anderson & Cabana 2007), thus it was assigned a trophic of 2. A value of 2.9 was used as the trophic enrichment constant (Vander Zanden & Rasmussen 2001).

Producer biomass and detritus were collected in the net sweep samples and were included as a reference point for consumer isotopic values. The detritus fraction included amorphous material that passed through a 0.25-mm sieve.

### 5.3 Results and Discussion

The isotopic values for the various macroinvertebrate taxa, producers, and detritus are given in Table 5.1. The trophic position of each macroinvertebrate is represented in Figure 5.1.

The odonates were all predators based on their  $\delta^{15}\text{N}$  signatures. These results agree with typical literature characterizations; odonate larvae are considered to be predators in nearly all circumstances (Corbett 1999). An examination of the gut contents of late-instar *Ischnura* nymphs from July sweeps revealed that chironomid larvae were the most common prey. Other prey items included copepods and unidentifiable invertebrates.

Among the Hemiptera, adult *Notonecta* were predators according to their  $\delta^{15}\text{N}$  signature, and this characterization is consistent with literature descriptions (e.g., Polhemus 2008). Late instars of *Notonecta* were included in the isotopic analysis to see if there was a difference in their  $\delta^{15}\text{N}$  signature compared to the adults. Late instars had a lower  $\delta^{15}\text{N}$  signature than the adults, indicating possible omnivory.

*Corisella* corixids are typically described as predators in literature descriptions (e.g., Polhemus 2008). Individuals from site WS-2 fit this description. However, individuals from site WS-6 has a lower  $\delta^{15}\text{N}$  signature, suggesting possible omnivory.

*Hesperocorixa* has been described “piercer-herbivore” (Polhemus 2008), and this characterization was used as a factor in including this corixid in the %PMI metric (Gray 2010). The  $\delta^{15}\text{N}$  signature of adult *Hesperocorixa*, however, indicated it was a predator in the Willard Spur.

Among the herbivores/detritivores, also known as collectors/grazers, all fit the typical characterization given for each in the literature (Barbour et al. 1999, Waltz & Burian 2008). The gut contents of *Caenis*, *Hyalella*, and *Chironomus* larvae were filled with fine detritus with few diatoms or other algae present. Snails consumed mostly fine detritus, but there were more diatoms present compared to the other detritivores..

Numerically, *Tanypus* is the most common midge in the subfamily Tanypodinae that is found in the Willard Spur. The Tanypodinae typically are characterized as predators of other invertebrates (Barbour et al. 1999, Ferrington et al. 2008). *Tanypus*, at least in the Willard Spur, was a detritivore as indicated by its  $\delta^{15}\text{N}$  signature and examination of its gut contents. In the literature, Barbour et al (1999) list *Tanypus* as a predator for its primary trophic level and collector-gatherer for its secondary trophic level. Ferrington et al. (2008) give a similar description. A laboratory study by Palavesam et al. (2009) found that *Tanypus* larvae could thrive on a diet consisting solely of algae and detritus.

The hydrophilid beetle *Enochrus* was included in the analysis, because it is a common beetle in the Willard Spur and the GSL wetlands in general. Hydrophilid beetles typically have predaceous larvae and herbivore/detritivore adults (Leech & Chandler 1956). *Enochrus*, however, is characterized as either a collector/gatherer (larvae) or as a piercer-herbivore (adults; White & Roughley 2008). In the Willard Spur,  $\delta^{15}\text{N}$  signatures indicate a trophic position of adults as herbivores, but the larvae may be more omnivorous.

## 6. Zooplankton Communities

Zooplankton samples in the Willard Spur were collected at the same time as macroinvertebrate samples during 2011 and 2012. For this study, the zooplankton community is defined as consisting of crustaceans (Cladocera and Copepoda) and plioimate rotifers. The qualitative nature of the sampling method means that comparisons between communities presented here are restricted to broad similarities and differences in relative abundance and species composition.

Samples were collected from all of the sites also sampled for macroinvertebrates, although not all sites were sampled on each date. In 2011, samples were collected on 8-24 June, 6-7 July, 8-12 August, and 11-13 October. Samples were taken in all of these periods at only 3 sites: Outfall Confluence, WS-1, and WS-10. The other open-water sites were sampled on 2 or 3 occasions, typically in August and October. Peripheral sites (those designated as "A or B") were only sampled in August. In 2012, samples were collected on 25-27 April, 23-24 May, 20-21 June, 18-25 July, 22-23 August, 19-20 September, 18-19 October, and 26-28 November. Samples were taken in all of these periods at only 3 sites: inside the Willard Bay tailrace, WS-3, and WS-6. Most sites could not be sampled from July to October due to insufficient water depth. Open-water sites in-between the regular sites (designated as "C" or "D") were sampled only in July.

A list of taxa, distributions, and peak abundance for zooplankters collected in the Willard Spur is given in Table 6.1. A total of 14 species of Cladocera have been recorded of which 9 species were found in both 2011 and 2012. Four species of copepods have been collected (3 species present in both years), and 3 genera of rotifers.

Copepods were common to abundant in nearly all samples collected in both years and were slightly more than one-half of all zooplankters in samples (Figs. 6.1 & 6.2). The most common species was *Eucyclops agilis* which comprised over 90% of individuals in collections. This species was found throughout the Willard Spur, including the tailrace sites, open-water sites, and peripheral sites. *Diacyclops thomasi* was rarely collected in 2011, but it was common throughout the Spur in October-November 2012 samples. The diaptomid copepods were rare in both years. *Skistodiaptomus* is a typical limnetic species; it was recorded only at the MZ tailrace site in April 2012. *Leptodiaptomus connexus* was present in small numbers throughout the Spur in both years. This species is tolerant of high salinities and is more abundant in the brackish/saline wetlands around the Great Salt Lake (Gray 2011, Wurtsbaugh & Marcarelli 2004). Compared to other impounded wetlands of the Great Salt Lake, the copepods of the Willard Spur are typical in terms of species present and relative abundance. Samples collected from other wetlands in 2012 also showed a dominance by *E. agilis* overall with an increase in *D. thomasi* in 2012.

Rotifers were a relatively minor component of the zooplankton communities in both years (Figs. 6.1 & 6.2). *Asplanchna* was the most common rotifer in collections in the Willard Spur, and it is the most common rotifer in other GSL impounded wetlands.

All of the species of Cladocera listed in Table 6.1 for the Willard Spur have been found in other GSL impounded wetlands (Gray 2011, unpubl. 2012 data). The families

Daphniidae and Chydoridae have the most species present and typically are the most abundant cladocerans in collections.

Two species of *Daphnia* were collected; *D. pulex* (rare, present only in May 2011) and *D. dentifera*. Both species are common in a variety of lentic habitats and widespread in distribution (Pennak 1978). *D. dentifera* is also abundant in Utah Lake (Barnes & Toole 1981). In other GSL wetlands, as well as the Willard Spur, *Daphnia* is common when water depth is sufficient to provide open water above submerged aquatic vegetation, but it becomes less common or absent in shallow water and when the vegetation extends to the surface. At the open-water sites, it was a significant part of the cladocera community in spring and early summer of both years (Figs. 6.3 & 6.4). *D. dentifera* was also a high percentage of cladocera in November 2012; however, these likely were individuals carried into the Willard Spur by inflows from Willard Bay and the Bear River wetlands.

*Simocephalus vetulus* is characteristic of ponds with extensive submerged vegetation to which it attaches itself to feed on seston (Hutchinson 1967, Pennak 1978). *Scapholeberis* is another species associated with aquatic vegetation, although this association is more indirect. *Scapholeberis* is known to be neustonic (i.e., associated with the surface film; CMU 2001), and vegetation beds provide reduced water turbulence that allow it to feed on the surface film. In other GSL wetlands, both species increase in abundance when the beds of vegetation become established and are good indicators of healthy vegetation growth (Gray 2011). In the Willard Spur, *S. vetulus* reached peak abundance in July of both years. *Scapholeberis* was most common in fall of 2011 and spring-early summer of 2012. Lemke & Benke (2003) found that *Scapholeberis* survival declined with temperature, and this may explain its rarity during the higher water temperatures in summer.

The other daphnid present in the Willard Spur, *Ceriodaphnia quadrangula*, was common in both years in the Willard Spur. In 2011, peak abundance occurred in August, whereas its peak in 2012 occurred May (although it was present in all months except July). *C. quadrangula* is described as a typical littoral zooplankter that feeds on seston (phytoplankton and bacteria). Differences in its seasonal abundance between years in the Willard Spur may be related to temperature, pH, and food quality and quantity (CMU 2001). In 2012, its abundance in September and October indicate it is tolerant of stagnant, shallow habitats.

Chydorids are a diverse group that typically is found in shallow, littoral habitats associated with bottom substrates. In 2011, chydorids comprised a majority of cladocera during the sampling period except in July (Fig. 6.3) and were common at all sites (Fig. 6.5a,b). Peak abundance was in August, except for *P. striatus* (Table 6.1). Chydorids were common at all sites in 2012 as well but comprised a lower proportion of the cladocera community during the sampling period (Figs. 6.4 & 6.6). Peak abundance was in June.

Whiteside et al. (1978) examined substrate preferences of various species of chydorids along a gradient from mud to vegetation (mostly *Chara*). They found that *C. sphaericus*, *Alona* spp., and *Pleuroxus procurvatus* (= *procurvus*) primarily were found in vegetation, whereas *Leydigia* was found only on mud. *P. aduncus* was found on both types of substrates equally often. *P. striatus* is noted as preferring vegetated habitats (Pennak 1978).

The substrate preferences for the various species correlated with habitat differences and season of peak abundance between the two years of sampling in the Willard Spur. In particular, species associated with vegetation were less abundant and had peak abundance earlier in 2012 than in 2011. Species favoring vegetation, such *C. sphaericus* and *Alona*, comprised  $\approx 41\%$  of cladocera collected in 2011 but only  $\approx 17\%$  in 2012.

*Moina macrocarpa* is a species often found in turbid, muddy waters. It is known to be tolerant of highly eutrophic conditions (including sewage lagoons), and it can produce hemoglobin to survive low oxygen conditions (Cole 1994, Thorp & Covich 1991). In a previous study of GSL wetlands zooplankton, *Moina* was an indicator species for stagnant conditions (Gray 2011). In 2011 in the Willard Spur, *Moina* was present only in the most downstream sites (WS 10 to 12; Fig. 6.5b) in August. In 2012, it was present from July to October at upstream sites (WS 2 & 4; Fig. 6.6). This pattern in distribution corresponds to decreasing water levels and increasingly stagnant conditions that occurred in the different areas of the Spur each year.

