Journal of Freshwater Ecology
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tjfe20

Recovery of stream invertebrates after catastrophic flooding in southeastern Minnesota, USA

Neal D. Mundahl [a] & Ashley M. Hunt [a]

[a] Department of Biology and Southeastern Minnesota Water Resources Center, Winona State University, Winona, Minnesota 55987, USA

Available online: 10 Oct 2011

Journal of Freshwater Ecology
2011, 1–13, iFirst

Taylor & Francis
Taylor & Francis Group

Recovery of stream invertebrates after catastrophic flooding in southeastern Minnesota, USA

Neal D. Mundahl* and Ashley M. Hunt

Department of Biology and Southeastern Minnesota Water Resources Center, Winona State University, Winona, Minnesota 55987, USA

(*Received 14 March 2011; final version received 12 May 2011*)

Widespread catastrophic flooding struck coldwater streams in southeastern Minnesota in August 2007, drastically scouring and altering stream channels and their biota. Post-flood invertebrate abundances and assemblages in streams in and near Whitewater State Park were compared to data collected from these same streams prior to flooding. Flooding reduced invertebrate densities by 75–95% in some streams. Taxa richness was reduced by 30–70%, and assemblage structure was reduced to poor and very poor levels in first- and second-order streams but not in the larger (fourth-order) system. Ephemeroptera, Plecoptera, and Trichoptera were especially impacted in small streams, and amphipods were virtually eliminated from both large and small streams. Densities of some invertebrate groups recovered within months of the flood, but others were still recovering after nearly two years. Taxa richness and community structure returned to pre-flood levels at most sites within one year, but total densities at many sites remained below long-term averages 22 months post-flood. Invertebrate assemblages were impacted differently by flooding in small versus large streams, resulting in differing patterns and degrees of recovery.

Keywords: stream flooding; invertebrate recovery; taxa richness; density; biomass; amphipods; EPT taxa

Introduction

Floods can have catastrophic effects on stream-dwelling invertebrates, with the impacts varying with flood magnitude and duration (e.g. Hynes 1970; Molles 1985; Boulton et al. 1992; Collier et al. 2002; Snyder and Johnson 2006). However, stream invertebrates can be highly resilient to flooding, with densities and community structure often returning quickly to pre-flood levels (Fisher et al. 1982; Hendricks et al. 1995; Elzinga et al. 2009). Recolonization and recovery of stream invertebrates can occur rapidly via downstream drift from less impacted upstream reaches (Williams and Hynes 1976), from deep interstitial refugia (Angradi 1997), from aerial dispersal from other streams nearby (Gray and Fisher 1981), and from reproduction of flood survivors (Collier et al. 2002).

Many streams and rivers in southeastern Minnesota, USA, experienced catastrophic flooding after a record-setting rain event in August 2007. A 24-hour

*Corresponding author. Email: nmundahl@winona.edu

ISSN 0270–5060 print/ISSN 2156–6941 online

DOI: 10.1080/02705060.2011.596657
http://www.informaworld.com

rainfall exceeded 30 cm and pushed many streams to their highest levels in recorded history. Streambeds and banks were reshaped, new channels were cut, riparian trees were undercut and dropped into the channels, and landslides delivered tons of rock and debris into the streams. The rainfall and flooding were described as once-in-2000-years events (Keillor 2010).

We examined the flood-induced decline and post-flood recovery of invertebrate assemblages in several coldwater trout streams within this region. It was speculated that drastic, long-term reductions in stream invertebrates could have major impacts on the health of the recreational salmonid fisheries in these systems. Consequently, we compared nearly two years of post-flood quantitative invertebrate collections to many years of pre-flood data to assess the magnitude of invertebrate losses in streams of differing sizes and their rates of recovery.

Materials and methods

Study sites

The Whitewater River is a coldwater tributary of the upper Mississippi River in southeastern Minnesota (N 44° 3′ 48″, W 92° 2′ 45″), draining an 830-km^2 watershed dominated by agriculture (66%) and wooded or wetland wildlife habitat (27%). In the center of the watershed, Whitewater State Park is bisected by the Middle Branch of the Whitewater River and its tributary, Trout Run/Dry Run (Figure 1). Rainfall exceeding 29 cm fell on the park and areas upstream during 18–19 August 2007, raising stream levels in the park by up to 5 m. Invertebrates were collected from two sites on the Middle Branch (fourth-order stream), three sites on Trout Run (first- and second-order stream), and one site on Dry Run (first-order stream).

Garvin Brook (N 44° 0′ 5″, W 91° 48′ 46″) is another coldwater tributary of the Mississippi River, draining a 256-km^2 watershed (46% agriculture, 36% wooded) immediately east of the Whitewater River drainage. This stream system also experienced record high flooding as a result of the August 2007 rainfall. Invertebrates were collected from two sites within 5 km of the headwaters of Garvin Brook (second-order stream).

