



Watershed Protection Development Review

Recolonization and succession of macroinvertebrate communities during drought and flood stressors in perennial Austin area streams.

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Abstract

In Central Texas wadeable streams, flow permanency and the effects of frequent spates on benthic macroinvertebrate communities has not been studied sufficiently. We sampled riffle habitats in three, 3rd order streams in the Austin, Texas area following both drought and flood conditions to assess how these events affect stream invertebrate community stability and recolonization. These three streams also exhibited a gradient of urbanization, allowing for assessment of the relative effect of impervious cover on these communities under varying natural disturbance conditions. Our results suggest that a 3-4 year flood event is much more damaging to the benthic community, both spatially and temporally, than a moderately stressful drought period. This was evident in both immediate loss of taxa richness and biomass and the length of time for the community to recover from each. The effect of urbanization on recovery indicated that a more cosmopolitan, tolerant community, found in our most urban stream, recovered density quickly, but not taxa richness and that there was no difference in recovery and treatment effect (drought and flood) among the two lesser urbanized streams. For bioassessment monitoring efforts in this area, we recommend at least a one month recovery period following large spates (>2 yr storm), but depending on extent of drought, recovery is in the order of weeks after flow returns.

Introduction

Only recently have macroinvertebrates received attention in assessing surface water quality. With increasing anthropogenic disturbance, water is increasingly contaminated from agricultural, industrial and urban organic compounds which are persistent and mobile in surface and groundwater (Stauffer 1998). One economical and efficient way of detecting effects of contaminants is through the use of macroinvertebrates (Karr 1987, Karr and Chu 1999). Rapid Biological Assessments (RBAs) are used to evaluate the “health” of the stream and to assess effects of non-point source pollution which may not be apparent in traditional water chemistry analysis (Barbour et al. 1999, Karr and Chu 1999, Plafkin et al. 1989, Resh and McElravy 1993). Macroinvertebrate assemblages are good indicators of localized conditions because their sessile nature allows determination of spatial extent of impacts and their relatively long life cycles (\pm 1 year) allow assessment of temporal pollution impacts (Rosenberg and Resh 1993).

Stream macroinvertebrates also are periodically decimated by natural disturbances, such as floods and droughts (Resh et al. 1988). Recovery after disturbance is achieved through recolonization (Gray and Fisher 1981). Hynes (1970) identified -*the principal recolonization pathways for the benthos as eggs from aerial adults or downstream drift, upstream migration and vertical movements from below the substrate by larval or immature forms. Fisher et al. (1982) found that most aquatic insects recolonized through aerial pathways after a spate in a desert mountain stream. Many of the early colonizers, such as mayflies and midges are considered opportunistic species with multivoltine life histories believed to be disturbance coping strategies (Poff & Ward 1989, Rabeni and Minshall 1977, Williams 1996). Disturbances influence life histories and community dynamics of aquatic biota (Stanley et al. 1994). More is known on invertebrate response to flooding (Gray and Fisher 1981), than drought and intermittency.

In central Texas, the weather is characterized by flashy spates and long dry periods creating hydrologic conditions that are dramatically more variable than in most temperate regions (Baker 1977). Since bioassessment protocols were developed in temperate regions, understanding the effects of hydrology on the biological communities of streams in central Texas is crucial to the interpretation of bioassessment data. The biological response to hydrologic disturbance is well documented in studies of relatively pristine systems (Angradi 1997, Dole-Olivier et al. 1997, Scrimgeour and Winterbourn 1989), as is the biological, physical and chemical response of streams to urbanization (Britton et al. 1993, Pratt et al. 1981, Tikkanen et al. 1994). However, the effects of hydrologic variability on biological assessments and their interpretation in monitoring programs are not well understood.

Urban streams in Austin, Texas, have the same hydrological problems encountered in densely developed areas all over the world. Urbanization accompanied by impervious cover exaggerates stream flow patterns, producing greater runoff volumes, higher peak flows and reduced baseflow (Elliot et al. 1997, Schueler 1994, Scoggins 2001, Sponseller et al. 2001). This creates a very unstable system ranging from destructive floods to total dewatering in very short time intervals and subject the biological communities to frequent disturbance and adjustment. Macroinvertebrate community composition, resilience, and recolonization may be negatively affected by such conditions (Angradi 1997, Clausen and Biggs 1997, Death and Winterbourn 1995, Poff and Ward 1989). These variables reflect a distinct physical disturbance regime, outside of any chemical non-point source effects.

Stability of a community is measured by its resistance, resilience or both. Resistance is the ability to resist change and resilience is the rate of recovery following disturbance (Miller and Golladay 1996). Recovery is defined as the re-establishment of community structure and function to pre-disturbance conditions which is accomplished through the pathways of recolonization, viz. drift, oviposition by aerial adults and instream refugia (Miller and Golladay 1996). The time required for recolonization varies depending upon stream type and the severity of disturbance (Lake et al. 1989). Fisher et al. (1982) noted that the physical and morphometric conditions typical of the pre-disturbance levels were restored quickly. Additionally, several studies of benthic macroinvertebrate communities in areas of naturally high disturbance show that they also recover quickly from disturbance events due to evolutionary adaptations (Lake et al. 1989, Poff & Ward 1989).

High resilience is crucial for recovery from drought since community composition is negatively affected due to reductions in habitat availability and increased intensity of biotic interactions with the decline in water level (Boulton et al. 1992 b, Miller and Golladay 1996). Greater resistance to drought than flooding would be hypothesized since flooding is less predictable and more sudden in onset (Filho and Maltchik 2000). However, drought tends to be longer in temporal scale and potentially more lethal in its effect on overall aquatic communities.

The objectives of this study were to: (1) Compare patterns of composition of benthic macroinvertebrates among watersheds differing in degree of impervious cover and their corresponding levels of urbanization. (2) determine patterns in the recolonization dynamics of benthic macroinvertebrates following a drought and a flood disturbance and (3), evaluate the dynamics of resilience and resistance among study streams as it pertains to hydrologic disturbance.

In addition to the main objective, the following ecological principles were examined. MacArthur and Wilson (1967) recognized two groups of species that comprise a community and inferred that the predominance of one group over the other could be used to distinguish between community types. "Opportunistic" (nonequilibrium) communities should be largely r-strategists with high dispersal and reproductive potential that are more common in unstable, unpredictable environments. "Equilibrium" communities should consist mainly of K-strategists that predominate under more stable environmental conditions (Minshall et al. 1985). Based on r/K selection theory (MacArthur and Wilson 1967), we hypothesize that the most urbanized watershed in this study (Walnut Creek, 30% impervious cover) will have higher population densities following recovery from disturbance and that those communities will be dominated by r-strategists organisms.

Based on the intermediate disturbance hypothesis (Connell 1978) which is widely applied in lotic studies (Resh et al. 1988, Ward and Stanford 1983), diversity will be greatest at intermediate levels of disturbance, with competitive exclusion and physical elimination leading to lower species richness at either end of the disturbance continuum (Russell and Winterbourn 1995). Therefore, we hypothesize that the moderately urbanized watershed (Barton Creek, 7% impervious cover) would have the highest species richness. At Walnut Creek (30% impervious cover) high levels of disturbance will reduce species richness and diversity and at Onion Creek (1.6% impervious cover) low levels of disturbance permits competition thus reducing richness and diversity.

Methods

Site Selection

The study streams were selected based on their degree of impervious cover in the watershed corresponding to their level of urbanization. Streams were selected after consulting City of Austin staff and examining data on degree development within the watersheds. Impervious cover was estimated based on aerial photography and historic land use mapping data using geographic information system (GIS) by the city of Austin. Sampling sites on each stream were selected based on their proximity to United States Geological Survey (USGS) gauging stations.

The Walnut Creek study site (30°16'59"N, 97°39'17"W) was located 500m downstream of Webberville road approximately 1.5 km upstream of Walnut Creek's confluence with the Colorado River (Figure 1). The Walnut Creek study site has a drainage area of 132.9 km², the smallest of the three study sites, and represents the most urbanized (30% impervious cover) watershed among our study streams. The Barton Creek study site (30°04'58"N, 98°00'27"W) represents the moderately urbanized (7% impervious cover) watershed and has a drainage area of 321.2 km² and lies off of Capitol of Texas Highway on Lost Creek Boulevard. The Onion Creek study site (30°16'26"N, 97°50'40"W) is in the least urbanized (1.6% impervious cover) watershed and has a drainage area of 277.1 km² and lies northwest of San Marcos off of FM 1826 at Driftwood.