*Macrothrix rosea* was collected in the Willard Spur only in August 2012, but it was found in many of the other GSL wetlands sampled in 2012. *M. rosea* is described as a benthic detritivore (Hutchinson 1967), and its abundance in August 2012 samples suggests the population was responding to the increase in detritus derived from senescent vegetation.

## 7. Literature Cited

- Anderson, C. & G. Cabana. 2007. Estimating the trophic position of aquatic consumers in river food webs using stable nitrogen isotopes. *Journal of the North American Benthological Society* 26: 273-285.
- Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C. Full text available online at: <http://water.epa.gov/scitech/monitoring/rsl/bioassessment/index.cfm>
- Barnes, J. R., and T. W. Toole. 1981. Macroinvertebrate and zooplankton communities of Utah Lake: A review of the literature. *Great Basin Naturalist Memoirs*, No. 5.
- CMU (Central Michigan University; various authors). 2001. Zooplankton of the Great Lakes. Available online at: <http://www.cst.cmich.edu/users/mcnau1as/zooplankton> web
- Cole, G. A. 1994. *Textbook of Limnology*, 4<sup>th</sup> Ed. Waveland Press, Prospect Heights, IL
- Corbet, P. S. 1999. *Dragonflies: Behavior and ecology of Odonata*. Comstock Publishing Associates. 829 p.
- Dillon, R. T., Jr. 2000. *The ecology of freshwater molluscs*. Cambridge University Press. 509 p.
- Edmunds, G. F., Jr., S. L. Jensen, and L. Berner. 1976. *The mayflies of North and Central America*. University of Minnesota Press, Minneapolis, MN. 330 p.
- Ferrington, L. C., Jr.; Berg, M. B., & W. P. Coffman. 2008. Chapter 26: Chironomidae In: Merritt, R. W., K. W. Cummins, & M. B. Berg. *An introduction to the aquatic insects of North America*, 4<sup>th</sup> ed. Kendall/Hunt, Dubuque, IA.
- Frouz, J., A. Arshad, and R. J. Lobinskei. 2002. Influence of temperature on developmental rate, wing length, and larval head capsule size of pestiferous midge *Chironomus crassicaudatus* (Diptera: Chironomidae). *Journal of Economic Entomology* 95(4): 699-705.
- Galat, D. L., M. Coleman, and R. Robinson. 1988. Experimental effects of elevated salinity on three benthic invertebrates in Pyramid Lake, Nevada. *Hydrobiologia* 158: 133-144.
- Gladyshev, M. I. 2009. Stable isotope analyses in aquatic ecology (a review). *Journal of Siberian Federal University, Biology* 4: 381-402.

- Goedkoop, W.; Kerblom, N. A., & M. H. DeMandt. 2006. Trophic fractionation of carbon and nitrogen stable isotopes in *Chironomus riparius* reared on food of aquatic and terrestrial origin. *Freshwater Biology* 51: 878–886.
- Gray, L. J. 2009. Macroinvertebrates of the wetlands of the Great Salt Lake: 2007. Report to the Utah Department of Environmental Quality, Division of Water Quality.
- Gray, L. J. 2010. Macroinvertebrate and Zooplankton Communities in the Impounded Wetlands of the Great Salt Lake: November 2009. Report to the Utah Department of Environmental Quality, Division of Water Quality.
- Gray, L. J. 2011. Macroinvertebrate and Zooplankton Communities in the Impounded Wetlands of the Great Salt Lake May-November 2010. Prepared for the Utah Department of Environmental Quality, Division of Water Quality, Salt Lake City, Utah.
- Gray, L. J. 2012. Macroinvertebrates of the Willard Spur Wetlands: Literature Review and Results of Sampling in 2011. Prepared for the Willard Spur Steering Committee and Science Panel and the Utah Department of Environmental Quality, Division of Water Quality, Salt Lake City, Utah. (30 September 2012)
- Harman, W. N. Snails (Mollusca: Gastropoda). pp. 275-312 In: Hart, C. W., Jr., and S. L. H. Fuller. 1974. *Pollution Ecology of Freshwater Invertebrates*. Academic Press. 389 p.
- Hutchinson, G.E. 1967. *A treatise on limnology, Volume II: Introduction to lake biology and the limnoplankton*. Wiley, New York.
- International Atomic Energy Agency (IAEA). 2009. *Manual for the use of stable isotopes in entomology*. Entomology Unit, AEIA Laboratories, Vienna, Austria.
- Johnson, B. R., D. C. Tarter, and J. J. Hutchens, Jr. 2000. Life history and trophic basis of production of the mayfly *Callibaetis fluctuans* (Walsh) (Ephemeroptera: Baetidae) in a mitigated wetland, West Virginia, USA. *Wetlands* 20: 397–405.
- Lauck, D. R. 1979. Family Corixidae. pp. 87-123 In: Menke, A. S. (ed.) *The semiaquatic and aquatic Hemiptera of California*. Bulletin of the California Insect Survey 21, University of California Press. 176 p.
- Leech, H. B., and H. P. Chandler. 1956. Aquatic Coleoptera. In: Usinger, R. L.. *Aquatic Insects of California*. Univ. of California Press, Berkeley.
- Lemke, A. M., and A. C. Benke. 2003. Growth and reproduction of three cladoceran species from a small wetland in the south-eastern U.S.A. *Freshwater Biology* 48: 589–603

- Marzoq, M. K., M. H. Ali, and M. R. Annon. 2004. A laboratory study on the life cycle of *Ischnura evansi* (Morton) (Odonata: Coenagrionidae) from a pond at Basrah. Iraqi J. Aqua. 2: 59-69.
- Mulholland, P. J., Tank, J. L., Sanzone, D. M., Wolheim, W. M., Peterson, B. J., Webster, J. R., & J. L. Meyer. 2000. Food resources of stream macroinvertebrates determined by natural-abundance stable C and N isotopes and a <sup>15</sup>N tracer addition. Journal of the North American Benthological Society 19: 145-157.
- Palavesam, A., Somanath, B., & I. Grasian. 2009. Effect of detritus quality on energy allocation in chironomids. European Journal of Biological Sciences 1: 1-9.
- Pennak, R. W. 1978. Fresh-water invertebrates of the United States, 2nd edition. John Wiley & Sons, New York. 803 p.
- Polhemus, J. T. 2008. Chapter 15: Aquatic and Semiaquatic Hemiptera. In: Merritt, R. W., K. W. Cummins, & M. B. Berg. An introduction to the aquatic insects of North America, 4<sup>th</sup> ed. Kendall/Hunt, Dubuque, IA.
- Ross, H. H. 1944. The caddis flies, or Trichoptera, of Illinois. Bulletin of the Illinois Natural History Survey 23: 1-326.
- Shiozawa, D. K., and J. R. Barnes. 1977. The microdistribution and population trends of larval *Tanyptus stellatus* Coquillett and *Chironomus frommeri* Atchley and Martin (Diptera: Chironomidae) in Utah Lake, Utah. Ecology 58: 610-618.
- Strong, D. R. 1972. Life History Variation Among Populations of an Amphipod (*Hyalella azteca*). Ecology 53(6): 1103-1111.
- Sweeney, B. W., and J. A. Schnack. 1977. Egg development, growth, and metabolism of *Sigara alternata* (Say) (Hemiptera: Corixidae) in fluctuating thermal environments. Ecology 58: 265-277.
- Taylor, J. M., and J. H. Kennedy. 2006. Life history and secondary production of *Caenis latipennis* (Ephemeroptera: Caenidae) in Honey Creek, Oklahoma. Annals of the Entomological Society of America 99(5): 821-830
- Thorp, J. H., and A. P. Covich (eds.). 1991. Ecology and classification of North American freshwater invertebrates. Academic Press, San Diego, CA. 911 p.
- Trost, L. M. W., and L. Berner 1963. The biology of *Callibaetis floridanus* (Banks) (Ephemeroptera: Baetidae). The Florida Entomologist 46(4): 285-300.
- Vander Zanden, M. J., & J. B. Rasmussen. 2001. Variation in  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  trophic fractionation: implications for aquatic food web studies. Limnology & . Oceanography 46: 2061–2066.

Waltz, R. D., & S. K. Burian. 2008. Chapter 11: Ephemeroptera. In: Merritt, R. W., K. W. Cummins, & M. B. Berg. An introduction to the aquatic insects of North America, 4<sup>th</sup> ed. Kendall/Hunt, Dubuque, IA.

White, D. S., & R. E. Roughley. 2008. Chapter 20: Aquatic Coleoptera. In: Merritt, R. W., K. W. Cummins, & M. B. Berg. An introduction to the aquatic insects of North America, 4<sup>th</sup> ed. Kendall/Hunt, Dubuque, IA.

Whiteside, M. C., J. B. Williams and C. P. White. 1978. Seasonal abundance and pattern of chydorid, Cladocera in mud and vegetative. Ecology 59: 1177-1188

Wurtsbaugh, W., and A. M. Marcarelli. 2004. Phytoplankton and Zooplankton in Farmington Bay and the Great Salt Lake, Utah (2003). Report to Central Davis Sewer Improvement District, Kaysville, UT.