All stream sites generally had similar physical and biological characteristics. Streams were shallow (<50 cm) with abundant riffle habitats, bottom sediments were dominated by coarse substrates (boulders, rubble, gravel), and stream channels were well shaded by riparian forests (Table 1). Fish assemblages in all streams were dominated by salmonids (brown trout (*Salmo trutta*), brook trout (*Salvelinus fontinalis*)) and sculpins (slimy sculpin (*Cottus cognatus*), mottled sculpin (*Cottus bairdii*)), with the Middle Branch of the Whitewater River also containing various suckers, darters, and dace.

Invertebrate collections

We sampled invertebrates in both drainages before and after the 2007 floods. Pre-flood data were of two types. First, we used annual collections from a long-term (1994–2006) data set for study streams in Whitewater State Park to establish 'expected' values for several invertebrate assemblage variables described below. Second, we used June pre-flood invertebrate collections from study streams in 2005,

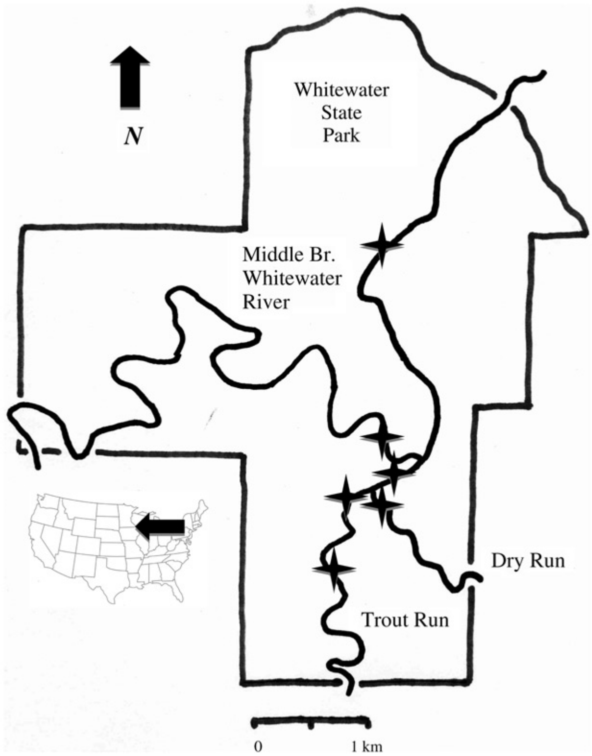

Figure 1. Map of streams within Whitewater State Park. Inset highlights location of study area in southeastern Minnesota. Invertebrate sample sites are designated by crosses.

Table 1. Physical habitat characteristics of four coldwater trout streams in southeastern Minnesota. Values are means of 13 to 52 measurements made in late-June 2004. Standard deviations are in parentheses.

Variable	Garvin	Trout Run	Dry Run	Middle Branch
Width (m)	4.8 (1.2)	4.4 (0.9)	2.1 (0.9)	7.0 (1.7)
Depth (cm)	37 (21)	29 (17)	17 (15)	42 (21)
Current velocity ($cm\,s^{-1}$)	23 (21)	18 (18)	6 (6)	20 (13)
Discharge ($m^3\,s^{-1}$)	0.41	0.23	0.02	0.59
Percentage of coarse substrates	92.3	84.6	88.4	92.0
Percentage of riffles	31 (48)	40 (45)	32 (45)	13 (30)
Percentage of shading at noon	43 (39)	70 (30)	65 (32)	70 (37)

2006, and 2007 to make more direct comparisons to post-flood samples from June 2008 and 2009. After flooding, we sampled invertebrates at six sites (two Middle Branch, three Trout Run, one Dry Run) in Whitewater State Park in October 2007, April, June, August, and October 2008, and April and June 2009. In Garvin Brook, we sampled invertebrates post-flood at one site in August 2007 and two sites in June 2008.

We collected invertebrates with a Hess sampler (0.1 m^2 sampling area). Three samples were collected at each stream site. Each sample was comprised of the invertebrates dislodged by vigorously disturbing coarse bottom substrates for 30 s at each of the two locations within a single riffle, one in fast-flowing water and one in slower-flowing water, for a total sampling area of 0.2 m^2 per sample. Organisms were separated from rocks and other coarse debris by repeated rinsing and sieving, and invertebrates and fine debris were retained and preserved in 70% ethanol.

In the laboratory, samples were sorted and invertebrates were identified (mostly to genus) and counted. For each sample, we determined the following: density, total taxa richness, Ephemeroptera-Plecoptera-Trichoptera (EPT) taxa richness, and a benthic index of biotic integrity (BIBI) score and rating (Wittman and Mundahl 2003). These variables were compared between pre- and post-flood samples collected from Whitewater River watershed streams (Trout Run, Dry Run, Middle Branch), as well as between pre- and post-flood samples from Garvin Brook. Changes in total densities and total taxa richness were compared over time post-flood with a series of two-factor (year X site) analyses of variance (ANOVAs) to assess recovery.

