MACROINVERTEBRATE RECOLONIZATION DYNAMICS IN RESPONSE TO DROUGHT AND FLOOD IN THREE AUSTIN, TEXAS, STREAMS: EFFECTS OF URBANIZATION

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ABSTRACT

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Impervious cover of urbanized areas exaggerates the hydrologic disturbance (intensity of spates and duration of dry periods) common in central Texas. The objective of this study was to determine how benthic macroinvertebrate community composition, diversity, resilience, and recolonization in three Austin, Texas, streams that vary (3%, 16%, 55%) in degree of impervious cover are affected by such conditions. Benthic macroinvertebrates were quantified in 3 riffles in each of the 3 streams. Recovery from drought and flood were determined by: 1) 2 bi-weekly samples after flow resumed in September 2001, following the summer dry period and monthly sampling until flood disturbance; 2) 2 bi-weekly samples after flows receded in November 2001, and monthly sampling thereafter for four months.

Hydrologic disturbance had a larger effect in the most urbanized watershed, where taxa richness and abundance were lowest and chironomids dominated. Greatest species richness occurred at the moderate and least disturbed streams, where *Fallceon*, *Stenelmis*, *Argia* and Chironomidae were dominant. Results indicated that rate of recolonization following disturbance was inversely related to degree of impervious cover. Impervious cover appears to interact with natural hydrologic disturbances in determining structure and function of the benthic community in urbanized streams.

INTRODUCTION

Stream communities are structured by hydrologic regime, physical and chemical characteristics, and biological interactions (Bott et al. 1985). Human impacts on streams such as non-point source pollution, habitat alteration, reduced stream flow, and introduced species are not often apparent through physical and chemical monitoring, but are detected through biological monitoring (Karr 1987). Macroinvertebrates are frequently used in water quality assessments of freshwater systems (Rosenberg and Resh 1993). Aquatic insects are useful in evaluating water quality because their sedentary nature allows determination of the spatial extent of impacts, and their long life cycles allow assessment of temporal changes (Rosenberg and Resh 1993).

In central Texas, flashy spates and long dry periods are common (Baker 1977), and impervious cover of urbanized areas exaggerates this dramatic hydrological cycle. Impervious cover causes dry periods to last longer by reducing baseflow and results in severe scouring of the stream bottom and banks by increasing flood intensity (Baker 1977, Gordon et al. 1992, Britton et al. 1993, Elliot et al. 1997, Poff et al. 1997, USEPA 1997). The strength of interactions between hydrologic conditions and impervious cover are most pronounced in heavily urbanized watersheds and benthic macroinvertebrate taxonomic composition, richness, and abundance are negatively affected by such conditions

(Poff and Ward 1989, Scrimgeour and Winterbourn 1989, Flecker and Feifarek 1994, Death and Winterbourn 1995, Angradi 1997, Clausen and Biggs 1997).

Flow regime plays a major role in structuring habitat conditions for stream macroinvertebrates through direct effects, as well as interaction with substrate, food supply and physico-chemical parameters (Ward 1992). Generally, in streams with a highly variable or unpredictable flow regime, abiotic factors such as flooding frequency and predictability play an important role in structuring the macroinvertebrate community; whereas in streams with a more consistent discharge pattern, biotic interactions such as predation and competition become more important and moderate disturbance from flooding can facilitate the coexistence of species (Peckarsky 1983, Ward and Stanford 1983, Resh et al. 1988, Poff and Ward 1989, Death and Winterbourn 1995). High biotic diversity is a function of moderate perturbation, maintained by species replacement as changing environmental conditions favor different assemblages of species (Patrick 1970, Ward and Stanford 1983).

Numerous studies show significant effects of hydrologic variability on benthic stream communities (Fisher et al. 1982, Miller and Golladay 1996, Paltridge et al. 1997, Filho and Maltchik 2000). In addition to altering the flow regime, urban runoff may contain non-point source pollutants such as metals, organic hydrocarbons, nutrients and sediment (Lemly 1982, Lenat 1988, Sponseller et al. 2001). Scoggins (2001) showed that antecedent hydrologic conditions (drought and flood) have marked effects on the results of rapid biological assessments (RBA) (Barbour et al. 1999), and may not reflect degradation due to non-point source pollutants. These antecedent hydrologic conditions affect the community structure and life history tactics of aquatic insects (Resh et al. 1988, Feminella 1996).

Stability of a community is measured by its resistance and resilience, where resistance is ability to resist change and resilience is the rate of recovery following disturbance (Miller and Golladay 1996, Maltchik and Filho 2000, Lake 2003). A stable benthic macroinvertebrate community is one which is highly resistant, highly resilient, or both (Miller and Golladay 1996). Recovery after disturbance is the re-establishment of community structure and function to pre-disturbance conditions and is accomplished by organisms through downstream drift, aerial adults, and from instream refugia (Williams and Hynes 1976, Miller and Golladay 1996). The severity of disturbance, predominant recolonization pathways and distance from refugia varies among streams and watersheds and will influence time to recovery, and subsequent taxonomic composition and abundances (Delucchi 1988, Miller and Golladay 1996, Filho and Maltchik 2000).

Droughts have marked effects, direct and indirect, on macroinvertebrate densities, taxonomic composition, diversity, and overall ecosystem processes (Boulton 2003, Lake 2003). Direct effects of drought include decreased flow, reduced habitat, alteration of water quality and lack of habitat connectivity (Lake 2003). Indirect effects include reduced water quality, reduced food resources and alteration of biotic interactions such as predation and competition (Lake 2003). As water level declines, shallow stream sections including riffles are the first to go dry and the proportion of lentic habitat increases, which will favor some species over others (Lake 2003). Mechanisms of resistance to drought conditions include: 1) desiccation resistant life stages, 2) life history adaptation, 3) physiological mechanisms; and 4) behavioral adaptations (Williams 1996, Magoulick and Kobza 2003).

Flooding also has severe impacts on macroinvertebrate communities due to substrate movement and associated dislodgement, scouring and abrasion (Ward 1992, Townsend et al. 1997, Collier and Quinn 2003), and negatively affects macroinvertebrate communities by reducing densities, diversity, and abundances (Fisher et al. 1982, Molles 1985, Miller and Golladay 1996, Shivoga 2001). Mechanisms of resistance to flooding include:
1) instream refugia, 2) nearby stream refugia, 3) morphological adaptations, 4) life history adaptation; and 5) behavioral avoidance (Lancaster and Belyea 1997, Collier and Quinn 2003).

Stream macroinvertebrate communities are generally highly resistant and resilient to drought, if drought resistant taxa are present (i.e. capable of recolonization upon rewetting, or surviving in the hyporheos or intermittent pools); whereas resistance to flooding is low and resilience high (Resh et al. 1990, Boulton and Lake 1992, Stanley et al. 1994, Miller and Golladay 1996, Boulton 2003, Lake 2003). Filho and Maltchik (2000) suggested that benthic macroinvertebrate community structure had greater resistance to drought than flooding because flooding is less predictable and more sudden in onset. Although macroinvertebrate densities have low resistance and resilience to flood disturbance, taxonomic composition has high resistance and resilience (Miller and Golladay 1996). This ability of taxonomic composition to remain intact is an important mechanism of recovery to pre-disturbance conditions following drought and flood (Miller and Golladay 1996).

Study Objectives

The objectives of this study were to: 1) determine how hydrologic variability of streams differs among watersheds having contrasting levels of urbanization; 2) quantify patterns of macroinvertebrate recolonization and community structure (i.e. taxonomic composition and abundances) in urban streams in response to alteration of hydrology by impervious cover; 3) compare recovery dynamics following a drought as opposed to a flood disturbance in relation to life histories of dominant taxa and 4) evaluate how the above factors influence the effectiveness of current rapid biological assessment protocols in the evaluation of water quality in urban streams of central Texas. Information gained will be applied by the City of Austin in their environmental monitoring program when interpreting biological assessment data and possibly in modification of RBA protocols for the Austin area. This research is the next step towards determining how hydrologic disturbance influences RBA results. Hydrologic variability is known to be a confounding factor of RBA macroinvertebrate community and habitat integrity scoring. One goal is to differentiate response of the macroinvertebrate community to hydrologic disturbance, RBA indices of pollution, and habitat degradation.

In addition to the above objectives, the following ecological hypotheses were examined. 1) Based on r/K selection theory (MacArthur and Wilson 1967) the most urbanized (disturbed) watershed (Shoal Creek) should reach pre-disturbance taxonomic richness faster and have the highest population densities, since r-strategists have higher dispersal and reproductive potential than K-strategists. 2) The intermediate disturbance hypothesis (IDH) was proposed by Connell (1978) to account for patterns of diversity in tropical rainforests and coral reefs, and has been widely applied to lotic ecosystems (Ward and Stanford 1983, Resh et al. 1988, Townsend et al. 1997). The IDH predicts that diversity will be greatest at intermediate levels of disturbance, because high levels of disturbance reduce the biotic community to only highly adapted species, and at low levels of disturbance resource levels and environmental consistency favor highly competitive species (Connell 1978, Feminella and Resh 1990, Death and Winterbourn 1995). The IDH can be applied to these central Texas streams because flooding disturbances vary in frequency and intensity relative to the proportion of impervious cover in the watershed. If levels of urbanization also represent levels of disturbance, then the moderately urbanized watershed (Bull Creek) should have the greatest species diversity.

MATERIALS AND METHODS

Study Sites

Three riffles along each of three streams with contrasting levels of urbanization were selected for study. The three creeks have similar drainage areas: Shoal Creek (30° 16' 35" N, 97° 45' 00" W) drains 31.9 km^2, Bull Creek (30° 22' 19" N, 97° 47' 04" W) drains 57.8 km^2, and Bear Creek (30° 09' 19" N, 97° 56' 23" W) drains 31.6 km^2. Impervious cover was estimated by City of Austin (COA) using aerial photography and historic land use mapping. Streams were selected after reviewing COA water quality data and degree of impervious cover within the watershed. Also, sites were selected near United States Geological Survey (USGS) gauging stations having a daily mean flow record. Shoal Creek (Figure 1) is located in the most urbanized watershed, having the highest (55%) percentage of impervious cover among the three streams. Bull Creek is in a watershed with a moderate (16%) level of urbanization and Bear Creek is in the least (3%) urbanized watershed. Bear Creek served as the reference stream (Karr and Chu 1999) because it is minimally influenced by human activities. The study area occurs along the central Texas Plateau, having karst limestone geology (Omernick 1987). Along the selected streams, riffles are common, composed of cobble and gravel based on the modified Wentworth scale (Cummins 1962).

Physical and Hydrologic

Physicochemical parameters (pH, specific conductance, dissolved oxygen and temperature) were measured at each site using a Hydrolab Minisonde4*a*. Discharge data was obtained from USGS gauging stations in the streams.

Biological

For each of the 3 streams a Hess sample was collected from each of 3 riffles (n = 3). The Hess sampler had a cylindrical diameter of 0.36 m and samples an area of 0.10 m^2; a bag with mesh of 500 μm connects from the main drum and tapers to a small collecting container. After implanting the sampler into the streambed, any stones and debris were scrubbed into the collecting net of the Hess sampler to remove any attached invertebrates. The substratum was then disturbed 5-10 cm by hand, allowing the current to sweep sediment, organic matter, and macroinvertebrates into the net. Organisms in the retention device were transferred into appropriately sized containers and stored in 90% EtOH. Recovery from drought and flood was determined by: 1) 2 bi-weekly samples after flow resumed on 26 August 2001 following the summer dry period and 2) 2 bi-weekly samples following flooding on 15 November 2002, and monthly sampling thereafter for each disturbance. The last sampling event was on 23 March 2002.

Laboratory

Organisms were removed from samples by gentle washing in a 200 μm sieve followed by elutriating in a pan of water. Individuals were enumerated and identified under a 40X variable microscope to the lowest possible taxonomic unit, usually genus, using the keys of Merritt and Cummins (1997) and Thorp and Covich (2001). All organisms were archived in vials containing 70% EtOH. Head capsule widths were measured using a 100X stereo-microscope with an ocular micrometer and used to determine life history characteristics such as voltinism, growth and size class structure.

