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Response of the Stonefly *Pteronarcys dorsata* in Enclosures from an Urban North Carolina Stream

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Recent studies have indicated laboratory bioassay tests can estimate ambient water quality. Eagleston et al. (1990) showed a strong agreement between *Ceriodaphnia dubia* chronic bioassays and diversity of benthic macroinvertebrates inhabiting streams. Similarly, Lenat (1993a) related *Chironomus* mentum deformities to *Ceriodaphnia* chronic bioassays as a predictor of in-stream toxicity. However, chronic bioassay procedures do not accurately portray in-stream conditions such as diel dissolved oxygen sags or episodic pollutant loading. *In situ* experiments offer the opportunity to observe benthic macroinvertebrate response to actual water quality and not to unnatural conditions found in laboratory bioassays. Enclosure studies have examined benthic macroinvertebrate mortality to experimental acidification of Welsh streams (McCahon & McKavanagh 1987; Merrett *et al.* 1991; McCahon and Pascoe 1989; Ormerod *et al.* 1987). To study *in-situ* toxicity, the benthic macroinvertebrate *Pteronarcys dorsata* (Plecoptera: Pteronarcyidae), which is considered to be intolerant to pollution, was placed in enclosures along Morgan Creek, N.C. Benthic macroinvertebrate mortality was chosen as the primary indicator of effect and leaf pack depletion was examined as a sub-lethal indicator.

MATERIALS AND METHODS

Morgan Creek is an urban creek (17.5 km long) which starts west of the Towns of Carrboro and Chapel Hill, North Carolina, flows past the Mason Farm Wastewater Treatment Plant (WWTP), and empties into B. Everett Jordan Lake (Figure 1). Morgan Creek is relatively narrow (8-10 m wide) and shallow, with average depths during base flow not exceeding 0.5 m. Morgan Creek drains the Towns of Carrboro and Chapel Hill receiving storm water runoff from Meeting of the Waters, Wilson Creek, and Chapel Creek. Three sites along Morgan Creek were chosen for a mortality study of benthic macroinvertebrates. A reference site was located above the effects of urban runoff in a relatively undeveloped portion of the watershed (HWY54). Substrate at the HWY54 site was 70 % large particles [boulder (20%) rubble (30%) and gravel (20%)] and 30 % fine particles [sand (25%) and silt (5%)].

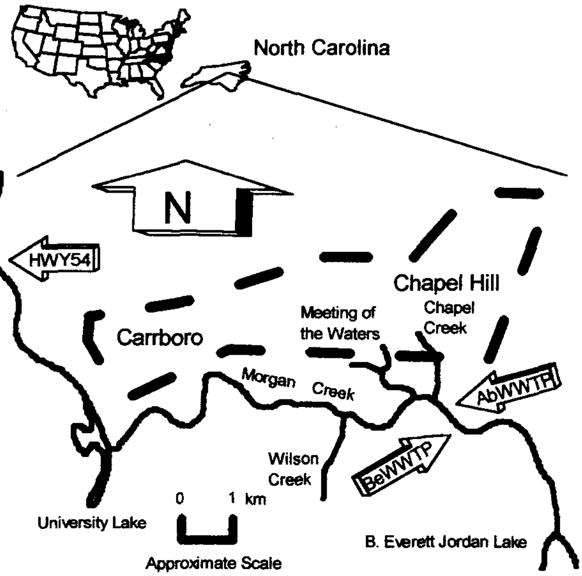

Figure 1. Location sites for the enclosure study in Morgan Creek, Orange County, North Carolina.

The North Carolina Biotic Index (NCBI) ranks species tolerance from 0-10 (with the least tolerant species having the lowest values) and water quality ratings or bioclassification ratings of Excellent, Good, Good-Fair, Fair and Poor are assigned to streams based on metric calculations (Lenat 1993b). The bioclassification rating for Morgan Creek is Excellent at the HWY54 site The .other two sites were established in the urban reach of Morgan Creek above (AbWWTP) and below (BeWWTP) the WWTP effluent discharge Substrate at these two sites were comprised of gravel (20 %) and fine particles [sand (70 %) and silt (10 %)]. Bioclassifications for the AbWWTP/BeWWTP sites were Fair/Poor, Fair/Fair, and Fair/Poor for July 1988, September 1990, and September 1994, respectively (North Carolina Department of Environment, Health and Natural Resources 1991; NCDEHNR, unpublished data).

This experiment was designed to examine benthic macroinvertebrate mortality in enclosures along various stretches of Morgan Creek The stonefl y *Pteronarcys dorsata* was chosen for the study because of ease of identification, abundance in a local stream, a univoltine life cycle in the southeastern United States which allows access to similarly sized and aged organisms (Lechleitner and Kondratieff 1983), shredding and not predacious feeding habit which deters cannibalism (Harden and Mickel 1952), and a relatively low tolerance value (NCBI = 1.7) which denotes a potential sensitivity to pollutants *P. dorsata* and leaf packs were obtained from Richland Creek, a stream with a bioclassification rating of Good, 68 km east of Morgan Creek above Wake Forest, North Carolina *P. dorsata* does not inhabit Morgan Creek.

