

**Macroinvertebrates of the Willard Spur Wetlands:  
Literature Review and Results of Sampling in 2011**

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## Summary

This report summarizes the results of macroinvertebrate sampling in the Willard Spur wetlands during 2011. Overall, the macroinvertebrate communities in the Willard Spur were very similar to communities previously found in other impounded wetlands of the Great Salt Lake. Community composition was dominated by midges (Chironomidae), snails, corixids, mayflies, amphipods, and damselflies. As in other GSL wetlands, composition varied seasonally with midges dominant in spring through early summer, whereas corixids and snails dominated from summer through early fall. Trophic structure was nearly identical between the Willard Spur and other wetlands. The abundance of macroinvertebrates in Willard Spur was lower than that of other wetlands during 2011 and was likely the result of high runoff and the subsequent extension of low water temperatures. Community metrics (percentage of phytophilous taxa and Simpson's index) were similar between areas. Both metrics decreased as the abundance of SAV decreased in the Willard Spur, and these responses were the same as that found in other GSL wetlands in previous studies. Perimeter and channel sites in Willard Spur typically had a greater abundance of snails, hemipterans, and aquatic beetles compared to open-water sites, reflecting shallower water depths, differences in aquatic vegetation, and more extreme water chemistry (i.e., higher salinities and lower dissolved oxygen).

Background information on previous wetlands studies and life history characteristics of the macroinvertebrates are presented. In addition, recommendations are given for future research.

## **Introduction**

This report presents currently available information regarding the macroinvertebrate community 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, a general background review of the literature is given with emphasis on the potential impacts of eutrophication on the macroinvertebrates present. Part of the background is a comparison of macroinvertebrates present in the Willard Spur, based on 2011 collections, and those present in prior collections from nearby impounded wetlands, including the Bear River Migratory Bird Refuge, Public Shooting Grounds, and Farmington Bay. The second section presents the macroinvertebrate data from field samples collected during 2011. These preliminary data are used to present an overview of the relationship between macroinvertebrates to habitat and water quality parameters. The third section outlines recommendations for further research.

# 1. Willard Spur Macroinvertebrates: Literature Review

## 1.1. Macroinvertebrates as Indicators of Water Quality

From the standpoint of bioassessment in freshwater ecosystems, benthic macroinvertebrates have had a long history as an important group for indicating water quality conditions. By convention, the term “benthic macroinvertebrate,” or simply “macroinvertebrate,” refers to any invertebrate phyla associated with aquatic substrates that are retained by a 0.5 mm-mesh net or sieve (Hauer and Resh 1996). Common taxa include a number of orders of aquatic insects (e.g., mayflies, dragonflies, true flies, etc.), mollusks (snails and clams), annelids (e.g., oligochaetes and leeches), and crustaceans (e.g., amphipods). Not included in the macroinvertebrate designation are taxa considered to be part of the “meiofauna,” such as ostracods and benthic rotifers.

Macroinvertebrates have a number of advantages, and some disadvantages, as indicators of water quality (Barbour et al. 1999). Advantages of using macroinvertebrates include:

- a) relatively limited movement, thus reflecting local conditions;
- b) diverse communities composed of species that exhibit varying tolerances to changes in water quality and habitat conditions;
- c) integration of short-term changes in environmental conditions as reflected in their abundance, diversity, and life cycles;
- d) assessment of food web changes (macroinvertebrates often serve as important foods for other wildlife, such as fishes and birds); and
- e) sampling is relatively easy in terms of requiring few people and inexpensive gear.

Disadvantages of macroinvertebrates include:

- a) difficulties in identification of taxa;
- b) effort required to process field samples (e.g., separation of animals from sediments and detritus); and
- c) lack of detailed knowledge of life cycles and environmental tolerances, particularly for local populations.

The use of macroinvertebrates in biological assessments may include the examination of the abundance and distribution of individual taxa in relation to water quality and other environmental variables, particularly for taxa highly sensitive to the stressor(s) of interest (the “indicator” taxa). More commonly, however, the effects of stressors are evaluated through the use of “metrics,” or derived measures from community-level data. Common categories of metrics are diversity indices (e.g., total taxa, Simpson’s Index) and proportions of subsets of taxa based on trophic level, tolerance/intolerance rankings, habitat preferences, etc. (Barbour et al. 1999). Proposed metrics for the wetlands communities are discussed in Part II.

## **1.2. Previous Studies of Macroinvertebrates in the Wetlands of the Great Salt Lake**

There have been some previous studies of macroinvertebrates present in the Great Salt Lake (GSL) wetlands and the surrounding region, although these studies primarily have been focused on aspects unrelated to water quality assessment. Several papers have concentrated on describing what species of specific groups of aquatic insects are present and their regional distribution in Utah, including areas in and around the GSL wetlands. These studies have included damselflies (Provonsha 1975), dragonflies (Musser 1962), oligochaetes (Spencer and Denton 2003), leeches (Beck 1954), snails (Chamberlin and Roscoe 1948, Oliver and Bosworth 1999), and mayflies (Edmunds 1952). Shiozawa and Barnes (1977) studied the dominant chironomids (midges) in Utah Lake; these chironomids are also abundant in the GSL wetlands (Gray 2010). Wollheim and Lovvorn (1995, 1996) and Hart and Lovvorn (2003) studied the macroinvertebrates of marshes in Wyoming with salinities similar to that found in some GSL impounded wetlands. Their emphasis was on the relationships between macroinvertebrate taxa and macrophytes and macroinvertebrates as food for shorebirds. Cox and Kadlec (1995) sampled macroinvertebrates during the summers of 1988 and 1989 in wetlands north of the Willard Spur, including the Bear River Migratory Bird Refuge, Public Shooting Grounds, and local duck clubs, to evaluate their availability as potential food for ducks. Their data included the taxa present (although macroinvertebrates were only identified to family/order level) and biomass estimates from core samples. Huener and Kadlec (1992) examined macroinvertebrate abundance in relation to marsh vegetation management strategies in the Bear River MBR.

The most extensive work relating macroinvertebrates to water quality and habitat characteristics in the GSL wetlands has been my reports on the wetlands (Gray 2005, 2009, 2010, 2011a). The focus of these reports was the impounded wetlands of the Public Shooting Grounds, Bear River MBR, Farmington Bay Waterfowl Management Area, Inland Sea Shorebird Reserve, and private duck clubs (Ambassador, New State, and Harrison). Some "sheetflow" wetlands in the Farmington Bay area were also sampled in 2004 (Gray 2005). Willard Spur macroinvertebrates were sampled from March through October 2011 (Gray 2011b). The results of the Willard Spur sampling and comparisons to these other GSL wetlands are discussed in Section 2. Field sampling and laboratory protocols follow SOPs developed for the GSL impounded wetlands by the Utah Division of Water Quality.

### 1.3. Wetlands macroinvertebrates

The following discussion is intended to introduce the macroinvertebrate fauna of the Willard Spur in terms of its taxonomic composition and, for the most common taxa, describe their life cycle, food habits, habitat preferences, and general tolerances to potential environmental stressors. The final part discusses community-level responses to nutrient enrichment, including a description of the macroinvertebrate metrics that have been proposed for the GSL wetlands.

#### 1.3.1. Taxonomic composition and Characteristics of Taxa

The list of macroinvertebrate taxa that have been collected in the GSL wetlands, including Willard Spur, is given in Table 1. The most abundant taxa listed in Table 1, such as mayflies, damselflies, corixids, Chironomidae, amphipods, and snails, are all characteristic of wetlands throughout North America (e.g., Adamus 1996, Adamus and Brandt 1990, Wollheim and Lovvorn 1996, Zimmer et al. 2000). Although the particular species may vary geographically, several genera, including *Callibaetis*, *Caenis*, *Chironomus*, *Physella* (*Physa*), *Gyraulus*, and *Hyaella*, are ubiquitous in wetland habitats. None of the taxa listed in Table 1 are threatened or endangered (US Fish & Wildlife Service 2011).

The following discussion provides brief descriptions of the life cycles, feeding habits, and habitat preferences of the common taxa. More details on tolerances of these taxa to selected physical/chemical components of water quality are given in the succeeding section.

##### 1.3.1.1. Mayflies (Ephemeroptera)

*Callibaetis* has been found 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) give a developmental time of 6 weeks (presumably during the summer), and Johnson et al. (2000) found 3, possibly 4, generations per year for *C. fluctuans* in a West Virginia marsh. Due to the longevity of the females, nymphal generations often overlap throughout the summer and fall. The fall generation then overwinters as nymphs and emerges in spring.

*Callibaetis* nymphs are characterized as collector-gatherers in terms of feeding habitats (Merritt and Cummins 2007). Collector-gatherers feed on fine particulate detritus and algae. Nymphs are “clingers,” that is, they typically are found within submerged aquatic vegetation (SAV). In the GSL wetlands, nymphs are most abundant where extensive growths of *Stuckenia* are present (Gray 2010).

*Caenis* is the other species of mayfly present in the GSL wetlands and typically is found in abundance in the same habitats as *Callibaetis* (see Note 2). Like *Callibaetis*, it also is associated with SAV beds, but nymphs can also reach high densities in algal mats (Gray 2010). Nymphs are collector-gatherers (Merritt and Cummins 2007). It is

thought to be bivoltine, but extended emergence periods result in all size classes being present during summer and fall. Adults live for only a few hours (Edmunds et al. 1976).

#### **1.3.1.2. Dragonflies and Damselflies (Odonata)**

Odonates are an abundant component of the macroinvertebrate communities in the GSL wetlands (Gray 2010; see Note 3). *Ischnura* and *Enallagma* are common genera found throughout the region. *Archilestes* was also common in Willard Spur. Common dragonflies include *Aeschna*, *Erythemis*, and *Tramea* (see Note 3).

Damselflies typically have one generation per year, although some *Ischnura* are bivoltine (Pennak 1978). Libellulid dragonflies (*Erythemis* and *Tramea*) typically are univoltine, whereas *Aeschna* can require 3 years for development (Pritchard and Smith 1956). Odonate populations in the GSL wetlands exhibit an extended period of reproduction with larvae of all age classes present from mid-summer through fall.

All larval odonates are predators on other invertebrates and occasionally small fish (Corbet 1999). All of the damselflies and the libellulid dragonflies (*Erythemis* and *Tramea*) are strongly associated with submerged vegetation in the GSL wetlands; *Aeschna* is found in a variety of habitats, including shoreline areas near emergent vegetation and beds of submerged vegetation in open water (Gray 2010).

#### **1.3.1.3. Water boatmen (Corixidae) and Backswimmers (Notonectidae) (Hemiptera: Heteroptera)**

The “true” bugs are abundant and widespread in the GSL wetlands (Gray 2010, see Note 4). The corixids and notonectids are found in all aquatic habitats as both adults and immatures. Except for *Hesperocorixa*, all are predators (Usinger 1956). *Hesperocorixa* is considered a piercer-herbivore (included here in the “shredder” category), feeding on aquatic vegetation (Merritt and Cummins 2007), and it is closely associated with SAV in the GSL wetlands (Gray 2010). Reproduction occurs from early summer through early fall in the GSL wetlands (Gray 2010). Development of corixids and notonectids from egg to adult typically requires 8-10 weeks. Both adults and immatures rely on atmospheric air for respiration, and adults are capable of flight (Lauck 1979, Truxal 1979).