Community Analysis

$$\text{Simpson's diversity index: } D_s = 1 - \frac{\sum n_I\,(n_I - 1)}{N\,(N - 1)},$$

was used to measure diversity; where N is the total number of individuals and n_I is the proportion of the total that occurs in each species (Brower et al. 1998). The measure of evenness associated with the Simpson's diversity index:

$$E_D = D_s / D_{max} \quad \text{where} \quad D_{max} = \frac{(s-1)}{(s)}\frac{(N)}{(N-1)},$$

where s is the number of species and D_{max} is the maximum possible diversity in a community with N individuals and s species (Brower et al. 1998). This index was used to quantify diversity and evenness within and among streams. A measure of community similarity associated with Simpson's dominance, which is $1 - D_s$, is Morisita's index:

Morisita's index: $$I_M = \frac{2\sum x_i y_i}{(l_1 + l_2)N_1N_2},$$

where l_1 is $1 - D_s$ for community 1 and l_2 is $1 - D_s$ for community 2, N_1 is the total number of individuals in community 1 ($N_1 = \sum x_i$) and N_2 is the total number of individuals in community 2 ($N_2 = \sum y_i$), x_i is the number of individuals in species *i* in community 1 and y_i is the number of individuals in species *i* in community 2. Morisita's index is a measure of community similarity ranging from 0 (no similarity) to 1.0 (identical), with higher values indicating a higher degree of similarity. It is the probability that a randomly drawn individual from each community will belong to the same species, relative to the probability of selecting two of the same species from within either community (Brower et al. 1998). This index will be used to determine community similarity within each stream following drought and flooding as well as similarity among streams.

RESULTS

Physical and Hydrologic

Mean depth of riffles in all three streams were similar and increased following flooding, then steadily decreased (Table 1, Figure 2A). Temperature steadily decreased at all three streams during fall and winter and increased slightly in spring (Figure 2B), and there was little variation of annual mean temperatures among the three streams (Table 1). Dissolved oxygen (DO) increased at all three streams during fall and winter, then declined through spring (Figure 2B). Patterns of DO showed Shoal Creek consistently had lower values than Bull and Bear creeks throughout the study. DO values were only slightly lower (1.5 mg/L) at Bear Creek than at Bull Creek (Table 1). The lowest value (580 μS) of specific conductance occurred at the least urbanized stream (Bear Creek), specific conductance was moderate (645 μS) at Bull Creek, and the highest value (953 μS) occurred at the highly urbanized stream (Shoal Creek, Figure 3A). Annual mean specific conductance was lowest to highest in the order: Bear < Bull < Shoal (Table 1). At Shoal Creek specific conductance fluctuated greatly, whereas at Bull and Bear creeks it was fairly consistent over time (Figure 3A). Values for pH were fairly consistent over time at each stream, ranging from a minimum of 7.0 standard units (s.u.) at Shoal Creek to a maximum of 8.5 s.u. at Bull Creek. Shoal Creek had the lowest pH values, Bull

Creek the highest, and Bear Creek pH values were intermediate (Figure 3B). Stream discharge data (Figure 4) were used to determine number of low flow days and frequency and intensity of flooding. Prior to resumption of flow on 26 August 2001, Shoal Creek was dry for 23 d, Bear Creek for 42 d and Bull creek did not go dry, but had less than 0.5 cfs for 39 d (Table 2). A major flood event occurred in the Austin area on 15 November 2001, affecting all three streams. During December, two less intense rain events occurred in the Shoal Creek and Bear Creek watersheds, and one in the Bull Creek watershed. Over the course of the study greatest peak discharges occurred at Shoal Creek (Figure 4). The post-drought study period spans from 26 August 2001 until the flood event on 15 November 2001. The post-flood study period then, was from 15 November 2001 to 23 March 2002.

Biological

Richness

A total of 54 macroinvertebrate taxa were collected from the three streams from 15 September 2001 to 23 March 2002. Taxonomic richness, as numbers of insect genera or families was lowest at Shoal Creek (highly urbanized) with a total of 29 taxa, Bear Creek (least urbanized) had the greatest number of taxa with 54, and Bull Creek had 51 (Table 3). Shoal Creek had greater richness during the post-drought period, whereas at Bull and Bear creeks richness was greater during the post-flood period (Table 3). Taxonomic richness at Bull and Bear creeks increased in the month following resumption of flow on 26 August and showed a decrease two weeks prior to flooding, whereas at Shoal Creek richness was variable during the post-drought period (Figure 5A). For Bull and Bear creeks greater taxonomic richness occurred in the post-drought period 41 days (6 October) after resumption of flow, and 27 days (22 September) for Shoal Creek (Figure 5A). In the first collection after flood disturbance number of taxa had declined by 10 species at Bull Creek and remained unchanged at Shoal and Bear creeks (Figure 5A). After flood disturbance taxonomic richness did not recover to maximum post-drought values at any of the three creeks. Taxonomic richness after flooding steadily increased from 26 January through 23 March at Shoal and Bull creeks, but slightly declined at Bear Creek (Figure 5A). More than 3 times as many EPT taxa (Ephemeroptera, Plecoptera, Trichoptera) occurred at Bull and Bear creeks than at Shoal Creek following both drought and flood and EPT richness was similar between Bull and Bear creeks (Figure 5B).

Abundance

Macroinvertebrate densities were generally greatest during the post-drought period, with the exception of Shoal Creek (Figure 6A). In Bull Creek, both maximum (Table 3) and mean macroinvertebrate post-drought abundances (Figure 6A) were at least twice that of the post-flood period, at Bear Creek maximum and mean densities were slightly greater during post-drought, and at Shoal Creek mean abundance was greater during post-flood and maximum abundance occurred 26 January in the post-flood period (Figure 6B). Bull Creek had the greatest densities overall, with maximum abundance more than twice that of Shoal and Bear creeks (Table 3). At all three creeks the greatest post-drought densities occurred on 22 September, abundances then generally declined for the following two sample dates and declined further following the 15 November flood in all three streams (Figure 6B). Following flooding there was a 76% reduction from pre-flood (3 November) macroinvertebrate abundances at Shoal Creek, 57% at Bull Creek and only 26% at Bear Creek. Shoal Creek recovered to 100% maximum post-drought abundance (22 September) 72 days following the 15 November flooding, but reached a maximum of 44% at Bull Creek after 72 days, and 61% recovery at Bear Creek after 128 days (Figure 6B).

Assemblages and Dominance

Shoal Creek had fewer core taxa (more than one percent total macroinvertebrate abundance) than Bull and Bear creeks (Table 4). Chironomidae was the numerically dominant taxa at all streams during both post-drought and post-flood. At Shoal Creek 66% of the abundance was made up of Chironomidae, this was 2 and 2.5 times greater than chironomid relative abundance at Bull and Bear creeks respectively (Table 4). Among the core taxa was the blackfly *Simulium* (14%) and gastropod *Physa* (6%) (at Shoal Creek), the mayfly *Fallceon* (23%) and riffle beetle *Stenelmis* (12%) (at Bull Creek), and the damselfly *Argia* (13%) and caddisfly *Chimarra* (9%) (at Bear Creek) (Table 4). Comparisons of the five most dominant taxa between post-drought versus post-flood periods showed generally similar taxa, but the rank ordering occasionally differed (Figure 7).

Throughout the post-drought period Bull and Bear creeks had greater taxonomic richness, diversity, evenness, and abundances than did Shoal Creek. During post-drought, relative abundance of the five dominant taxa at Shoal Creek comprised 90% of the assemblage, 75% at Bull Creek and 70% at Bear Creek (Figure 7). Following flooding the relative abundance of the five most dominant taxa increased at Shoal Creek to 96% and to 81% at Bull Creek, but decreased to 60% at Bear Creek (Figure 7). After the November flood event, *Fallceon* was reduced by 10% at Shoal Creek, whereas *Physa* and *Simulium* increased by 17% and 5%. At Bull Creek the three most dominant taxa remained the same during post-drought and post-flood, although relative abundance of Chironomidae and *Fallceon* increased by 14% and 15%, and *Stenelmis* decreased by 12%. At Bear Creek relative abundance of Chironomidae was reduced by 15%, *Argia* by 13% and *Caenis* by less than 1%, associated with an increase of 16% and 5% in *Chimarra* and *Stenelmis* (Figure 7).

Community Analysis

Post-drought and post-flood comparisons of macroinvertebrate composition in the three streams showed differing degrees of similarity from highest to lowest in the order Shoal > Bull > Bear creeks (Table 5). Bull and Bear creeks had a more similar macroinvertebrate community than either did to Shoal Creek (Table 6). Following drought and flood disturbance, similarity in macroinvertebrate compositions between Shoal and Bull creeks increased and then declined, likely due to a shift in assemblage composition at Bull Creek (Figure 8). For example, at Bull Creek 41 d after flow resumed Chironomidae abundance decreased and *Argia* abundance increased; and 165 d after flood disturbance at Bull Creek, Chironomidae abundance decreased and *Stenelmis* abundance increased. During post-drought, Bull and Bear creeks also showed an increase in community similarity following resumption of flow and a decline prior to flooding, likely in response to changes in abundances of Chironomidae, *Caenis*, and *Argia*. Following flooding, Bear Creek had low similarity to either Shoal or Bull creeks, due to reduced abundance of Chrionomidae and increased abundance of *Stenelmis*, *Simulium*, and *Chimarra*.

Diversity and Evenness

Over the entire study period, Simpson's diversity and evenness was greatest at the least urbanized stream (Bear Creek) and least at the most urbanized stream (Shoal Creek). Diversity and evenness was also high at the moderately urbanized stream (Bull Creek). During the post-drought period Bull Creek had a slightly greater diversity and evenness than did Bear Creek, but during the post-flood period diversity and evenness were considerably greater at Bear Creek than at Bull Creek (Table 3).

Fallceon Life History

The single dominant taxa that was consistently present throughout the study was *Fallceon* spp. Head capsule widths of 794 larval *Fallceon* were measured from Shoal, Bull and Bear creeks collectively. Based on the distribution of larval head capsule widths, *Fallceon* spp. had eleven larval instars (Figure 9). During post-drought and post-flood collections most instars were always present

(Figure 10).

DISCUSSION

Shoal Creek, the most urbanized stream in this study, exhibited the highest values for specific conductance, lowest DO and lowest pH following resumption of flow in August. All three streams had elevated water temperature and associated low dissolved oxygen values. Other studies also show that an increase in urbanization may increase conductivity and reduce DO levels (Matthews 1988, Stanley et al. 1997, Caruso 2002). The increased urbanization and subsequent removal of the riparian zone that has occurred at Shoal Creek and is increasing at Bull Creek can lead to increased temperature variation, higher summer maximum temperatures and removal of an important food source of detritus and associated consumers, resulting in decreased macroinvertebrate species diversity and densities (Minshall 1968, Sponseller et al. 2001).

Each stream experienced low or no flow preceding resumption of flow on 26 August. Throughout summer the Bull Creek watershed experienced rain showers that the other two watersheds did not, providing baseflow to that stream. During flooding Shoal Creek had the greatest discharge, an order of magnitude greater than at Bear Creek and is consistent with findings that hydrologic disturbance is more pronounced in urbanized watersheds. Impervious cover reduces rainfall percolation, thereby decreasing baseflow during dry periods and also results in increased runoff by elevating peak discharge during spates

(USEPA 1997, Finkenbine et al. 2000, Scoggins 2001). Other studies have also found a positive correlation among degree of impervious cover, number of low flow days and discharge (Klein 1979, USEPA 1997, Scoggins 2001). Interactions between disturbance type and watershed land use can strongly influence severity of disturbance impacts and rates of post-disturbance recovery of diversity and total density (Collier and Quinn 2003).