**Table 3.1. List of macroinvertebrate taxa collected in the Willard Spur, 2012.**

Feeding Groups: gatherer-collector (GC), scraper (SC), shredder (SH), and predator (PR)

<b>1. Aquatic Insects:</b>				
<b>Order</b>	<b>Family</b>	<b>Genus</b>	<b>Species</b>	<b>Feeding Group</b>
Ephemeroptera	Baetidae	<i>Callibaetis</i>	sp.	GC
Ephemeroptera	Caenidae	<i>Caenis</i>	<i>amica</i>	GC
Trichoptera	Leptoceridae	<i>Ylodes</i>	sp.	SH
Odonata	Coenagrionidae	<i>Ischnura</i>	spp.	PR
Odonata	Coenagrionidae	<i>Archilestes</i>	sp.	PR
Odonata	Aeshnidae	<i>Aeshna</i>	sp.	PR
Odonata	Libellulidae	<i>Erythemis</i>	sp.	PR
Hemiptera	Corixidae	<i>Corisella</i>	spp.	PR
Hemiptera	Corixidae	<i>Hesperocorixa</i>	sp.	PR
Hemiptera	Notonectidae	<i>Notonecta</i>	sp.	PR
Diptera	Ephydriidae	<i>Ephydra</i>	sp.	GC
Diptera	Ceratopogonidae	subfamily Ceratopogoninae	sp.	PR
Diptera	Dolichopodidae		sp.	PR
Diptera	Chironomidae	<i>Chironomus</i>	sp.	GC
Diptera	Chironomidae	tribe Tanytarsini	sp.	GC
Diptera	Chironomidae	subfamily Tanypodinae	sp.	PR
Diptera	Chironomidae	subfamily Orthoclaadiinae	sp.	GC
Coleoptera	Dytiscidae	<i>Hydroporus</i>	sp.	PR
Coleoptera	Dytiscidae	unidentifiable early instar larvae	sp.	PR
Coleoptera	Dytiscidae	<i>Stictotarsus</i>	sp.	PR
Coleoptera	Hydrophilidae	<i>Enochrus</i>	sp.	CG
Coleoptera	Hydrophilidae	<i>Tropisternus</i>	sp.	CG
Coleoptera	Hydrophilidae	<i>Berosus</i>	sp.	PR
Coleoptera	Chrysomelidae		sp.	SH
<b>Non-Insects</b>				
2. Crustacea: Amphipoda	Hyaellidae	<i>Hyaella</i>	<i>azteca</i>	GC
3. Mollusca: Gastropoda	Lymnaeidae	<i>Stagnicola</i>	sp.	SC
3. Mollusca: Gastropoda	Physidae	<i>Physella</i>	sp.	SC
3. Mollusca: Gastropoda	Planorbidae	<i>Gyraulus</i>	sp.	SC
4. Annelida (Oligochaeta)	Naididae		sp.	GC
5. Acarina: Trombidiformes			sp.	PR

**Table 4.1. Mean temperatures and monthly degree-day totals at WS-2 and WS-6, data collected from May 2 through September 19-20 by DWQ monitoring probes at each site.**

<b>Site</b>	<b>WS-2</b>	<b>WS-2</b>		<b>WS-6</b>	<b>WS-6</b>
<b>Month</b>	<b>mean °C</b>	<b>degree-days</b>		<b>mean °C</b>	<b>degree-days</b>
<b>May</b>	17.5	526		16.8	503
<b>June</b>	20.1	603		20.6	619
<b>July</b>	25.9	804		25.8	799
<b>August</b>	23.2	719		24.4	757
<b>Sept.</b>	18.3	366		20.3	387

**Table 4.2. Summary of life cycles for macroinvertebrate taxa in the Willard Spur for 2012.**

<b>Taxon</b>	<b>Number of generations per year</b>	<b>Peak abundance</b>
<i>Callibaetis</i>	2	July
<i>Caenis amica</i>	2	July-August
<i>Ischnura</i>	1	September
<i>Corisella decolor</i>	2 (3?)	July
<i>Hesperocorixa</i>	1	July
<i>Notonecta</i>	1	July-August
<i>Chironomus</i>	2	July & September
<i>Tanypus</i>	2	September
<i>Hyalella</i>	2+	July & September
<i>Physella</i>	2	July
<i>Gyraulus</i>	2	July
<i>Ylodes</i>	1 (2?)	June-July

**Table 5.1. Stable isotope signatures of macroinvertebrates, producers, and detritus from the Willard Spur in 2012 (means  $\pm$  1 sd from triplicate analyses of the same sample).**

<b>A. Macroinvertebrates</b>	$\delta^{15}\text{N}$ , ‰	$\delta^{13}\text{C}$ , ‰
<b>a. Diptera</b>		
Chironomidae: <i>Chironomus</i> (3rd & 4th instars)	5.9 $\pm$ 0.1	-14.6 $\pm$ 0.2
Chironomidae: <i>Tanypus</i> (4th instar)	5.6	-19.3
<b>b. Hemiptera</b>		
Corixidae: <i>Corisella decolor</i> (adult) (WS-2)	8.3 $\pm$ 0.1	-19.2 $\pm$ 0.0
Corixidae: <i>Corisella decolor</i> (adult) (WS-6)	7.4 $\pm$ 0.1	-18.0 $\pm$ 0.1
Corixidae: <i>Hesperocorixa</i> (adult)	8.4 $\pm$ 0.2	-18.7 $\pm$ 0.2
Notonectidae: <i>Notonecta</i> (adult)	8.4 $\pm$ 0.0	-18.0 $\pm$ 0.1
Notonectidae: <i>Notonecta</i> (4th & 5th instars)	7.5 $\pm$ 0.1	-17.9 $\pm$ 0.0
<b>c. Ephemeroptera</b>		
Caenidae: <i>Caenis amica</i> (late instar)	6.2 $\pm$ 0.2	-19.7 $\pm$ 0.1
<b>d. Odonata</b>		
Coenagrionidae: <i>Ischnura</i> (late instar)	8.2 $\pm$ 0.0	-18.5 $\pm$ 0.0
Aeschnidae: <i>Aeschna</i> (late instar)	8.7 $\pm$ 0.1	-17.9 $\pm$ 0.0
<b>e. Coleoptera</b>		
Hydrophilidae: <i>Enochrus</i> (adult)	5.6 $\pm$ 0.2	-20.3 $\pm$ 0.3
Hydrophilidae: <i>Enochrus</i> (larvae)	7.1 $\pm$ 0.1	-18.9 $\pm$ 0.1
<b>f. Gastropoda</b>		
Planorbidae: <i>Gyraulus</i> (2-5 mm)	5.7 $\pm$ 0.1	-12.3 $\pm$ 0.1
Physidae: <i>Physella</i> (3-8 mm)	6.3 $\pm$ 0.1	-14.8 $\pm$ 0.3
<b>g. Amphipoda</b>		
Hyalellidae: <i>Hyalella azteca</i> (3-6 mm)	6.3 $\pm$ 0.2	-18.0 $\pm$ 0.1
<b>B. Producers and Detritus</b>		
1. Fine Detritus (< 0.25 mm)	5.3 $\pm$ 0.3	-11.1 $\pm$ 0.2
2. <i>Stuckenia</i> (pondweed)	5.4 $\pm$ 0.1	-14.5 $\pm$ 0.0
3. Filamentous Green Algae	5.2 $\pm$ 0.1	-13.9 $\pm$ 0.0

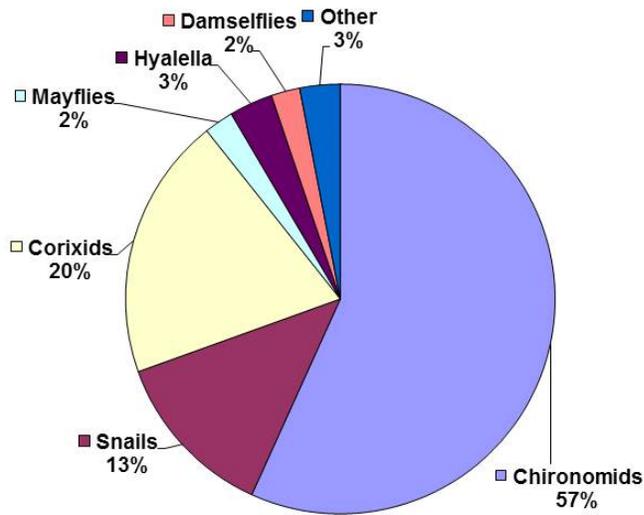
**Table 6.1. Species of zooplankton collected in the Willard Spur, 2011-12. Occurrence refers distribution of the species, either by sampling site or throughout the Spur (i.e., “widespread”). Common/uncommon/rare designations based on frequency of occurrence in samples. “Peak” refers to the sampling period of greatest relative abundance.**

<b>Cladocera</b>			
<b>Family</b>	<b>Species</b>	<b>2011 Occurrence</b>	<b>2011 Peak</b>
Daphniidae	<i>Daphnia dentifera</i> (Sars)	widespread; uncommon	July
Daphniidae	<i>Daphnia pulex</i> Leydig	widespread; rare	August
Daphniidae	<i>Simocephalus vetulus</i> (O.F.M.)	widespread; common	July
Daphniidae	<i>Scapholeberis</i> sp.	widespread; uncommon	October
Daphniidae	<i>Ceriodaphnia quadrangula</i> (O.F.M.)	widespread; common	August
Chydoridae	<i>Pleuroxus striatus</i> Schödler	widespread; uncommon	October
Chydoridae	<i>Pleuroxus aduncus</i> (Jurine)	(not collected)	
Chydoridae	<i>Pleuroxus procurvatus</i> Birge	Outfall Confl., WS-1; rare	August
Chydoridae	<i>Alona</i> sp.	widespread; common	August
Chydoridae	<i>Chydorus sphaericus</i> (O.F.M.)	widespread; common	August
Chydoridae	<i>Leydigia</i> sp.	WS-7 to 9; rare	August
Moinidae	<i>Moina macrocarpa</i> Straus	WS-10 to 12; common	October
Bosminidae	<i>Bosmina longirostris</i> (O.F.M.)	widespread; uncommon	October
Macrothricidae	<i>Macrothrix rosea</i> (Jurine)	(not collected)	
Copepoda			
Family	<i>Species</i>		
Cyclopidae	<i>Eucyclops agilis</i> (Koch)	widespread; common	October
Cyclopidae	<i>Diacyclops thomasi</i> (Forbes)	widespread; uncommon	October
Diaptomidae	<i>Leptodiaptomus connexus</i> Light	widespread; uncommon	July
Diaptomidae	<i>Skistodiaptomus oregonensis</i> (Lilljeborg)	(not collected)	
Rotifera			
Family	<i>Species</i>		
Asplanchnidae	<i>Asplanchna</i> sp.	widespread; common	August
Brachionidae	<i>Brachionus</i> sp.	widespread; uncommon	August
Brachionidae	<i>Notholca</i> sp.	widespread; rare	August

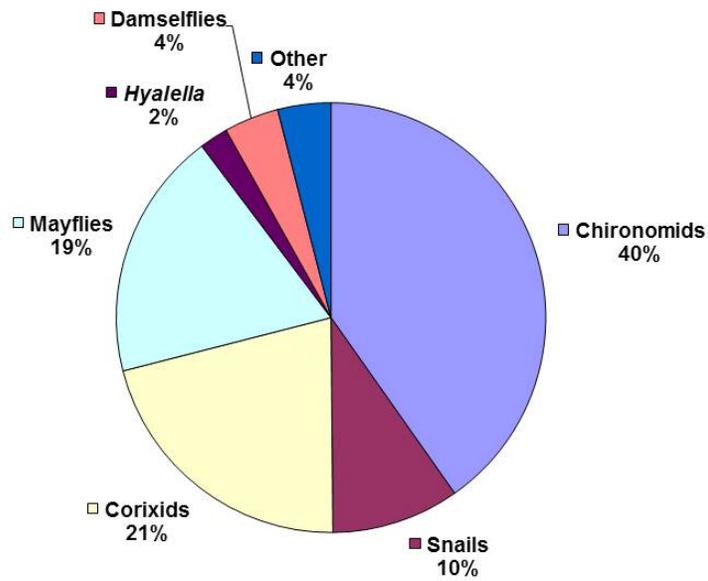
Table 6.1 (continued)