#### **1.3.1.4. Midges (Diptera: Chironomidae)**

Midge larvae are abundant in the GSL wetlands and can reach extremely high densities; for example, FBWMA Unit 2 in May 2010 had a midge density greater than 200,000 individuals per m<sup>2</sup> (Gray 2010). The common midges are in the subfamilies Tanypodinae (*Tanytus* and others), Orthocladiinae, and Chironominae (*Chironomus* and Tanytarsini). Midge larvae inhabit all types of habitats, but *Chironomus*, the most abundant midge, reaches its greatest densities in areas with bare mud as a substrate (Gray 2010). *Chironomus* and Tanytarsini larvae are red in color due to the presence of a respiratory pigment, an adaptation for low dissolved oxygen concentrations (Pennak 1978). Most midges are collector-gatherers and feed on fine detritus and algae, but the Tanypodinae are predators on smaller invertebrates (Merritt and Cummins 2007).

Shiozawa and Barnes (1977) found that *Tanypus* was bivoltine in Utah Lake, whereas *Chironomus* had three generations per year. Adult emergence is continuous from early spring through fall.

#### 1.3.1.5. Aquatic Beetles (Coleoptera)

Beetles are the most diverse group of aquatic insects in the GSL wetlands (Table 1) and many more genera are likely to be collected in addition to those listed. The majority of beetles are in the families Hydrophilidae and Dytiscidae. Most of the genera listed in Table 1 are uncommon in collections.

The most common and widespread genera are *Enochrus*, *Berosus*, and *Halipus*. *Enochrus* and *Berosus* adults and larvae are found in a variety of habitats, whereas *Halipus* is only found in SAV beds. Larvae of all 3 genera are collectors-gatherers of detritus, and adults are piercer-herbivores or “shredders” of vegetation and algae (Merritt and Cummins 2007). *Enochrus* and *Halipus* adults and larvae breathe atmospheric air. *Berosus* adults also breathe atmospheric air, whereas the larvae have gills and rely on dissolved oxygen. These beetles are univoltine with reproduction occurring during summer.

#### 1.3.1.6. *Hyaella* (Crustacea: Amphipoda)

*Hyaella* amphipods are widespread in the GSL wetlands (Gray 2010; see Note 5). *Hyaella* feeds mostly on detritus and algae, and highest densities tend to occur in impounded wetlands where SAV detritus and filamentous algae are abundant (Gray 2010). Hart and Lovvorn (2003) found that “amorphous” detritus, primarily derived from algae, was a key component in the diet of *Hyaella*. During the warmer months, *Hyaella* females are capable of producing multiple broods (Pennak 1978).

#### 1.3.1.7. Snails (Mollusca: Gastropoda)

The pulmonate snails (snails with “lungs” rather than gills) are common throughout the GSL wetlands. The most collected genera are *Physella* (*Physa*), *Stagnicola*, and *Gyraulus*. Snails are “scrapers” that feed by rasping detritus, algae, and biofilms from substrates. *Physella* and *Stagnicola* are common throughout the GSL wetlands and are often most abundant in accumulations algae and plant detritus (*Physella* can also be abundant in *Stuckenia*). *Gyraulus* is abundant in aquatic vegetation, especially *Stuckenia* (Gray 2010). Two or more generations are produced in summer and early fall.

### 1.3.2. Tolerance of Wetlands Macroinvertebrates to Physical/Chemical Parameters

#### 1.3.2.1. Effects of Salinity Levels on Macroinvertebrates

Levels of salinity in the GSL wetlands can show considerable variation due to the influence of the Great Salt Lake water levels and local hydrology. Individual taxa of macroinvertebrates in the GSL wetlands exhibit variation in tolerance to salinity, particularly when salinities are relatively high compared to typical freshwater habitats.

The taxa most tolerant to salinities at or above that of seawater in the GSL wetlands are the corixid *Trichocorixa*, brine fly larvae (Ephydriidae), and brine shrimp (*Artemia*). In general, these taxa are restricted to highly saline wetlands. In recent sampling, these taxa have only been found in wetlands where salinity exceeded 10 ppt (Gray 2005, 2007).

For the other common taxa, many can tolerate salinities of 10 ppt. For example, chironomids, *Notonecta*, and the other corixids have been found co-occurring in typical densities with the above 3 taxa in GSL wetlands with salinity levels of 10 ppt (Gray 2005). *Ischnura* and *Aeschna* larvae have been reported to tolerate this level of salinity (Corbet 1999). Other common taxa, such as mayflies, other odonates, amphipods, and snails, appear to have long-term tolerance to salinity levels below 6 ppt ( $\approx 10,000$   $\mu\text{mhos/cm}$  specific conductance); densities sharply decline as salinities increase beyond that limit (Gray, general observation from 2004-2010 data). This limit generally corresponds to those found for some of these taxa in other studies. For example, Galat et al. (2004) conducted laboratory bioassays of salinity tolerance of *Hyaella azteca* and *Chironomus utahensis* from Pyramid Lake, Nevada. *Hyaella* could tolerate short-term (3 days) exposure to salinities up to 19.5 ppt, but long-term exposure to salinities above 5.6 ppt caused significantly lowered densities. The upper limit for *Chironomus* was 13.3 ppt in short-term exposures; densities and adult emergence were significantly reduced at salinities above 8 ppt.

#### 1.3.2.2. Tolerance of Macroinvertebrates to Drought and Changes in Water Levels

The extent of water permanence and water depth are known to be important factors affecting macroinvertebrates in wetlands (Adamus 1996, Adamus and Brandt 1990, Zimmer et al 2000). Water permanence affects the availability of habitat relative to life cycles and food/substrate resources, and water depth may be important in development of suitable substrates, such as aquatic vegetation.

Under drought conditions where wetlands substrates are completely exposed to drying, those macroinvertebrates that cannot leave by aerial adults (e.g., beetles, corixids, and emergent adults of other aquatic insects) typically will be extirpated. If some moist habitats are present, those that breathe atmospheric air (e.g., most beetle larvae) may be able to survive a short time after the surface water recedes. Pulmonate snails have the ability to aestivate during drought, either aboveground (Jokinen 1978) or by burrowing into bottom muds (Pennak 1978), which allows them to survive several months or longer. Shiozawa and Barnes (1977) found *Chironomus* larvae at depths of 30 cm in the bottom muds of Utah Lake, thus midges (and potentially other mud

dwellers, such as oligochaetes) could survive, at least for short periods, without surface water. None of the macroinvertebrates in the GSL wetlands are known to possess extreme physiological mechanisms to tolerate drying, such as anhydrobiosis (Crowe and Crowe 1992).

Recolonization after drought in any area of the GSL wetlands is likely to be relatively fast given the proximity of other wetlands and mobility of most taxa. In the Willard Spur, the most important routes of recolonization would be from aerial adults and drift from the canals that enter from the Bear River refuge and other impounded wetlands. Adults of many aquatic insects are able to disperse over several kilometers; strong flyers, such as hemiptera adults, adult odonates, and beetle adults can fly many kilometers in a single day (Corbet 1999, Pennak 1978, Stonedahl and Lattin 1986). Amphipods may also recolonize wetlands via dispersal by waterfowl and aquatic mammals (Swanson 1984).

Low water levels likely would affect macroinvertebrates by reducing the total area of habitat available and by changing the abundance of submerged aquatic vegetation and algae (discussed below). Previous sampling in the GSL wetlands has shown that all of the common taxa are present in "sheetflow" wetlands with water depths of only a few centimeters of water as well as in impounded wetlands with water depths greater than 1 meter (Gray 2005). However, in the ponded wetlands, low water levels during drought result in a community dominated by air-breathing taxa, such as pulmonate snails, corixids, and beetles. This shift in community composition likely reflects increased stress caused by physical/chemical changes, such as increased salinity and greater fluctuations in temperature and dissolved oxygen (Gray 2011a).

### 1.3.2.3. Effects of Nutrient Enrichment on Individual Taxa of Macroinvertebrates

Unlike macroinvertebrates in other freshwater ecosystems, such as streams, the ones present in the GSL wetlands generally exhibit a high tolerance to physical/chemical stressors. This tolerance is evident in the relatively high HBI tolerance values given for the taxa listed in Table 1 (Barbour et al. 1999).

Direct effects of nutrient enrichment on macroinvertebrates involve one or more chemical parameters exceeding the tolerance limits for that species. The discussion presented here emphasizes the two parameters, dissolved oxygen and ammonia, that may exceed tolerance limits of the taxa present in Willard Spur under extreme conditions.

The common taxa of the GSL wetlands are tolerant of low oxygen conditions, and some can survive anoxia. Taxa that breathe atmospheric air, including most beetles, hemipterans, some dipterans (Ephydriidae, Tabanidae), and pulmonate snails, are relatively unaffected by low oxygen levels and can survive in anoxic conditions, at least for short periods (although their eggs do require some oxygen for development, e.g., Harman 1974). Dragonfly and damselfly larvae are known to crawl out of the water on emergent vegetation at night due to lack of dissolved oxygen (Corbet 1999).

Those taxa present that must rely on dissolved oxygen, such as mayflies, chironomids, amphipods, and odonate larvae, are well-known to tolerate low dissolved oxygen concentrations, although exact limits of tolerance are largely unknown. In an extensive summary of the literature, Roback (1974) noted that *Callibaetis*, *Caenis*, dytiscid, hydrophilid, and haliplid beetle larvae, *Ischnura*, and many chironomids are

tolerant of dissolved oxygen concentrations less than 4 mg/L and/or BOD concentrations greater than 5.9 mg/L. A similar range of tolerance to low DO/high BOD was found for *Archilestes* (Moscowitz and Bell 1998). In previous sampling of the GSL wetlands, these taxa were present in habitats where dissolved oxygen concentrations were below 2 mg/L (Gray 2005). The common taxa present that are least tolerant of low oxygen conditions are *Hyaella* amphipods and orthoclad chironomids (Pennak 1978, Roback 1974), although *Hyaella* has been found in GSL wetlands where dissolved oxygen was only 2 mg/L (Gray 2005).

Less is known about the tolerance of macroinvertebrates to dissolved ammonia/ammonium; most information is from laboratory studies using common bioassay animals, such as *Hyaella* and *Chironomus*. In general, acute tests indicated that common aquatic insects (*Chironomus*, *Callibaetis*), snails (*Physa*), and amphipods are tolerant of ammonia levels (70 to over 100 mg/L as N; EPA). Chronic toxicity levels for *Hyaella*, however, were less than 2 mg/L (USEPA 1998). *Hyaella* has been collected from GSL wetlands with levels of ammonia as high as 6.5 mg/L (Gray 2005). In the Willard Spur, von Stackelberg (2010) estimated ammonia concentrations of slightly less than 2 mg/L after 5 years of high nutrient loading with no flushing. The highest concentrations of ammonia during the 2011 sampling were found at the Willard Perry outfall site where ammonia (as N) was 17-25.8 mg/L in March 31-April 27 samples. All other samples, including later samples at this site, had ammonia concentrations less than 0.35 mg/L.

#### **1.3.2.4. Community Metrics and Community Responses to Nutrient Enrichment**

Metrics are summary statistics calculated from raw data collected on macroinvertebrate community composition and abundance. Examples include species diversity, such as number of taxa (total or within specific taxonomic groups) and calculated indices (e.g., Simpson's index); proportions based on sample count, such as ratios of specific taxa within a related group of taxa, feeding habits, or habitat preferences; and presence/absence of specific species that are tolerant or intolerant of the stressor(s) impacting the system (e.g., Barbour et al. 1999). Typically, a large number of potential metrics are evaluated for a system, and a subset selected based on statistical significance of the correlation between the metric value and the stressor. The selected set of metrics often is combined into a composite score (referred to either as MMI--macroinvertebrate multimetric index or IBI--index of biotic integrity; e.g., Lunde and Resh 2012, Gernes and Helgen 2002).