Recolonization

Following resumption of flow in August, early colonists at Shoal Creek included *Simulium* and chironomid larvae, which were also pioneer species in a study of drought response in Australian streams (Boulton 2003). Recovery from drought at Shoal Creek was due primarily to resilience, largely due to Chironomidae comprising 70% of the post-drought assemblage. Although larval mayflies are not as capable of tolerating short dry periods as chironomids and elmids (Ward 1992), *Fallceon* was the second most dominant taxa at Shoal Creek during post-drought. Collier and Quinn (2003) also found that following drought chironomids, mayfly and caddisfly taxa were dominant largely as a result of rapid recolonization within the two weeks following flooding (resilience) rather than via surviving high flows (resistance). The presence of *Fallceon* among the dominants at Shoal Creek during the post-drought period may have been due to oviposition by aerial adults from a nearby perennial source in one of the surrounding watersheds. At Bull and Bear creeks both drought resistant and resilient taxa were among the core taxa (Amphipoda, *Caenis*, Chironomidae, *Stenelmis*) during the post-drought period. Post-drought abundance of *Fallceon* and *Argia* at Bull Creek was likely due to persistence in pool refugia, considering that the stream only had diminished flow prior to 26 August. Recovery through resilience following drought disturbance was rapid at all three streams with the greatest post-drought taxonomic richness and high abundances occurring one month after resumption of flows, likely due to a wide range of refugia (i.e. instream pools, hyporheic zone) and aerial adults from nearby streams. Recovery of greater taxonomic richness and abundances at Bull Creek after drought was possibly a result of the short duration of the dry period, in conjunction with observed areas of deeper hyporheos which would provide refugia for certain taxa like *Stenelmis* and amphipods to persist. Resistance to drought was difficult to assess in this study without knowing the pre-disturbance community composition, but clearly refugia are critical for rapid recovery to pre-drought conditions (Hynes 1958, Larimore et al. 1959, Miller and Golladay 1996, Ledger and Hildrew 2001, Shivoga 2001).

At Shoal Creek taxonomic richness did not decline until one month following flooding, possibly as a result high initial resistance through adaptation (physiological and/or behavioral) or refugia, followed by four additional rain events of less intensity from 28 November 2001, through 6 January 2002. Collier and Quinn (2003) also found that taxonomic richness and total density declined drastically following flooding in two New Zealand streams and the reduction occurred sooner at the less disturbed stream, and that this reflected greater initial resistance by flood adapted taxa at the more disturbed stream. Recovery of abundances after flooding was slower than during post-drought at my study streams. Following flooding, recovery of total density at Shoal and Bull creeks was largely due to the resilience of chironomid abundance. Chironomidae was important to recovery at each stream following drought and flooding, likely due to short-generation time and life history variability (Collier and Quinn 2003). Streams containing a predominance of organisms with short life cycles recover most rapidly from disturbance (Resh et al. 1988). The resistance of total density to flood was greatest at Bear Creek and least at Shoal Creek, likely due to abundances of the spate resistant *Fallceon* and *Caenis* at Bear Creek. In two southern Oklahoma streams a 90% reduction in total density following flooding was attributed to low resistance of community structure, as may be the case at Shoal Creek (Miller and Golladay 1996). Bull and Bear creeks likely had instream refugia or nearby recolonization sources, but Shoal Creek did not have sufficient instream refugia to maintain high abundances because the severity of flooding scoured the shallow substrate to the bedrock. At Shoal and Bull creeks there was a reduction in the relative abundance of *Fallceon*, this could be due to the large quantity of gravel transported throughout the stream during flooding. Mayflies were also eliminated following flooding in a Welsh mountain stream due to scouring by large quantities of gravel (Ward 1992).

In response to flooding, resilience of total density was slowest at Bear Creek, due to two additional spates in that watershed during the month of December leading to a longer recovery time for the macroinvertebrate community (Brown 1971). In streams prone to flooding, such as these central Texas streams, macroinvertebrate density will generally decline following flood disturbance with a subsequent gradual recovery in numbers until the next disturbance (Ward 1992). Time required for recovery of total density following flood disturbance at Shoal and Bull creeks (72 d, 175% and 72 d, 44% respectively) was somewhat comparable to that of a southern Oklahoma perennial stream which required 67 d for 85% recovery to pre-spate densities (Miller and Golladay 1996). In contrast, time required at Bear Creek was similar (128 d, 61%) to the 125 d for 67% recovery of pre-spate densities in a southern Oklahoma intermittent stream (Miller and Golladay 1996). Recovery of densities and taxonomic richness in response to a localized disturbance can take as little as 8-30 days (Doeg et al. 1989, Lake et al. 1989), whereas in response to a catchement wide disturbance (in this region a multi-watershed disturbance given the small size of the watersheds) can take as long as 5-7 months (Collier and Quinn 2003). With recovery times greater than 30 d the 15 November flood could be considered a multi-watershed disturbance that affected numerous recolonization sources.

Generally high abundances at each of the three streams during the post-drought period suggest greater resistance to and resilience from drought disturbance than flooding. Pre-flood abundances were achieved only at Shoal Creek after flooding, which suggests that in this study recovery was generally faster following drought disturbance. Filho and Maltchik (2000) concluded that greater resistance to drought could be due to flooding being less predictable and more sudden in onset than drought. High abundances I observed during the 69 day post-drought recovery period may be an adaptation to hydrologic variability in these central Texas streams considering drying and flooding typically occur on an annual basis. A possible explanation for the slow recovery following flooding is that the post-flood recovery occurred during the winter season and lower temperatures may affect the availability of colonists and their growth rates, as occurred in two Oklahoma streams (Miller and Golladay 1996).

Ecological

Findings in this study support r/K selection theory (MacArthur and Wilson 1967) in that as disturbance increases the macroinvertebrate community will tend to be comprised of rapid colonizers and tolerant taxa, as was observed with the recovery of taxonomic richness and abundances following flood disturbance at Shoal Creek. Tolerant taxa (*Simulium*, *Physa* and Oligochaeta) were predominant at Shoal Creek whereas intolerant taxa (Plecoptera) were absent, although present at Bull and Bear creeks. Highest abundances at Bull Creek and lowest at Shoal Creek is contrary to my hypothesis based on r/K selection theory of higher densities at the most disturbed stream. Reduced total abundances at Shoal Creek may have less to do with r-selected species traits that promote high abundance and more to do with insufficient habitat available to support such populations. For instance, Shoal Creek has a relatively shallow substrate layer sitting over limestone bedrock and although chironomids (considered r strategists due to their rapid life cycle and high dispersal capability, Johnson et al. 1993, Miller and Golladay 1996) made up a large proportion of the assemblage at Shoal Creek, they did not result in higher abundances than at the other two creeks.

A key prediction of the Intermediate Disturbance Hypothesis (Connell 1978, Townsend et al. 1997) is that diversity will be greatest at intermediate levels of perturbation, and I found the greatest taxonomic richness occurred at both the moderate and least urbanized streams. This could be a result of factors other than hydrologic disturbance at Bear Creek (i.e. non-point source effects of adjacent livestock pastures), or that difference in impervious cover (3% and 16%) was not great enough to cause a community response. Low taxonomic richness at high frequency and intensity of disturbance did occur at Shoal Creek and is consistent with IDH predictions. One component of low taxonomic richness is the poor ability of some taxa to colonize or persist through high frequency and intensity of disturbance (Townsend et al. 1997). A more natural flow regime, such as at Bull and Bear creeks, can actually facilitate the coexistence of species and lead to higher diversity (Ward 1992). For example, McAuliffe (1984) found that in a lake outlet stream the caddisfly *Leucotrichia* competitively excludes other taxa on large stones in consistently deep water, but in areas with small stones and shallow water where high flow overturns the substrate and low flow periodically exposes the substrate, *Leucotrichia* had decreased dominance and was replaced by taxa with shorter generation times. High evenness at the least disturbed stream (Bear Creek) is consistent with findings by Townsend et al. (1997) that evenness is higher in less disturbed areas and could be due to competitive forces eliminating rare species or to rare taxa gaining more members. To the degree that competition is not an organizing factor in lotic communities (Bradt et al. 1999, Death 2002) the alternative of rare taxa gaining more numbers is likely, and could account for deviation (high diversity at the least disturbed stream) from the IDH prediction of reduced diversity at the most and least disturbed habitats. Perhaps Bull and Bear creeks lay somewhere between a moderate and low level of perturbation, in which case species richness will peak at sites of greatest stability, whereas evenness will peak at sites of intermediate stability (Death and Winterbourn 1995). Other studies have shown that support of IDH patterns are more commonly found in studies of sessile than mobile organisms (Mackey and Currie 2001, Shea 2004).

A major difficulty in applying the IDH to central Texas and Austin streams is an accurate characterization of disturbance in relation to effects on the macroinvertebrate community. Generally, IDH has greater predictive success when examined in relation to communities where there is a single dominant disturbance that can be graded along a continuum (Mackey and Currie 2001). Studies addressing single disturbance regimes such as fire frequency in prairies, logging intensity in forests, or flooding in streams, are more likely to fit the IDH model than studies addressing multiple sources and levels of disturbance (McAuliffe 1984, Collins 1992, Townsend et al. 1997, Mackey and Currie 2001, Brown and Gurevitch 2004). Mackey and Currie (2001) found the IDH to be more applicable in studies which examine few disturbance levels, and a disturbance regime of natural rather than anthropogenic origin. In my study streams, multiple acute and chronic, natural and anthropogenic disturbances occur separately and interactively to structure the benthic macroinvertebrate community. Consequently, it is not surprising that diversity was not strongly peaked at the moderately disturbed stream given the variation in disturbance dynamics within these central Texas watersheds.

Lowest number of EPT taxa at Shoal Creek is consistent with the idea that RBA metric scores will be higher while hydrologic variability and degree of impairment will be lowest in a less urbanized watershed (Scoggins 2001). EPT is a metric used by the EPA (Barbour et al. 1999) as a measure of taxonomic richness of pollution sensitive aquatic insect orders and decreases with a decrease in water quality. One question is to what degree does a low EPT score result from hydrologic variability (urbanization) rather than non-point source pollution. Perhaps Shoal Creek has a lower achievable metric score than Bull and Bear creeks due to severity of the disturbance regime relative to water quality effects associated with increased urbanization in the form of impervious cover. This issue could be addressed by the use of an ecoregion specific RBA scoring criteria which takes into account percent impervious cover within the watershed.

Using Morisita's Index the macrobenthic communities of Shoal and Bull creeks showed high similarity following flooding, corresponding to similar high abundances of Chironomidae. If flooding is severe and frequent, the fauna will generally be dominated during the initial stages of recovery by pioneer species such as chironomids and simuliids, which have a rapid life cycle and high dispersal capability. Similar studies have shown that initially during recovery there may be a phase of dominant colonizers (i.e. chironomids and simuliids) that increase in density and then decline as species with longer life cycles and are better competitors increase in numbers (Harrison 1966, Iversen et al. 1978, Ladle and Bass 1981, Lake 2003). The benthic macroinvertebrate community of Shoal Creek showed strong taxonomic resistance to flooding by having highly similar post-drought to post-flood composition, and yet also showed a lack of resilience in community structure with a shift in taxonomic composition from *Fallceon* following drought to *Physa* following flooding. At Bear Creek, lower similarity of post-drought and post-flood communities indicates less resistance by some of the community to flooding. Specifically, *Chimarra* and *Stenelmis* replaced *Argia* and *Caenis* as dominants after the flood. The greater instability in community composition at Bear Creek following the November flood may be due to the additional floods in December in a watershed that does not have a benthic macroinvertebrate community as adapted to such frequency of flood disturbance. Collier and Quinn (2003) found that community structure (relative abundance of invertebrate taxa compared with preflood composition) was less stable at the more disturbed stream and concluded that community structure at the disturbed stream had high resistance and low resilience to flood disturbance, a pattern exhibited in Shoal Creek. Only at Bull Creek did taxonomic composition remain intact. Bull Creek was the more stable of the three streams in terms of hydrology and biology with the lowest number of low flow days, rapid recovery of high abundances and taxonomic richness during post-drought, and recovery of community structure following flood disturbance.

Recruitment of *Fallceon* spp. was continuous, with early instars present throughout the study period, suggesting an asynchronous life cycle. The fact that most instars were present throughout the sampling period suggests that *Fallceon* spp. is multi-voltine in these central Texas streams, producing more than two generations per year. This asynchronous multi-voltine life history may be an adaptation to the narrow timeframe from the typical resumption of flow in early fall and flooding which is common on an annual basis in early winter. Length of life cycle and voltinism depends on factors (i.e. temperature, nutrition, photoperiod and discharge) that influence growth and development in all life cycle stages (Butler 1984, Lake et al. 1986).