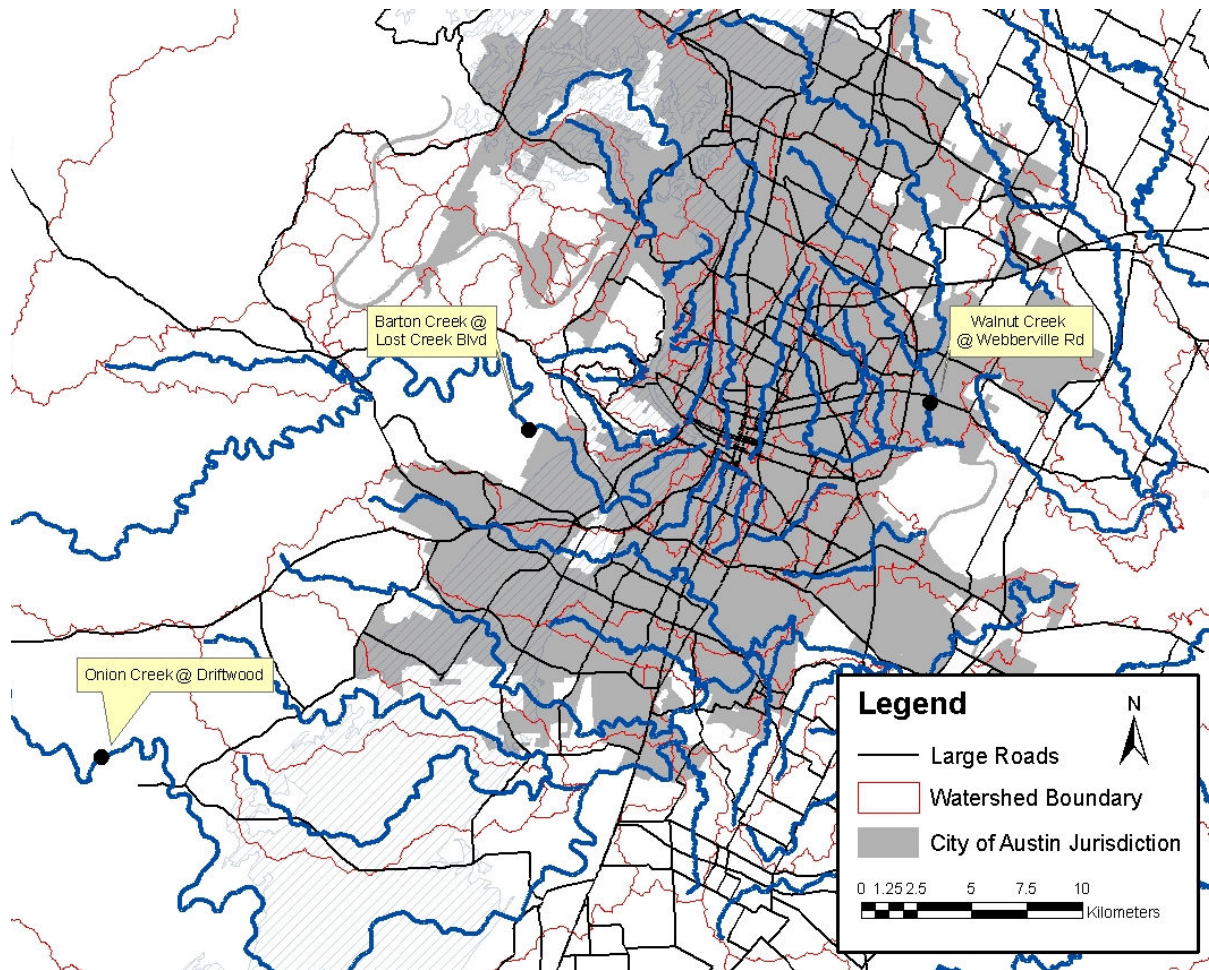


Figure 1. Sample sites at USGS gages on Onion, Barton and Walnut Creeks in Austin, Texas.

Field Sampling, Processing and Analysis

All sampling was carried out during 10 monitoring events between September 15, 2001 – and March 23, 2002. After four very dry summer months, with stressful drought conditions at all three study sites, a moderate rain event on August 26th, 2001, rewetted the streams, raising flows above their previous low flow condition (<1.0 cfs). Four post-drought events were completed, ending with a large flood event on November 15, 2001, followed by 6 post-flood sampling events. Three Hess samples were collected in three discrete riffles in each of the three study streams. The Hess sampler had a cylindrical diameter of 0.34 m and samples an area 0.09 m²; a bag with a mesh-size of 500 μm connects from the main drum and tapers to a small collecting container. For the purposes of this analysis, all samples from an individual site were composited, resulting in one sample per stream per date representing a 0.81 m² area. Each sample was sorted in its entirety and preserved in the laboratory in 70% ethanol. Macroinvertebrates were processed and identified to the lowest possible taxonomic unit, usually genus, using a 40X dissecting scope and dichotomous keys (Merrit & Cummins 1996, Thorp and Covich 1991). Physicochemical parameters (pH, conductivity, dissolved oxygen, temperature) were measured at each site using a Hydrolab Minisonde 4a. Data on discharge were obtained from USGS gauging stations on the streams and basic hydrologic statistics were calculated to determine if there was a relationship between hydrologic variability and benthic macroinvertebrate community structure. Head capsule widths of *Baetis sp.* were measured using a 100X stereo-microscope with an ocular micrometer. To determine life history characteristics, plots of size-abundance relationships using head capsule width against sample times were used to determine growth and size class structure.

Results

Physicochemical Variation

Specific conductance was generally higher for Barton Creek than Walnut and Onion creeks (Figure 2A). Barton Creek showed a general decline in conductance after flows resumed, whereas Onion Creek remained relatively low during the course of the study and Walnut Creek was intermediate. Dissolved oxygen at the three sites generally increased over the study period, as temperatures decreased (Figure 2B). pH Temperature steadily declined from September ($\approx 26^{\circ}\text{C}$) through December ($\approx 10^{\circ}\text{C}$) (Figure 2C), but due to an equipment failure, temperature was not measured at three sampling dates between Dec 15, 2001 and Jan 26, 2002. pH was very similar at all three study sites, with a mean of 7.3 at Barton, 7.4 at Onion and 7.8 at Walnut.

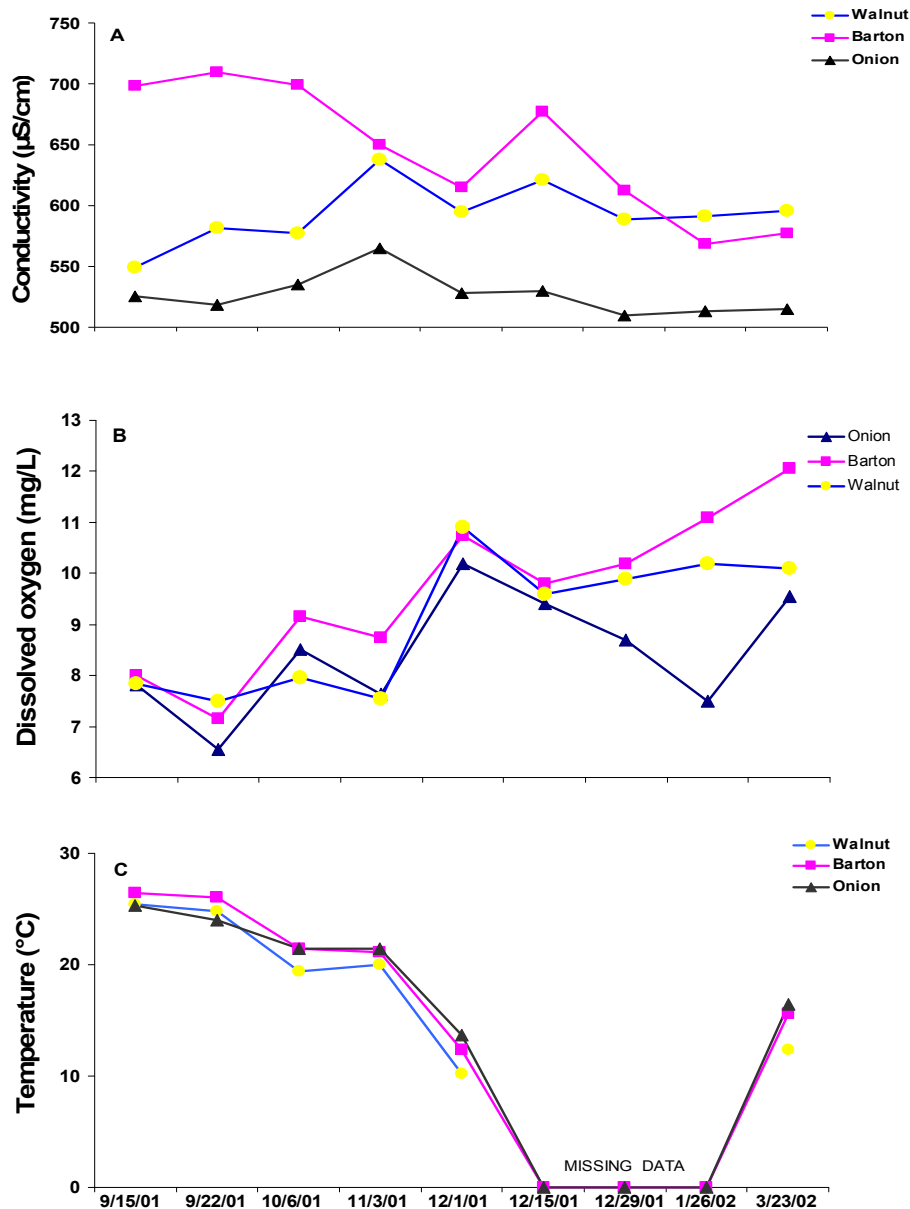


Figure 2. Temporal variation in A- Conductance, B-Dissolved Oxygen and C-Temperature of Walnut, Barton and Onion creeks in Austin, Texas.

Data on discharge were obtained from USGS gauging stations on the streams to determine the number of low or no flow days and the frequency and magnitude of floods. Walnut Creek had less than 1.0 cubic feet per second (cfs) for 13 days prior to rewetting, Onion Creek had 18 days at less than 1.0 cfs and Barton Creek 50 days, including 20 days with no flow. Walnut and Onion creek had no zero flow days during this period. Following the November 15 flood event, Walnut Creek and Onion creeks had peak discharges on the same day as the rain event (2330 and 3550 cfs, respectively) while Barton Creek had peak flow (2930 cfs) on the day following the event (November 16th). This flood was larger than the 99th percentile of all historical flows at all three of these sites. On Walnut and Barton creeks this flow event was equivalent to a 3 year event (average amount of time between events), while the Onion site experienced a 4 year event.