In addition to the above, we measured several additional variables for each sample to assess faunal recovery post-flood. We determined total invertebrate dry weight biomass for each post-flood sample by drying for >24 h at 30°C, and changes in biomass were compared over time post-flood with a series of two-factor (year X site) ANOVAs. We also examined densities of key invertebrate groups (Amphipoda, Hydropsychidae, Simuliidae, Chironomidae, Baetidae, Ephemerellidae) over time to assess differences in rates of recovery of these groups.

Results

General information

During the course of this study, we collected and processed 129 benthic macroinvertebrate samples. These samples contained 47,797 organisms representing 54 different taxa (Table 2). These included nine non-insect taxa, five genera of stoneflies (Plecoptera), seven genera of mayflies (Ephemeroptera), 10 genera of caddisflies (Trichoptera), and 12 taxa of true flies (Diptera). Individual samples ranged in size from 42 to 1054 organisms, averaging 371 organisms. The five most common and abundant taxa across all sites and sampling dates were blackfly larvae of the genus *Simulium*, larvae and nymphs of the midge family Chironomidae, Hydropsychidae caddisfly larvae, nymphs of the mayfly genus *Baetis*, and amphipods of the genus *Gammarus*.

Density and biomass

Invertebrate assemblages were reduced significantly by the August flooding. Densities of invertebrates in Trout Run, Dry Run, and the Middle Branch Whitewater River were $\sim$75% lower than expected (500–1000 organisms/m^2 versus 2600–3700 organisms/m^2) based on collections from previous years (Figure 2). Had we made collections immediately after the floods in August rather than 2 months later, even lower numbers (similar to the $<$200 organisms/m^2 found in August in

Table 2. Taxa collected from Whitewater State Park streams during the October 2007 to June 2009 post-flood study period.

Non-insects	Insects	
AMPHIPODA	PLECOPTERA	EPHEMEROPTERA
Gammarus	*Isoperla*	*Baetis*
	Paragnetina	*Ephemerella*
DECAPODA	*Nemoura*	*Stenonema*
Orconectes	*Amphinemura*	*Isonychia*
	Allocapnia	*Tricorythodes*
ISOPODA		*Pseudocloeon*
Asellus	TRICHOPTERA	*Paraleptophlebia*
	Hydropsyche	
ASCHELMINTHES	*Cheumatopsyche*	COLEOPTERA
Nematomorpha	*Brachycentrus*	*Macronychus*
	Hydroptila	*Optioservus*
ANNELIDA	*Rhyacophila*	*Stenelmis*
Oligochaeta	*Limnephilus*	*Dubiraphia*
Hirudinea	*Pycnopsyche*	*Agabus*
	Micrasema	*Hydrobius*
GASTROPODA	*Glossosoma*	*Gyrinus*
Physella	*Hesperophylax*	*Pronoterus*
BIVALVIA	DIPTERA	MEGALOPTERA
Sphaeriidae	Chironomidae	*Nigronia*
	Simulium	*Sialis*
ARACHNIDA	*Dicranota*	
Acari	*Tipula*	HEMIPTERA
	Antocha	*Belostoma*
	Limnophora	
	Limonia	
	Pericoma	
	Empididae	
	Stratiomyidae	
	Atherix	
	Erioptera	

Garvin Brook and other nearby streams) may have been observed. October densities at one Middle Branch site were slightly, but not significantly (one-factor ANOVA, $p < 0.2$), higher than those in Trout Run and Dry Run.

Subsequent sampling during the 20 months following initial collections revealed a gradual increase in invertebrate densities at most sites, excluding slight seasonal changes likely associated with insect life cycle changes (Figure 2). Significant increases in densities were observed between samples collected one year apart (Table 3). Despite these increases, average invertebrate densities in both Trout Run/Dry Run and the Middle Branch Whitewater River generally remained below pre-flood summer levels even 22 months after flooding.

Dry biomass of benthic invertebrates followed a pattern of change somewhat different from that of densities. Although no pre-flood biomass data were available for comparison, flooding likely produced greatly reduced biomass of benthic invertebrates at Whitewater State Park stream sites. Biomass measurements were very low in October 2007, especially at the Trout Run/Dry Run sites (Figure 2).