Although community metrics are not as well developed or standardized in wetlands as in other freshwater systems, the overall community response to eutrophication/nutrient enrichment is similar (Lunde and Resh 2012). In general, macroinvertebrate communities respond to eutrophication through decreased diversity, shifts in the relative abundance of species, and changes in overall abundance, both in terms of numbers of individuals and biomass. These changes occur due to direct toxicity of chemical constituents to sensitive taxa (e.g., low dissolved oxygen and increased ammonia), and impacts on habitats, such as shifts in the nature and quality of food resources (detritus, algae) and alterations to the abundance of key habitat

structure (substrates, vegetation) (Adamus 1996, Adamus and Brandt 1990, Cyr and Downing 1988).

Previous sampling in the GSL wetlands has been oriented towards developing macroinvertebrate metrics that reflect community responses to variations in nutrient levels among different sites (Gray 2009, 2010, 2011a). Given that these were rapid bioassessment studies, the goal was not to ascertain specific causal factors linking changes in nutrient levels to changes in abundance and diversity of specific taxa. Instead, the goal was to derive macroinvertebrate community metrics that consistently reflected the overall condition of the wetlands habitat.

After the initial study in 2007 (see Appendix), it became apparent that significant differences did exist in community composition and relative abundance of individual taxa in impounded wetlands that varied both in terms of nutrient levels and habitat condition (Gray 2010). The abundance of SAV (*Stuckenia*) and filamentous algae were highly correlated with shifts in macroinvertebrate community composition, both between different wetlands sites and seasonally within individual wetlands (Gray 2011a). Other studies have shown that wetlands macroinvertebrate communities often reflect the nature and abundance of the vegetation present (Cyr and Downing 2006, Feldman 2001). The type of abundance of vegetation in the GSL wetlands has been shown to be correlated with nutrient levels; specifically, *Stuckenia* is less abundant in ponds with high nutrients and undergoes more rapid senescence, in part due to increases in filamentous algae (CH2M Hill 2009). Thus the most likely impact of nutrient enrichment in Willard Spur on macroinvertebrate communities would be the effects on the aquatic vegetation.

Several macroinvertebrate metrics were found to be correlated with nutrient levels in the initial examination of a limited number of samples collected from the impounded GSL wetlands in 2007, including total taxa, percentage of mayflies to total number, percentage of amphipods to total number, number of beetle taxa, and Simpson's diversity index (Gray 2009). Subsequent sampling in 2009-2010 in additional impounded wetlands (including samples taken in both summer and fall seasons) was used to refine the metrics by including field data on the abundance of SAV, filamentous algae, and other habitat parameters. Two metrics that showed the highest correlation with habitat characteristics were the percentage of "phytophilous" macroinvertebrates to total count (% PMI) and Simpson's diversity index (Gray 2010, 2011a). Simpson's index was correlated with total taxa, and %PMI was found to correlate with % mayflies, % amphipods, and number of beetle taxa. Simpson's index and %PMI typically were not correlated with each other.

Phytophilous macroinvertebrates are those taxa that are closely associated with SAV, either as a preferred substrate or as a food resource (Cyr and Downing 1988, 2006). In the GSL wetlands, these taxa include mayfly nymphs (*Callibaetis* and *Caenis*), damselfly larvae (*Ischnura*, *Enallagma*, *Archilestes*), dragonfly larvae (*Erythemis* and *Tramea*), *Hesperocorixa* corixids, *Gyraulus* snails, *Ylodes* caddisfly larvae, and the beetle *Halipus* (Gray 2010). The proportion of total density comprised of individuals of these taxa increase with increasing abundance of SAV. In impounded wetlands with little SAV, the dominant macroinvertebrates in summer are chironomids, *Corisella* corixids, and the snails *Physella* and *Stagnicola* (referred to as the "base" community in Gray 2010). *Hyaella* amphipods increased in relative abundance in

wetlands where filamentous algae and duckweed had replaced the SAV. This metric is similar to the “EOT” (Ephemeroptera-Odonata-Trichoptera) metric of Lunde and Resh (2012) and the “ETSD” (Ephemeroptera-Trichoptera-Sphaeriidae-Dragonfly) metric used in Minnesota wetlands (Gernes and Helgen 2002).

Simpson’s diversity index (SI) incorporates both overall diversity (i.e., number of species) and the relative abundance of each species (“evenness”) in a sample (see Note 6). The value of SI in nutrient enrichment studies, particularly in the GSL wetlands, is that it reflects the gradient of conditions from reduced diversity and increased dominance by a few taxa (such as snails and chironomids) as wetlands become more eutrophic (Gray 2010). The SI metric is correlated with a metric referred to as the “Top 3%” or “Dominant 3” metric. This metric is the percentage of total sample count accounted for by the three most abundant taxa, thus it also reflects the degree of evenness in the community. It has been a significant macroinvertebrate metric in bioassessment studies in other wetlands IBIs (e.g., Lunde and Resh 2012, Gernes and Helgen 2002).

## 2. Analysis of 2011 Macroinvertebrate Samples

### 2.1 Introduction

This section presents the results of analyses of macroinvertebrate samples collected in the Willard Spur from March through October 2011. The primary emphasis is on the “open water” community as this habitat represents the majority of habitat area sampling and is comparable to similar communities in other impounded wetlands that have been studied. The sampling sites located in channels in the upper part of Willard Spur (Outfall-NPS, Willard Perry outfall, and Irrigation Return Flow 1) and perimeter sites sampled in August 2011 (designated “A” and “B”) are discussed in later sections. Figure 1 gives a map showing locations of the 2011 sampling sites.

For the open water habitat, sampling results are presented that characterize the overall community in terms of taxonomic composition, abundance, community metrics, and trophic composition. Seasonal changes in these attributes are also discussed. Due to the variable number of samples taken at the open-water sites during different months, data from adjacent, similar sites were combined to allow statistical analysis and more clearly detect overall trends. The groupings used were the Upper Spur group (sites clustered near the outlets for the treatment plant and Willard Bay tailrace, including the Outfall Confluence to WS 3), Middle Spur group (sites influenced by outflows from the Harold Crane WMA, including WS 4 to WS 7), and the Lower Spur group (sites closest to the Great Salt Lake, including WS 8 to WS 12). Comparisons between the attributes of the macroinvertebrate communities of the Willard Spur and previously-studied impounded wetlands are also included.

In addition to the macroinvertebrate data, water chemistry data collected and analyzed by the Utah Division of Water Quality were also available. DWQ personnel collecting the macroinvertebrate samples also recorded the following information on habitat conditions at a majority of sites: % SAV cover, % filamentous algae cover, % duckweed cover, SAV condition (relative scale), height of SAV growth, and water depth.

## 2.2. Open-Water Sites

### 2.2.1. Abundance, Composition, and Community Metrics

The similarity between the macroinvertebrate taxa present in the Willard Spur and those present in other GSL wetlands was discussed in Section 1 (Table 1). This discussion extends the comparison by taking global averages for all open-water samples from Willard Spur taken during 2011 and global averages for sites sampled in 2010 (May, July, and November) and 2011 (July and November) from the impounded wetlands (data from Gray 2011a, b).

A summary of the community characteristics from both areas is given in Table 2. Compared to the impounded wetlands, the Willard Spur had lower overall abundance. Total taxa per sample was also lower in the Willard Spur samples. However, the community metrics (% PMI and Simpson's Index) were similar in both areas.

The reasons why the Willard Spur sites had lower average abundance and diversity compared to the other GSL wetlands cannot be definitively determined. Speculatively, the extended period of above-normal runoff could have affected macroinvertebrates in three general ways:

- 1) The greater surface area resulting from higher flows may have "diluted" population densities. In the impounded GSL wetlands used for comparison, surface area does not change much with runoff conditions due to the morphometry of the ponds and active management of water levels.
- 2) Cold water temperatures persisting longer into summer would slow developmental times of all taxa and reduce the number of generations of multivoltine taxa.
- 3) Organic detritus on substrates, an important food for many collector taxa, may have been flushed out with the higher flows.

Abundance of macroinvertebrates varied little between seasons (Table 3). There was no significant difference in total counts between the different months of sampling at the main Willard Spur sites (1-way ANOVA  $F = 0.49$ ,  $P = .75$ ,  $df = 4, 59$ ). For biomass, the only significant difference between months occurred between the July and October samples ( $F = 4.70$ ,  $P = 0.04$ ,  $df = 7, 20$ ). These patterns were similar to those found in previous sampling of other GSL wetlands.

Community metrics showed a peak in total taxa in July with highest values for %PMI and Simpson's Index occurring in October. The other GSL wetlands also showed a peak in taxa in July. Simpson's index and %PMI were similar in all seasons in the GSL wetlands; however, this similarity between seasons may be coincidental and the result of each month's sampling occurring at different sites. Within the different areas of Willard Spur, %PMI showed the strongest seasonal difference among the metrics with highest percentages occurring in August in the upper sites and October in the lower sites (Fig. 2).

The overall taxonomic composition of the macroinvertebrates in the open-water sites of Willard Spur generally was similar to that found in other GSL wetlands (Figs. 2a, 3a). Communities in both areas primarily were comprised of 6 main groups: midges (Chironomidae), snails, corixids, mayflies, amphipods, and damselflies. Chironomidae was the most abundant taxon in both areas, and included common midges such as *Chironomus*, *Tanytus*, and *Orthoclaadiinae*. Corixids and mayflies were higher in

relative abundance in Willard Spur, whereas snails and amphipods were lower. Damselflies and other taxa (e.g., beetles, other Diptera) were similar in relative abundance in both areas.

Willard Spur communities followed seasonal changes in taxonomic composition similar to that of other GSL wetlands (Figs. 3b-f, 4b-d). Communities in both areas were dominated by *Chironomus* and other chironomids in spring and early summer with increasing populations of other species after June. The primary differences between the two areas were the greater relative abundance of corixids and mayflies during the summer and fall months and fewer amphipods in Willard Spur during the fall.

### 2.2.2. Trophic Composition

The overall trophic structure of Willard Spur and that of the other GSL wetlands are given in Figures 5 and 6. The annual percent composition of the Willard Spur open-water sites was nearly identical to that of the GSL wetlands. The seasonal trophic composition was also similar between the areas (although samples were not taken in the same months). Collectors dominated in both areas in the spring and fall seasons, reflecting the abundance of mayflies and most genera of chironomids. Scrapers and shredders had peak relative abundance during the summer during the reproductive peaks for snails and *Hesperocorixa*, respectively. Predators rapidly increased during early summer and were an important group through the late fall. This pattern reflected a succession of predator taxa from an early dominance by Tanypodinae chironomids to gradual increases in reproduction during summer by hemipterans (*Corisella* and *Notonecta*), damselflies, and predaceous beetles.

### 2.2.3. Macroinvertebrate Biomass

Because biomass of macroinvertebrates was highly correlated with sample counts, trends in quantity and composition were similar. In the open-water sites, biomass peaked in July due to increases in snail populations (Fig. 7). Seasonal changes in the relative contribution of the various taxa followed that of sample counts (Fig. 8).

Although interest has been expressed in using biomass as a potential macroinvertebrate metric, it has several limitations:

- 1) Biomass has been highly correlated with sample counts in all previous data sets from the GSL wetlands (e.g., Gray 2010), particularly if snails were excluded from sample totals. Thus, it duplicates information from sample counts.
- 2) If measured directly, then biomass is underestimated in a sample due to loss in preservative and individuals damaged during collection. Neither factor is constant from one sample to the next. If measured indirectly (e.g., calculated using known weights of individual size classes for each taxon), then the procedure increases processing time for each sample.
- 3) Biomass has a high variance between samples resulting from the patchy distribution of macroinvertebrates in the habitat. In a previous study where 15 sweeps from Pintail Pond in the Public Shooting Grounds were analyzed separately (Gray 2010), the 95% confidence limits for biomass were the mean +/- 300% for a typical 5-

sweep sample (compared to mean  $\pm$  10% for other metrics, such as % PMI and Simpson's Index). Unless additional samples (at least 6) are taken at each site to reduce the variance, comparisons between samples would require differences of an order of magnitude or greater to discern statistical significance.