Post-Drought and Post-Flood Comparisons

A total of 58 macroinvertebrate taxa were collected in the three study streams from September 15, 2001 through March 23, 2002. Overall taxonomic richness, as numbers of insect genera or families, was similar in Onion (least urbanized) and Barton creeks (moderately urbanized) with totals of 50 and 49 taxa respectively, and somewhat lower in Walnut Creek (highly urbanized) with 41 taxa (Figure 3A). Barton Creek had more taxa (38) than either Onion (30) or Walnut (31) creeks during the post-flood period. During the post-drought period, Onion and Barton creeks had similar taxa richness (44, 42 taxa respectively), while Walnut was lower (34 taxa).

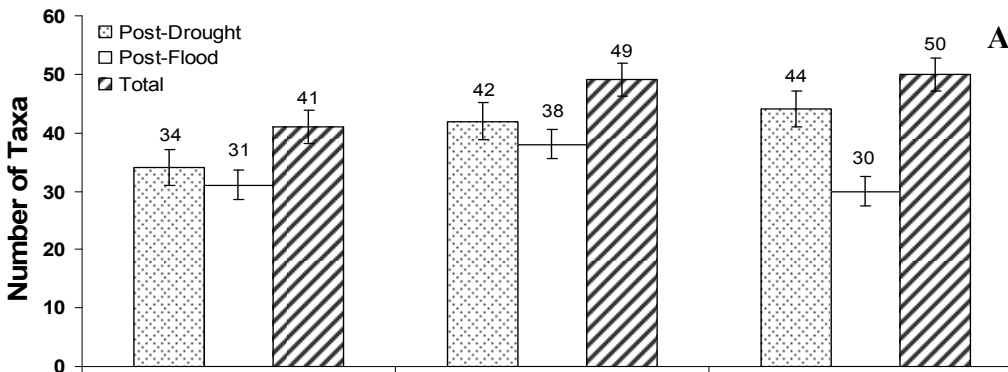


Figure 3. Variation in overall taxonomic richness during post-drought and post-flood periods in three Austin, Texas streams. Error bars represent 1 standard deviation.

Recolonization of macroinvertebrates post-drought was more rapid relative to post-flood abundance at all study streams (Figure 5). This higher rate of recovery was largely associated with a few dominant taxa. Overall Chironomidae made up the bulk of the organisms at all sites comprising one-third of the total invertebrates and Simulium and Baetis combined made up another one-third of the total invertebrates collected. Walnut Creek had 13 times greater abundance of Simulium during the post-drought relative to post-flood abundance. Abundance of Chironomidae was 1.5 times greater during the post-drought relative to its post-flood, and abundance of Baetis during post-drought and post-flood periods remained similar (Figure 5A). At Barton Creek, Chironomidae and Caenis were almost 2 times greater during the post-drought compared to post-flood abundance. In contrast, Baetis was almost 5 times greater in abundance during the post-flood relative to post-drought (Figure 5B). At Onion Creek, Chironomidae was 3 times, Baetis 4 times and Chimarra 7 times greater during the post-drought relative to post-flood abundances (Figure 5C).

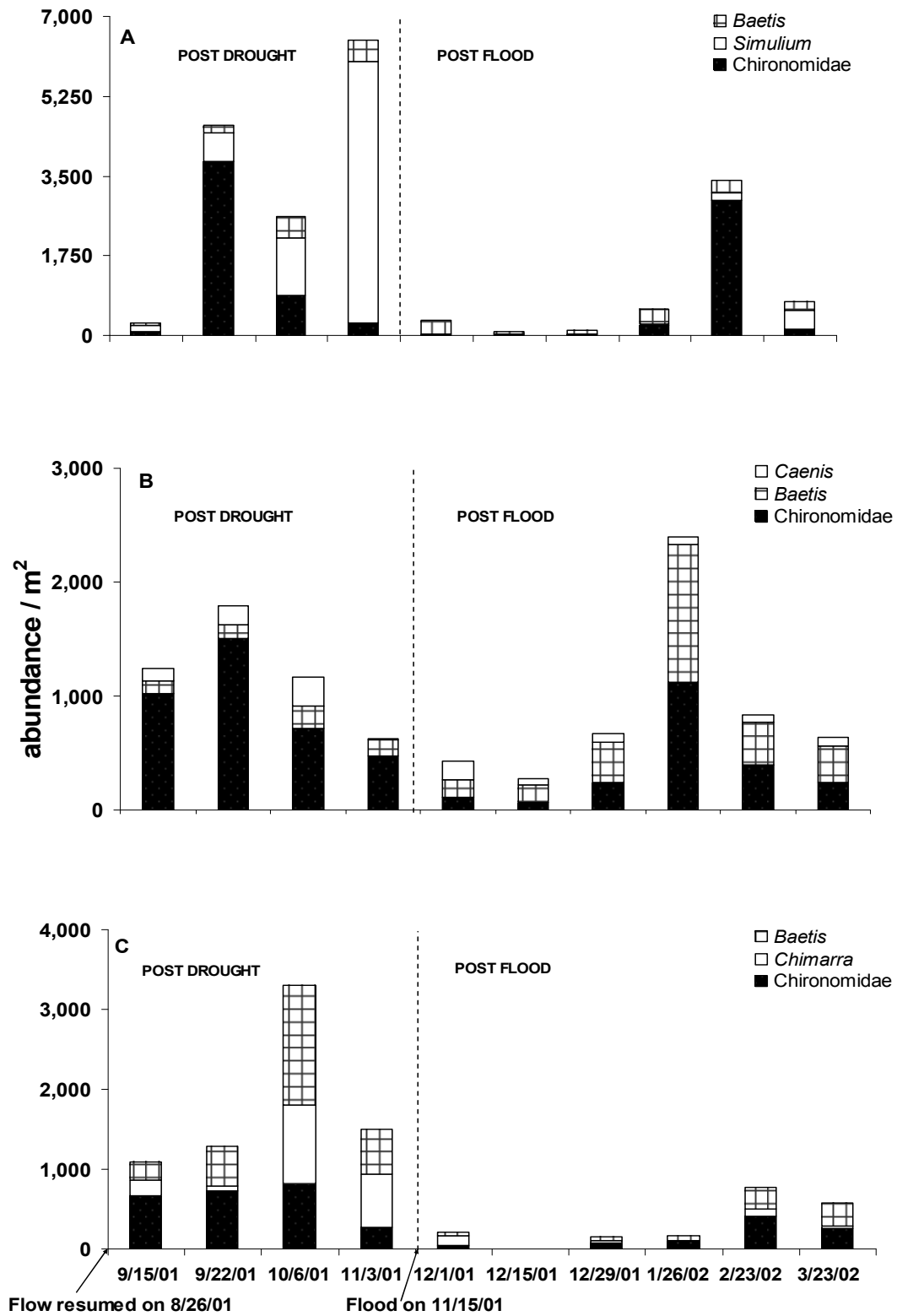


Figure 5. Temporal dynamics in abundance of dominant taxa at A- Walnut Creek, B-Barton Creek and C-Onion Creek after the post-drought and post-flood disturbances.

During the post-drought period, macroinvertebrate abundance generally increased over time at Onion and Walnut Creeks, whereas abundances at Barton Creek remained similar throughout both the post-drought period and the post-flood period (Figure 6). Macroinvertebrate abundances at Walnut Creek decreased by 50% for the October 6 sampling event and there was a subsequent increase until the November flood, which reduced the abundance dramatically. Macroinvertebrate abundance at Onion Creek also reduced substantially after the flood. However, macroinvertebrate abundance at Barton Creek gradually declined following a September 22 peak and abundance was apparently not affected by the flood. During the post-flood recovery, macroinvertebrate abundance remained low for 69 days at all streams. Barton Creek had consistently higher macroinvertebrate abundance than the other streams following the flood event, with the exception of Walnut Creek on a single occasion on February 23, 2002. Onion Creek had consistently lower macroinvertebrate abundance relative to Walnut and Barton creeks.

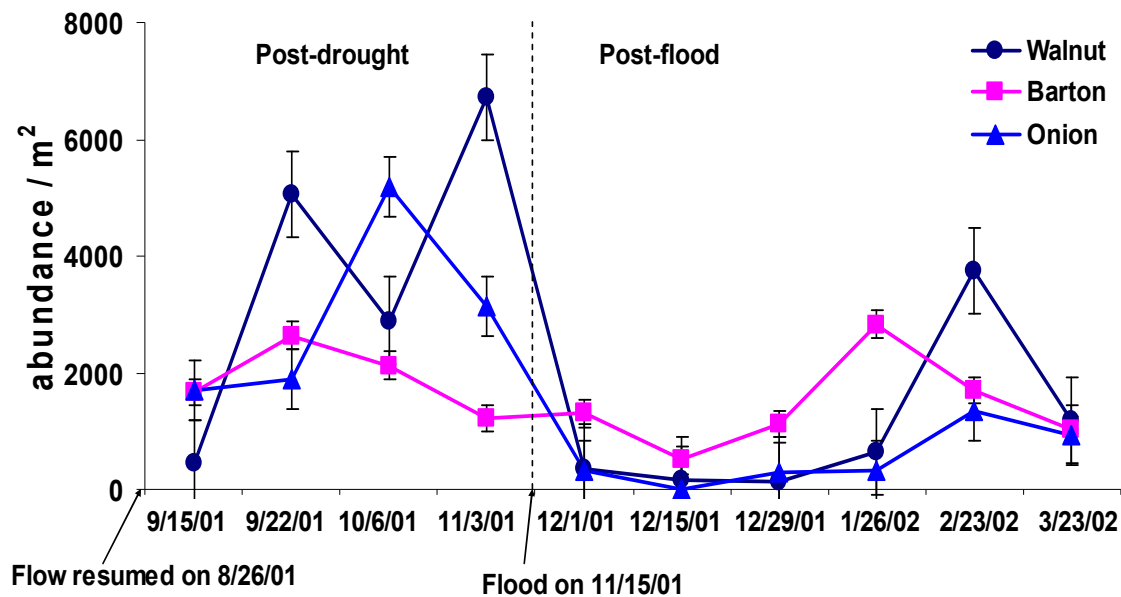


Figure 6. Temporal variation in macroinvertebrate abundance at Walnut, Barton and Onion creeks following drought and flood. Error bars represent 1 standard deviation.