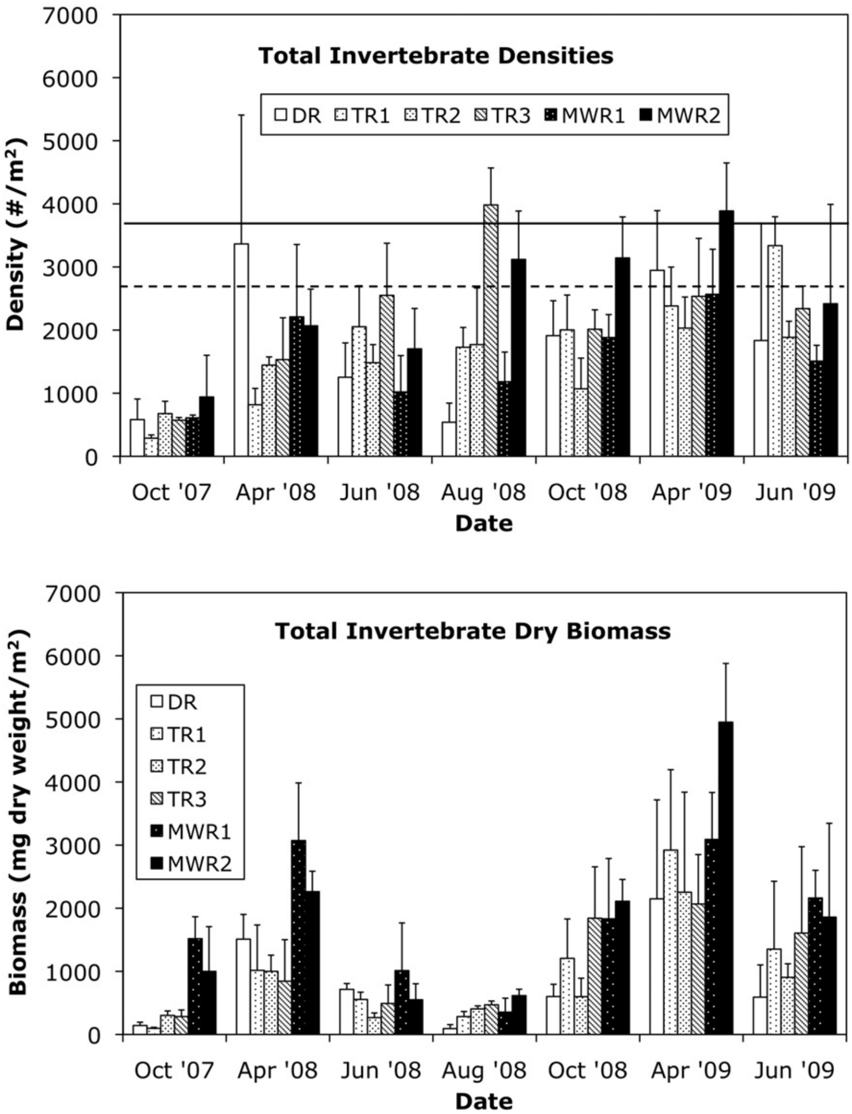

Figure 2. Invertebrate densities and dry biomass (mean ± SD) in streams in Whitewater State Park after August 2007 flooding. Solid and dashed horizontal lines represent average pre-flood invertebrate densities at Middle Branch Whitewater River sites and Trout Run sites, respectively. DR = Dry Run, TR1-TR3 = Trout Run sites (upstream to downstream), MWR1-MWR2 = Middle Branch Whitewater River sites (upstream to downstream).

Invertebrate biomass in subsequent months followed an expected pattern of low values in summer (emergence of adults), increasing values during fall (hatching of eggs, individual growth), and highest values during spring (continued individual growth). However, significant increases in biomass were observed between samples collected one year apart during each of these three seasons (Table 2). We assumed that, since densities had not yet returned to pre-flood levels by June 2009, biomass as well may still have been below pre-flood levels at that time.

Table 3. Results (p values) of two-factor ANOVA tests (year X site) comparing total invertebrate densities, dry weight biomass, and total taxa richness between years at six stream sites in Whitewater State Park. p values are shown for the variable 'year' only. For taxa richness, Trout Run (including Dry Run) and Middle Branch Whitewater River (MWR) sites were analyzed separately.

			Taxa richness	
Comparison	Density	Biomass	Trout Run	MWR
October 2007 versus 2008	<0.01	0.01	0.03	0.50
April 2008 versus 2009	0.05	0.02	<0.01	0.08
June 2008 versus 2009	0.04	0.01	<0.01	0.32

The amphipod *Gammarus* was adversely affected by flooding, both in small and large streams within the park. Amphipods were common inhabitants of all streams within the park prior to flooding, and were often one of the dominant organisms present in Trout Run and Dry Run (average densities > 150 organisms/m^2). After flooding, amphipods were virtually absent from all streams within the ark (Figure 3), as well as other streams nearby. Amphipod numbers did not begin to increase in Trout Run until June 2008 and increased steadily after that date. After August 2008, amphipod densities in Trout Run were similar to pre-flood levels, but amphipods were more sporadic and uncommon in both Dry Run and the Middle Branch Whitewater River, remaining well below pre-flood values.

Densities of blackfly larvae (genus *Simulium*) were extremely low after the flood but, like the amphipods, increased steadily in numbers throughout the study period in Trout Run and Dry Run (Figure 3). Very few *Simulium* were collected in the Middle Branch during any month.

Chironomidae larvae were the most abundant invertebrates after the flood, and they continued to comprise a large proportion (~25–50%) of the invertebrate assemblage throughout the study (Figure 3). Abundances were similar at Trout Run/Dry Run and Middle Branch sites, with both streams displaying a general increase in numbers throughout the study period.

Hydropsychidae caddisfly larvae and *Ephemerella* mayfly nymphs displayed density changes different from amphipods and blackfly larvae. Hydropsychids and *Ephemerella* were present in low numbers after flooding in the Middle Branch but were mostly absent from Trout Run/Dry Run until August or October 2008 (Figure 3). Because of their life cycles, highest densities of these taxa are expected in October of each year.