Conclusion

In this study and in Scoggins (2001) there were many similarities regarding community structure at Bull and Bear creeks, but a contrast with Shoal Creek. Community structure is shaped by a myriad of physical, chemical and biological variables acting synergistically (Ward and Stanford 1983), and apparently community response to urbanization has a threshold beyond which there is degradation of the macroinvertebrate community. In general, significant physical and biological degradation occurs somewhere between 5 and 18% imperious cover (Schueller 1995, Horner et al. 1996, Booth and Jackson 1997, Kennen and Ayers 2002, Roy et al. 2003). This could account for such similarities among Bull and Bear creeks, since the degree of impervious cover at both was less than 18% and therefore may not have been a great enough variation to cause differences in degree of physical and biological disturbance. Hydrologic variability increased by impervious cover alters the structure and function of the macroinvertebrate community by increasing the severity of disturbance and decreasing predictability of flow conditions (Collier and Quinn 2003). To improve biological assessment of macroinvertebrate communities in central Texas there is a need to incorporate or at least plan around the effects of hydrologic variability as a cause of impaired conditions and low metric scores. Further work should be done to track the increasing urbanization in the Bull and Bear creek watersheds and the effects on the aquatic communities.

APPENDIX I

Table 1. Physico-chemical characteristics of Bear, Bull and Shoal creeks in Austin, Texas, during the study period. *n* represents the total number of samples.

	Depth (meter)	**Temp (°C)**	**Dissolved Oxygen (mg / L)**	**Specific Conductance (μS / cm)**	**pH (s.u.)**
Shoal					
mean	0.12	17.1	6.6	810	7.2
min	0.05	11.0	2.9	619	7.0
max	0.28	25.3	9.5	953	7.4
n	*10*	*10*	*10*	*10*	*9*
Bull					
mean	0.16	17.5	10.8	702	8.1
min	0.09	9.6	9.2	648	7.9
max	0.32	28.4	13.3	751	8.5
n	*10*	*10*	*10*	*10*	*9*
Bear					
mean	0.11	18.9	9.3	637	7.7
min	0.09	12.7	5.5	580	7.3
max	0.15	26.0	14.1	703	8.0
n	*9*	*9*	*9*	*9*	*8*

Table 2. Overview of stream watershed characteristics and hydrology.

	Impervious Cover (%)	Drainage Area (km^2)	Days of flow < 0.5 cfs	Days of 0 cfs	Peak Discharge (cfs)
Shoal	55	31.9	62	62	1,040 (11/15)
Bull	16	57.8	39	0	864 (11/15)
Bear	3	31.6	61	42	101 (11/15) 119 (12/08) 170 (12/15)

- Flow resumed on 8/26/2001
- Discharge values are from USGS gauging stations.

Table 3. Overall macroinvertebrate density, taxonomic richness, diversity and evenness following drought and flood in three Austin, Texas streams.

	Maximum Abundance / m^2	Taxonomic Richness	Simpson's Diversity and Evenness
Shoal			
Overall		29	0.557 (0.571)
Post-Drought	3,030 (9/22)	22	0.501 (0.518)
Post-Flood	5,300 (1/26)	20	0.572 (0.597)
Bull			
Overall		51	0.835 (0.849)
Post-Drought	11,970 (9/22)	40	0.860 (0.879)
Post-Flood	5,220 (1/26)	43	0.741 (0.756)
Bear			
Overall		54	0.889 (0.902)
Post-Drought	5,180 (9/22)	36	0.840 (0.859)
Post-Flood	3,170 (3/23)	42	0.905 (0.924)

Table 4. Abundance (individuals per m^2) and relative abundance (%) of dominant macroinvertebrate taxa (i.e., taxa composing 1% or more of total invertebrate densities, shown in bold) in Shoal, Bull and Bear creeks from 15 September 2001 to 23 March 2002. C = Class, O = Order, F = Family, G = Genus

	Shoal Creek		**Bull Creek**		**Bear Creek**	
	abundance	%	abundance	%	abundance	%
F: Chironomidae	15,120	**65.51**	15,950	**30.64**	7,500	**27.11**
F: Simuliidae G: *Simulium*	3,310	**14.34**	710	**1.36**	1,270	**4.59**
F: Physidae G: *Physa*	1,450	**6.28**	710	**1.36**	800	**2.89**
F: Baetidae G: *Fallceon*	1,190	**5.16**	11,750	**22.57**	2,050	**7.41**
C: Oligochaeta	770	**3.34**	730	**1.40**	520	**1.88**
F: Coenagrionidae G: *Argia*	250	**1.08**	4,970	**9.55**	3,590	**12.98**
F: Hydroptilidae G: *Hydroptila*	170	0.74	680	**1.31**	70	0.25
F: Ceratopogonidae	140	0.61	230	0.44	790	**2.86**
O: Amphipoda	130	0.56	1,240	**2.38**	120	0.43
F: Planariidae G: *Dugesia*	110	0.48	530	**1.02**	90	0.33
F: Elmidae G: *Stenelmis*	80	0.35	6,100	**11.72**	2,230	**8.06**
F: Hydrophilidae G: *Berosus*	60	0.26	890	**1.71**	310	**1.12**
F: Philopotamidae G: *Chimarra*	40	0.17	250	0.48	2,420	**8.75**
F: Hydropsychidae G: *Arctopsyche*	10	0.04	850	**1.63**	850	**3.07**
F: Caenidae G: *Caenis*	10	0.04	1,370	**2.63**	1,890	**6.83**
F: Lymnaeidae	0	0	110	0.21	310	**1.12**
F: Elmidae G: *Heterelmis*	0	0	170	0.33	310	**1.12**
F: Leuctridae G: *Perlomyia*	0	0	0	0	500	**1.81**
F: Heptageniidae G: *Stenonema*	0	0	150	0.29	680	**2.46**
F: Perlidae G: *Claassenia*	0	0	540	**1.04**	140	0.51
F: Coleoptera G: *Psphenus*	0	0	690	**1.33**	20	0.07
Total abundance	23,080		52,060		27,660	
Number of core taxa	6		15		16	

Table 5. Community similarity using Morisita's index comparing the post-drought and post-flood macroinvertebrate communities of Shoal, Bull and Bear creeks in Austin, Texas. *n* represents the number of taxa present during post-drought and post-flood.

Post-Drought versus Post-Flood	Morisita's Index
Shoal *n* = 22, 20	0.951
Bull *n* = 40, 43	0.812
Bear *n* = 36, 42	0.702

Table 6. Community similarity using Morisita's index comparing the macroinvertebrate communities of Shoal, Bull and Bear creeks over the entire study period. *n* represents the number of taxa present at each of the streams being compared.

Stream Comparisons	Morisita's Index
Shoal Creek and Bull Creek *n* = 29, 51	0.696
Shoal Creek and Bear Creek *n* = 29, 54	0.664
Bull Creek and Bear Creek *n* = 51, 54	0.874

APPENDIX II

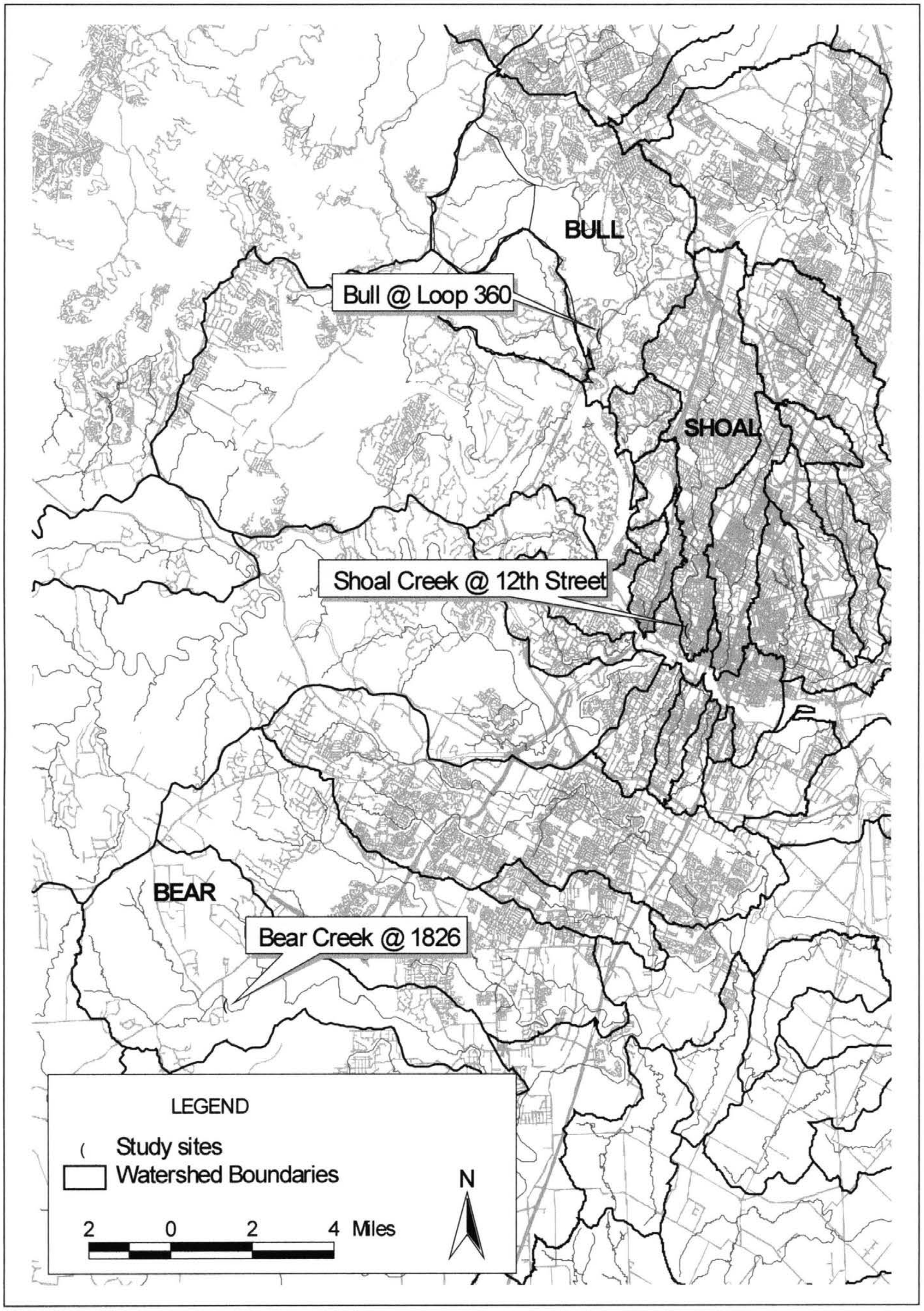

Figure 1. Location of study streams in Austin, Texas.