<b>Cladocera</b>			
<b>Family</b>	<b>Species</b>	<b>2012 Occurrence</b>	<b>2012 Peak</b>
Daphniidae	<i>Daphnia dentifera</i> (Sars)	widespread; common	Apr-May
Daphniidae	<i>Daphnia pulex</i> Leydig	(not collected)	
Daphniidae	<i>Simocephalus vetulus</i> (O.F.M.)	widespread; common	July
Daphniidae	<i>Scapholeberis</i> sp.	widespread; common	June
Daphniidae	<i>Ceriodaphnia quadrangula</i> (O.F.M.)	widespread; common	May
Chydoridae	<i>Pleuroxus striatus</i> Schödler	widespread; uncommon	June
Chydoridae	<i>Pleuroxus aduncus</i> (Jurine)	widespread; common	June
Chydoridae	<i>Pleuroxus procurvatus</i> Birge	(not collected)	
Chydoridae	<i>Alona</i> sp.	widespread; rare	July
Chydoridae	<i>Chydorus sphaericus</i> (O.F.M.)	widespread; common	June
Chydoridae	<i>Leydigia</i> sp.	(not collected)	
Moinidae	<i>Moina macrocarpa</i> Straus	WS-2 to 5; common	July-Oct.
Bosminidae	<i>Bosmina longirostris</i> (O.F.M.)	WS-1; rare	August
Macrothricidae	<i>Macrothrix rosea</i> (Jurine)	WS-4, 5; uncommon	August
<b>Copepoda</b>			
<b>Family</b>	<b>Species</b>		
Cyclopidae	<i>Eucyclops agilis</i> (Koch)	widespread; common	Aug.-Sept.
Cyclopidae	<i>Diacyclops thomasi</i> (Forbes)	widespread; common	Sept.
Diaptomidae	<i>Leptodiaptomus connexus</i> Light	widespread; uncommon	Sept.-Nov.
Diaptomidae	<i>Skistodiaptomus oregonensis</i> (Lilljeborg)	MZ Tailrace; rare	April
<b>Rotifera</b>			
<b>Family</b>	<b>Species</b>		
Asplanchnidae	<i>Asplanchna</i> sp.	widespread; common	June-Aug.
Brachionidae	<i>Brachionus</i> sp.	widespread; uncommon	June
Brachionidae	<i>Notholca</i> sp.	(not collected)	

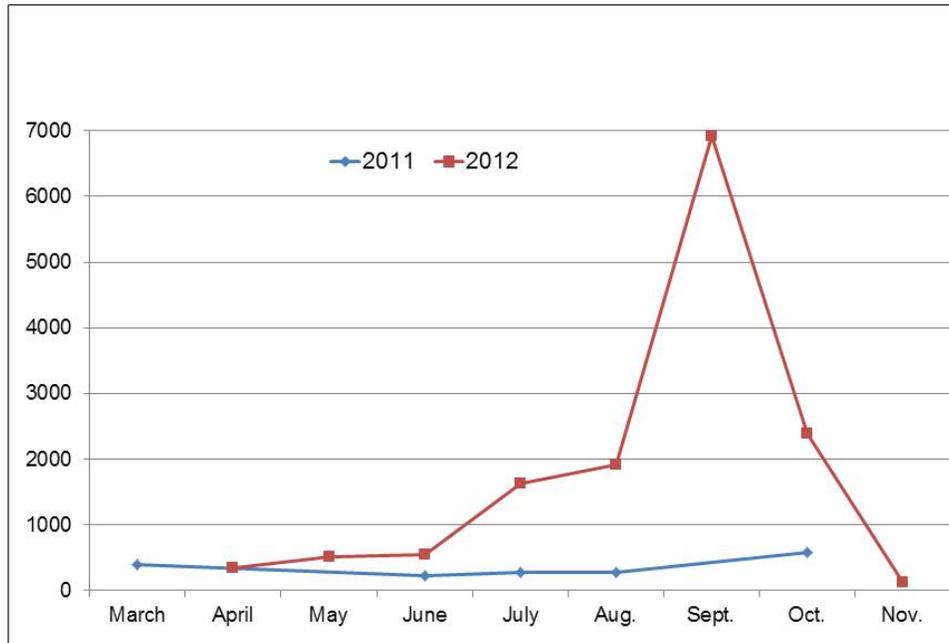
**Figure 3.1a. Composition of the macroinvertebrate community in the Willard Spur, April-November 2012.**



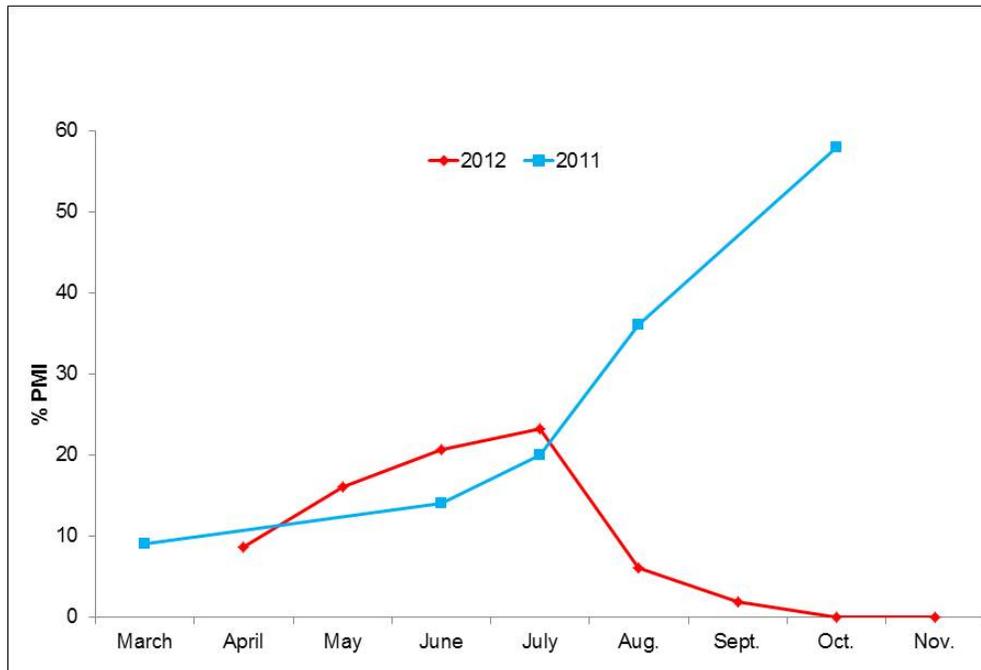
**Figure 3.1b. Composition of the macroinvertebrate community in the Willard Spur, March-October 2011.**



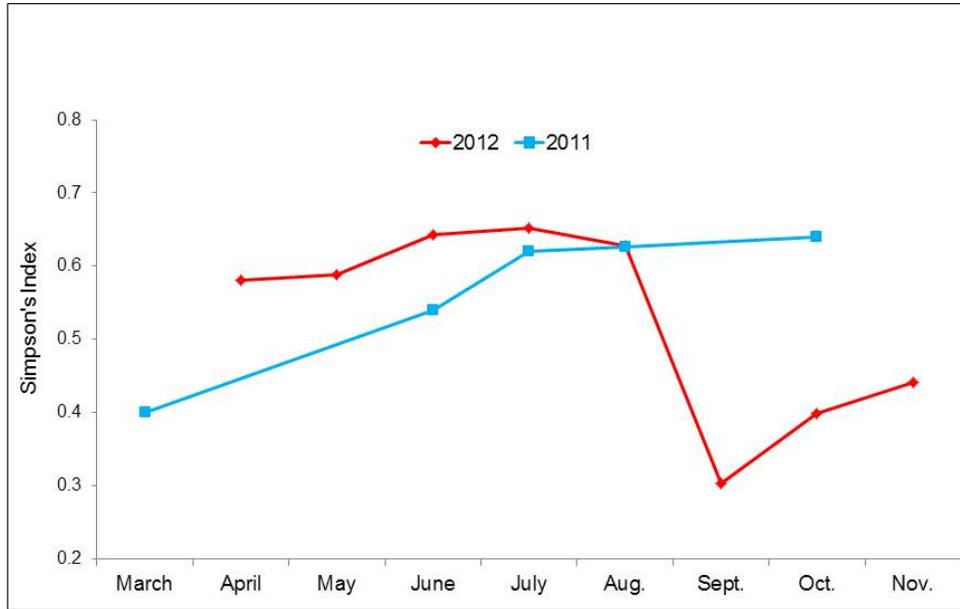
**Figure 3.2. Total counts of macroinvertebrates per sample by sampling period in 2011 and 2012 (means of ln-transformed data for open-water sites sampled on each date).**



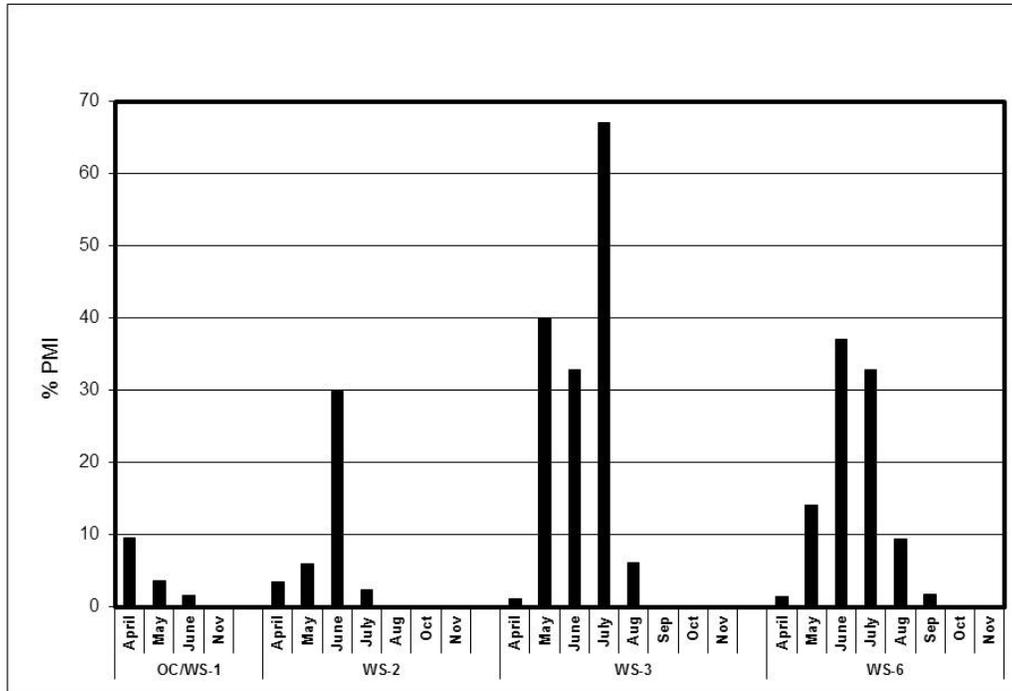
**Figure 3.3. Values of the %PMI metric in the Willard Spur for 2011-12 (means of all open-water sites sampled on each date).**