Densities of Baetidae mayfly nymphs were extremely low post-flood, but numbers rebounded more than 20-fold by April 2008 (Figure 3). For the remainder of the study period, densities fell and rose in both Trout Run/Dry Run and the Middle Branch, with little apparent change between June 2008 and June 2009.

Community structure

Prior to flooding, individual invertebrate samples from small and large streams in Whitewater State Park typically contained 12 different taxa. Two months after

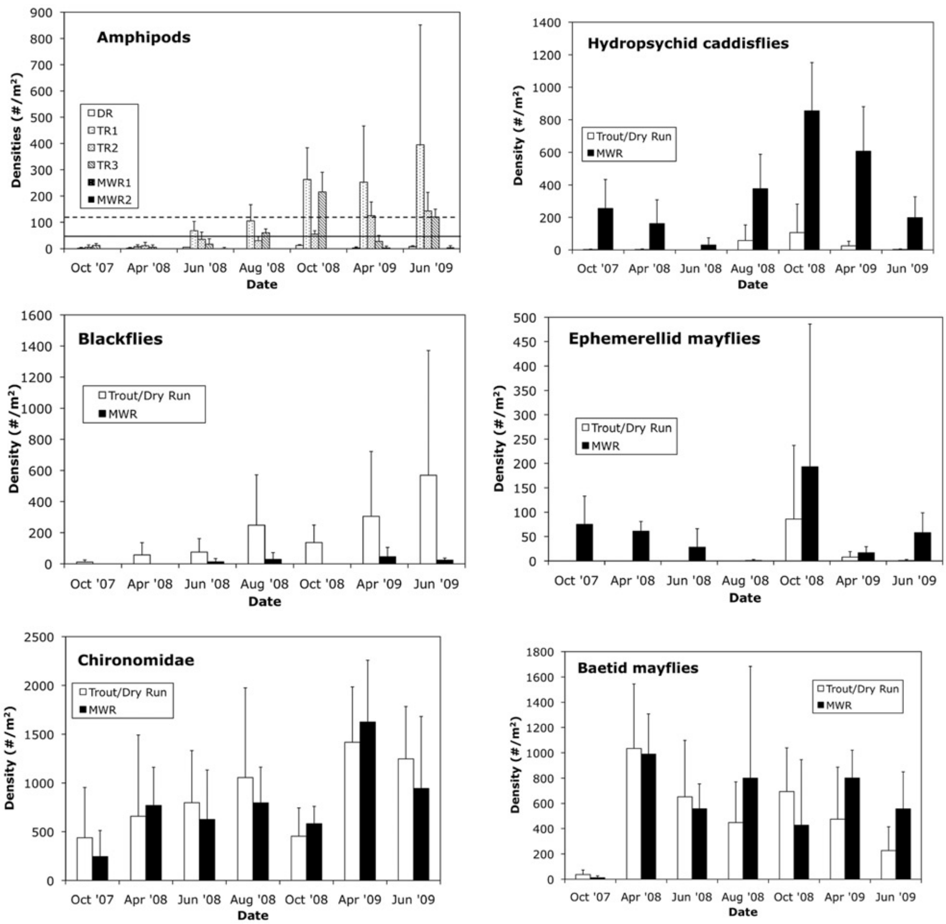

Figure 3. Densities (mean ± SD) of key invertebrate groups in streams in Whitewater State Park after August 2007 flooding. Solid and dashed horizontal lines represent average pre-flood amphipod densities at Middle Branch Whitewater River sites and Trout Run sites, respectively. Site abbreviations as in Figure 2.

flooding, samples from Trout Run and Dry Run contained an average of only seven different kinds of organisms (Figure 4). However, October 2007 samples from the Middle Branch contained an average of 13 taxa, not significantly different from pre-flood levels. It is not known whether the Middle Branch lost taxa from flooding and recovered them by October, since no sampling was done prior to October. It is most probable that no taxa were lost, since every sample collected in October had at least 12 taxa present, with some samples containing as many as 15 taxa.

After October 2007, taxa richness remained at or near pre-flood levels in the Middle Branch, whereas Trout Run and Dry Run sites showed a slower return to normal levels (Figure 4). Taxa richness in Trout Run and Dry Run changed very little from October 2007 through June 2008, but most sites on those streams achieved pre-flood taxa richness levels by October 2008 and remained near that level through June 2009. As assessed by a series of month-to-month comparisons, taxa richness did