During the post-drought period, the number of taxa collected from Onion Creek did not change much over time, going from 28-30 taxa (Figure 7). Barton Creek did not have a consistent trend during this period either, bouncing between 24 and 28 taxa during the four sample events. Walnut Creek had fairly consistent increases post-drought, going from 18 to 23 taxa. Following flood disturbance, the number of taxa was reduced by nearly 50% for Walnut and Onion creeks whereas Barton Creek showed little change in taxonomic richness. During the post-flood recovery period, taxonomic richness remained static on Barton Creek except for low richness during the last survey (12 taxa on 3/23/02). Walnut had some increases in richness over time during post-flood recovery, going from 11-19 taxa, but did reach the pre-flood taxa richness of 23 taxa. Onion appeared to not have recovered during our post-flood study period either, bouncing around between 16 and 18 taxa, well below the 30 taxa it had pre-flood.

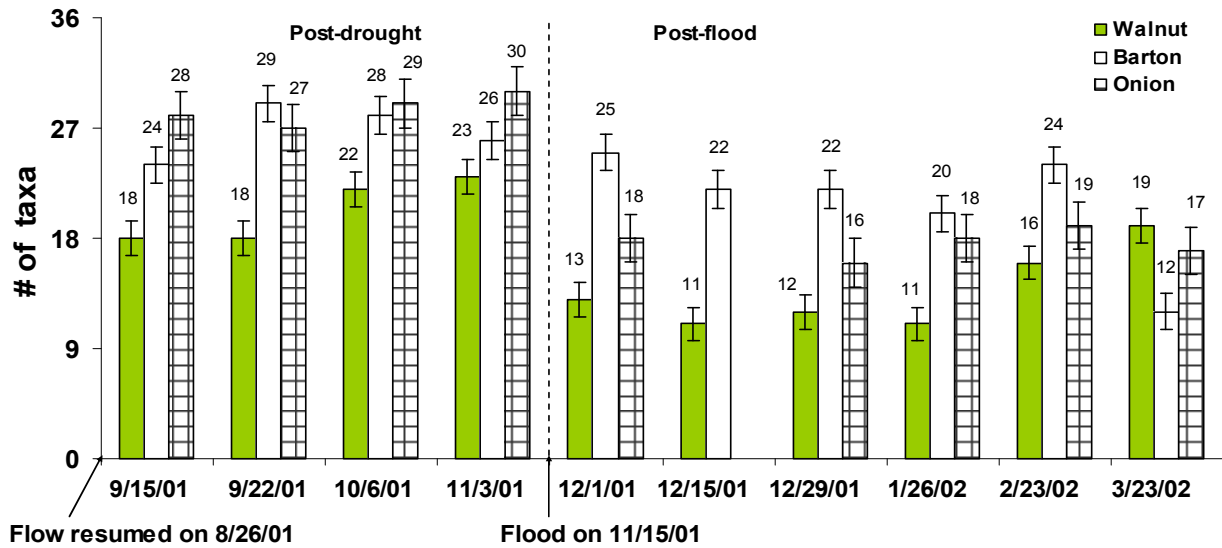


Figure 7. Temporal variation in macroinvertebrate taxonomic richness in Walnut, Barton and Onion creeks following drought and flood. Error bars represent 1 standard deviation.

Baetis species was the dominant taxa found consistently at all streams throughout the study. *Baetis* had eleven instars (Figure 8). There is a greater number of later instars (X and XI) during the post-flood than during post-drought suggesting that relatively few individuals would have emerged between the time of rewetting in August and the November spate.

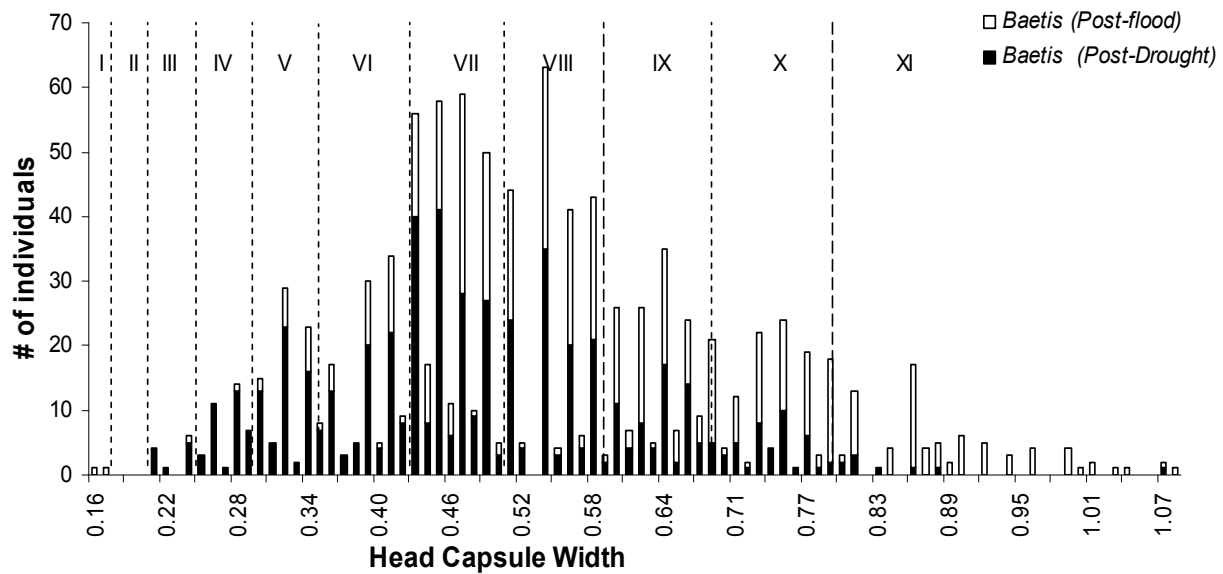


Figure 8. Distribution of larval head capsule widths of *Baetis* spp. from September 2001 to March 2002. Roman numerals and dashed lines indicate the approximate instar size ranges.

Discussion

Effects of Urbanization

Disturbances on macroinvertebrates in streams addressed in this study are hydrologic variability associated with drought and flooding exaggerated by impervious cover (level of urbanization). With a

higher percentage of impervious cover in a watershed the number of low flow days may increase, as do discharge peaks during flooding (Finkenbine et al. 2000, Scoggins 2001). The number of low flow days is a measure of how often a stream has minimum flow (<1.0 cfs) at the gage station and should be positively correlated to impervious cover (Klein 1979, USEPA 1997). As percentage of impervious cover (level of urbanization) increases, amount of surface water infiltrating into ground water decreases, consequently increasing the number of low flow days (Klein 1979) in that watershed. This hypothesis was not fully supported by flow dynamics at our study creeks as the most urbanized stream, Walnut Creek, had the fewest low flow days (13). However, this is likely due to soil and ecoregion changes that occur in this watershed as it moves from Central Texas Plateau, with shallow loamy soils to Blackland Prairie with deeper clay soils (Omernick 1987). Barton Creek had 50 days of low flow while Onion had only 18 days, suggesting that impervious cover may be influencing flow in these two less developed watersheds. In general, taxonomic richness and all other estimates of community health were consistent with the hypothesis that increasing urbanization will result in decreasing stream health. Walnut creek, at 30% impervious cover, had the lowest stream health, while Barton and Onion creeks, at 7 and 1.6% impervious cover, had proportionately healthier stream communities. Differences in Barton and Onion communities were minimal, suggesting that possibly a threshold of degradation had not been reached in Barton Creek or that our measures weren't high enough resolution to identify changes that may have occurred.

Variation in specific conductivity and dissolved oxygen (DO) is usually attributed to the level of urbanization in the watershed (Hynes 1970, Klein 1979, Lenat and Crawford 1994). The major causes of low DO are increases in water temperature, algal blooms, human waste, and animal waste (Warren 1971). Lower DO at Onion Creek may be due to the pollution from human and dogs at the sampling site (personal observation) during weekends, when sampling was generally done. It is also possible that these trends, based on grab samples, are temporally and location specific, not necessarily reflecting the entire diel DO pattern, or the entire stream reach. It is surprising that Barton Creek had consistently higher conductance with higher DO. Normally conductance and DO are inversely related (Warren 1971), i.e. if a stream has higher DO (more pristine or lower pollution) it will have lower conductance and vice versa. Adequate DO is necessary for the life of fish and other aquatic organisms. About 3 to 5 mg/L or ppm is the lowest limit for support of fish life over a 24-hour period. These slightly lower DO values are not a significant concern since all study streams had DO well above 6 mg/L. The effect of temperature on DO shows a normal trend, i.e. with gradual decrease in temperature there is a steady increase in DO. Conductivity values did not correspond with higher levels of urbanization in the study streams, with Barton having the highest means, Walnut median and Onion lowest. Again, this pattern is likely due to geological and ecoregion-specific influences that overwhelmed any urbanization effect.