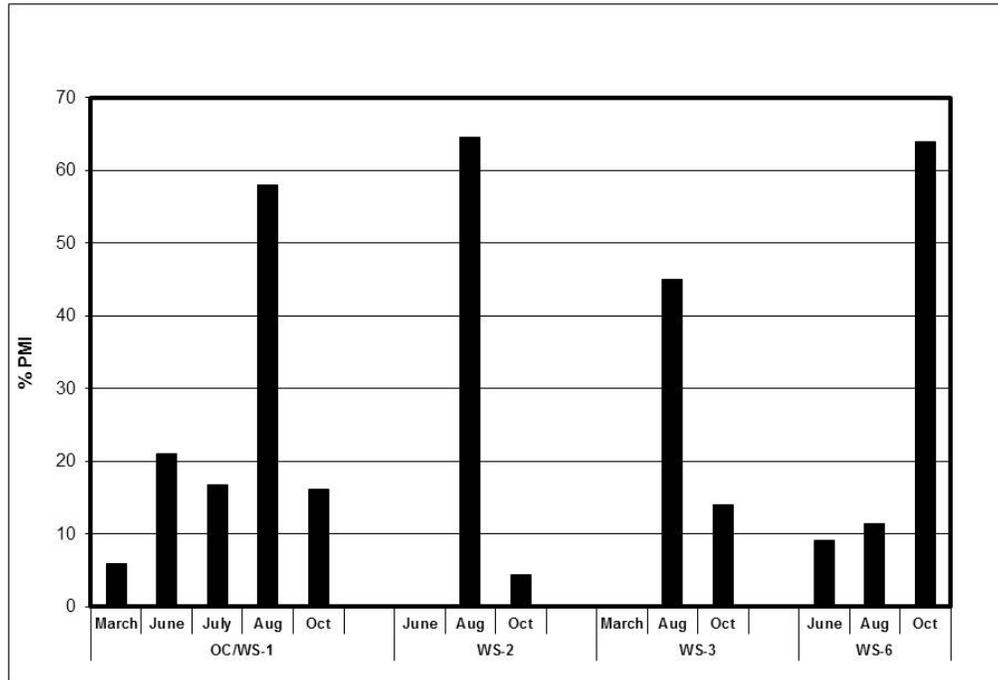
**Figure 3.4. Values of Simpson's Index in the Willard Spur, 2011-2012 (means of all open-water sites sampled on each date).**



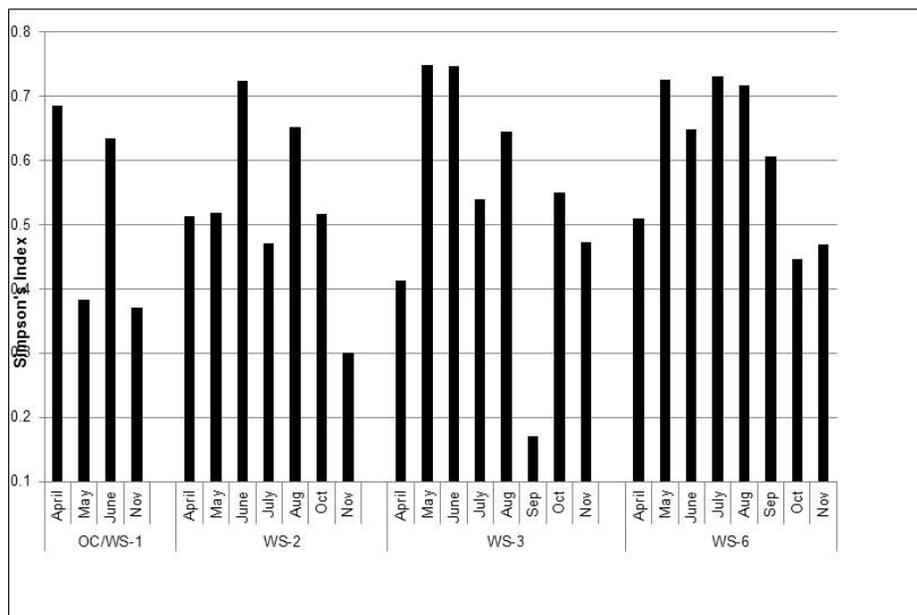
**Figure 3.5. Values of the %PMI metric at selected sites in the Willard Spur, 2012.**



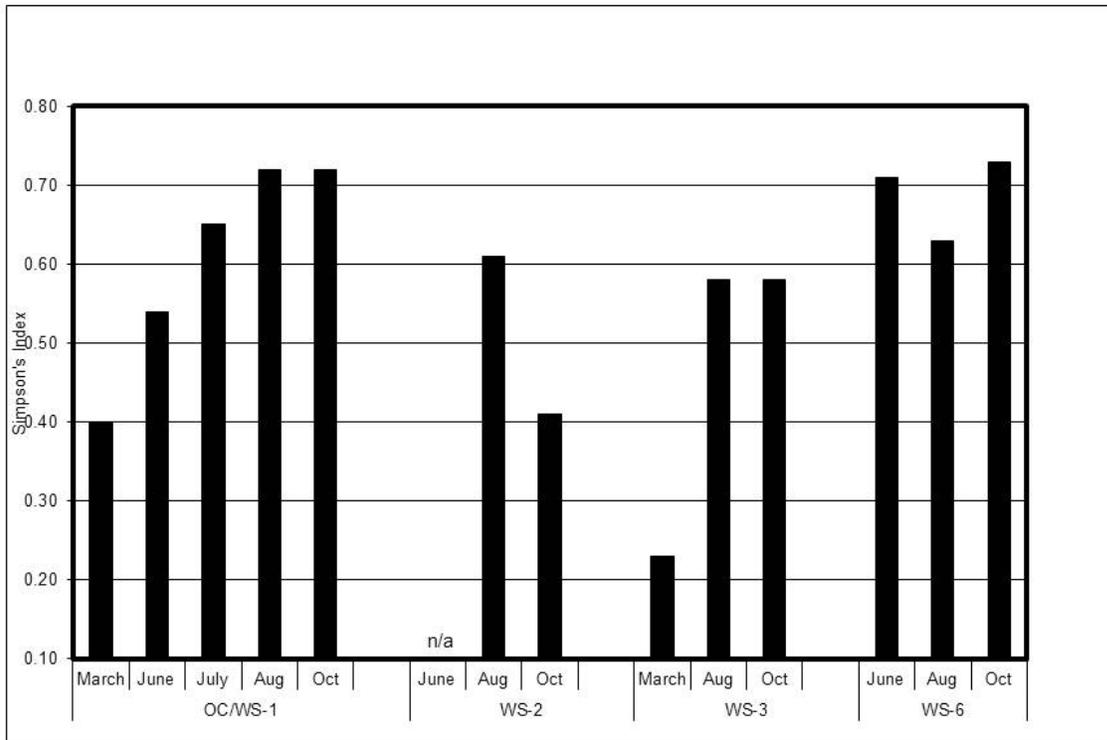
**Figure 3.6.** Values of the %PMI metric at selected sites in the Willard Spur, 2011.



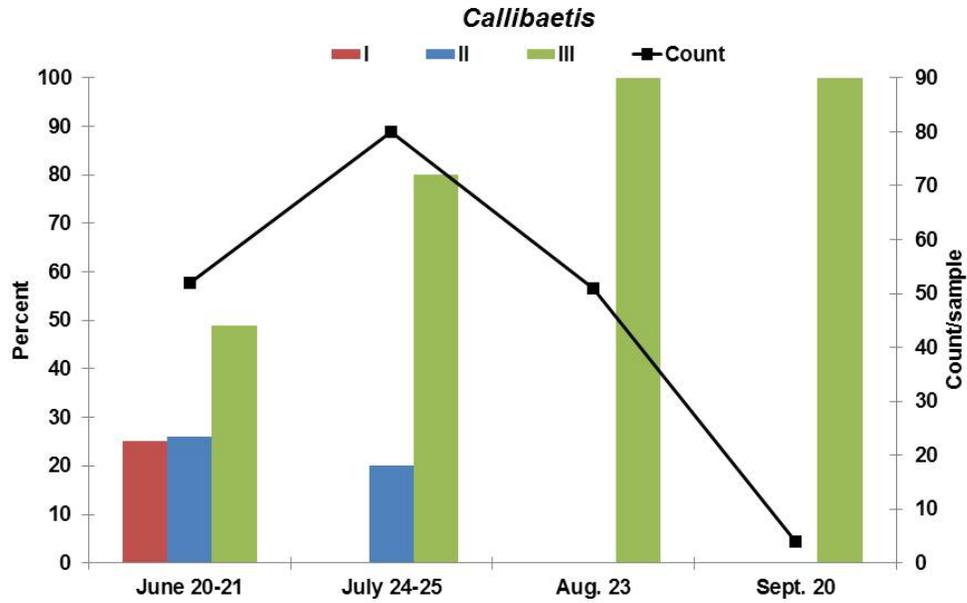
**Figure 3.7.** Values of Simpson's Index at selected sites in the Willard Spur, 2012.