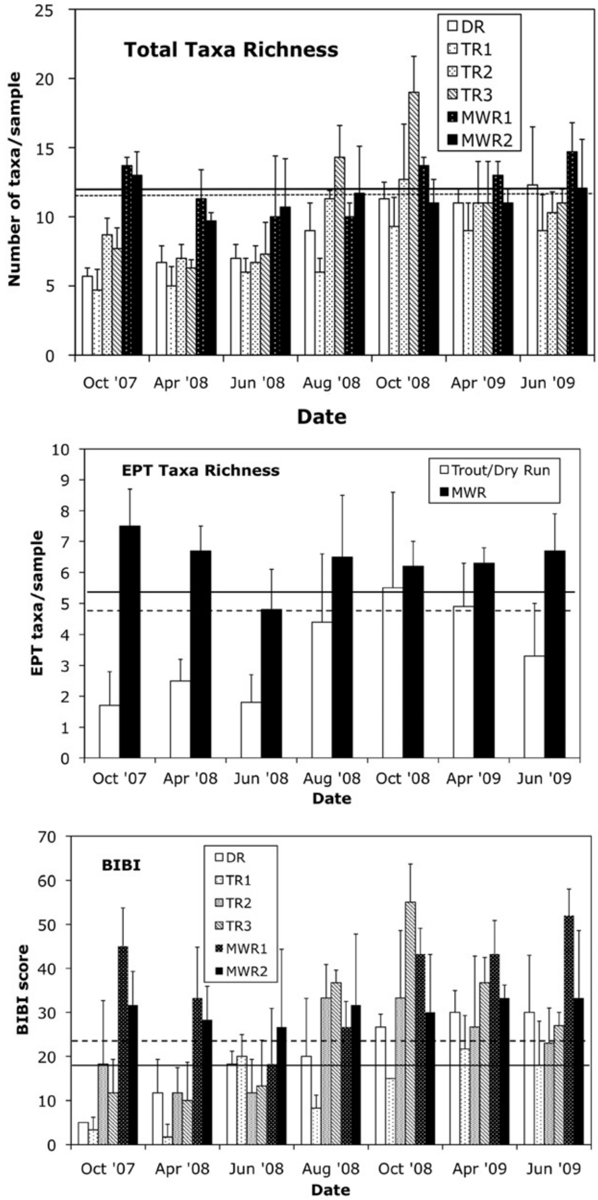

Figure 4. Total invertebrate taxa richness, EPT taxa richness, and BIBI scores (mean ± SD) in streams in Whitewater State Park after August 2007 flooding. Solid and dashed horizontal lines represent average pre-flood condition at Middle Branch Whitewater River sites and Trout Run sites, respectively. Site abbreviations as in Figure 2.

not change during the study period in the Middle Branch but increased significantly in Trout Run/Dry Run (Table 3).

Of the taxa that were lost from Trout Run and Dry Run, many were EPT taxa (Figure 4). Trout Run/Dry Run sites appeared to lose half or more of their EPT taxa to flooding. Many of the taxa missing after flooding were those that graze algae from the surfaces of rocks (e.g. the mayflies *Ephemerella* and *Stenonema*, the caddisflies *Glossosoma* and *Limnephilus*), a feeding position that might make them especially vulnerable to flooding and scouring. However, Middle Branch sites, with triple the EPT taxa of Trout Run in October 2007, apparently were able to retain their EPT taxa with no obvious losses. EPT taxa richness remained at or above pre-flood levels at these Middle Branch sites through June 2009, whereas pre-flood EPT taxa richness was not achieved in Trout Run/Dry Run until August–October 2008.

Benthic IBI ratings for park streams prior to flooding typically were fair (Trout Run/Dry Run typical BIBI score = 30–45) or poor (Middle Branch typical score = 10–25), with invertebrate assemblages usually lacking the expected number of EPT taxa, intolerant taxa, long-lived taxa, and taxa that are filterers or predators. Following flooding, the loss of additional taxa in Trout Run resulted in BIBI ratings of poor (score = 10-25) and very poor (score = 0–5) in this system (Figure 4). The Middle Branch, which lost density, but not taxa, to the flooding, had BIBI ratings of fair (score = 30–45) in October 2007. In subsequent months, BIBI scores improved for Trout Run/Dry Run sites, so that by August and October 2008, two of the four sites reached or exceeded pre-flood BIBI ratings, with one site achieving a rating of good (score = 50–60). Middle Branch sites generally had BIBI scores higher than pre-flood levels throughout the study period, often achieving a rating of fair.

Trout Run/Dry Run and Middle Branch versus Garvin Brook

Garvin Brook invertebrates also suffered from the catastrophic flooding in August 2007. With the exception of densities (total and amphipod), Garvin Brook's invertebrate assemblage was very similar to that in Trout Run/Dry Run during the 2 years preceding the 2007 flooding (Table 4). As in the Whitewater State Park streams, the August 2007 flooding significantly reduced invertebrate densities, taxa richness, and overall community structure in Garvin Brook. Densities (total and amphipod) were reduced by >95% compared to June 2007 values. Total taxa richness fell by >70%, EPT taxa declined by >60%, and BIBI score was reduced by 90%. However, by June 2008, the Garvin Brook invertebrate community had largely returned to its pre-flood levels of density, taxa richness, and community structure. By this date, Trout Run/Dry Run sites were still in recovery mode for amphipod density, total and EPT taxa richness, and BIBI score.