Impacts of Drought on Stream Biota

Droughts can have direct and indirect impacts on stream biota. Direct impacts are those caused by loss of water and flow, and habitat reduction and reconfiguration, whereas indirect impacts are those associated with changes in phenomena such as interspecific interactions, especially predation and competition, and the nature of food resources (Lake 2003). Mortality after water loss should be severe as only few macroinvertebrate taxa can survive longer than 10 days (Stanley et al. 1994). The abundance of *Caenis* at all sites during the post-drought exceeded that of the post-flood. The ability of *Caenis* to persist during low flow may be due to diapausing eggs and also to morphological adaptations such as specialized gills, thickened opercula and interlacing fringes (Miller and Golladay 1996), which protect underlying gills from siltation and improve oxygen uptake in stagnant water and isolated pools. Similar persistence by *Caenis*, *Baetis* and chironomids was reported in a study by Stanley et al. (1994) in an intermittent Sonoran Desert stream in Arizona.

Recolonization commenced rapidly after flow resumed at all study streams. Recolonization of disturbed reaches by stream macroinvertebrates took anywhere from a few days to about 2 months in other experimental studies (Reice 1985, Robinson and Minshall 1986) and from months to several years

following larger scale natural disturbances (Fisher et al. 1982). Simuliids were the most abundant macroinvertebrate at Walnut Creek where they constituted 70% of the insects after flows resumed. Simuliids and chironomids can be considered r strategists (MacArthur and Wilson 1967) due to their rapid life cycle and high dispersal capability. These taxa are found to be among the first to colonize rewetted areas of intermittent streams in Australia (Boulton 1989), Arizona (Boulton et al. 1992 a), New York (Delucchi 1998), and Scotland (Morrison 1990). Simuliids can survive during dry conditions for several months by remaining in a dormant egg stage and develop rapidly upon rewetting (Crosskey 1990). With the resumption of flow upon rewetting, fine particulate organic matter (FPOM) transport increases (Ward 1992). Also, food quantity apparently increased after re-wetting, as algal mats grew (personal observation) and diatoms and FPOM increased. Greater availability of food could be part of the explanation for why Walnut Creek had higher abundance of macroinvertebrates relative to Barton and Onion creeks. On all creeks, collector/ gatherer Chironomidae were abundant. The abundance of chironomids may be indicative of the abundance of FPOM available to this functional feeding group. Small and fine gravel substrate (≈ 1 cm diameter) rather than large cobble substrate (≈ 8.5 cm diameter), maintain the highest densities of macroinvertebrates (Minshall 1984, Reice 1980), as small particles of detritus do not accumulate in large substrates where interstices are larger and current velocities higher. Walnut Creek had fine gravel substrate (personal observation) that could harbor more FPOM and subsequently be able to support higher abundance of macroinvertebrates relative to Onion or Barton creeks.

Impacts of the Flood on Stream Biota

Declines in macroinvertebrate density and diversity (measured as number of taxa) following floods were frequently observed in studies on the effects of hydrological disturbances on stream ecosystems (Scrimgeour and Winterbourne 1989). Following flood disturbance in our study streams, the number of taxa for Walnut and Onion creeks decreased almost by half relative to the pre-flood number of taxa. Such impacts are typically caused by combinations of high shear stress leading to dislodgement, scouring and abrasion from high sediment loads and substrate mobilization (Collier and Quinn 2003). Recovery of macroinvertebrate abundances to the pre-flood conditions was 2 times faster at Barton Creek (reached 50% of pre-flood abundance in 45 days) than at Walnut and Onion creeks (reached 50% of pre-flood abundance in 90 days). Recovery was associated with the reestablishment of dominant taxa Chironomidae, *Caenis* and especially *Baetis*. *Baetis* abundance during the post-flood was more than 4 times greater relative to post-drought which largely contributed to the higher recovery of the community following spate at Barton Creek. *Baetis* abundance during the post-flood at Walnut Creek was 2 times relative to post-drought and Onion Creek had a slight decrease in *Baetis* abundance during the post-flood. The recovery at Barton Creek following the spate was faster than that of an intermittent stream in southern Oklahoma (Miller and Golladay 1996) which took 126 days for invertebrates to recover to 67% of pre-spate density. Chironomidae, *Caenis* and *Baetis*, which are more resistant to spate, were the dominants at Barton Creek as well as in the southern Oklahoma intermittent stream. Similarly, Collier and Quinn (2003) found that 90% of the density and 80% of taxa richness recovered to pre-disturbance levels within 12 months following a pulse disturbance in a hill-country stream in northern New Zealand. Chironomids were the dominant taxa in the hill-country stream of New Zealand as well.

The post-drought recovery period lasted for 69 days and there may have been adult macroinvertebrate emergence for certain taxa preceding the flood event. The presence of aerial adult macroinvertebrates (such as dipterans, mayflies and caddisflies) would mean they would be available to oviposit following disturbance. Macroinvertebrates in larval stage may exhibit persistence in response to disturbance through: (i) morphological or physiological adaptations (e.g. hooks, claws and body shape) that enable individuals to withstand flood flows, (ii) behavioral changes that led to changes in habitat and avoidance of high flows, (iii) the ability to utilize within habitat refugia and (iv) the ability to persist in spatial refugia such as unaffected tributaries or adjacent catchments (Lancaster and Belyea 1997). Despite these adaptations, recovery following flood was much slower compared to the recovery after rewetting, which

was at least 2 times faster. The flood may have drastically eliminated algae and invertebrate standing crop and reduced its overall abundance. Algae and invertebrate standing crop was reduced by 98% in Sycamore Creek, Arizona (Fisher et al. 1982) following a flood event. Such an enormous reduction in standing crop may be due to the sandy substrate of the Sycamore desert stream that tends to be washed away more easily. Elimination of algae may have been accompanied by reduction in food quantity that may have accelerated mortality (Fisher 1983). On the other hand, there was a lower reduction in invertebrate density following a flood in an Australian stream which could be due to the more stable cobble substrate and dense algal mats that are known to harbor many invertebrates and are highly resistant to spates (Boulton et al. 1992 a).

Recolonization Processes

Chironomidae and *Simulium* were the first to colonize at the study streams following disturbance and is consistent with Collier and Quinn's (2003) conclusion that recolonization times for major lotic groups generally following the order Diptera < Ephemeroptera < Trichoptera < Plecoptera. This pattern is apparently related to generation times and life history variability (Collier and Quinn 2003).

The presence of a greater number of later *Baetis* instars, particularly X and XI, during the post-flood suggests that fewer number of individuals would have emerged between the rewetting on 26 August and the flooding on 15 November. This also indicates that the 4 months following flooding was enough time for *Baetis* species to complete its aquatic stage or complete a generation. Recruitment was continuous since early instars were present throughout the study period. The fact that at least from the 3rd instar and larger (Head capsule width 0.20 – 0.26 mm) were present through out the sampling period indicates that *Baetis* species is multivoltine in these streams, producing at least two generations a year.

Our study streams were located in the Edwards Plateau region of central Texas where a hyporheic refugia and source of recolonization is unlikely because of the karst geomorphology (Omernick 1987), which is either exposed or close to the surface thereby severely limiting the depth of hyporheic development. Colonization by aerial pathways is the principal recolonization mechanism for the majority of insect taxa, and sole pathway for some groups (Benzie 1984, Gray and Fisher 1981, Townsend and Hildrew 1976). Aerial colonization may occur from oviposition by terrestrial adults or from immigration by aquatic adults capable of flight (i.e. some Coleoptera and Hemiptera). Ovipositing by aerial adults could be the principal source of colonization in my study streams because the ovipositing adults may have persisted through the drought period (Gray and Fisher 1981) as the adult insects are capable of flight during disturbances. Aquatic adults are also known to exhibit behavioral avoidance of floods and therefore suffer few losses. Isolated floods have relatively little effect on all populations, despite high losses of immatures, because adults that left the stream prior to flooding are present to rapidly recolonize. Gray and Fisher (1981) tested the hypothesis that aerial pathways are used by most macroinvertebrate taxa to recolonize after flooding (summer and winter flood) in Sycamore Creek, a desert mountain stream in Arizona. They found that two-thirds of the macroinvertebrate taxa recolonized by aerial pathways in both seasons of the study.

Resistance and resilience were evaluated using invertebrate density and indices of community structure. Resistance was quantified as the percent reduction relative to predisturbance densities of the entire invertebrate assemblage as well for the individual taxa. Resistance was considered to be higher for a population in which percent reduction was relatively low. Resilience was measured by time to recover to predisturbance density, a method used by Grimm and Fisher (1989) and also by monitoring density over time.

More taxa were collected during post-drought (20 days after rewetting) at all streams relative to the post-flood (28 days after the flood event) recovery. Relative abundance of macroinvertebrate was also at least 2 times greater during the post-drought than during post-flood. Greater resistance to drought than flooding may be because flooding is less predictable and sudden in onset (Filho and Maltchik 2000). Resilience

following flood was slow. However, Barton Creek showed a greater resilience by recovering faster to the pre-flood conditions compared to the other two creeks. Greater abundance of spate-resistant taxa at Barton Creek viz. *Baetis* and *Caenis* which preceded the flood disturbance, may have helped Barton Creek to exhibit greater resilience following the flood.