- 4) Biomass typically is quantified as a general measure of the "productivity" of a site or habitat. However, biomass is difficult to correlate with secondary production. High instantaneous biomass is often associated with taxa with low production-to-biomass ratios, such as hemipterans, odonates, and snails, whereas taxa with high P/B ratios, such as chironomids, often have relatively low instantaneous biomass. Furthermore, the absence of life cycle data from populations in the GSL wetlands means that the P/B ratios for common taxa are not known with certainty.
- 5) The intent of macroinvertebrate metrics is to reflect habitat conditions in the wetlands. As with sample counts, biomass has not been found to be correlated with any of the physical/chemical or habitat conditions in the GSL wetlands.

#### **2.2.4. Effects of Changes in Aquatic Vegetation on Community Metrics**

As noted above, the metrics % PMI and Simpson's Index have been found useful in indicating changes in the macroinvertebrate community in relation to in water quality and habitat conditions, particularly changes in the aquatic vegetation, in the impounded GSL wetlands. These relationships were explored using the data from the primary open-water sites, since most sites were sampled throughout the summer and fall and had records of habitat and vegetation characteristics.

The % PMI metric was chosen to reflect the quantity and quality of SAV growth (primarily *Stuckenia*). Because of the monthly or bimonthly sampling frequency, the Willard Spur data allowed an examination of the amount of change in % PMI at a site from one sampling period to the next as compared to the amount of change in % SAV cover between sampling dates (previous studies could only compare the two metrics as static values for a particular sampling date). Using the amount of change in the metrics more accurately accounts for the lag in response of macroinvertebrate communities to changes in SAV. For example, SAV growth can be rapid in early summer, yet PMI macroinvertebrates, such as damselflies, will not select the habitat for oviposition until sufficient SAV growth is present. In addition, SAV senescence during summer and fall can be rapid also; measurable declines in PMI taxa would not occur until after the generations begun before SAV senescence had either emerged or otherwise declined in number with habitat loss. Figure 9 shows the example of the Outfall Confluence site and how changes in percentages of PMI "tracked" changes in SAV cover.

Figure 10a shows that there was a significant positive relationship between the proportion of PMI individuals and SAV cover for the main open-water sites, thus the Willard Spur PMI taxa show an overall response similar to that of PMI taxa in other GSL wetlands. SAV cover, however, does not necessarily capture the full change in vegetation between periods (for example, it does not take into account changes in height, i.e., the total volume of SAV present). Figure 10b, SAV abundance (a combination of changes in SAV cover and changes in SAV height), also showed a positive relationship between changes in the two metrics between sampling periods.

Simpson's Index (SI) has been used as a general metric to reflect overall changes in abundance and diversity with respect to habitat and water quality variables, particularly for detection of changes related to eutrophication. SI increased with increasing SAV abundance (Fig. 11a), but few sites could be included in the analysis due to low sample counts (see Note 6). The "% Top3" metric showed a similar relationship to SAV as SI (Fig. 11b).

Changes in the macroinvertebrate communities at the main sites relative to changes in the amount of filamentous algae present were more difficult to assess. In general, correlations between changes in metrics and filamentous algae cover were not statistically significant. The difficulty in assessing responses to algal coverage stemmed from the relatively lack of algae at many sites as well as the lack of large changes in percent cover (see Note 7). Unlike the rooted SAV, algal mats can change in coverage and abundance (thickness) due to external factors, such as the effects of wind and wave action. In addition, there is the common interaction between algae and SAV whereby increased algal growth often corresponds to, and may precipitate, decreases in SAV abundance and condition.

At the main sites, those where the SAV remained relatively abundant and in good condition in August (e.g., WS 6, 8, & 10), %PMI doubled from August to October even though % filamentous algae cover was 4-18% in August. SI at these sites either remained the same or increased. At sites where the SAV had senesced in August (e.g., WS 1 and WS 2), %PMI values in October were one-third of those in August, and SI values had declined by one-fourth. Filamentous algae cover in August at these sites was 4-33%.

### **2.3. Macroinvertebrate Communities and Habitat Characteristics: Perimeter Sites**

August sampling included sites located along the northern and southern edges of the Willard Spur designated as "A" and "B" sites, respectively, in order to assess a greater diversity of habitats in addition to the main open-water sites in the thalweg (Fig. 1). In addition to the perimeter sites associated with the main sites, samples were taken in June, August, and October at a site located outside of the entrance of a drainage ditch from the Harold Crane WMA (STORET 59846950).

Perimeter sites generally had different habitat characteristics than the thalweg sites, including shallower water depths, less SAV cover, and more filamentous algae (Fig. 12). In addition, the condition ("healthiness") of the SAV was lower at the perimeter sites and duckweed was more common (although percent cover of duckweed was low at the few sites where it occurred). Seven sites had water depths of less than 16 cm (3A, 8A, 10A, 10B, 11B, 12A, and 12B), and two sites (9B and 11A) had high salinity levels.

Macroinvertebrate communities at the perimeter sites showed changes that paralleled the changes in habitat conditions (Table 4). Taxonomic composition shifted to a dominance by hemipterans and snails with the percentage of these two groups increasing as water depths decreased and filamentous algae cover increased (Fig. 13). Two sites (9A and 10A) had exceptionally high densities of snails due to a burst of reproductive activity. The percentage of PMI taxa decreased by 20-25% at the "A" and "B" sites overall, reflecting the 25-40% average decrease in SAV cover. Values for

Simpson's index also decreased at the perimeter sites by an average of 10-20%. Nearly 80% of the total individuals at the seven sites within the shallowest water depths were either snails, *Corisella* corixids, or *Notonecta*.

Site 11B was atypical of the perimeter sites in that amphipods comprised more than half of the total count (see Note 8). However, the habitat characteristics at this site were similar to conditions found in other GSL wetlands in late summer (e.g., New State 20 and Middle Unit ponds) where amphipods are abundant. In particular, the combination of warm water temperatures, increasing filamentous algae, and declining SAV condition appear to be highly favorable for increases in amphipod populations.

Salinity at site 11A was 27 ppt and well above the tolerance limits of typical freshwater taxa in the GSL wetlands. Only 10 individuals were collected in the sample, and most were aquatic beetles. Site 9B had a salinity of 12 ppt, and the fauna was almost entirely hemipterans and snails (Fig. 13). It is not known how long high salinities had been present at these two sites, but neither had taxa typical of long-term saline habitats, such as *Trichocorixa* and *Ephydra*.

#### **2.4. Macroinvertebrate Communities and Habitat Characteristics: Channel Sites**

Three sites in the channels flowing into the upper part of Willard Spur (designated as Willard Perry Outfall, Irrigation Return Flow 1, and Outfall-NPS channel) were sampled at various times during summer/fall 2011. Water chemistry data was taken at all sites on the dates of sampling, but the only habitat data recorded was for the Outfall-NPS channel site in July and October. Summary macroinvertebrate community characteristics are given in Table 5 for each sampling date at each site.

The WP-Outfall site was sampled in late August, mid September and in October. The August sample was dominated by snails; a small number of other taxa, such as corixids and chironomids, were also present at that time. The September and October samples were nearly devoid of macroinvertebrates. Field measurements by DWQ indicate that this site had very low dissolved oxygen (0.9-1.6 mg/L) beginning in August.

Macroinvertebrate abundance at the Irrigation Return Flow 1 site also had a sharp decline in macroinvertebrate abundance between August and September. The community at this site was comprised of snails (40% of total numbers), amphipods (50%), and aquatic beetles (4%).

The Outfall-NPS channel site was sampled in June, July, and October. In June, the community consisted mainly of chironomids (more than 80% of total numbers). From July to October, snails comprised 92% of total numbers and reached densities of several thousand per sample. Habitat data indicate that most of the site was covered with filamentous algae during this time with little SAV present. This site also had very low dissolved oxygen beginning in July.

### 3. Recommendations for Further Research

Sampling in 2012 incorporated additional data gathering for two major gaps in understanding the dynamics of the macroinvertebrate communities in the Willard Spur. The first was a tracking of life cycles and generation times of the common taxa using size class/instar measurements of individuals in benthic samples. Knowledge of when reproduction and adult emergence occur is important for separating natural cycles in abundance from potential external effects on habitats and water quality. Although life cycle analysis using only benthic samples has limitations (e.g., the inability to separate immatures if two or more species are present, unknown extent of emergence periods, etc.), it will aid in understanding the behavior of community metrics in different seasons.

The second addition was an analysis of trophic habits of individual taxa and potential food sources (algae, SAV, and detritus) using stable isotopes. This information will help clarify the feeding habits of common taxa and the overall food web structure. Results from samples collected in August 2012 are not yet available; these results will assist in determining if additional isotope analyses are warranted.

An important goal in the future will be to examine other potential metrics in terms of macroinvertebrate community responses to changes in the aquatic vegetation, particularly the appearance of filamentous algae. As discussed above, current metrics do well in tracking the response to changes in SAV abundance. This response is most pronounced during the early to mid-summer period when the SAV (primarily *Stuckenia*) is increasing. From late summer to early fall, however, the response of the metrics is more variable as the *Stuckenia* declines and filamentous algae increases. This variability results from the potentially more rapid change in the SAV compared to the changes in the populations of PMI and other taxa. Many PMI taxa do not show a particular affinity to the type of vegetation present; for example, damselfly larvae do as well in suspended growths of filamentous algae as in stands of *Stuckenia* as long as other water quality parameters (e.g., dissolved oxygen) remain in tolerable ranges. Insufficient data were available from the 2011 sampling at the open-water sites to do a detailed analysis of responses due to filamentous algae independent of responses to SAV changes.

#### 4. Notes

Note 1: According to Lugo-Ortiz and McCafferty (1996), *Callibaetis montanus*, the species typically reported for this region, is restricted to the southwestern US, and *C. fluctuans* is the common species north of Arizona/New Mexico. Adults have not been collected from the GSL wetlands, and there are no keys that separate larvae to species, thus the identify of the species present is not yet known. *C. fluctuans* (Walsh) is a common species in this region.

Note 2: *Caenis amica* Hagen is the species found in recent sampling in the GSL wetlands. It is common over much of North America and has been previously recorded in northern Utah (Provonsha 1990).

Note 3: I have collected a small number of adult damselflies from the GSL wetlands and observed adults in the field. Damselflies identified from collections were *Ischnura barberi* Currie and *I. cervula* Selys. *Ischnura* and *Enallagma* nymphs, however, are difficult to separate from each other. Provonsha (1975) found both *Ischnura* species and five common *Enallagma* species in the region. *Archilestes grandis* (Rambur) was the only species of this genus recorded by Provonsha (1975) from Utah.

From specimens of mature nymphs, dragonfly species identified from collections include *Aeschna californica* Calvert, *Erythemis collocata* (Hagen), and *Tramea lacerata* Hagen. All of these species have been previously recorded around the Great Salt Lake (Musser 1962).

Note 4: Species of hemiptera identified from adults in field collections include *Corisella decolor* (Uhler), *C. inscripta* (Uhler), *Trichocorixa verticalis* Fieber, *Hesperocorixa laevigata* (Uhler), and *Notonecta undulata* Say (keys in Dunn 1979, Lauck 1979, Truxal 1979, Usinger 1956, Zalom 1977). Other genera and species are likely to be present in the GSL wetlands.

Note 5: The only species given in common references for the genus *Hyaella* is *H. azteca* (Saussure). This species is found throughout North America in springs, ponds, lakes, and wetlands (Pennak 1978). Recent studies suggest that *H. azteca* may actually be more than one species (Rogers 2005; D. C. Rogers, *personal communication*).