Discussion

Biotic recovery from catastrophic flooding in Whitewater State Park was expected to be rapid (Resh et al. 1988; Lamberti et al. 1991; Elzinga et al. 2009), as benthic assemblages typically are adapted to natural disturbances such as substratum movement, which is the primary disturbance during flooding (Cobb et al. 1992). Typical benthic assemblage recovery times vary from weeks to months even after massive flood-induced mortality (Yount and Niemi 1990).

Stream invertebrates in Whitewater State Park were negatively impacted by the August 2007 floods that devastated the Park. Densities were reduced in both large and small streams by 60 to 80%, and recovery to normal densities had not yet been achieved by June 2009, 22 months after flooding. Benthic invertebrate losses exceeding 95% are not uncommon during severe stream flooding (e.g. Scrimgeour

Table 4. Comparison of benthic invertebrate assemblage parameters for Garvin Brook, Trout Run (including Dry Run), and the Middle Branch of the Whitewater River before and after August 2007 flooding. All invertebrate samples were collected in June, except for 2007 post-flood samples (late-August for Garvin, October for Trout Run and the Middle Branch). Values are means with Standard Deviations in parentheses.

			2007			
Parameter/Site	2005	2006	pre-flood	post-flood	2008	2009
Total density (no./m^2)						
Garvin	1448 (622)	4008 (2213)	1940 (176)	69 (47)	4028 (1662)	—
Trout Run	587 (315)	895 (718)	—	530 (224)	1835 (740)	2349 (1048)
Middle Branch	1000 (720)	2690 (670)	—	774 (457)	1362 (661)	1963 (1125)
Amphipod density (no./m^2)						
Garvin	128 (91)	240 (103)	53 (23)	2 (4)	310 (27)	—
Trout Run	58 (31)	175 (123)	—	5 (7)	31 (34)	166 (247)
Middle Branch	457 (426)	13 (12)	—	0 (0)	1 (2)	3 (4)
Taxa richness						
Garvin	10.5 (2.3)	11.3 (2.1)	16.0 (1.0)	4.6 (1.5)	12.0 (2.0)	—
Trout Run	10.8 (1.7)	11.1 (3.7)	—	6.7 (2.0)	6.8 (1.4)	10.7 (2.6)
Middle Branch	8.5 (1.4)	11.5 (1.2)	—	13.3 (1.2)	10.3 (3.6)	13.3 (3.0)
EPT taxa richness						
Garvin	4.5 (1.2)	5.7 (1.2)	6.7 (0.6)	2.6 (0.9)	4.7 (1.2)	—
Trout Run	4.7 (0.5)	5.6 (2.1)	—	1.7 (1.1)	1.8 (0.9)	3.3 (1.7)
Middle Branch	3.2 (0.8)	4.7 (0.8)	—	7.5 (1.2)	4.8 (1.3)	6.7 (1.2)
BIBI score						
Garvin	24 (10)	33 (8)	52 (10)	5 (6)	25 (10)	—
Trout Run	25 (7)	37 (12)	—	10 (9)	16 (7)	25 (9)
Middle Branch	17 (10)	22 (11)	—	38 (10)	23 (14)	43 (14)

and Winterbourn 1989; Lytle 2000), and rates of recovery are dependent on the sources of potential recolonizers. The slow recovery of invertebrate assemblages in Whitewater State Park streams suggests that typical sources of recolonizers, such as unimpacted upstream reaches and less impacted drainages nearby (Williams and Hynes 1976; Gray and Fisher 1981), may not have been available given the region-wide nature of the August 2007 flooding. The return to normal densities may have depended largely on natural reproduction among flood survivors (Collier et al. 2002) and those returning from interstitial refugia (Angradi 1997), especially in these small, headwater streams.

Various taxa displayed different rates of recovery from the flood event. Baetidae mayflies and Chironomidae midges recovered very quickly post-flood, a result generally attributed to the mobility of their adult stages (Robinson et al. 2003). Blackflies also typically return quickly (Robinson et al. 2003), although their recovery was very protracted in both Trout Run and the Middle Branch in the present study. The larger Ephemerellidae mayflies and Hydropsychidae caddisflies were greatly reduced in the Middle Branch and virtually absent from Trout Run for a year after flooding. Because many of these taxa do not disperse widely as adults, the recovery process tends to be slow (Collier et al. 2002). Post-flood recovery of amphipods and other non-flying invertebrates (e.g., snails, isopods, leeches, oligochaetes) may depend largely on their abilities to survive flooding and how quickly they reproduce (Hynes 1970; Collier et al. 2002). It required over a year for amphipod densities in Trout Run to reach normal levels, but Middle Branch numbers remained at minimal levels nearly 2 years post-flood.