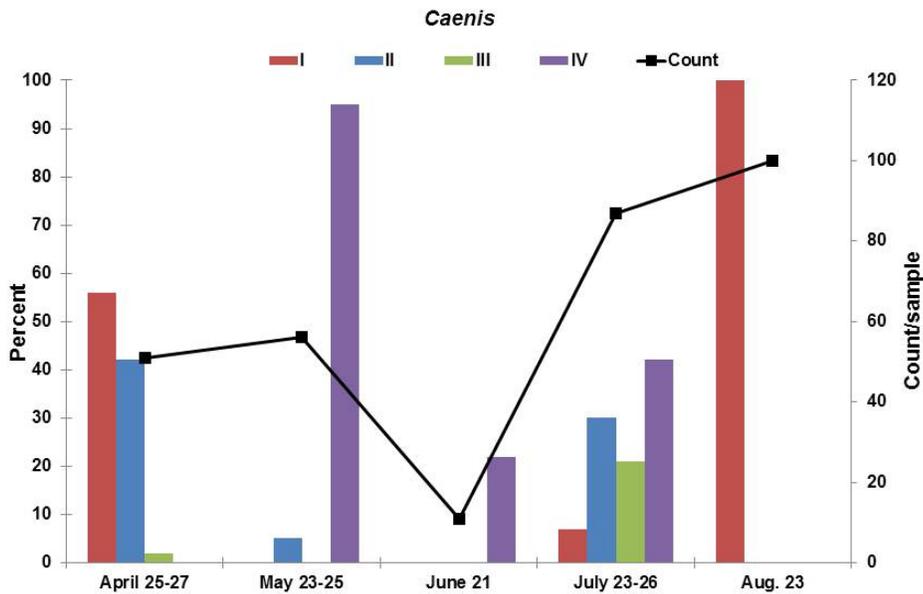
**Figure 3.8. Values of Simpson's Index at selected sites in the Willard Spur, 2011. (n/a: index value could not be calculated as only 1 taxon was present)**



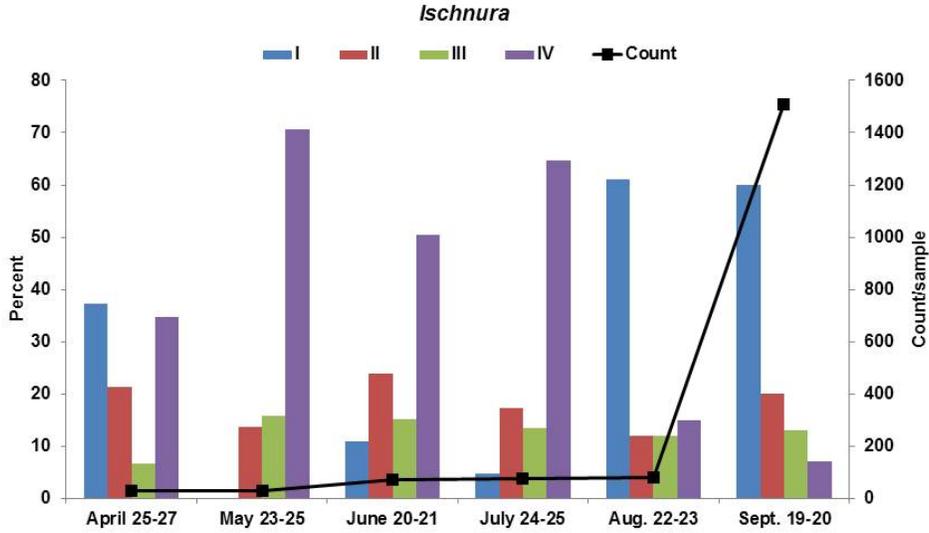
**Figure 4.1. Sample counts and age structure of *Callibaetis* mayflies (as size classes based on total length excluding cerci) in the Willard Spur, 2012.**



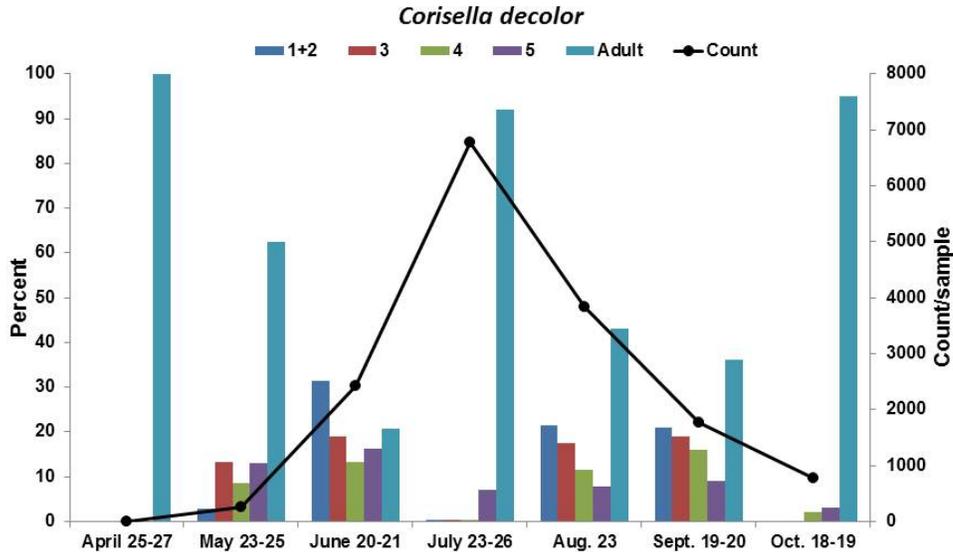
**Figure 4.2. Sample counts and age structure of *Caenis* mayflies (as size classes based on total length excluding cerci) in the Willard Spur, 2012.**



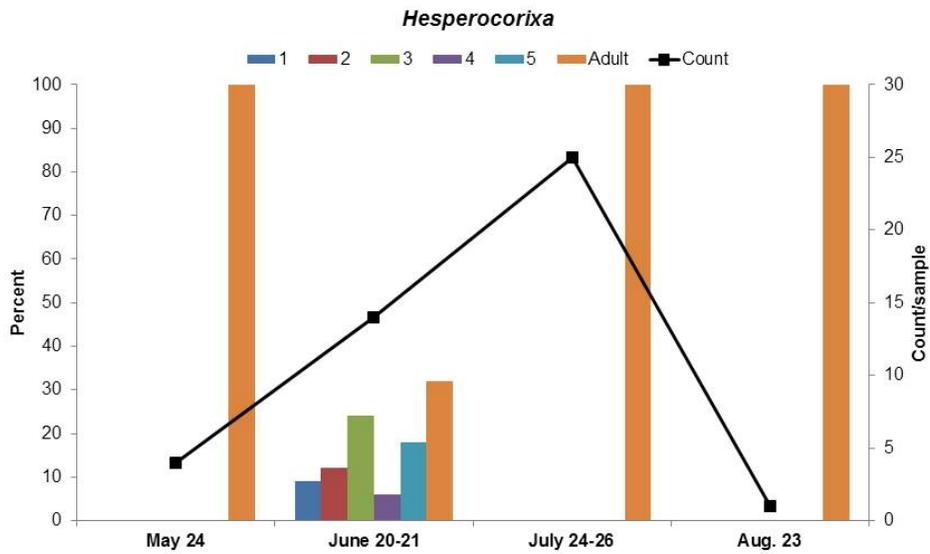
**Figure 4.3. Sample counts and age structure of *Ischnura* damselflies (as size classes based on total length and head capsule width) in the Willard Spur, 2012.**



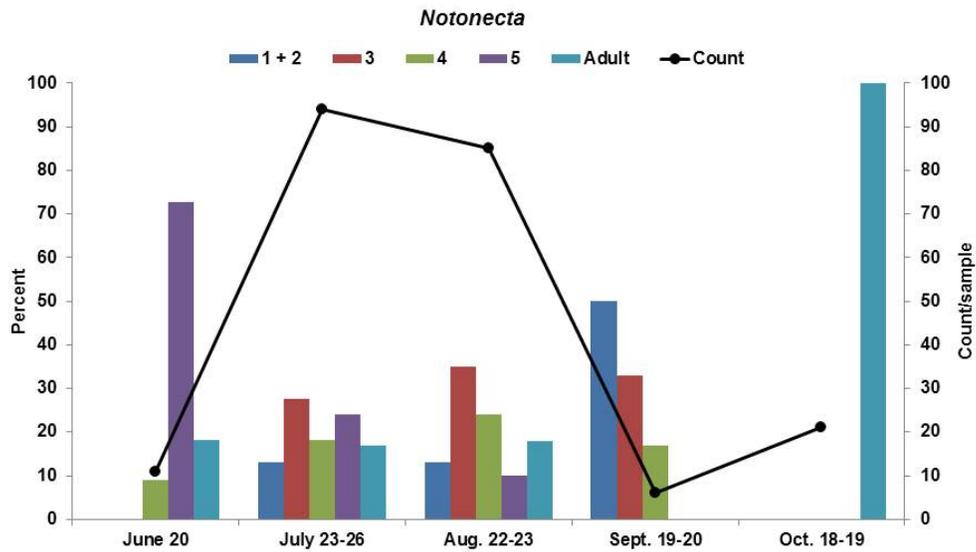
**Figure 4.4. Sample counts and age structure of *Corisella decolor* corixids (based on instars) in the Willard Spur, 2012.**



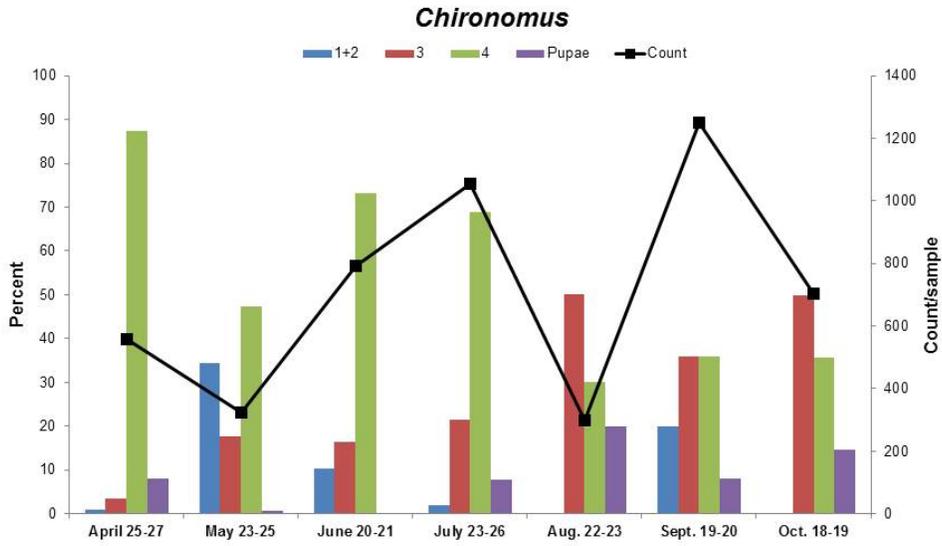
**Figure 4.5. Sample counts and age structure of *Hesperocorixa* corixids (based on instars) in the Willard Spur, 2012.**