Note 6: Simpson's index is considered to be a species-dominance measure in which evenness has a greater effect on the index value than the number of species. The index measures the probability that 2 individuals drawn at random from a sample will belong to the same species. It is calculated by the formula:  $D_s = (N(N-1)) / \sum (n_i(n_i-1))$  where  $n_i$  = number of individuals of species  $i$  and  $N$  = total number in the sample from all species. The index value often is reported as either  $1/D_s$  (range of values from 0 to 10+) or  $1 - D_s$  (range of values from 0.0 to 1.0). In both cases, higher values indicate greater diversity and/or evenness (Norris and Georges 1993, Simpson 1949).

Simpson's Index is sensitive to sample size. One of the reasons for the relatively large area sampled using the sweep net was to obtain sufficient animals to avoid this

effect (ideally, the goal was to have a sample count of at least 400 individuals). In previous work on other GSL wetlands (e.g., Gray 2010, 2011a), samples with less than this ideal count comprised less than 5% of the total. In contrast, 70% of the main site samples in the Willard Spur in 2011 had less than 400 individuals (one-half had less than 100 individuals).

The “Top 3%/Dominant 3” metric is an alternative to Simpson’s index and has some advantages. It essentially provides the same desired information (i.e., the evenness of distribution of individuals among taxa), it is easier to calculate, and it is independent of sample size. Past experience with GSL wetlands samples indicated that the value of a sample SI is as sensitive to total taxa as it is to evenness in samples with less than 8 taxa (a common occurrence), and it cannot be calculated on samples with only one species present.

Note 7: In examining the relationship between vegetation and macroinvertebrate metrics, it also did not help the analysis that vegetation cover data was missing for approx. one-fourth of the main site samples, particularly for October.

Note 8: Site 3B also had a high proportion of amphipods. However, no habitat characteristics were recorded for this site in August.

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**Table 1: List of Macroinvertebrate Taxa collected from the Willard Spur, March-October 2011.**

1. Aquatic Insects: Order	Family	Genus	Species	Taxon Code	Feeding Group
Ephemeroptera	Baetidae	<i>Callibaetis</i>	sp.	273	GC
	Caenidae	<i>Caenis</i>	<i>amica</i>	286	GC
Trichoptera	Leptoceridae	<i>Ylodes</i>	sp.	432	SH
Odonata	Coenagrionidae	<i>Ischnura</i>	spp.	350	PR
	Coenagrionidae	<i>Archilestes</i>	sp.	354	PR
	Aeshnidae	<i>Aeshna</i>	sp.	345	PR
	Libellulidae	<i>Erythemis</i>	sp.	356	PR
	Corixidae	<i>Corisella</i>	sp.	330	PR
Hemiptera	Corixidae	<i>Hesperocorixa</i>	sp.	330	PH
	Notonectidae	<i>Notonecta</i>	sp.	335	PR
Diptera	Ephydriidae		sp.	235	GC
	Ceratopogonidae	subfamily Ceratopogoninae	sp.	80	PR
	Stratiomyidae		sp.	225	GC
	Tabanidae	<i>Chrysops</i>	sp.	249	PR
	Tipulidae	<i>Prionocera</i>	sp.	pri	SH
	Chironomidae	<i>Chironomus</i>	sp.	84	GC
	Chironomidae	tribe Tanytarsini	sp.	84	GC
	Chironomidae	subfamily Tanypodinae	sp.	89	PR
	Chironomidae	subfamily Orthoclaadiinae	sp.	86	GC
Coleoptera	Dytiscidae	<i>Agabus</i>	sp.	16	PR
	Dytiscidae	(early instar larvae)	sp.	46	PR
	Hydrophilidae	<i>Enochrus</i>	sp.	eno	CG
	Hydrophilidae	<i>Tropisternus</i> (adult)	sp.	69	CG
	Hydrophilidae	<i>Berosus</i> (larvae)	sp.	59	PR

**Table 1 (con't.)**

Other Taxa	Family	Genus	Species	Taxon Code	Feeding Group
2. Acarina: Trombidiformes			sp.	7	PR
3. Crustacea: Amphipoda	Hyalellidae	<i>Hyalella</i>	<i>azteca</i>	489	GC
3. Crustacea: Isopoda	Asellidae	<i>Caecidotea</i>	sp.	493	GC
4. Mollusca: Gastropoda	Lymnaeidae	<i>Stagnicola</i>	sp.	503	SC
4. Mollusca: Gastropoda	Physidae	<i>Physella</i>	sp.	504	SC
4. Mollusca: Gastropoda	Planorbidae	<i>Gyraulus</i>	sp.	505	SC
5. Annelida (Hirundinea)	Glossiphoniidae	<i>Helobdella</i>	<i>stagnalis</i>	3	PR
5. Annelida (Hirundinea)	Erpobdellidae		sp.	1	PR
5. Annelida (Oligochaeta)	Naididae		sp.	5	GC

Feeding Groups
SH = shredder
GC = gatherer-collector
PR = predator
SC = scraper
PH = piercer-herbivore

**Table 2.** Comparison of community characteristics between all open-water Willard Spur sites sampled in 2011 and all GSL impounded wetlands sampled in 2010-2011 (N = total number of individual samples = 64 for WS and 60 for GSL.) Values represent means for a standard sweep sample (a = arithmetic mean, b = natural log-transformed mean). Biomass is given as grams dry weight.

<b>Community Characteristic</b>	<b>Willard Spur</b>	<b>GSL Impounded Wetlands</b>
Total Count (a)	347	1712
Total Count (b)	160	929
Total Taxa	7.1	9.9
% PMI	27	21
Simpson's Index (1-D)	0.57	0.61
Biomass, g (a)	0.44	1.67
Biomass, g (b)	0.17	0.85

**Table 3.** Comparison of seasonal community characteristics between all open-water Willard Spur sites sampled in 2011 and all GSL impounded wetlands sampled in 2010-2011. Values represent means for a standard sweep sample (a = arithmetic mean, b = natural log-transformed mean). Biomass is given as grams dry weight.

<b>Willard Spur</b>					
<b>Community Characteristic</b>	<b>March</b>	<b>June</b>	<b>July</b>	<b>August</b>	<b>October</b>
Total Count (a)	385	225	267	276	580
Total Count (b)	169	100	168	144	219
Total Taxa	5.0	7.0	9.0	7.4	7.3
%PMI	12%	18%	21%	36%	51%
Simpson's Index (1-D)	0.40	0.54	0.62	0.63	0.64
Biomass, g (a)	0.26	0.23	0.97	0.49	0.32
Biomass, g (b)	0.13	0.10	0.62	0.24	0.10
<b>GSL Wetlands</b>					
<b>Community Characteristic</b>	<b>May</b>	<b>July</b>	<b>November</b>		
Total Count (a)	1405	1968	1503		
Total Count (b)	957	898	958		
Total Taxa	9.6	11.4	8.3		
%PMI	23	22	24		
Simpson's Index (1-D)	0.56	0.65	0.58		
Biomass, g (a)	1.51	2.37	0.96		
Biomass, g (b)	0.90	1.29	0.54		

**Table 4.** Comparison of macroinvertebrate community characteristics between the main (thalweg) open-water Willard Spur sites and the "A" and "B" perimeter sites sampled in August 2011 (mean values; count and biomass means from ln-transformed data).

<b>Site Category</b>	<b>Count</b>	<b>Taxa</b>	<b>Simpson's Index</b>	<b>Biomass</b>
Main	141	7.8	0.62	0.18
"A"	369	8.7	0.49	0.66
"B"	111	6.3	0.56	0.29

**Table 5.** Macroinvertebrate community characteristics of the channel sites in the upper part of Willard Spur.

<b>STORET</b>	49847620	49847620	49847620
<b>Site Name</b>	Willard Perry Outfall	Willard Perry Outfall	Willard Perry Outfall
<b>Date</b>	30-Aug-11	12-Sep-11	19-Oct-11
Total Count	423	2	33
Total Taxa	8	2	3
%PMI	0.5	0.0	0.0
Simpson's Index	0.55	0.67	0.17
Biomass, g	7.07	0.00	0.02

<b>STORET</b>	4984760	4984760	4984760
<b>Site Name</b>	Irrigation Return Flow 1	Irrigation Return Flow 1	Irrigation Return Flow 1
<b>Date</b>	30-Aug-11	12-Sep-11	19-Oct-11
Total Count	446	58	97
Total Taxa	7	9	6
%PMI	0.0	10.3	1.0
Simpson's Index	0.55	0.72	0.57
Biomass, g	6.61	1.08	0.30

<b>STORET</b>	5984630	5984630	5984630	5984630
<b>Site Name</b>	Outfall-NPS Channel	Outfall-NPS Channel	Outfall-NPS Channel	Outfall-NPS Channel
<b>Date</b>	8-Jun-11	24-Jun-11	7-Jul-11	11-Oct-11
Total Count	447	1584	828	3752
Total Taxa	6	13	10	8
%PMI	0.4	22.2	1.2	0.3
Simpson's Index	0.25	0.66	0.44	0.45
Biomass, g	0.36	4.66	0.46	11.38