Another key component of resistance and resilience, and hence overall survival of fauna in a drought, is the use of refugia (Lake 2003). This may be passive, such as retreat downstream as the headwaters dry, or active such as the possession of desiccation-resistant life stages. Greater abundance of macroinvertebrates during the post-drought relative to post-flood may be the result of more taxa able to use refugia or diapause stages during the drought period. The fauna of intermittent streams with seasonal droughts have acquired, through evolution, a range of adaptations, such as life-history schedules, physiological mechanisms and behaviors that provide refugia (Williams 1996). Thus, the fauna of intermittent streams would be expected to be both resistant and resilient.

Walnut Creek (most heavily urbanized) had greater overall abundance of macroinvertebrates than Barton and Onion creeks during post-drought. Barton Creek had greater abundances during the post-flood period than either of the other streams. Chironomidae and *Baetis* were the dominant taxa at all creeks during both post-drought and post-flood. Walnut and Barton creeks also had the greatest abundance of r-strategists. More abundance of r-strategists in a given stream may mean that it will recover faster after a disturbance and reach the pre-disturbed conditions faster than streams with fewer r-strategists. Barton and Walnut creeks are consistent with the hypothesis that an increase in the disturbance (impervious cover) will favor taxa that are r strategists (MacArthur and Wilson 1967) and will result in faster recovery of abundance times and result in greater population densities.

Use of the intermediate disturbance hypothesis (IDH, Connell 1978) has been advocated for stream ecosystems (Ward & Stanford 1983). The moderately urbanized stream, Barton Creek had more taxa than either Onion Creek or Walnut Creek during the post-flood, conforming to the bell-shaped IDH species richness curve. This result is similar to the finding of Townsend and Scarsbrook (1997) in their study in 54 stream sites in seven sub-catchments of the Taieri River in New Zealand that differed in the frequency and intensity of flood related episodes. Taxon richness was highest at intermediate intensities and frequencies of disturbance and conformed to the IDH. Although this is a very limited test of the IDH, using only three streams, it appears to be a viable hypothesis for Austin area streams.

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Appendix A. Total abundance and relative abundance of macroinvertebrate taxa at Walnut, Barton and Onion creeks during the study period.

Taxa	WALNUT CREEK		BARTON CREEK		ONION CREEK		Total	
	Abundance	Percent	Abundance	Percent	Abundance	Percent	abundance	Percent
<i>Ambrysus</i>	0	0.0	4	0.2	1	0.1	5	0.1
<i>Arctopsyche</i>	47	2.2	70	4.3	198	13.1	315	6.0
<i>Argia</i>	23	1.1	64	3.9	92	6.1	178	3.4
<i>Baetis</i>	240	11.2	310	19.3	349	23.1	899	17.1
<i>Berosus</i>	5	0.2	59	3.7	21	1.4	85	1.6
<i>Brechmorhoga</i>	3	0.1	0	0.0	6	0.4	9	0.2
<i>Caenis</i>	24	1.1	82	5.1	16	1.0	121	2.3
<i>Caloparyphus</i>	1	0.0	2	0.1	1	0.1	4	0.1
Cambaridae	0	0.0	4	0.2	0	0.0	4	0.1
<i>Camelobaetis</i>	16	0.8	13	0.8	11	0.7	40	0.8
Ceratopogonidae	13	0.6	21	1.3	62	4.1	96	1.8
<i>Chimarra</i>	14	0.6	74	4.6	219	14.5	307	5.8
Chironomidae	844	39.6	591	36.7	336	22.3	1771	33.7
<i>Claassenia</i>	5	0.2	13	0.8	9	0.6	27	0.5
Cladocera	0	0.0	1	0.1	0	0.0	1	0.0
Copepoda	0	0.0	3	0.2	1	0.1	4	0.1
<i>Corydalus</i>	0	0.0	0	0.0	1	0.1	1	0.0
Curculionidae	0	0.0	0	0.0	1	0.1	1	0.0
<i>Dugesia</i>	10	0.4	29	1.8	32	2.1	70	1.3
Ephydriidae	0	0.0	0	0.0	1	0.1	1	0.0
<i>Farrodes</i>	7	0.3	6	0.3	18	1.2	30	0.6
Glossosomatidae	1	0.0	2	0.1	2	0.1	5	0.1
<i>Helicopsyche</i>	0	0.0	10	0.6	1	0.1	11	0.2
<i>Heterelmis</i>	8	0.4	1	0.1	2	0.1	11	0.2

<i>Heterosternuta</i>	0	0.0	0	0.0	2	0.1	2	0.0
Hirudinea	3	0.1	6	0.4	0	0.0	9	0.2
<i>Hyalpella</i>	9	0.4	24	1.5	8	0.5	40	0.8
Hydracarina	5	0.2	11	0.7	3	0.2	18	0.3
<i>Hydroperla</i>	0	0.0	2	0.1	0	0.0	2	0.0
<i>Hydropsyche</i>	22	1.0	0	0.0	11	0.7	32	0.6
<i>Isonychia</i>	4	0.2	2	0.1	15	1.0	21	0.4
Isopoda	3	0.1	3	0.2	1	0.1	7	0.1
<i>Lutrochus</i>	15	0.7	12	0.7	0	0.0	27	0.5
<i>Macrelmis</i>	12	0.5	5	0.3	2	0.1	18	0.3
<i>Macromia</i>	0	0.0	16	1.0	21	1.4	36	0.7
<i>Odontomyia</i>	1	0.0	18	1.1	11	0.7	30	0.6
<i>Oecetis</i>	0	0.0	6	0.4	0	0.0	6	0.1
Oligochaeta	12	0.5	41	2.5	67	4.5	120	2.3
Ostracoda	9	0.4	12	0.7	5	0.3	26	0.5
<i>Peltodytes</i>	3	0.1	0	0.0	0	0.0	3	0.0
Perlodidae	0	0.0	6	0.4	2	0.1	8	0.2
<i>Perlomyia</i>	22	1.0	20	1.2	38	2.5	79	1.5
<i>Petrophila</i>	5	0.2	3	0.2	23	1.5	31	0.6
<i>Physa</i>	12	0.5	26	1.6	8	0.5	45	0.8
Planorbidae	5	0.2	6	0.4	7	0.4	18	0.3
Planospiral	1	0.0	3	0.2	4	0.3	8	0.2
Polycentropodidae	15	0.7	5	0.3	102	6.7	122	2.3
<i>Promogomphus</i>	7	0.3	7	0.4	10	0.7	24	0.5
<i>Pspenus</i>	3	0.1	13	0.8	19	1.3	35	0.7
<i>Rheumatobates</i>	1	0.0	2	0.1	0	0.0	3	0.1
<i>Scirtes</i>	0	0.0	0	0.0	1	0.1	1	0.0
<i>Simulium</i>	838	39.3	102	6.3	60	4.0	999	19.0
Sphaeriidae	0	0.0	28	1.7	1	0.1	29	0.5
<i>Stenelmis</i>	89	4.2	65	4.0	38	2.5	192	3.7
<i>Stenonema</i>	8	0.4	61	3.8	32	2.1	101	1.9
<i>Tabanus</i>	0	0.0	0	0.0	2	0.1	2	0.0
<i>Thraulodes</i>	4	0.2	4	0.2	12	0.8	20	0.4
<i>Tricorythodes</i>	0	0.0	4	0.2	14	0.9	18	0.3
# Organisms	2132		1612		1509		5253	
# of Taxa	41		49		50		58	

Appendix B. Total abundance and relative abundance of macroinvertebrate taxa in Walnut Creek during post-drought and post-flood periods.

Walnut Creek Taxa	Post-drought		Post-flood	
	Abundance	percent	Abundance	percent
Hirudinea	3	0.2	0	0.0
Oligochaeta	6	0.4	6	0.9
Chironomidae	504	33.4	339	54.6
<i>Argia</i>	21	1.4	2	0.3
<i>Stenelmis</i>	49	3.2	40	6.5
<i>Macrelmis</i>	9	0.6	3	0.5
<i>Heterelmis</i>	4	0.3	4	0.6
<i>Lutrochus</i>	15	1.0	0	0.0
<i>Baetis</i>	118	7.8	122	19.6
<i>Camelobaetidius</i>	9	0.6	8	1.2
<i>Isonychia</i>	2	0.1	2	0.3
Ceratopogonidae	12	0.8	2	0.2
<i>Berosus</i>	1	0.1	4	0.6
<i>Simulium</i>	776	51.4	61	9.9
<i>Chimarra</i>	8	0.6	6	0.9
<i>Stenonema</i>	7	0.5	1	0.2
<i>Thraulodes</i>	4	0.3	0	0.0
<i>Farrodes</i>	1	0.1	6	1.0
<i>Helicopsyche</i>	0	0.0	0	0.0
<i>Caenis</i>	21	1.4	3	0.5
<i>Tricorythodes</i>	0	0.0	0	0.0
<i>Pspenus</i>	0	0.0	3	0.4
<i>Arctopsyche</i>	30	2.0	17	2.7