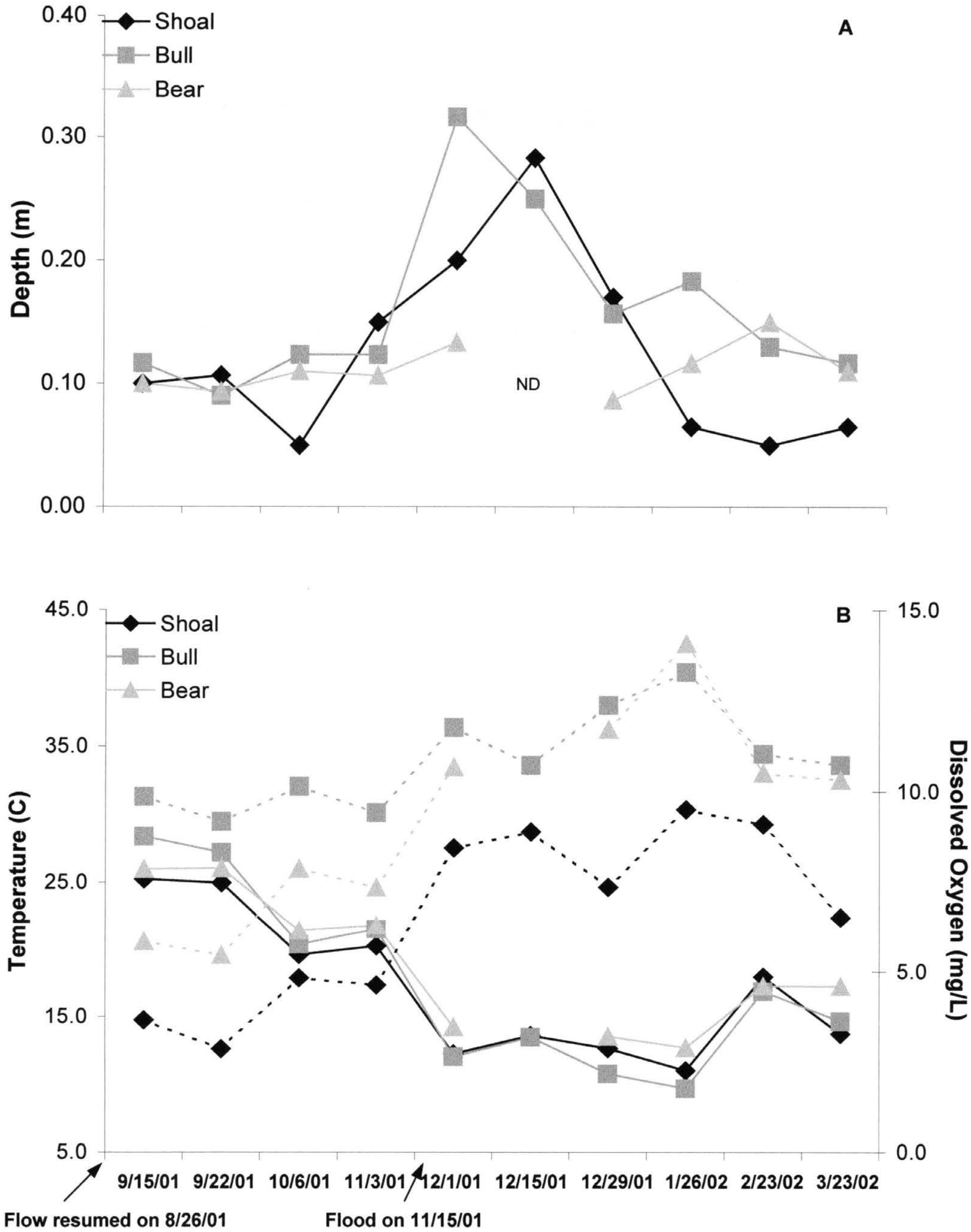

Figure 2. Mean seasonal variation in depth (A), temperature (solid) and dissolved oxygen (dashed) (B) in Shoal, Bull and Bear creeks of Austin, Texas. No data (ND).

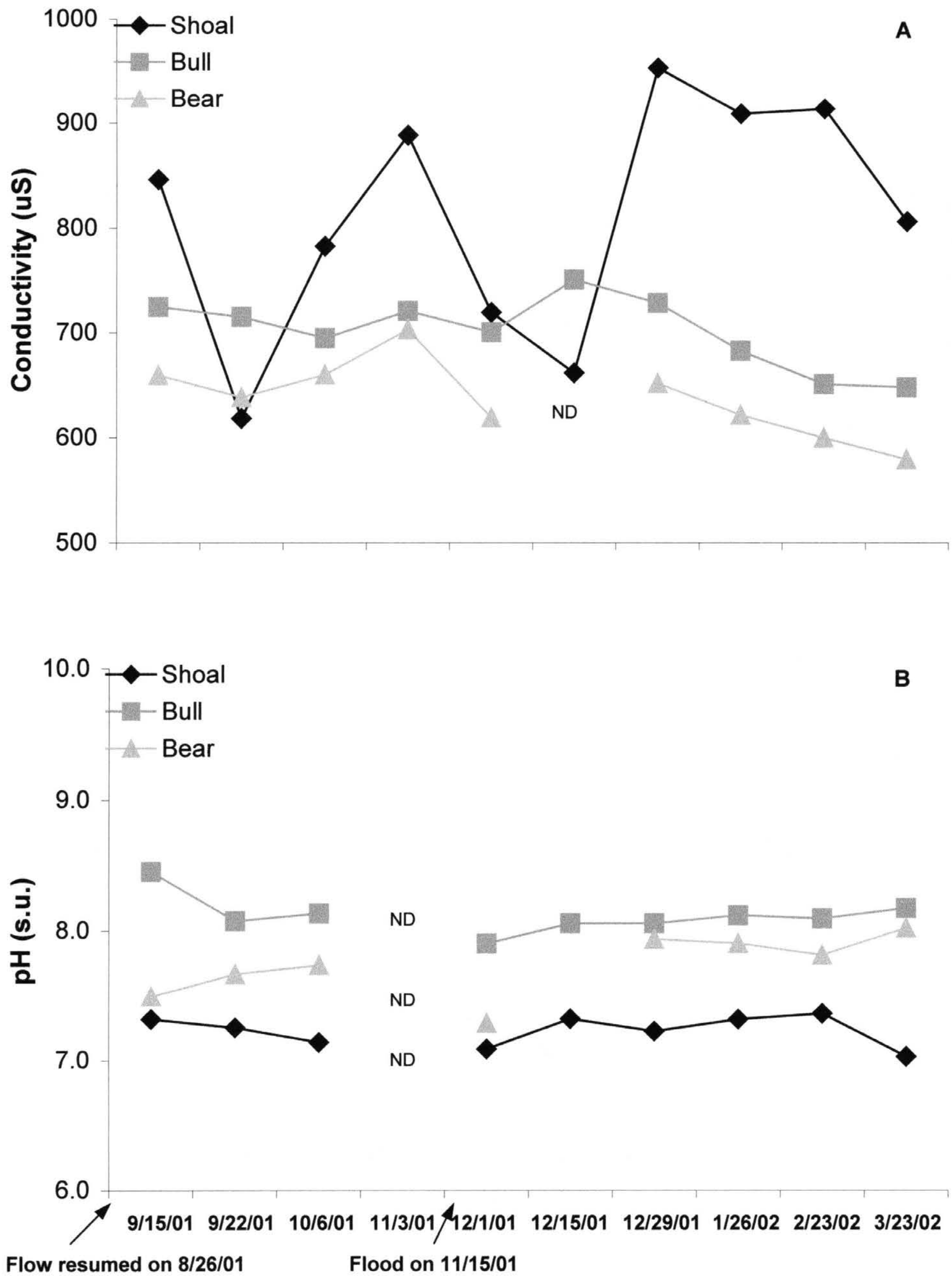

Figure 3. Mean seasonal variation in specific conductance (A) and pH (B) in Shoal, Bull and Bear creeks of Austin, Texas. No data (ND).

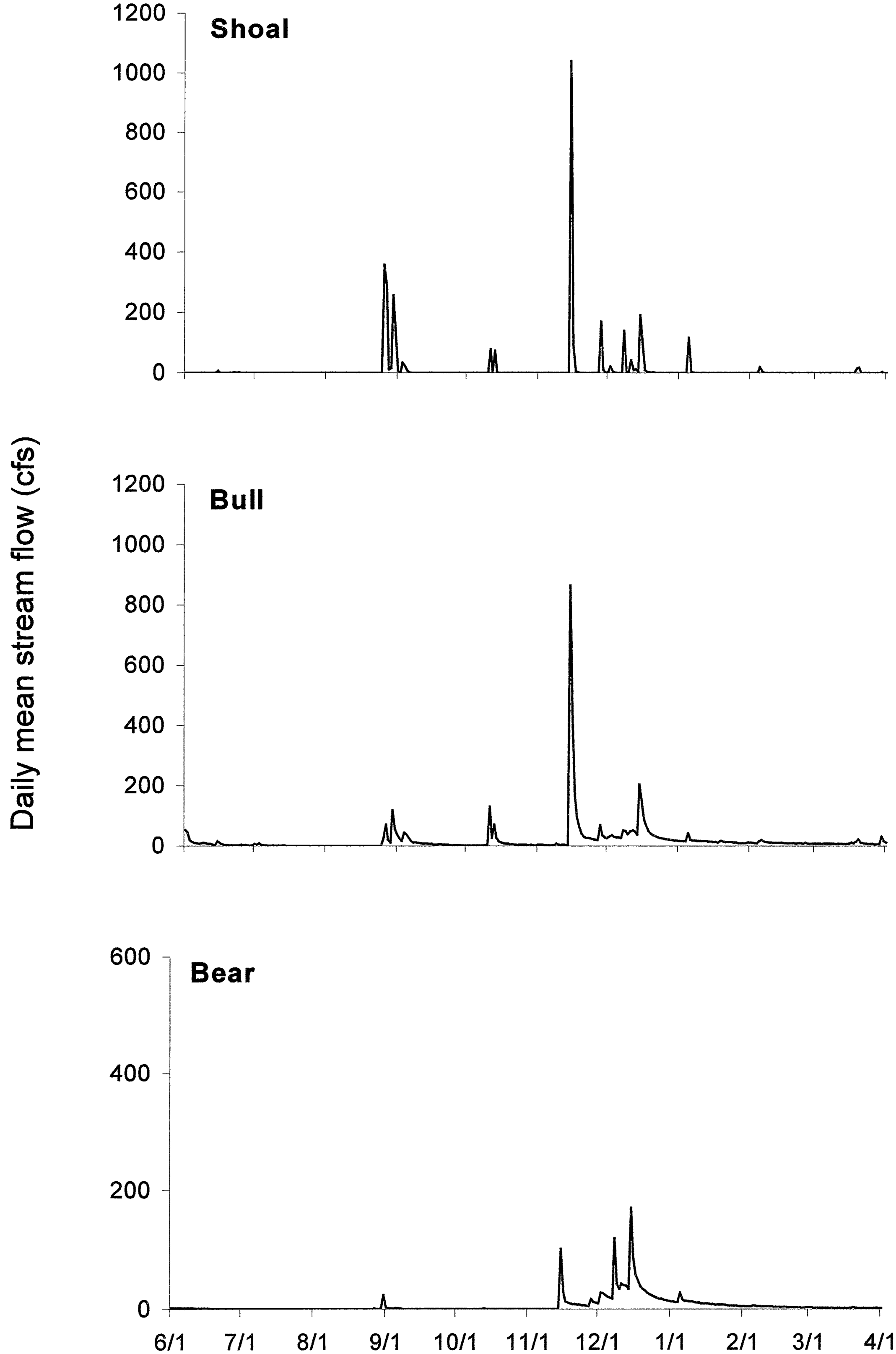

Figure 4. Hydrograph showing the daily mean stream flow at Shoal, Bull and Bear creeks in Austin, Texas, during the study.