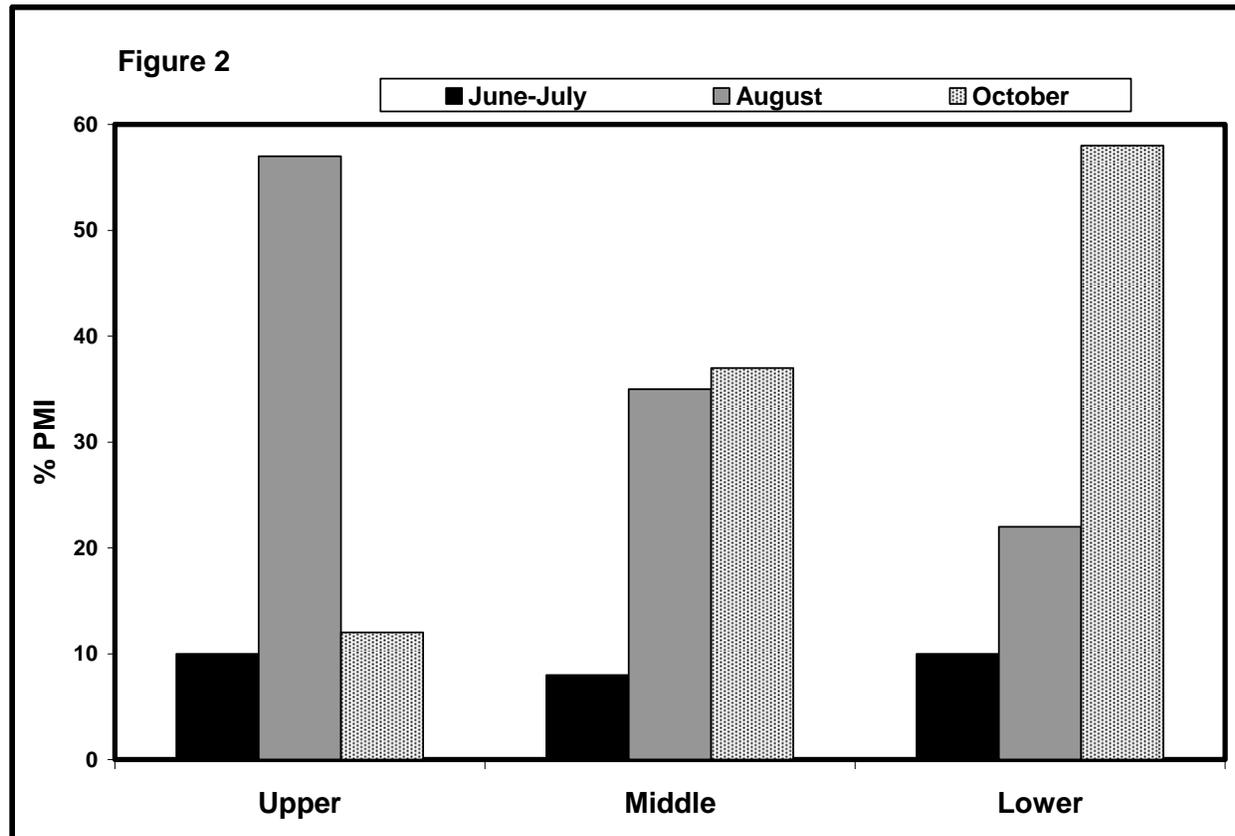
## Figure Legends

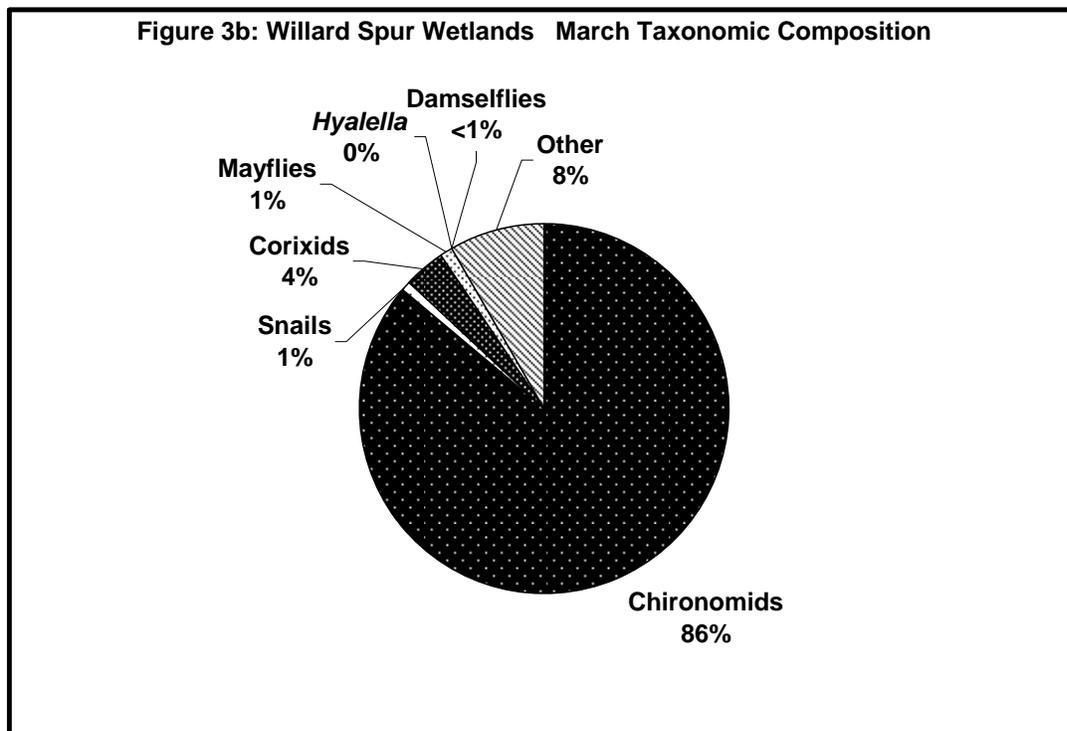
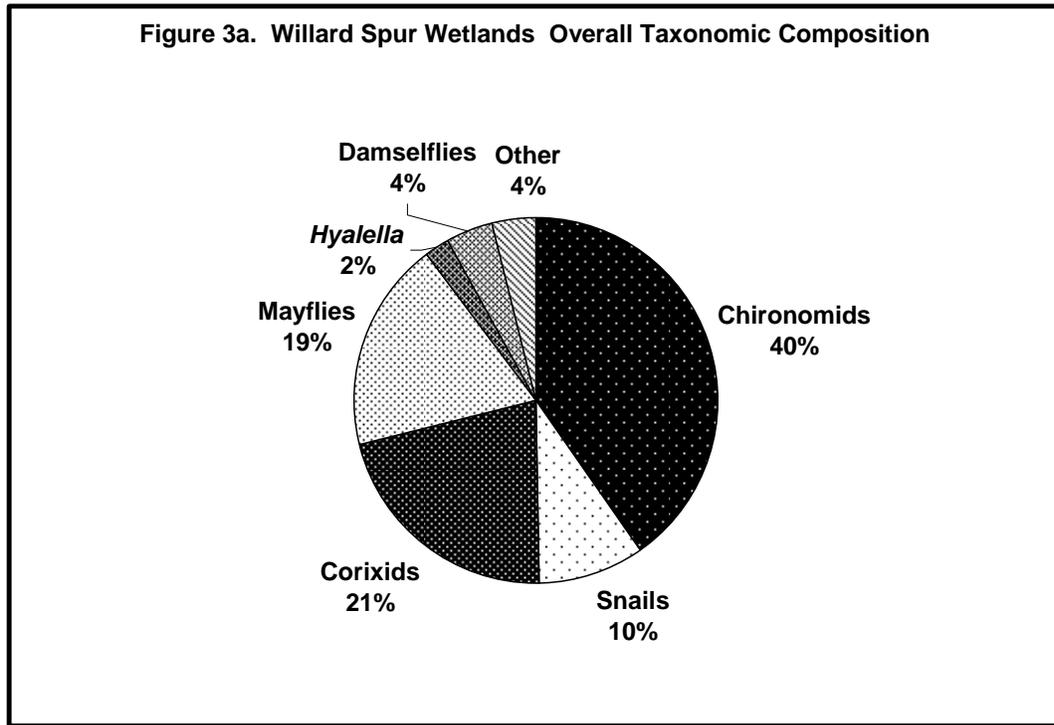
- Figure 1. Map showing locations of principal Willard Spur sampling sites, March-October 2011.
- Figure 2. Percentage of phytophilous macroinvertebrates (% PMI) in the upper, middle and lower portions of Willard Spur main open-water sites, June-October 2011.
- Figure 3. Taxonomic composition of the macroinvertebrate community at open-water sites in Willard Spur. Figure 3a gives the composition for all sites and dates from March-October 2011. Figures 3b-3f give the composition by month for all sites and dates. (Total N = 64; March N = 6, June N = 10, July N = 8, August N = 19, and October N = 21).
- Figure 4. Taxonomic composition of the macroinvertebrate community at open-water sites in other Great Salt Lake wetlands sampled in 2010 (May, July, and November) and 2011 (July and November) (Gray 2010, 2011a, 2011b). Figure 4a gives the overall composition based on means of all sites sampled on all dates. Figure 3b-3d give the composition by month for all sites sampled in that month for both years. (Total N = 55; May 2010 N = 7, July 2010 and 2011 N = 28, November 2010 and 2011 N = 20 ).
- Figure 5. Trophic composition of the macroinvertebrate community in Willard Spur. Figure 5a gives the composition for all sites and dates from March-October 2011. Figures 5b-5f give the composition by month for all sites and dates. (Total N = 64; March N = 6, June N = 10, July N = 8, August N = 19, and October N = 21).
- Figure 6. Trophic composition of the macroinvertebrate community at open-water sites in other Great Salt Lake wetlands sampled in 2010 (May, July, and November) and 2011 (July and November) (Gray 2010, 2011a, 2011b). Figure 6a gives the overall composition based on means of all sites sampled on all dates. Figure 6b-6d give the composition by month for all sites sampled in that month for both years. (Total N = 55; May 2010 N = 7, July 2010 and 2011 N = 28, November 2010 and 2011 N = 20 ).
- Figure 7. Total biomass of macroinvertebrates (g dry mass) at the main open-water sites in 2011. All OW = all sites and dates. (Total N = 64).
- Figure 8. Taxonomic composition of macroinvertebrate biomass at the main open-water sites in 2011.
- Figure 9. Changes in % PMI and % SAV cover between sampling dates at the Outfall Confluence site (STORET 59846400) from June-October 2011.

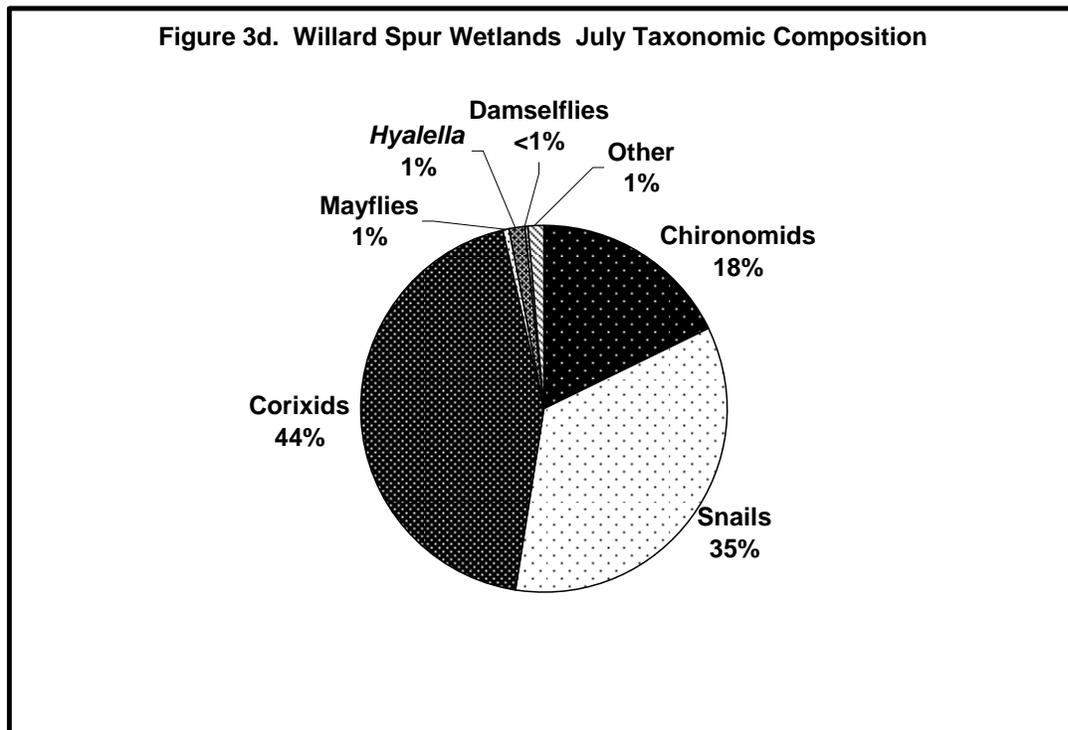
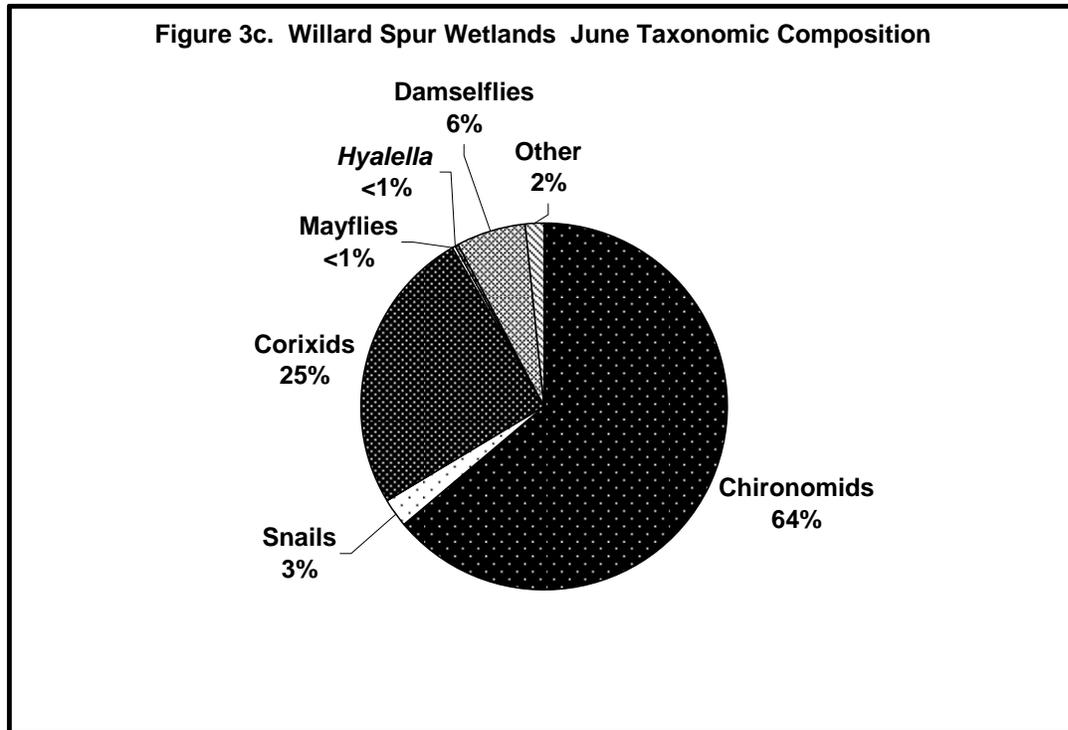
- Figure 10. Relationship between % PMI and SAV at the main open-water sites in Willard Spur, June-October 2011.  
Fig. 10a: changes in % PMI and % SAV cover between sampling dates ( $R_S = 0.72$ ,  $P = 0.001$ ,  $N = 17$ ).  
Fig. 10b: changes in % PMI and % SAV abundance (SAV cover adjusted for changes in SAV height) between sampling dates ( $R_S = 0.73$ ,  $P < 0.001$ ).
- Figure 11. a: Relationship between changes in Simpson's Index (1-D) and % SAV abundance between sampling dates at the main open-water sites in Willard Spur, June-October 2011. ( $R_S = 0.93$ ,  $P < 0.001$ ,  $N = 7$ )  
b: Same as Fig. 11a for %Top 3 metric at the same sampling sites. ( $R_S = -0.85$ ,  $P < 0.001$ ,  $N = 7$ )
- Figure 12. Habitat characteristics at the main open-water sites and perimeter sites in Willard Spur, August 2011. Main sites were located in the thalweg; "A" sites followed the northern perimeter next to the Bear River refuge, "B" sites followed the southern perimeter.
- Figure 13. Mean percentages of Hemiptera (corixids, notonectids), snails (primarily *Physella* and *Stagnicola*), and PMI taxa based on total counts in the main open-water sites, "A" and "B" perimeter sites, sites with shallow water depths (see text), and sites with high salinities (9B and 11A), August 2011.