Reduced taxa richness and changes in community structure are typical of benthic invertebrate assemblages subjected to severe flooding (e.g., Hynes 1970; Lytle 2000; Robinson et al. 2003; Snyder and Johnson 2006; Elzinga et al. 2009). In the streams of Whitewater State Park, taxa were lost and community structure modified, but only in the smaller systems. Trout Run lost approximately 50% of its taxa to flooding, in large part due to losses in EPT taxa, and BIBI ratings fell from fair to poor/very poor. Similar changes occurred in nearby Garvin Brook, but none of these changes occurred post-flood in the Middle Branch. Although flooding on all systems appeared to be equally devastating, impacts on the substrata and/or the availability of interstitial refugia must have differed dramatically among Trout Run/Dry Run, Garvin Brook, and the Middle Branch, eliminating many taxa temporarily from Trout Run/Dry Run and Garvin Brook but not from the Middle Branch.

The streams in and near Whitewater State Park were impacted differentially by the floods of August 2007. Although these record flows in Trout Run/Dry Run, Garvin Brook, and the Middle Branch led to dramatic stream channel cutting, substratum movement, and dramatic reductions in densities of benthic invertebrates in these streams, community structure was altered only in the small, first- and second-order streams. Community structure recovered in the smallest streams after approximately 1 year, but recovery of invertebrate densities in all park streams was still underway nearly 2 years after flooding.

Acknowledgements

The Minnesota Department of Natural Resources, Division of Parks and Trails, provided funding for this study. We thank the personnel of Whitewater State Park for granting access to the park while it was closed to the public, and Winona State Biology students M. Heinrich, M. Larson, and D. Mundahl, who assisted with sample collections, sorting, and counting.

References

Angradi TR. 1997. Hydrologic context and macroinvertebrate community response to floods in an Appalachian headwater stream. American Midland Naturalist. 138:371–386.

Boulton AJ, Peterson CG, Grimm NB, Fisher SG. 1992. Stability of an aquatic macroinvertebrate community in a multiyear hydrologic disturbance regime. Ecology. 73:2192–2207.

Cobb DG, Galloway TD, Flannagan JF. 1992. Effects of discharge and substrate stability on density and species composition of stream insects. Canadian Journal of Fisheries and Aquatic Sciences. 49:1788–1795.

Collier K, Parkyn S, Quinn J, Scarsbrook M. 2002. Bouncing back: how fast can stream invertebrates recolonise? Water and Atmosphere. 10(2):9–11.

Elzinga WJ, McCord SB, Scott CG, Pozzo Jr JC. 2009. Impacts of a catastrophic flood on a southeastern Missouri (USA) stream. Journal of Freshwater Ecology. 24:411–423.

Fisher SG, Gray LJ, Grimm NB, Busch DE. 1982. Temporal succession in a desert stream ecosystem following flash flooding. Ecological Monographs. 52:93–110.

Gray LJ, Fisher SG. 1981. Postflood recolonization pathways of macroinvertebrates in a lowland Sonoran desert stream. American Midland Naturalist. 106:249–257.

Hendricks AC, Willis LD, Snyder CD. 1995. Impact of flooding on the densities of selected aquatic insects. Hydrobiologia. 299:241–247.

Hynes HBN. 1970. The ecology of running waters. Liverpool, England: Liverpool University Press. p. 555.

Keillor L. 2010. Fishing after the flood. Minnesota Conservation Volunteer. 73(431):8–17.

Lamberti GA, Gregory SV, Ashkenas LR, Wildman RC, Moore KMS. 1991. Stream ecosystem recovery following a catastrophic debris flow. Canadian Journal of Fisheries and Aquatic Sciences. 48:196–208.

Lytle DA. 2000. Biotic and abiotic effects of flash flooding in a montane desert stream. Archiv fur Hydrobiologie. 150:85–100.

Molles MC. 1985. Recovery of a stream invertebrate community from a flash flood in Tesuque Creek, New Mexico. Southwestern Naturalist. 30:279–287.

Resh VH, Brown AV, Covich AP, Gurtz ME, Li HW, Minshall GW, Reice SR, Sheldon AL, Wallace JB, Wissmar RC. 1988. The role of disturbance in stream ecology. Journal of the North American Benthological Society. 7:433–455.

Robinson CT, Uehlinger U, Monaghan MT. 2003. Effects of a multi-year experimental flood regime on macroinvertebrates downstream of a reservoir. Aquatic Sciences. 65:210–222.

Scrimgeour GJ, Winterbourn MJ. 1989. Effects of floods on epilithon and benthic macroinvertebrate populations in an unstable New Zealand river. Hydrobioloia. 171:33–44.

Snyder CD, Johnson ZB. 2006. Macroinvertebrate assemblage recovery following a catastrophic flood and debris flows in an Appalachian mountain stream. Journal of the North American Benthological Society. 25(4):825–840.

Williams DD, Hynes HBN. 1976. The recolonization mechanisms of stream benthos. Oikos. 27:265–272.

Wittman E, Mundahl N. 2003. Development and validation of a benthic index of biotic integrity (B-IBI) for streams in southeastern Minnesota. Winona State University Floruit (Student and Faculty Research from the College of Science and Engineering). 1(1):41–48.

Yount JD, Niemi GJ. 1990. Recovery of lotic communities and ecosystems from disturbance – a narrative review of case studies. Environmental Management. 14:547–569.