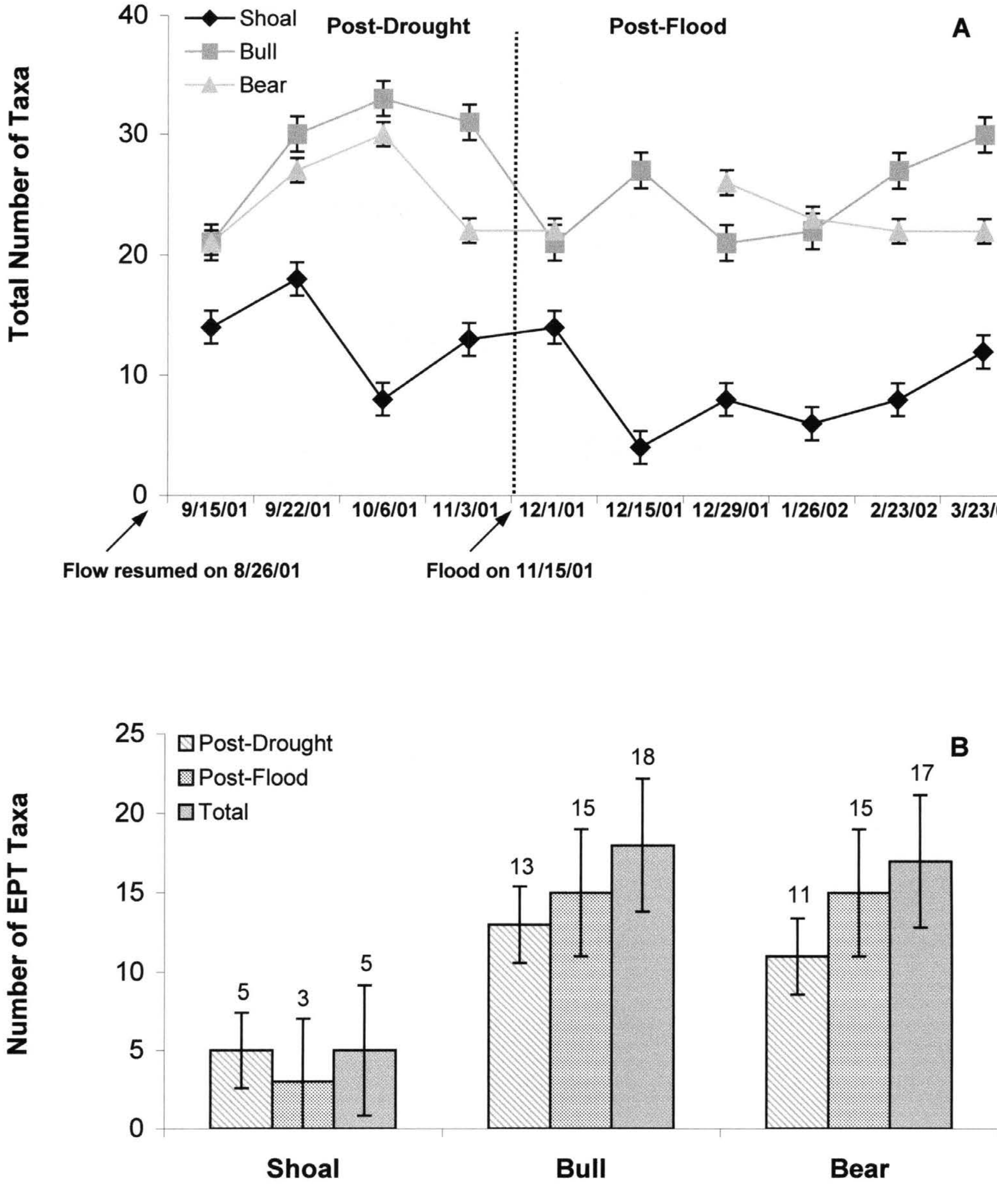

Figure 5. Temporal variation in macroinvertebrate taxonomic richness (A) and EPT taxonomic richness (B) in three Austin, Texas streams following drought and flood. Error bars represent 1 standard error.

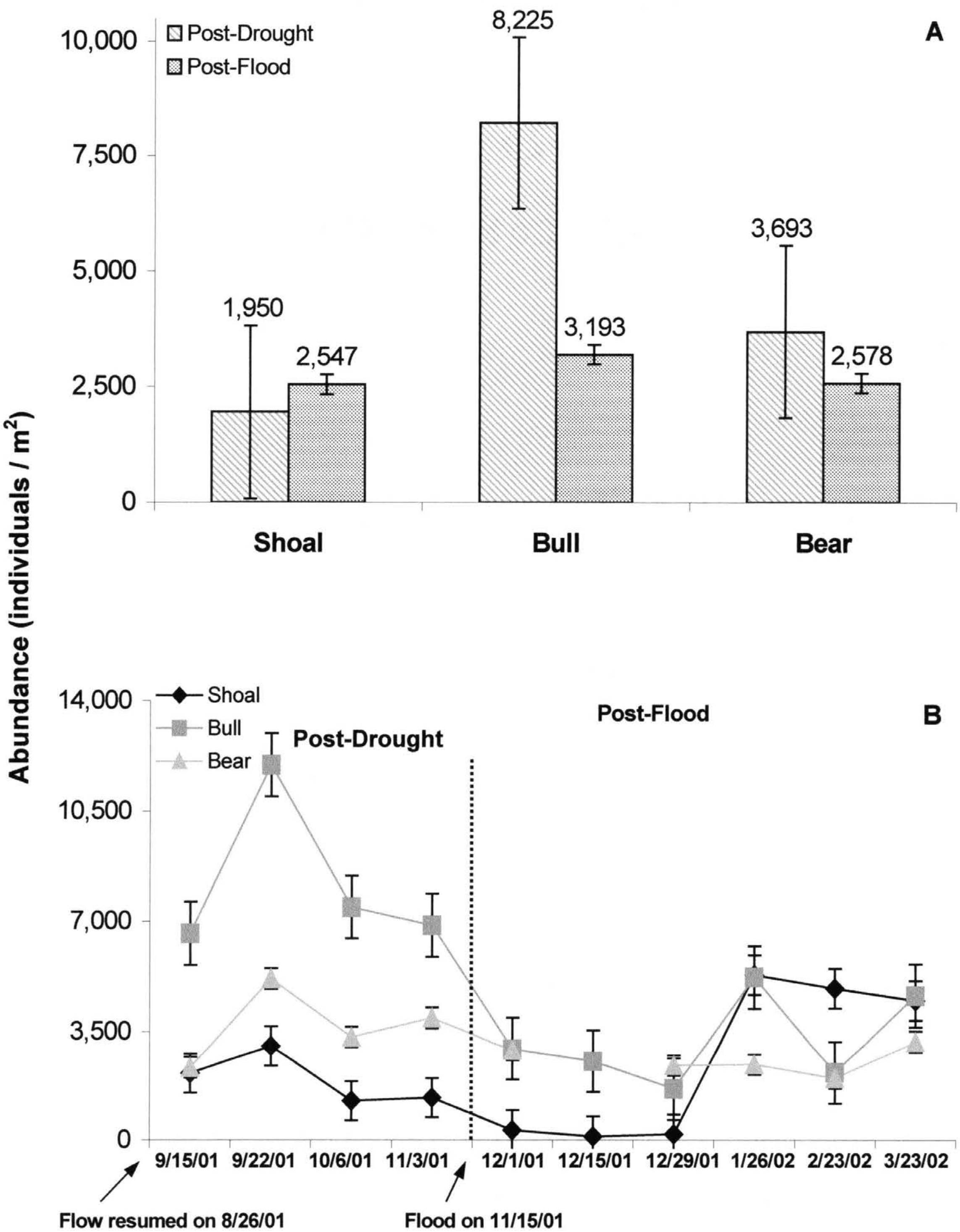

Figure 6. A – Mean macroinvertebrate abundance during post-drought and post-flood periods in three Austin, Texas streams. B – Temporal variation in macroinvertebrate abundance in three Austin, Texas streams following drought and flood. Error bars represent 1 standard error.

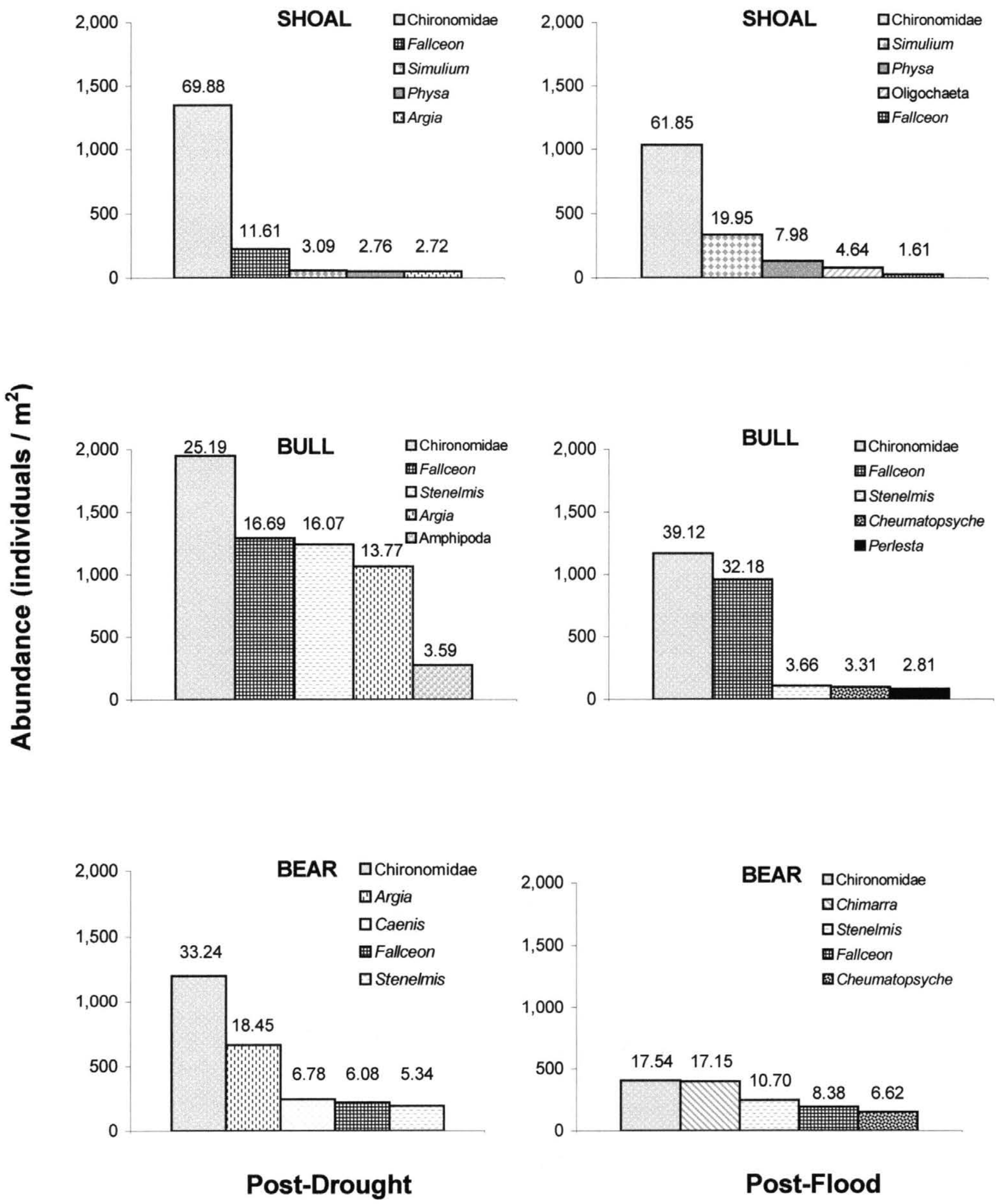

Figure 7. Mean monthly density of the dominant five macroinvertebrate taxa during post-drought (four sampling events) and post-flood periods (six sampling events) in three Austin, Texas streams. Above the histograms is relative abundance.