Figure 1.









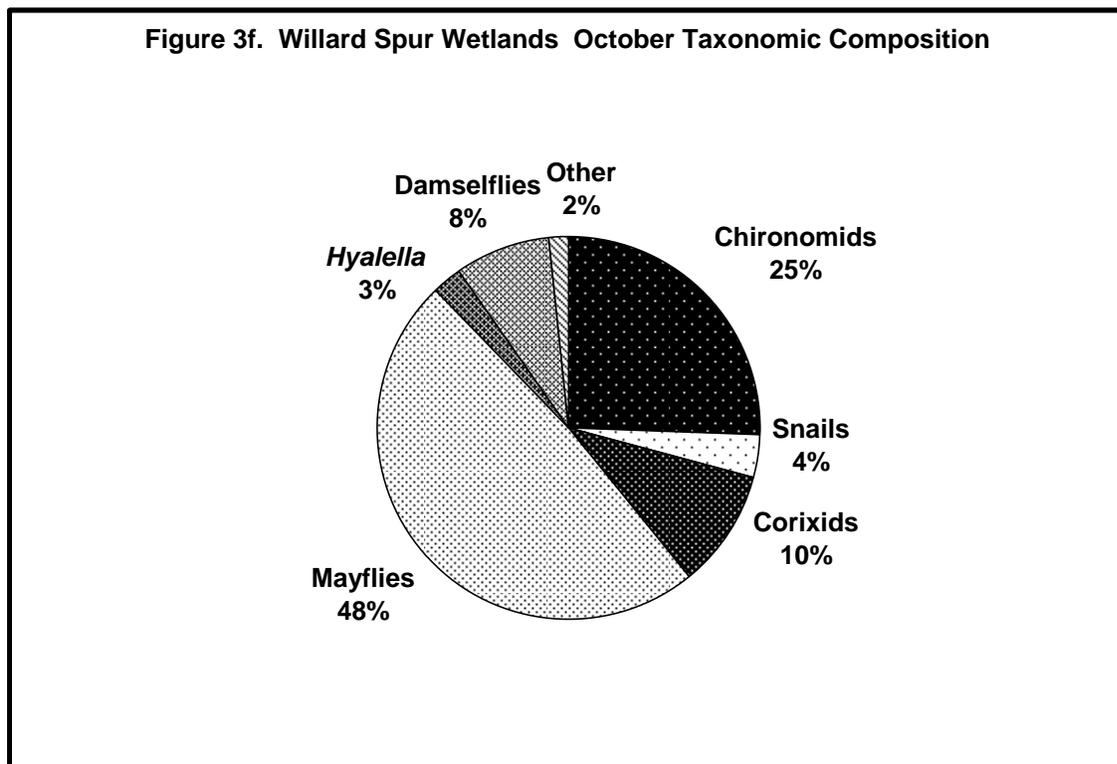
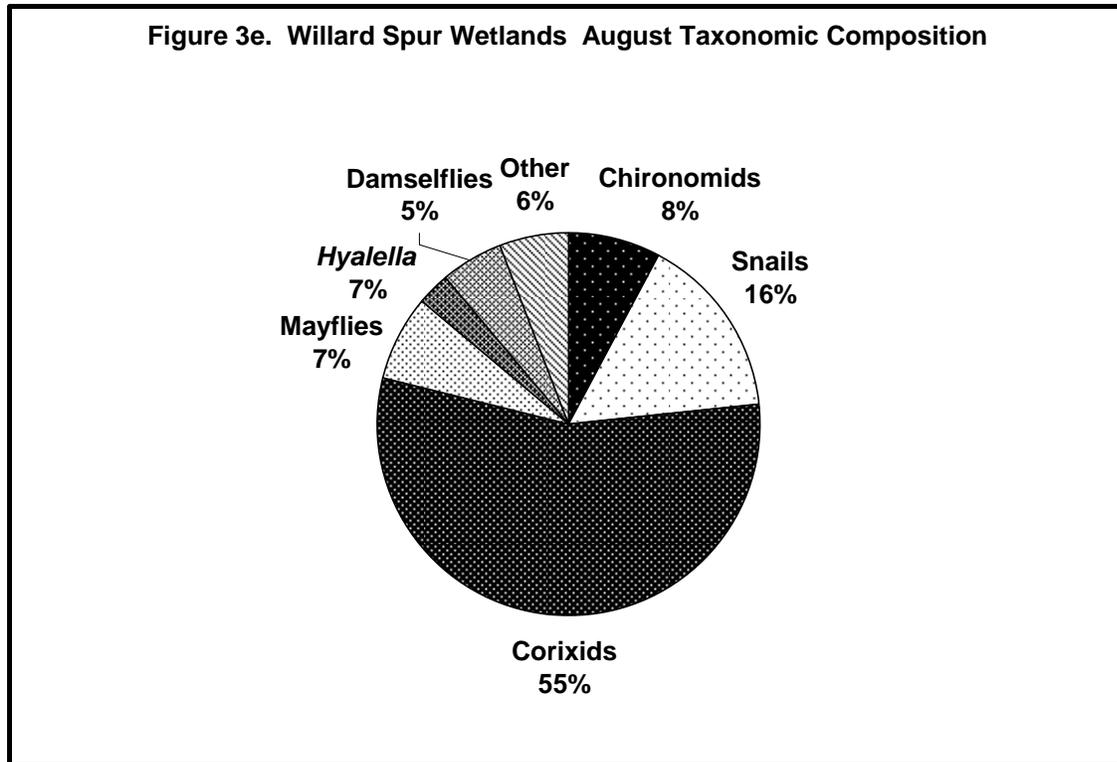