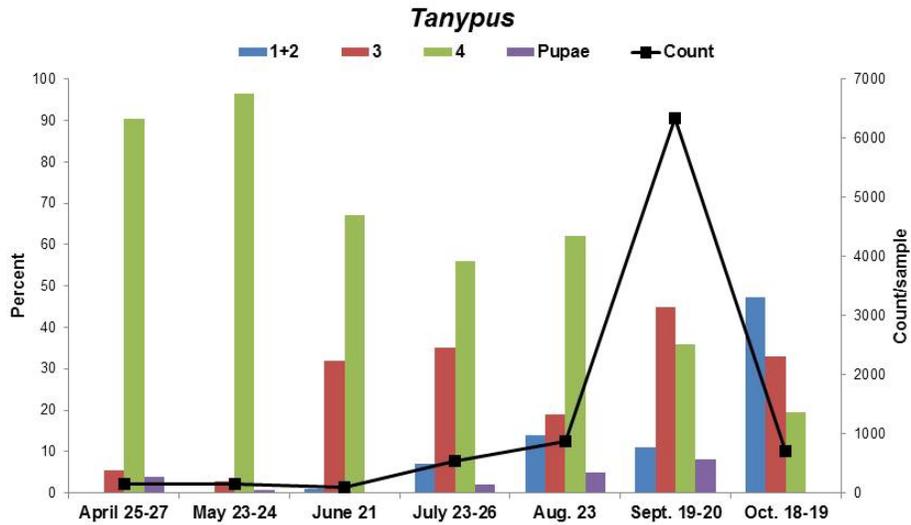
**Figure 4.6. Sample counts and age structure of *Notonecta* (based on instars) in the Willard Spur, 2012.**



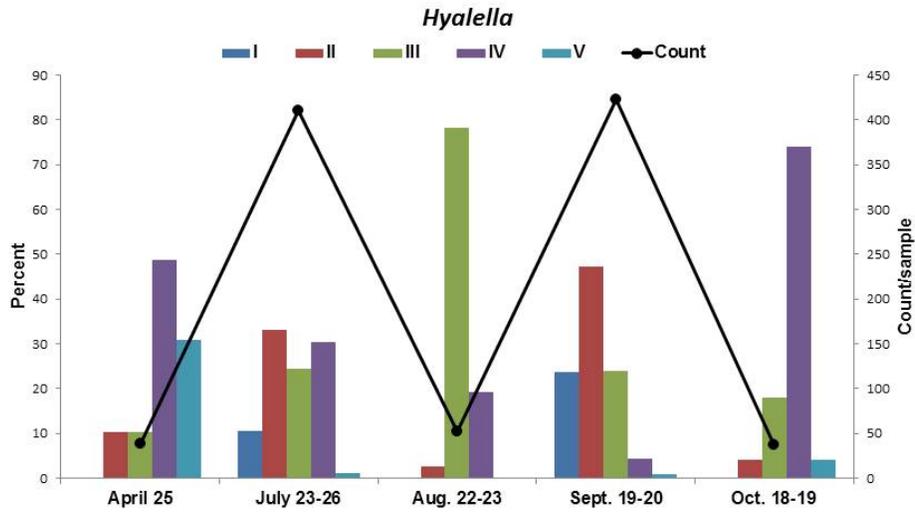
**Figure 4.7. Sample counts and age structure of *Chironomus* (as instars with 1<sup>st</sup> & 2<sup>nd</sup> instar counts combined) in the Willard Spur, 2012.**



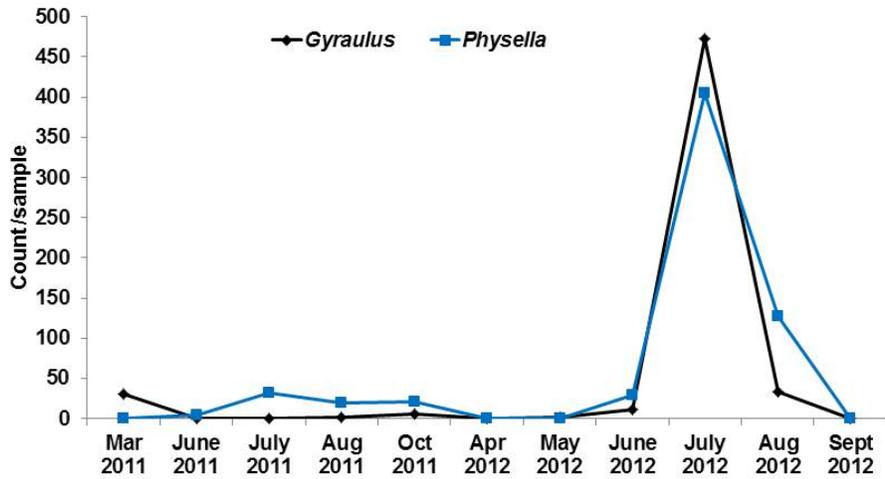
**Figure 4.8. Sample counts and age structure of *Tanypus* chironomids (as instars with 1<sup>st</sup> & 2<sup>nd</sup> instar counts combined) in the Willard Spur, 2012.**



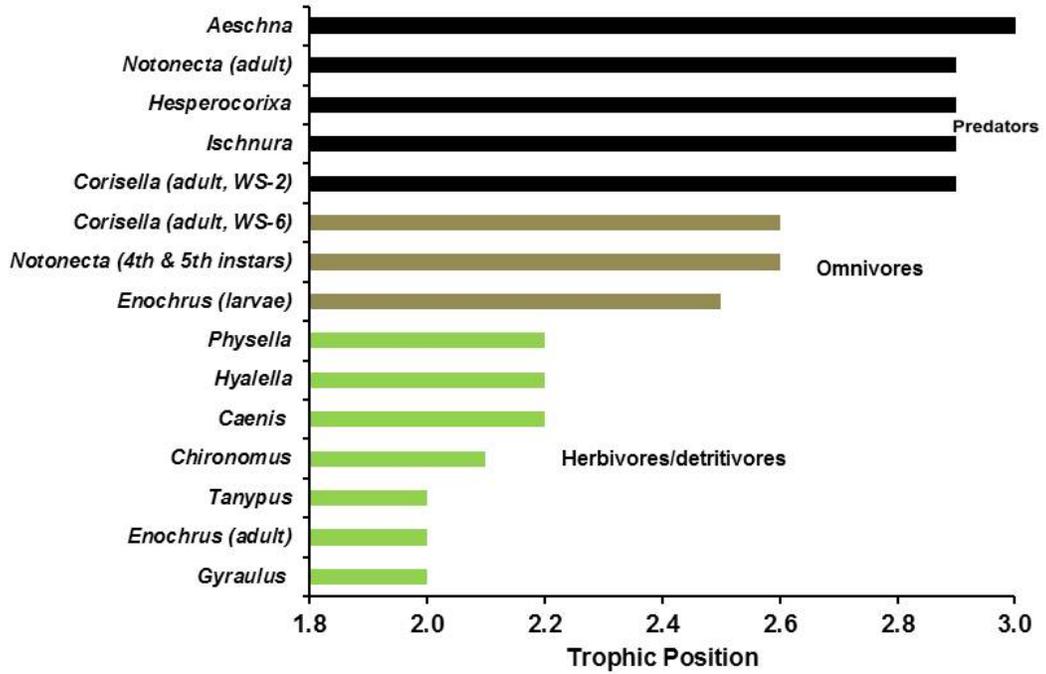
**Figure 4.9. Sample counts and age structure of *Hyalella* amphipods (size classes based on total length) in the Willard Spur, 2012.**



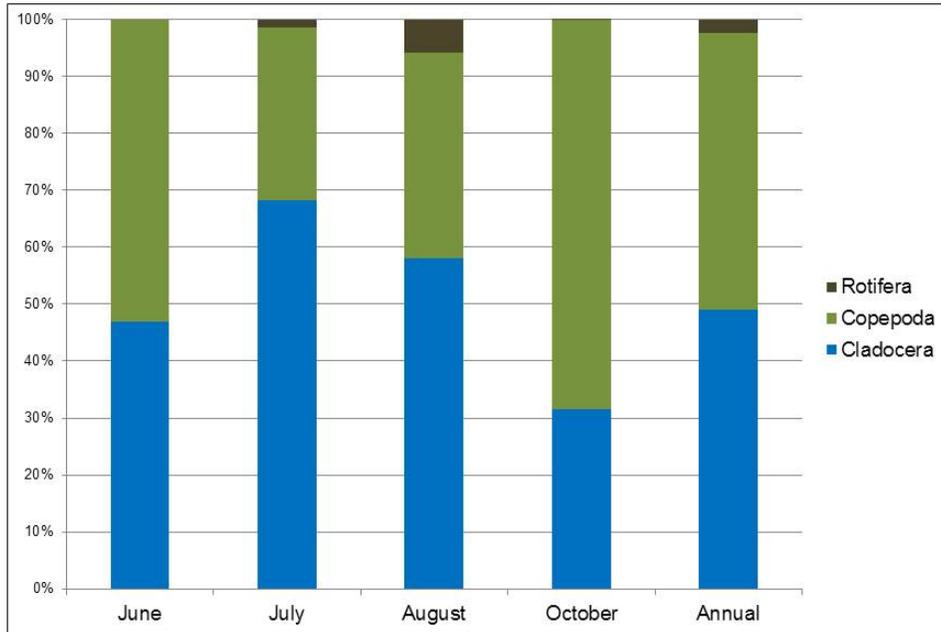
**Figure 4.10. Sample counts of *Physella* and *Gyraulus* snails in the Willard Spur, 2012.**