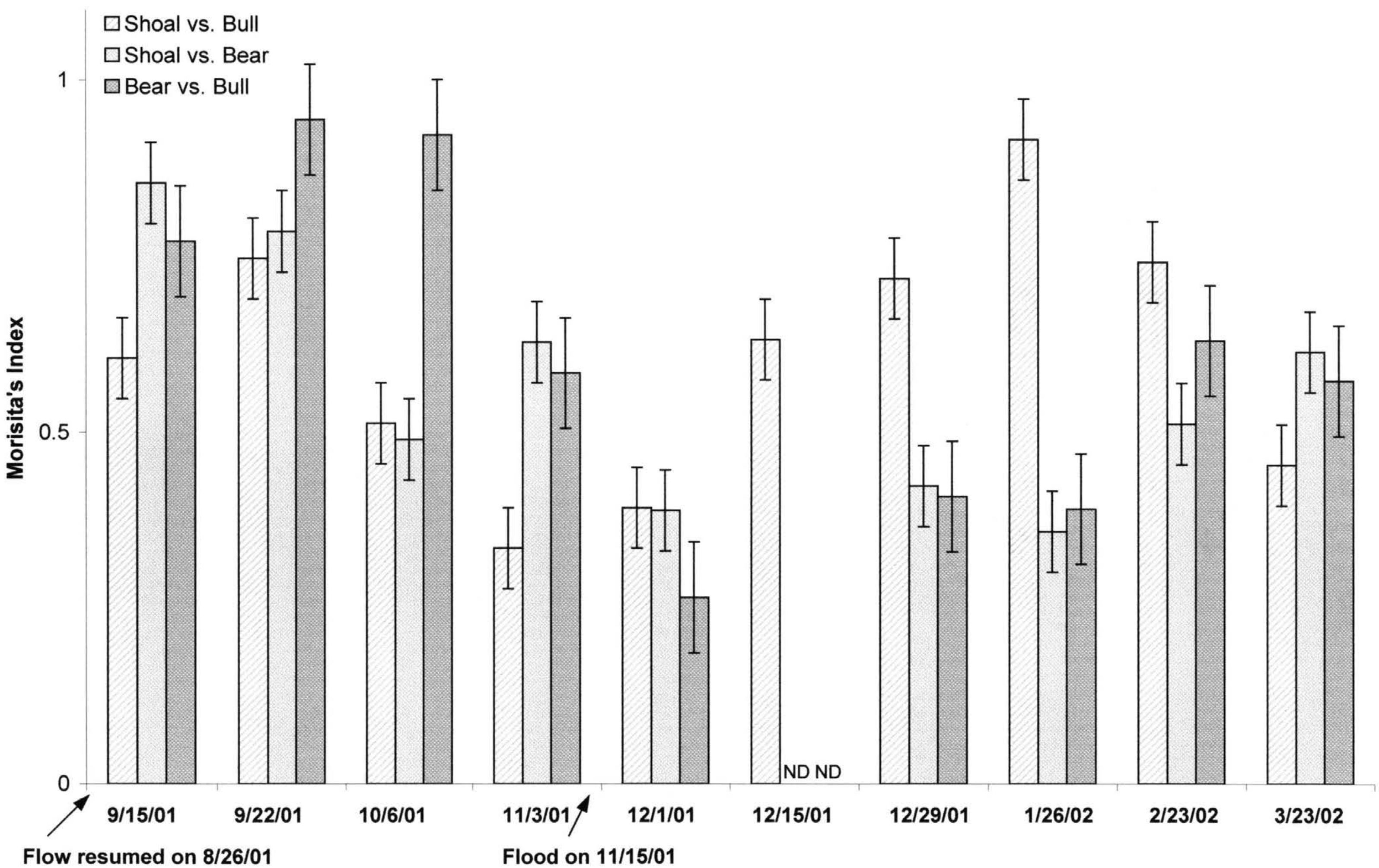

Figure 8. Morisita's Index from 15 September 2001 to 23 March 2002. Error bars represent 1 standard error. No data (ND).

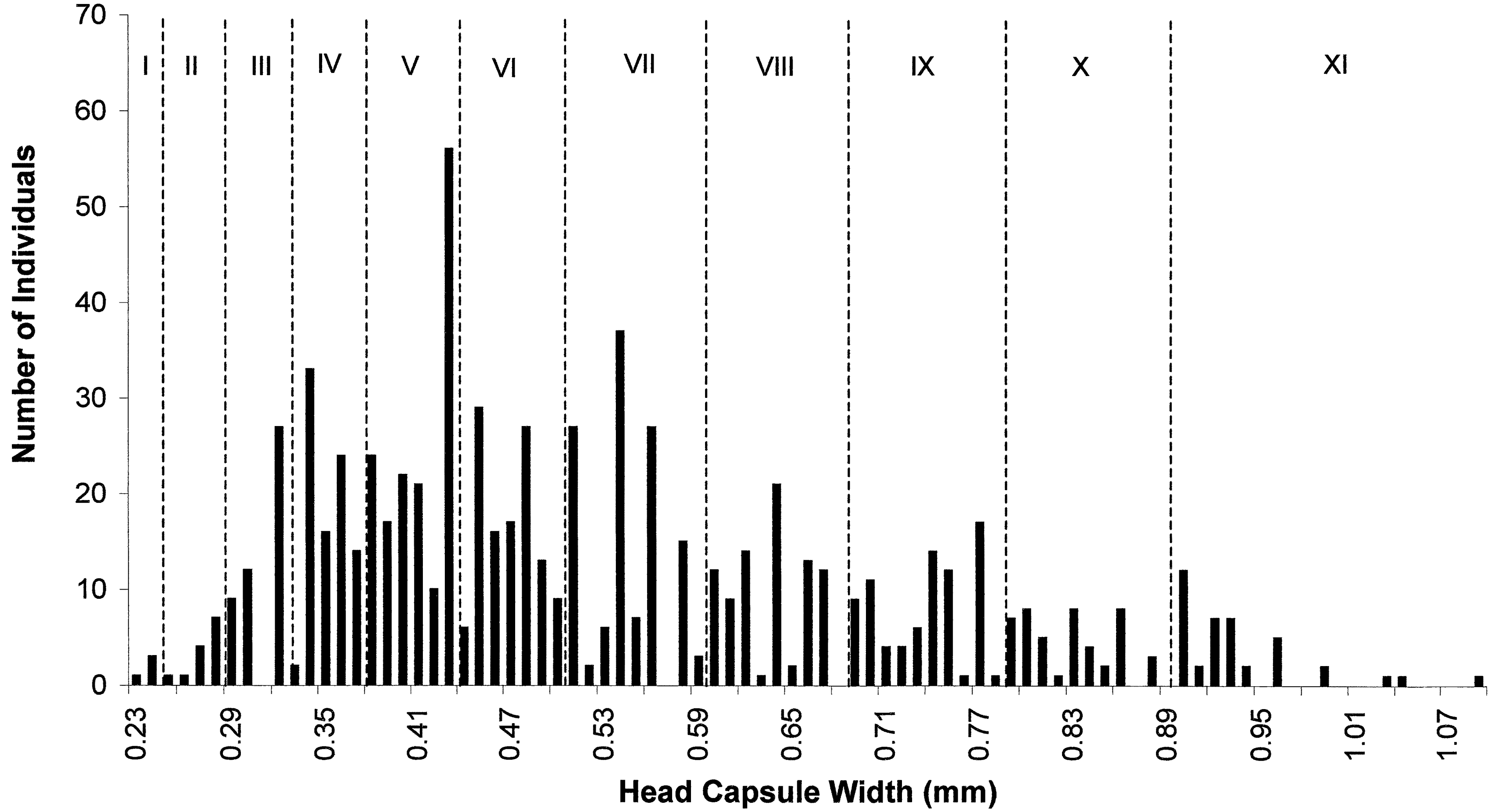

Figure 9. Distribution of larval head capsule widths of *Fallceon* spp. from 15 September 2001 to 23 March 2002. Roman numerals and dashed lines indicate the approximate instar size ranges.

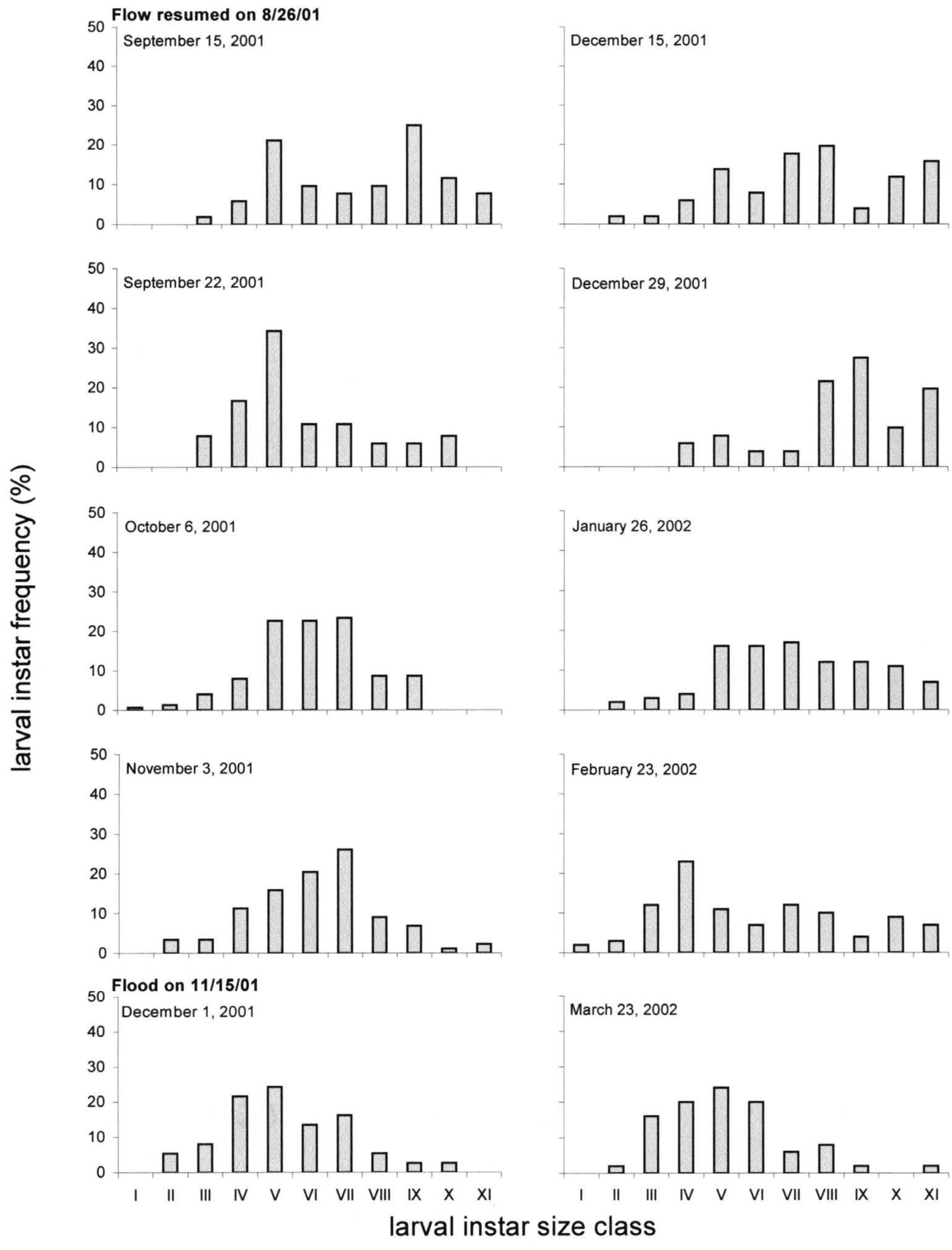

Figure 10. Temporal dynamics in distribution of *Fallceon* spp. instars from 15 September 2001 to 23 March 2002 in three Austin, Texas streams.