<i>Claassenia</i>	0	0.0	5	0.8
<i>Perlomyia</i>	0	0.0	22	3.5
<i>Hydroperla</i>	0	0.0	0	0.0
Perlodidae	0	0.0	0	0.0
<i>Odontomyia</i>	0	0.0	1	0.2
<i>Caloparyphus</i>	0	0.0	1	0.2
<i>Tabanus</i>	0	0.0	0	0.0
<i>Petrophila</i>	3	0.2	2	0.2
Sphaeriidae	0	0.0	0	0.0
<i>Hydropsyche</i>	11	0.7	11	1.8
<i>Hyalpella</i>	4	0.3	5	0.8
Hydracarina	4	0.2	1	0.2
Ostracoda	9	0.6	0	0.0
Copepoda	0	0.0	0	0.0
Cladocera	0	0.0	0	0.0
Cambaridae	0	0.0	0	0.0
<i>Brechmorhoga</i>	3	0.2	0	0.0
<i>Promogomphus</i>	6	0.4	1	0.2
Oecetis	0	0.0	0	0.0
Glossosomatidae	0	0.0	1	0.2
<i>Corydalus</i>	0	0.0	0	0.0
<i>Rheumatobates</i>	1	0.1	0	0.0
Isopoda	3	0.2	0	0.0
Scirtes	0	0.0	0	0.0
Ephydriidae	0	0.0	0	0.0
<i>Peltodytes</i>	3	0.2	0	0.0
<i>Heterosternuta</i>	0	0.0	0	0.0
<i>Macromia</i>	0	0.0	0	0.0
Curculionidae	0	0.0	0	0.0
<i>Ambrysus</i>	0	0.0	0	0.0
Polycentropodidae	15	1.0	0	0.0
<i>Physa</i>	6	0.4	6	1.0
Planorbidae	0	0.0	5	0.8
Planospiral	1	0.1	0	0.0
<i>Dugesia</i>	4	0.3	6	0.9
# Organisms	1510		622	
# of Taxa	34		31	

Appendix C. Total abundance and relative abundance of macroinvertebrate taxa in Barton Creek during post-drought and post-flood periods.

Barton Creek Taxa	Post-drought		Post-flood	
	Abundance	percent	Abundance	percent
Hirudinea	5	0.7	1	0.1
Oligochaeta	21	2.7	20	2.3
Chironomidae	372	48.6	219	25.9
<i>Argia</i>	39	5.0	25	3.0
<i>Stenelmis</i>	56	7.4	9	1.0
<i>Macrelmis</i>	5	0.7	0	0.0
<i>Heterelmis</i>	1	0.1	0	0.0
<i>Lutrochus</i>	12	1.6	0	0.0
<i>Baetis</i>	55	7.2	255	30.1
<i>Camelobaetidius</i>	1	0.1	12	1.4
<i>Isonychia</i>	0	0.0	2	0.2
Ceratopogonidae	12	1.6	9	1.1
<i>Berosus</i>	56	7.4	3	0.4
<i>Simulium</i>	20	2.6	82	9.7
<i>Chimarra</i>	5	0.7	69	8.1
<i>Stenonema</i>	18	2.4	43	5.1
<i>Thraulodes</i>	4	0.5	0	0.0
<i>Farrodes</i>	5	0.6	1	0.1
<i>Helicopsyche</i>	9	1.2	1	0.1
<i>Caenis</i>	53	6.9	29	3.4
<i>Tricorythodes</i>	4	0.5	0	0.0
<i>Psphenus</i>	11	1.4	3	0.3

<i>Arctopsyche</i>	46	6.0	24	2.8
<i>Claassenia</i>	0	0.0	13	1.5
<i>Perlomyia</i>	0	0.0	20	2.3
<i>Hydroperla</i>	0	0.0	2	0.2
Perlodidae	0	0.0	6	0.7
<i>Odontomyia</i>	7	0.8	12	1.4
<i>Caloparyphus</i>	0	0.0	2	0.2
<i>Tabanus</i>	0	0.0	0	0.0
<i>Petrophila</i>	3	0.4	0	0.0
Sphaeriidae	21	2.7	7	0.9
<i>Hydropsyche</i>	0	0.0	0	0.0
<i>Hyalala</i>	12	1.6	12	1.4
Hydracarina	6	0.7	5	0.6
Ostracoda	12	1.6	0	0.0
Copepoda	3	0.4	0	0.0
Cladocera	1	0.1	0	0.0
Cambaridae	3	0.4	1	0.1
<i>Brechmorhoga</i>	0	0.0	0	0.0
<i>Promogomphus</i>	5	0.7	2	0.2
Oecetis	4	0.5	2	0.2
Glossosomatidae	2	0.3	0	0.0
<i>Corydalus</i>	0	0.0	0	0.0
<i>Rheumatobates</i>	2	0.3	0	0.0
Isopoda	1	0.1	2	0.2
<i>Scirtes</i>	0	0.0	0	0.0
Ephydriidae	0	0.0	0	0.0
<i>Peltodytes</i>	0	0.0	0	0.0
<i>Heterosternuta</i>	0	0.0	0	0.0
<i>Macromia</i>	2	0.3	14	1.6
Curculionidae	0	0.0	0	0.0
<i>Ambrysus</i>	3	0.4	1	0.1
Polycentropodidae	4	0.5	1	0.1
<i>Physa</i>	18	2.3	8	0.9
Planorbidae	0	0.0	6	0.7
Planospiral	3	0.4	0	0.0
<i>Dugesia</i>	16	2.1	13	1.5
# Organisms	765		847	
# of Taxa	42		38	

Appendix D. Total abundance and relative abundance of macroinvertebrate taxa in Onion Creek during post-drought and post-flood periods.

Onion Creek Taxa	Post-drought		Post-flood	
	Abundance	percent	Abundance	percent
Hirudinea	0	0.0	0	0.0
Oligochaeta	57	4.7	11	3.4
Chironomidae	247	20.7	89	28.1
<i>Argia</i>	83	7.0	9	2.8
<i>Stenelmis</i>	32	2.6	7	2.1
<i>Macrelmis</i>	2	0.1	0	0.0
<i>Heterelmis</i>	2	0.2	0	0.0
<i>Lutrochus</i>	0	0.0	0	0.0
<i>Baetis</i>	279	23.4	70	21.9
<i>Camelobaetidius</i>	8	0.7	3	0.9
<i>Isonychia</i>	14	1.2	1	0.3
Ceratopogonidae	47	3.9	15	4.8
<i>Berosus</i>	21	1.7	0	0.0
<i>Simulium</i>	23	1.9	37	11.6
<i>Chimarra</i>	191	16.0	28	8.9
<i>Stenonema</i>	19	1.6	13	4.1
<i>Thraulodes</i>	12	1.0	0	0.0
<i>Farrodes</i>	18	1.5	0	0.0
<i>Helicopsyche</i>	1	0.1	0	0.0
<i>Caenis</i>	14	1.1	2	0.6
<i>Tricorythodes</i>	14	1.2	0	0.0

<i>Psphenus</i>	15	1.3	4	1.3
<i>Arctopsyche</i>	172	14.4	27	8.4
<i>Claassenia</i>	0	0.0	9	2.9
<i>Perlomyia</i>	0	0.0	38	11.8
<i>Hydroperla</i>	0	0.0	0	0.0
Perlodidae	0	0.0	2	0.6
<i>Odontomyia</i>	11	0.9	0	0.0
<i>Caloparyphus</i>	1	0.1	0	0.0
<i>Tabanus</i>	2	0.2	0	0.0
<i>Petrophila</i>	21	1.8	2	0.6
Sphaeriidae	0	0.0	1	0.3
<i>Hydropsyche</i>	8	0.6	3	0.9
<i>Hyalpella</i>	5	0.4	3	0.8
Hydracarina	2	0.2	1	0.3
Ostracoda	5	0.4	0	0.0
Copepoda	1	0.1	0	0.0
Cladocera	0	0.0	0	0.0
Cambaridae	0	0.0	0	0.0
<i>Brechmorhoga</i>	6	0.5	0	0.0
<i>Promogomphus</i>	10	0.8	0	0.0
Oecetis	0	0.0	0	0.0
Glossosomatidae	0	0.0	2	0.6
<i>Corydalus</i>	1	0.1	0	0.0
<i>Rheumatobates</i>	0	0.0	0	0.0
Isopoda	0	0.0	1	0.3
<i>Scirtes</i>	1	0.1	0	0.0
Ephydriidae	1	0.1	0	0.0
<i>Peltodytes</i>	0	0.0	0	0.0
<i>Heterosternuta</i>	2	0.2	0	0.0
<i>Macromia</i>	13	1.0	8	2.5
Curculionidae	1	0.1	0	0.0
<i>Ambrysus</i>	1	0.1	0	0.0
Polycentropodidae	100	8.3	2	0.6
<i>Physa</i>	2	0.2	6	1.7
Planorbidae	0	0.0	7	2.1
Planospiral	3	0.3	1	0.3
<i>Dugesia</i>	30	2.5	2	0.6
# Organisms	1192		317	
# of Taxa	44		30	

Appendix E. Taxa abundance for macroinvertebrates at Walnut Creek site during study period.