Figure 4a. GSL Wetlands Overall Taxonomic Composition

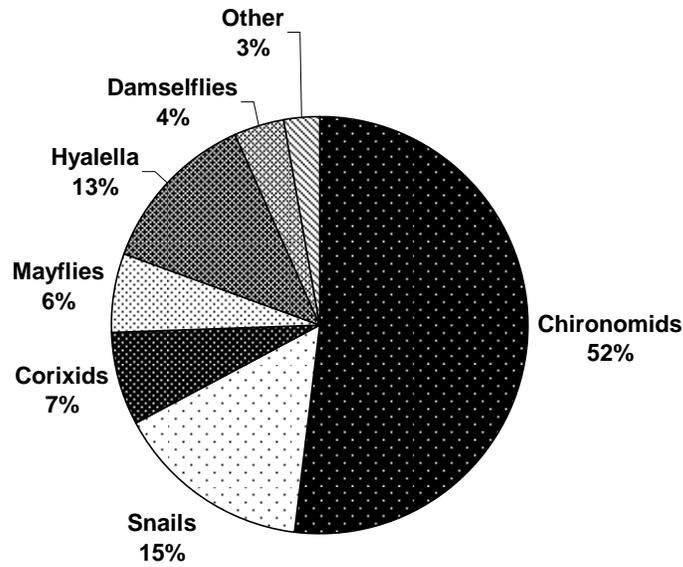


Figure 4b. GSL Wetlands May Taxonomic Composition

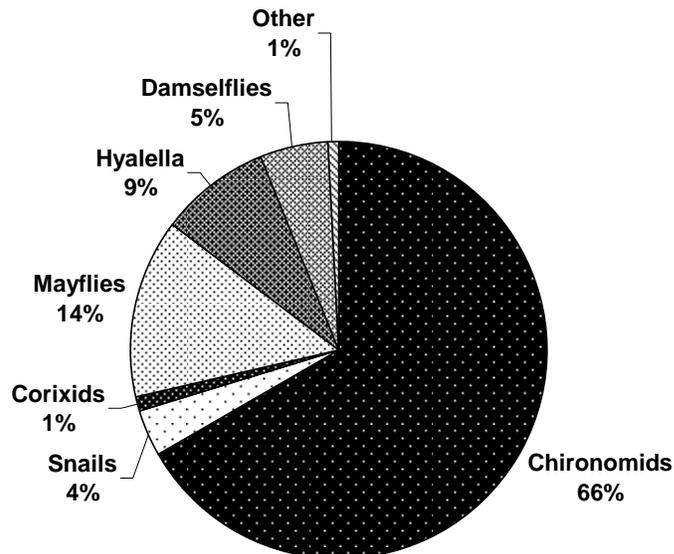


Figure 4c. GSL Wetlands July Taxonomic Composition

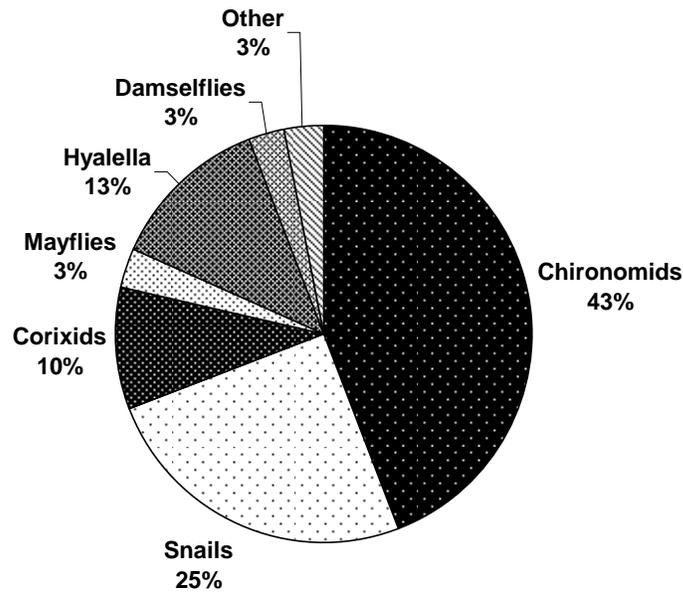


Figure 4d. GSL Wetlands November Taxonomic Composition

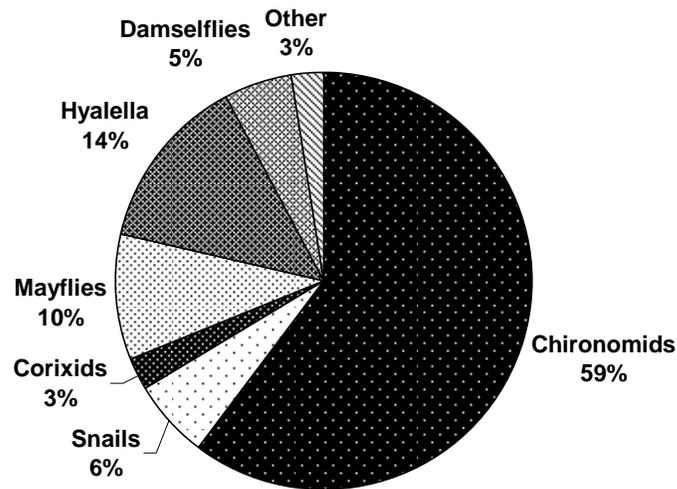


Figure 5a. Willard Spur Wetlands Overall Trophic Structure

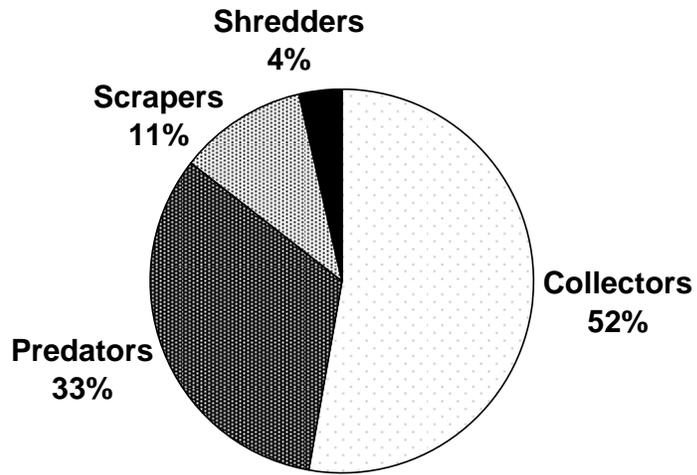


Figure 5b. Willard Spur Wetlands March Trophic Structure

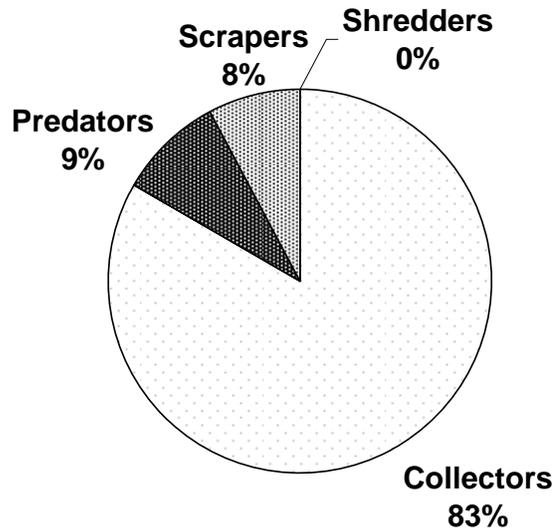


Figure 5c. Willard Spur Wetlands June Trophic Structure

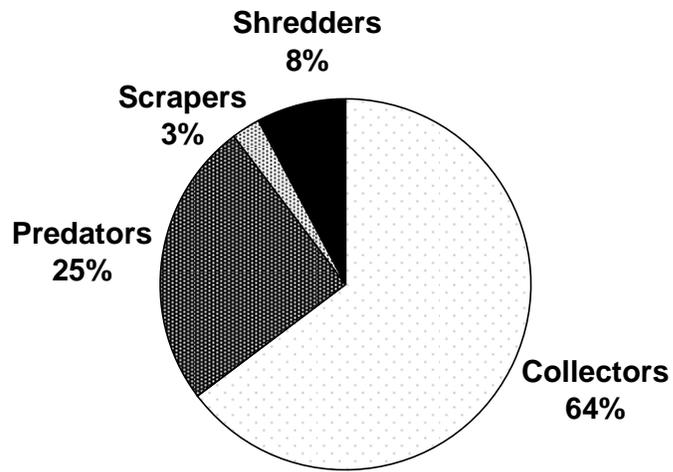


Figure 5d. Willard Spur Wetlands July Trophic Structure

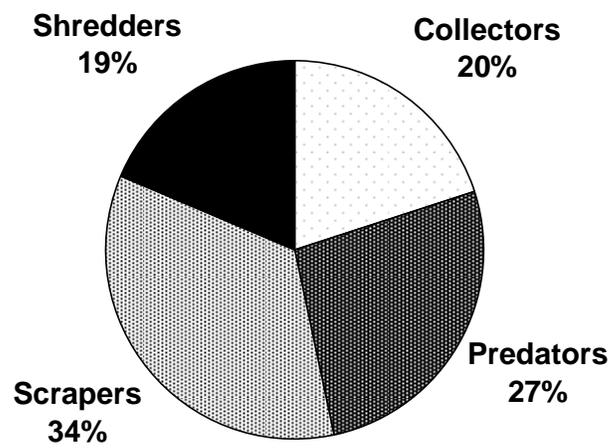


Figure 5e. Willard Spur Wetlands August Trophic Structure

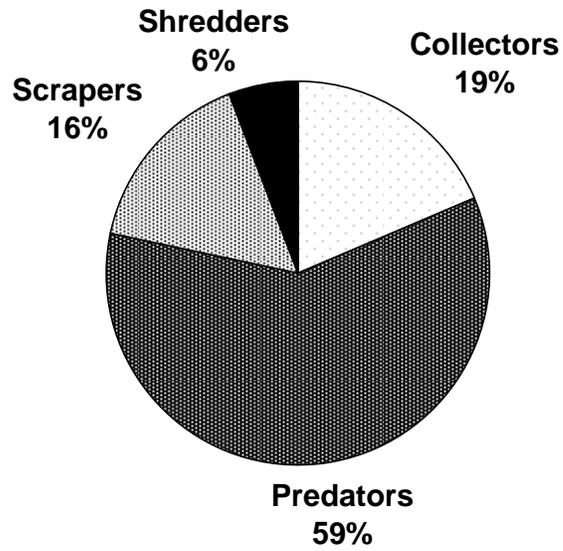


Figure 5f. Willard Spur Wetlands: October Trophic Structure

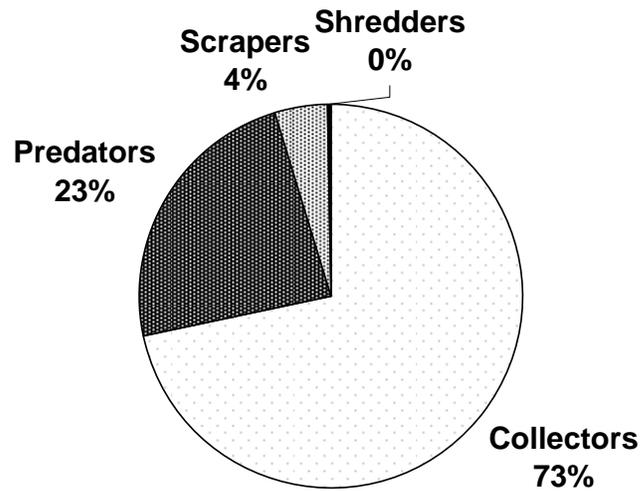


Figure 6a. GSL Wetlands Overall Trophic Structure

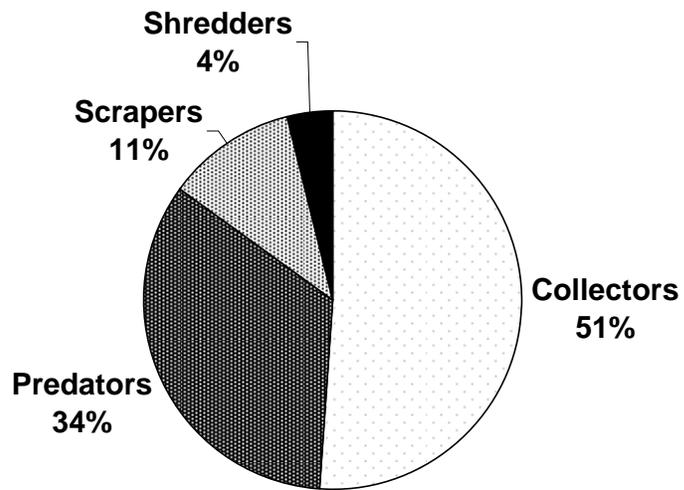


Figure 6b. GSL Wetlands May Trophic Structure

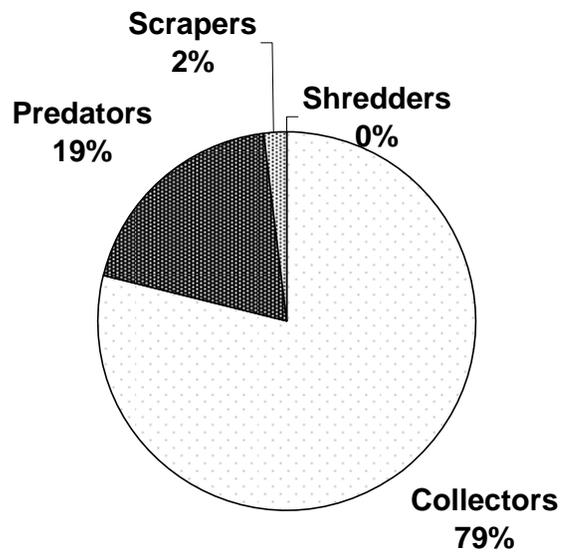


Figure 6c. GSL Wetlands July Taxonomic Composition

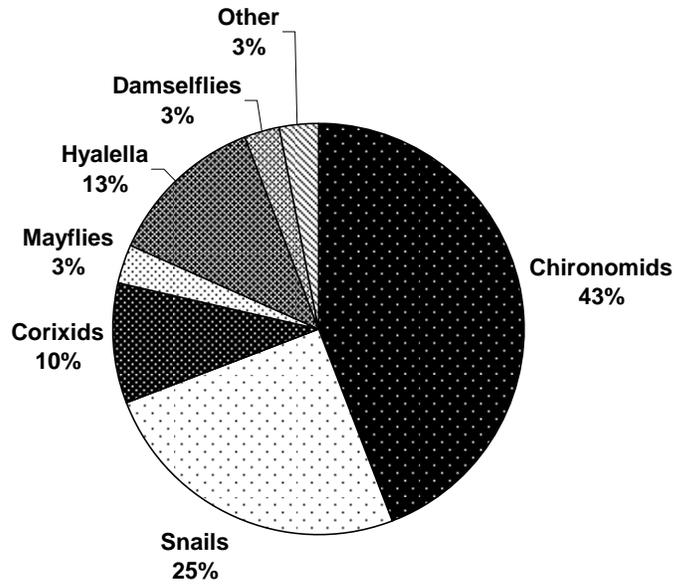


Figure 6d. GSL Wetlands November Taxonomic Composition