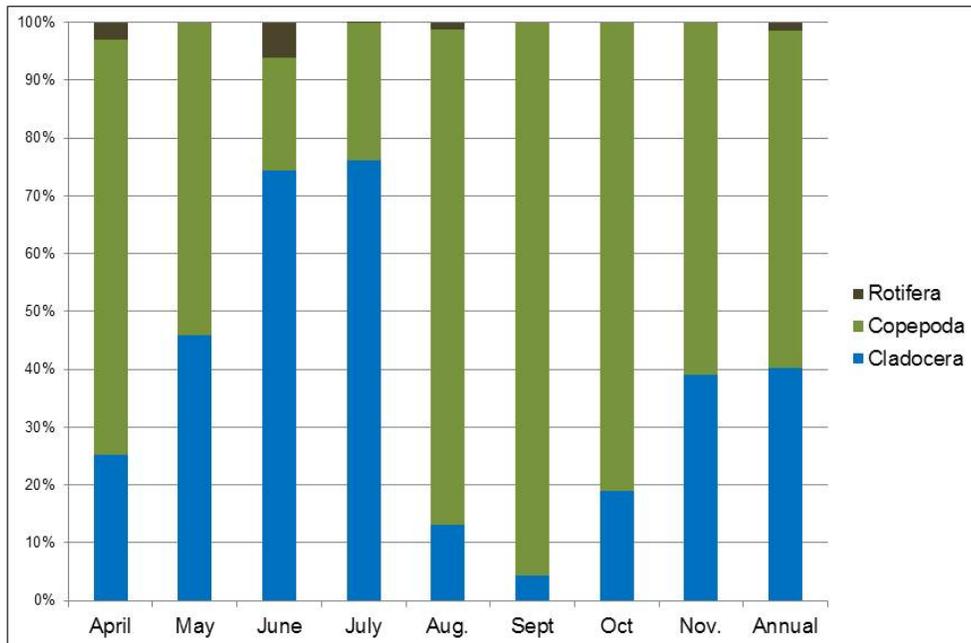
**Figure 5.1. Trophic position (feeding level) of macroinvertebrates in the Willard Spur based on  $\delta^{15}\text{N}$  analyses, 2012. (*Gyraulus* was designated as the reference primary consumer).**



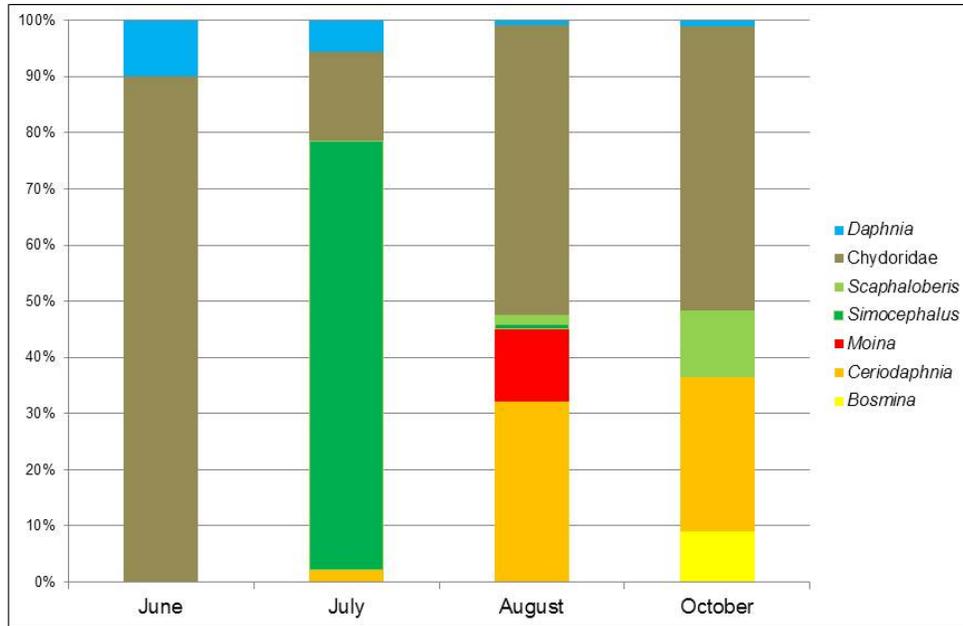
**Figure 6.1. Composition of the zooplankton community in the Willard Spur, June-October 2011 (combined data from all main Spur sites). "Annual" refers to an overall average of all sampling dates.**



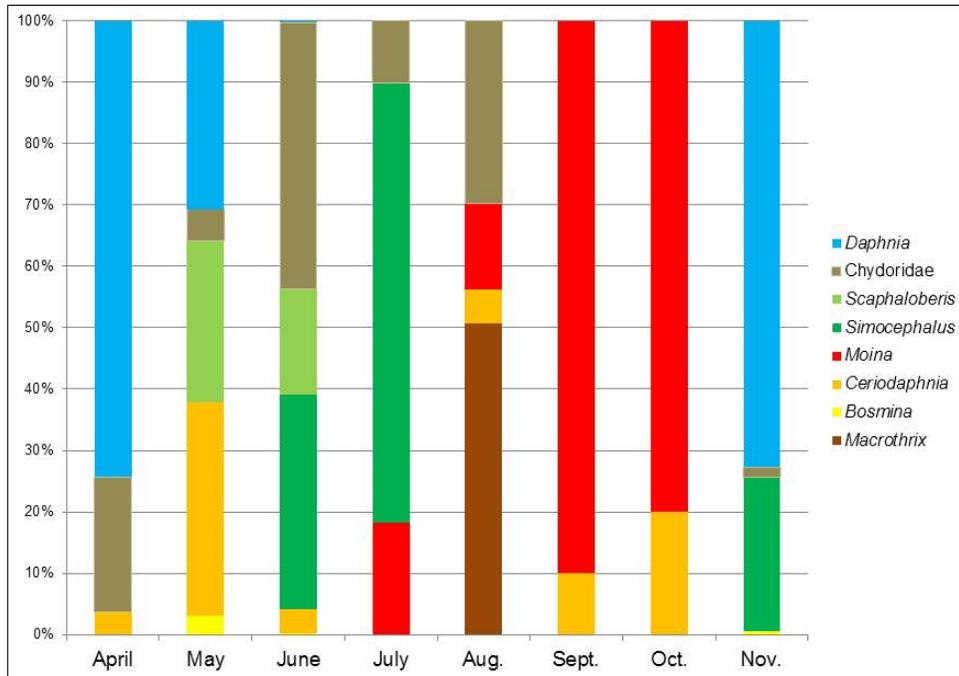
**Figure 6.2. Composition of the zooplankton community in the Willard Spur, April-November 2012 (combined data from all sites except tailrace). "Annual" refers to an overall average of all sampling dates.**



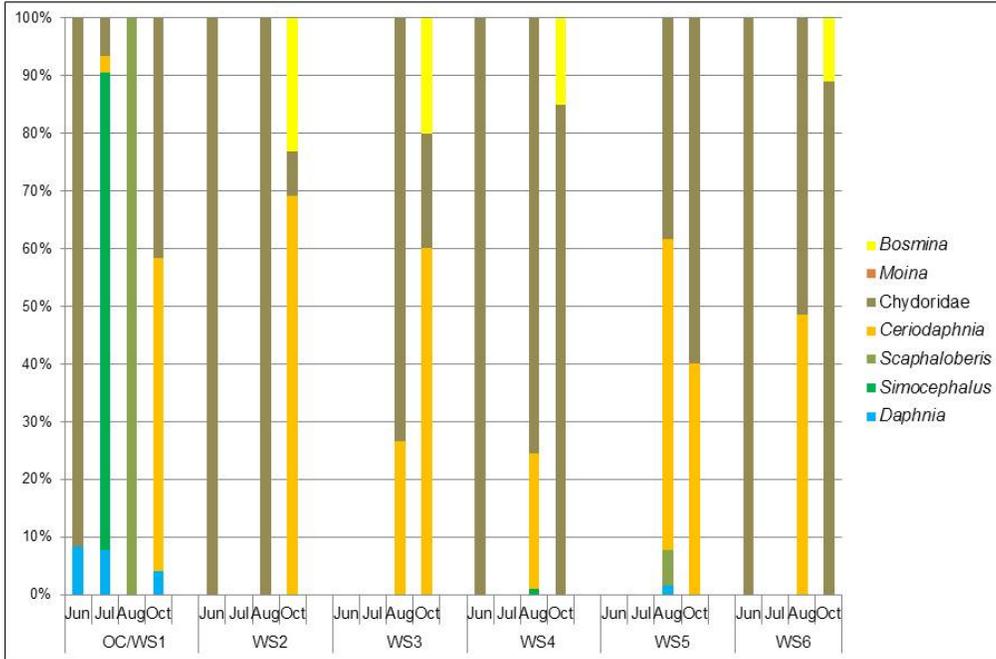
**Figure 6.3. Composition of Cladocera in the Willard Spur, June-October 2011 (combined data from all main Spur sites).**



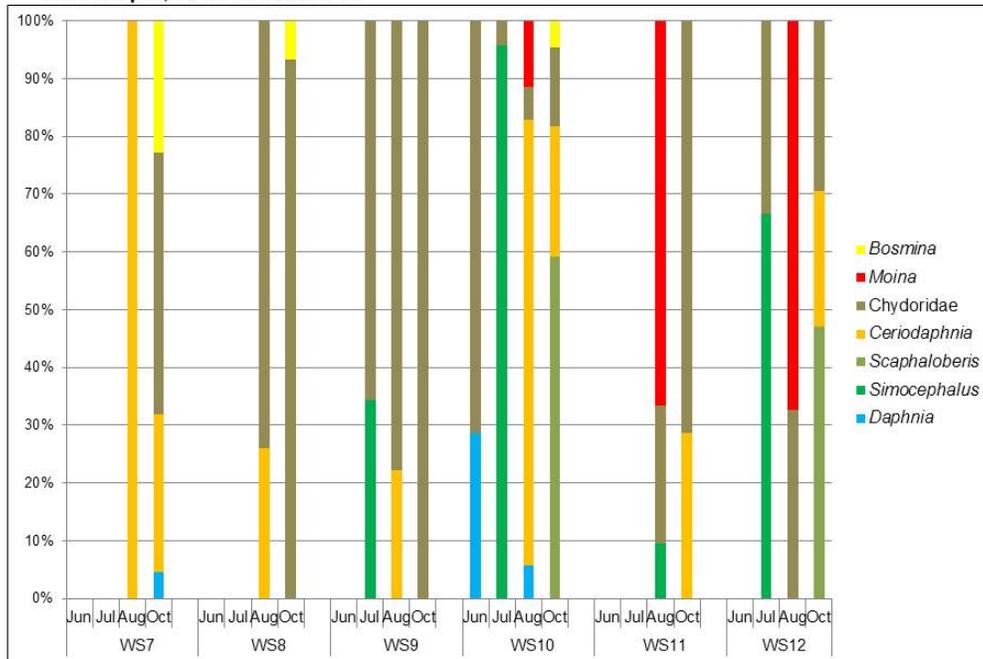
**Figure 6.4. Composition of Cladocera in the Willard Spur, April-November 2012 (combined data from all sites except tailrace).**



**Figure 6.5a. Composition of Cladocera at sites Outfall Confluence/WS-1 to WS-6 by sampling date in the Willard Spur, June-October 2011.**



**Figure 6.5b. Composition of Cladocera at sites WS-7 to WS-12 by sampling date in the Willard Spur, June-October 2011.**



**Figure 6.6. Composition of Cladocera at selected sites by sample date in the Willard Spur, April-November 2012.**