Family (Class/Order)	Genus	9/15/01	9/22/01	10/6/01	11/3/01	12/1/01	12/15/01	12/29/01	1/26/02	2/23/02	3/23/02
				1	2						
			3	2	1			1		1	4
Chironomidae		8	382	87	27	3	2	3	22	295	14
Coenagrionidae	<i>Argia</i>	2	3	8	8	2					
Elmidae	<i>Stenelmis</i>	5	16	20	7	7	4	1	2	20	7
Elmidae	<i>Macrelmis</i>	2	4	1	2		1			1	1
Elmidae	<i>Heterelmis</i>		1	3			1			2	1
Lutrochidae	<i>Lutrochus</i>	2	6	7							
Baetidae	<i>Baetis</i>	6	16	48	48	29	5	7	32	28	22
Baetidae	<i>Camelobaetidius</i>	2	2	3	3	4		1	2	1	
Isonychiidae	<i>Isonychia</i>				2						2
Ceratopogonidae			9	3						2	
Hydrophilidae	<i>Berosus</i>	1						1		2	1
Simuliidae	<i>Simulium</i>	13	63	126	575	1		1	2	18	39
Philopotamidae	<i>Chimarra</i>			6	2	4		1			1
Heptageniidae	<i>Stenonema</i>			3	4	1					
Leptophlebiidae	<i>Thraulodes</i>				4						

Leptophlebiidae	<i>Farrodes</i>				1				6		
Caenidae	<i>Caenis</i>	2	11	8		2				1	
Pspheidae	<i>Pspheus</i>						2				1
Hydropsychidae	<i>Arctopsyche</i>	1	4	21	5		3		1		13
Perlidae	<i>Claassenia</i>									2	3
Leuctridae	<i>Perlomyia</i>						1		4	7	10
Stratiomyidae	<i>Odontomyia</i>					1					
Stratiomyidae	<i>Caloparyphus</i>									1	
Pyralidae	<i>Petrophila</i>	1			2				2		
Hydropsychidae	<i>Hydropsyche</i>				11	7		1			3
Talitridae	<i>Hyalala</i>		4							2	3
(Hydracarina)			1	1	2						1
(Ostracoda)			9								
Libellulidae	<i>Brechmorhoga</i>		1		2						
Gomphidae	<i>Promogomphus</i>	1		4	1						1
Glossosomatidae							1				
Gerridae	<i>Rheumatobates</i>	1									
(Isopoda)		1	2								
Haliplidae	<i>Pelodytes</i>	3									
Polycentropodidae		1		12	2						
Physidae	<i>Physa</i>	3		1	2		2	2	1		1
Planorbidae						3	1	1			
Planospiral				1							
Planariidae	<i>Dugesia</i>			1	3	2		2	1	1	
	# of Taxa	18	18	22	23	13	11	12	11	16	19
	# Organisms	44	505	289	672	36	15	14	64	375	118

Appendix F. Taxa abundance for macroinvertebrates at Barton Creek site during study period.

Family (Class/Order)	Genus	9/15/01	9/22/01	10/6/01	11/3/01	12/1/01	12/15/01	12/29/01	1/26/02	2/23/02	3/23/02
(hirudinea)		2		1	2	1					
(Oligochaeta)		4	2	10	6	3	2	3	6	1	6
Chironomidae		102	151	71	48	11	7	24	112	40	25
Coenagrionidae	<i>Argia</i>	11	6	13	10	8	1	6	4	1	5
Elmidae	<i>Stenelmis</i>	10	20	16	10	2	1	2	1	3	
Elmidae	<i>Macrelmis</i>	4		1							
Elmidae	<i>Heterelmis</i>			1							
Lutrochidae	<i>Lutrochus</i>		3	9							
Baetidae	<i>Baetis</i>	9	12	20	14	16	15	35	121	37	31
Baetidae	<i>Camelobaetidius</i>				1	2	1	2	4	1	2
Isonychiidae	<i>Isonychia</i>					1				1	
Ceratopogonidae		4	4	4			4		2	2	2
Hydrophilidae	<i>Berosus</i>	17	16	15	8	3					
Simuliidae	<i>Simulium</i>	11	2	5	4	12	9	2	3	54	3
Philopotamidae	<i>Chimarra</i>	5				32	5	16	12	5	
Heptageniidae	<i>Stenonema</i>		5	13		14	2	6	6	13	4
Leptophlebiidae	<i>Thraulodes</i>		2		2						

Leptophlebiidae	<i>Farrodes</i>		5							1	
Helicopsychidae	<i>Helicopsyche</i>			2	7				1		
Caenidae	<i>Caenis</i>	11	16	25	1	17	2	8		3	
Tricorythidae	<i>Tricorythodes</i>		4								
Pspheidae	<i>Pspheus</i>	1	3	4	3	1					2
Hydropsychidae	<i>Arctopsyche</i>	2	3	28	13	4	3	2	6	5	5
Perlidae	<i>Claassenia</i>							1	3	2	7
Leuctridae	<i>Perlomyia</i>					3	1	3	4	10	
Perlodidae	<i>Hydroperla</i>									2	
Perlodidae						3		3			
Stratiomyidae	<i>Odontomyia</i>	6	1			3	3		5	1	
Stratiomyidae	<i>Caloparyphus</i>							1		1	
Pyralidae	<i>Petrophila</i>	1	1		1						
Sphaeriidae		5	7	5	4	1	1	2		3	
Talitridae	<i>Hyallela</i>	1	7		4	7	2		3		
(Hydrocarina)		2		3	1		1	1	1	2	
(Ostracoda)			4	6	2						
(Copepoda)		1		2							
(Claochera)			1								
Cambaridae			2		1		1				
Gomphidae	<i>Promogomphus</i>			2	3				2		
Leptoceridae	<i>Oecetis</i>		4					1		1	
Glossosomatidae			2								
Gerridae	<i>Rheumatobates</i>	1	1								
(Isopoda)					1			2			
Macromiidae	<i>Macromia</i>			2		8		6			
Naucoridae	<i>Ambrysus</i>			2	1	1					
Polycentropodidae		2		2			1				
Family (Class/Order)	Genus	9/15/01	9/22/01	10/6/01	11/3/01	12/1/01	12/15/01	12/29/01	1/26/02	2/23/02	3/23/02
Planorbidae						3	2	1			
Planospiral			1	1	1						
Planariidae	<i>Dugesia</i>	1	2	4	9	3	1		2	5	2
	# of Taxa	24	29	28	26	25	22	22	20	24	12
	# Organisms	167	264	213	122	130	50	111	283	170	102

Appendix G. Taxa abundance for macroinvertebrates at Onion Creek site during study period.

Family (Class/Order)	Genus	9/15/01	9/22/01	10/6/01	11/3/01	12/1/01	12/29/01	1/26/02	2/23/02	3/23/02
(Oligochaeta)		12	4	32	9	1	4		5	1
Chironomidae		67	73	81	27	4	8	10	41	26
Coenagrionidae	<i>Argia</i>	8	13	23	39	5	1	2	2	
Elmidae	<i>Stenelmis</i>	3	3	9	16	1	2	1	1	2
Elmidae	<i>Macrelmis</i>				2					
Elmidae	<i>Heterelmis</i>			2						
Baetidae	<i>Baetis</i>	23	50	151	56	4	4	6	28	28
Baetidae	<i>Camelobaetidius</i>		2	6		1			2	
Isonychiidae	<i>Isonychia</i>	1	3	2	8				1	

Ceratopogonidae		8	9	16	15	2	5	1	2	6
Hydrophilidae	<i>Berosus</i>	10	1	7	3					
Simuliidae	<i>Simulium</i>	3	2	7	12	7	1	3	25	1
Philopotamidae	<i>Chimarra</i>	19	6	99	67	13	3	1	9	3
Heptageniidae	<i>Stenonema</i>	5	4	11		5	4		1	3
Leptophlebiidae	<i>Thraulodes</i>	3		6	3					
Leptophlebiidae	<i>Farrodes</i>	4	4	9	1					
Helicopsychidae	<i>Helicopsyche</i>			1						
Caenidae	<i>Caenis</i>	10	4				2			
Tricorythidae	<i>Tricorythodes</i>			14						
Psphenidae	<i>Psphenus</i>	3	1	3	9			1	2	1
Hydropsychidae	<i>Arctopsyche</i>	16	13	99	44	5	5	1	5	10
Perlidae	<i>Claassenia</i>							1	5	3
Leuctridae	<i>Perlomyia</i>					4	2	4	15	14
Perlodidae								2		
Stratiomyidae	<i>Odontomyia</i>	2	2	7						
Stratiomyidae	<i>Caloparyphus</i>		1							
Tabanidae	<i>Tabanus</i>				2					
Pyralidae	<i>Petrophila</i>	4	2	12	4			1	1	
Sphaeriidae										1
Hydropsychidae	<i>Hydropsyche</i>	2		3	3	1			2	
Talitridae	<i>Hyallela</i>	1	1	1	2	1				2
(Hydrocarina)		2						1		
(Ostracoda)			1	2	2					
(Copepoda)		1								
Libellulidae	<i>Brechmorhoga</i>		3	3						
Gomphidae	<i>Promogomphus</i>	2	1		7					
Glossosomatidae										2
Corydalidae	<i>Corydalus</i>				1					
Family (Class/Order)	Genus	9/15/01	9/22/01	10/6/01	11/3/01	12/1/01	12/29/01	1/26/02	2/23/02	3/23/02
Scirtidae	<i>Scirtes</i>				1					
Ephydriidae					1					
Dytiscidae	<i>Heterosternuta</i>	2								
Macromiidae	<i>Macromia</i>	2	2	2	7	2	2	2		2
Curculionidae					1					
Naucoridae	<i>Ambrysus</i>				1					
Polycentropodidae		6	5	66	23				2	
Physidae	<i>Physa</i>	1		1		1	3	2		
Planorbidae						2	3	1	1	
Planospiral			1		2			1		
Planariidae	<i>Dugesia</i>	3	8	11	9	1	1			
	# of Taxa	28	27	29	30	18	16	18	19	17
	# Organisms	170	189	520	313	31	29	31	134	91