APPENDIX III

Phylum	Class	Order	Family	Genus	Shoal Creek @ 12th St. (USGS)									
					9/15	9/22	10/6	11/3	12/1	12/15	12/29	1/26	2/23	3/23
Annelida	Hirudinea	Gnathobdellida			1			2	1					
Annelida	Oligochaeta					2		2	4	4	1	34	22	8
Arthropoda	Crustacea	Amphipoda							4		1		3	5
Arthropoda	Crustacea	Astacoidea	Cambaridae						1					
Arthropoda	Insecta	Coleoptera	Elmidae	*Stenelmis*	1	1	2	3						1
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Berosus*		2					1		2	1
Arthropoda	Insecta	Diptera	Chironomidae		194	263	35	74	11	6	8	365	246	310
Arthropoda	Insecta	Diptera	Ceratopogonidae		5	9								
Arthropoda	Insecta	Diptera	Simuliidae	*Simulium*		1		24				117	183	6
Arthropoda	Insecta	Diptera	Culicidae			3								
Arthropoda	Insecta	Diptera	Tabanidae			1								
Arthropoda	Insecta	Diptera							1					
Arthropoda	Insecta	Diptera	Athericidae					1			1			
Arthropoda	Insecta	Ephemeroptera	Baetidae	*Fallceon*	5	3	70	16	2		1	1	4	17
Arthropoda	Insecta	Ephemeroptera	Caenidae	*Caenis*		1								
Arthropoda	Insecta	Lepidoptera	Pyralidae	*Petrophila*	1									
Arthropoda	Insecta	Lepidoptera	Cosmoptyerigidae			1								
Arthropoda	Insecta	Odonata	Coenagrionidae	*Argia*	1	3	9	9	1					2
Arthropoda	Insecta	Odonata	Libellulidae	*Brechmorhoga*			1				1			
Arthropoda	Insecta	Trichoptera	Philopotamidae	*Chimarra*				2		1				1
Arthropoda	Insecta	Trichoptera	Hydroptilidae	*Hydroptila*	4								2	11
Arthropoda	Insecta	Trichoptera	Hydropsychidae	*Cheumatopsyche*				1						
Mollusca	Gastropoda	Limnophila	Physidae	*Physa*	2	10	8	2	1			12	25	85
Mollusca	Gastropoda	Limnophila	Planorbidae						1					
Mollusca	Gastropoda	Limnophila	Planorbidae		1	3								
Mollusca	Gastropoda	Mesogastropoda	Pleuroceridae						1					
Mollusca	Gastropoda	Pelecypoda	Sphaeridae											1
Nematomorpha							1							
Platyhelminthes	Turbellaria	Tricladida	Planariidae	*Dugesia*					4	1	5	1		
				Total # of Taxa	14	18	8	13	14	4	8	6	8	12
				Total # organisms	230	314	128	138	38	12	19	530	487	448

Phylum	Class	Order	Family	Genus	Bull Creek @ Loop 360 (USGS)									
					9/15	9/22	10/6	11/3	12/1	12/15	12/29	1/26	2/23	3/23
Annelida	Hirudinea	Gnathobdellida				1	3	4					1	1
Annelida	Oligochaeta				10	14	14	15		5	2	2	3	8
Arthropoda	Decapoda	Astacoidea	Cambaridae				2	1						
Arthropoda	Insecta	Amphipoda			5	29	27	60	3					
Arthropoda	Insecta	Amphipoda								5	1		2	2
Arthropoda	Insecta	Coleoptera	Elmidae	*Stenelmis*	151	157	91	141	3	10	3	2	15	37
Arthropoda	Insecta	Coleoptera	Elmidae	*Macrelmis*	9	26	6							2
Arthropoda	Insecta	Coleoptera	Elmidae	*Heterelmis*			4		1	1				11
Arthropoda	Insecta	Coleoptera	Lutrochidae	*Lutrochus*	5	8	6	4		1			1	1
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Berosus*	10	25	21	16	2	3	2	3	1	6
Arthropoda	Insecta	Coleoptera	Psphenidae	*Psphenus*	4	7	11	27		4	1	3	3	9
Arthropoda	Insecta	Coleoptera	Haliplidae	*Peltodytes*										1
Arthropoda	Insecta	Coleoptera	Curculionidae							1				
Arthropoda	Insecta	Diptera	Chironomidae		218	492	98	39	54	76	45	366	106	101
Arthropoda	Insecta	Diptera	Ceratopogonidae		8	4				2	1	1	1	6
Arthropoda	Insecta	Diptera	Simuliidae	*Simulium*	15		12	20	2	3	3	1	1	14
Arthropoda	Insecta	Diptera	Stratiomyidae	*Caloparyphus*				3	2	2		1	1	1
Arthropoda	Insecta	Diptera	Tabanidae					1						
Arthropoda	Insecta	Diptera			1						1			
Arthropoda	Insecta	Diptera	Athericidae							2				
Arthropoda	Insecta	Diptera	Dytiscidae							2				1
Arthropoda	Insecta	Ephemeroptera	Baetidae	*Fallceon*	142	136	104	179	151	75	62	102	35	189
Arthropoda	Insecta	Ephemeroptera	Baetidae	*Camelobaetidius*		4	5	6	17	7	4	3	1	4
Arthropoda	Insecta	Ephemeroptera	Oligoneuriidae	*Lachlania*			1							
Arthropoda	Insecta	Ephemeroptera	Heptageniidae	*Stenonema*		2	3	4	1		1	1		3
Arthropoda	Insecta	Ephemeroptera	Leptophlebiidae	*Farrodes*			1							
Arthropoda	Insecta	Ephemeroptera	Caenidae	*Caenis*	32	72	14		10	6	1	1	1	
Arthropoda	Insecta	Ephemeroptera	Tricorythidae	*Tricorythodes*		2	18	3						1
Arthropoda	Insecta	Lepidoptera	Pyralidae	*Petrophila*		4		9						
Arthropoda	Insecta	Odonata	Coenagrionidae	*Argia*	9	107	243	105	6	6	10	2	3	6
Arthropoda	Insecta	Odonata	Libellulidae	*Brechmorhoga*			2	9				1		

Phylum	Class	Order	Family	Genus	Bull Creek @ Loop 360 (USGS)									
					9/15	9/22	10/6	11/3	12/1	12/15	12/29	1/26	2/23	3/23
Arthropoda	Insecta	Plecoptera	Perlidae	*Perlesta*				1	11	14	4	9	18	14
Arthropoda	Insecta	Plecoptera	Perlodidae	*Hydroperla*					3	3			2	
Arthropoda	Insecta	Plecoptera	Perlodidae		8	3								
Arthropoda	Insecta	Trichoptera	Philopotamidae	*Chimarra*		3		1	9	5	2	4	1	
Arthropoda	Insecta	Trichoptera	Helicopsychidae	*Helicopsyche*		1	1							1
Arthropoda	Insecta	Trichoptera	Hydroptilidae	*Hydroptila*	9	30	6	3			1	5	4	10
Arthropoda	Insecta	Trichoptera	Hydropsychidae	*Cheumatopsyche*		7	9	5	14	14	3	6	4	23
Arthropoda	Insecta	Trichoptera	Limnephilidae										1	2
Arthropoda	Insecta	Trichoptera	Leptoceridae	*Nectopsyche*				1					3	
Mollusca	Gastropoda	Limnophila	Physidae	*Physa*	9	24	28	2	2	3		1	1	1
Mollusca	Gastropoda	Limnophila	Planorbidae		1	9	4							
Mollusca	Gastropoda	Limnophila	Lymnaeidae			10	1							
Mollusca	Gastropoda	Mesogastropoda	Pilidae						1					1
Mollusca	Gastropoda	Mesogastropoda	Pleuroceridae										1	
Mollusca	Gastropoda	Mesogastropoda	Hydrobiidae			2	1	2						1
Mollusca	Gastropoda	Pelecypoda	Sphaeridae		13	15	6	6		1	1	4		1
Mollusca	Gastropoda	Pelecypoda	Corbiculidae	*Corbicula*		1		9	1				2	
Platyhelminthes	Turbellaria	Tricladida	Planariidae	*Dugesia*	2	2	3	11	1	3	16	4	5	6
Porifera	Demospongia												1	
				Total # of Taxa	21	30	33	31	21	27	21	21	27	30
				Total # organisms	682	1235	758	696	294	254	164	522	218	464

Phylum	Class	Order	Family	Genus	Bear Creek @ FM 1826 (USGS)								
					9/16	9/22	10/6	11/3	12/1	12/29	1/26	2/23	3/23
Annelida	Hirudinea	Gnathobdellida				1			14				
Annelida	Oligochaeta				4	6	6	7	17	3	2	4	3
Arthropoda	Decapoda	Astacoidea	Cambaridae					2					
Arthropoda	Insecta	Amphipoda			3	3	1	1		2	2		
Arthropoda	Insecta	Coleoptera	Elmidae	*Stenelmis*	6	14	39	26	31	44	26	25	12
Arthropoda	Insecta	Coleoptera	Elmidae	*Macrelmis*			1		1			1	
Arthropoda	Insecta	Coleoptera	Elmidae	*Heterelmis*			3			1	25	2	
Arthropoda	Insecta	Coleoptera	Lutrochidae	*Lutrochus*								2	
Arthropoda	Insecta	Coleoptera	Hydrophilidae	*Berosus*	5	17	1	2	3	1	2		
Arthropoda	Insecta	Coleoptera	Psphenidae	*Psphenus*	1	1							
Arthropoda	Insecta	Coleoptera											1
Arthropoda	Insecta	Coleoptera	Scirtidae						1				
Arthropoda	Insecta	Diptera	Chironomidae		130	246	55	94	27	38	34	34	92
Arthropoda	Insecta	Diptera	Ceratopogonidae		5	7	4	14	16	8	4	3	18
Arthropoda	Insecta	Diptera	Simuliidae	*Simulium*	3	4	33	4	16	25	19	23	
Arthropoda	Insecta	Diptera	Stratiomyidae	*Caloparyphus*						1			
Arthropoda	Insecta	Diptera	Stratiomyidae	*Odontomyia*	4								
Arthropoda	Insecta	Diptera	Tabanidae						1				2
Arthropoda	Insecta	Diptera								1			
Arthropoda	Insecta	Diptera	Dytiscidae										1
Arthropoda	Insecta	Diptera	Empididae							1	1	2	
Arthropoda	Insecta	Diptera				1	1						
Arthropoda	Insecta	Ephemeroptera	Baetidae	*Fallceon*	11	25	36	25	12	11	30	32	23
Arthropoda	Insecta	Ephemeroptera	Baetidae	*Camelobaetidius*	4		1		1	1	3	2	
Arthropoda	Insecta	Ephemeroptera	Heptageniidae	*Stenonema*	4	6	12	19	11	6	6	3	1
Arthropoda	Insecta	Ephemeroptera	Leptophlebiidae	*Thraulodes*			3						
Arthropoda	Insecta	Ephemeroptera	Caenidae	*Caenis*	22	59	15	11	41	16	11	3	11
Arthropoda	Insecta	Ephemeroptera	Tricorythidae	*Tricorythodes*				12					1
Arthropoda	Insecta	Hemiptera	Gerridae	*Rheumatobates*			1						
Arthropoda	Insecta	Hemiptera	Macroveliidae	*Macrovelia*		1							
Arthropoda	Insecta	Megaloptera	Corydalidae	*Corydalus*		1							

Phylum	Class	Order	Family	Genus	Bear Creek @ FM 1826 (USGS)								
					9/16	9/22	10/6	11/3	12/1	12/29	1/26	2/23	3/23
Arthropoda	Insecta	Odonata	Coenagrionidae	*Argia*	12	74	77	128	38	7	4	3	16
Arthropoda	Insecta	Odonata	Libellulidae	*Brechmorhoga*			6			1			2
Arthropoda	Insecta	Odonata	Aeshnidae	*Boyeria*		2							
Arthropoda	Insecta	Odonata	Gomphidae	*Promogomphus*			1		1				
Arthropoda	Insecta	Odonata	Calopterygidae	*Hetaerina*							1		
Arthropoda	Insecta	Plecoptera	Perlidae	*Perlesta*						1	3	4	7
Arthropoda	Insecta	Plecoptera	Leuctridae	*Zealeuctra*			1	7	5	10	6	3	18
Arthropoda	Insecta	Plecoptera	Perlodidae	*Hydroperla*							2		
Arthropoda	Insecta	Trichoptera	Philopotamidae	*Chimarra*	3	1	10	7	46	53	53	35	34
Arthropoda	Insecta	Trichoptera	Hydroptilidae	*Hydroptila*		1	1	3				2	
Arthropoda	Insecta	Trichoptera	Hydroptilidae	*Ochrotrichia*			1						
Arthropoda	Insecta	Trichoptera	Hydropsychidae	*Cheumatopsyche*			1		1	2	4	12	65
Arthropoda	Insecta	Trichoptera	Limnephilidae									1	1
Arthropoda	Insecta	Trichoptera	Leptoceridae							1			
Arthropoda	Insecta	Trichoptera	Glossosomatidae										1
Arthropoda	Insecta	Trichoptera	Limnephilidae								2		
Mollusca	Gastropoda	Basommatophora	Ancylidae					1		1			
Mollusca	Gastropoda	Limnophila	Physidae	*Physa*	8	38	7	17	4	2	1	1	2
Mollusca	Gastropoda	Limnophila	Planorbidae						1	1			5
Mollusca	Gastropoda	Limnophila	Planorbidae		1	3	8	4					
Mollusca	Gastropoda	Limnophila	Lymnaeidae		8	7	7	9					
Platyhelminthes	Turbellaria	Tricladida	Planariidae	*Dugesia*					1	3	2	2	1
				Total # of Taxa	21	27	30	22	22	26	23	22	22
				Total # organisms	266	579	344	400	289	241	243	199	317

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