Enclosures (cylinder cages) were placed 50 m above (AbWWTP) and 30 m below (BeWWTP) the Mason Farm WWTP discharge and 50 m upstream of the Highway 54 crossing (HWY54) of Morgan Creek. Enclosures were made of clear acrylic cylinder tubes (10.2 cm diameter and 30.5 cm long) secured by a galvanized steel clamp to a two-width brick (20 cm x 20 cm x 5 cm). The bricks served as anchors and held the cylinder tubes above the substrate. A 500 µ mesh nitex netting was secured with galvanized steel clamps to each end of the tubes. The netting and leaf packs provided physical substrata, and the leaves formed the food source. Reice (1974) used 1 to 40 g dry wt of leaves to represent natural leaf packs. Small leaf packs (1 g dry wt) from Richland Creek were chosen to facilitate water flow through the cylinder cages. The leaves were scrubbed of organisms and debris, dried in a drying oven at 50°C for 48 hr, and weighed on a Metler AE 160 balance (±0.001 g) prior to placement in the cylinder cages. At the end of the experiment leaf packs were removed from each cage, cleaned of debris, re-dried, and re-weighed. Weight loss of leaf packs was compared between cylinder cage sites by analysis of covariance (ANCOVA) adjusting for differential survival (organism density) by the end of the experiment. Percent weight loss for leaf packs was calculated according to Reice (1974):

$$\%\ \text{weight loss} = \frac{\text{initial dry weight (g) - dry weight remaining (g)}}{\text{initial dry weight (g).}} \times 100$$

Cylinder cages (3 replicate cages per site) containing dried leaves were placed in the Morgan Creek three days prior to the introduction of *P. dorsata* to condition cage materials. The cylinder cages were positioned with openings oriented with the direction of water flow, and discharge was measured in-front of each cylinder cage opening at the start and end of the experiment with a Price pygmy current meter. Water discharge at the beginning of the experiment (Day 1) was 0.015±0.002 (± SE), 0.028±0.001 and 0.019±0.001 m^3/sec at the HWY54, BeWWTP and AbWWTP sites, respectively. At the end of the experiment (Day 39) water discharge was 0.006±0.002 m^3/sec at the HWY54 site, 0.037±0.003 m^3/sec at the BeWWTP site and 0.026±0.001 m^3/sec at the AbWWTP site.

Ninety (90) early instar nymphs of *P. dorsata* (14 - 17 mm length) were collected in Richland Creek by carefully searching leaf packs with forceps. The stoneflies were placed with creek water into an aerated, insulated bucket and transported to Morgan Creek . The stoneflies were removed from the bucket and ten *P. dorsata* placed in each cylinder cage. The experiment was conducted from June 17 to July 26, 1996. The cages were opened and inspected for *P. dorsata* mortality every other day. Death was indicated by failure to respond to probing by forceps, and dead animals were removed from the cylinder cages. Debris collected on the outside of the cylinder cages was removed at each inspection date. The experiment was terminated on Day 39 because leaf pack mass was negligible in one cylinder cage at the HWY54 site. Sites were separated graphically by percent cumulative mortality curves. The log rank test compared mortality curves (Pollock et al. 1989).

Water chemistry samples were collected weekly for dissolved oxygen (YSI 51B meter), pH (Orion Model 920A meter), specific conductance (YSI Model 32 meter), and turbidity (Hach-ratio turbidimeter). Water temperatures were measured each time cages were inspected with a pocket field thermometer (+-1°C). Water temperatures were also measured in Richland Creek at the beginning and at the end of the experiment. Water discharge in Morgan Creek was obtained from U.S. Geological Survey water level recorder gauges on Morgan Creek, 600 m downstream of the BeWWTP site (Chapel Hill gauge), and 50 m downstream of the HWY54 site (HWY54 gauge) Water discharge for the Mason Farm WWTP gauge is for inflow to the plant and exceeds flow released to Morgan Creek. Rainfall data were obtained from the Mason Farm WWTP rainfall gauge.

RESULTS AND DISCUSSION

Stream flow decreased gradually throughout the experiment, although flow increased immediately after rain storms (Figure 2) By Day 20 of the experiment, stream flow in the urban stretch of Morgan Creek was dominated by WWTP effluent discharge. Six rain storms exceeding 0.5 cm/day caused peaks in storm hydrographs at the Chapel Hill gauge. No peaks in stream flow were recorded at the HWY54 gauge and only a slight increase in flow was observed from the Mason Farm WWTP in response to rain storms Sand and silt covered the bottom of cylinder cages to a depth of 2-3 mm following rain storms at the AbWWTP and BeWWTP sites. No deposition of sand and silt was observed in cylinder cages at the HWY54 site.

Water temperatures were usually between 19 and 24°C at all sites, but temperatures were about 2°C higher below the wastewater discharge Urban runoff increased specific conductance from 110 to 136 µmhos/cm at the control site to 151 to 193 µmhos/cm above the wastewater discharge. A much larger increase was observed below the wastewater discharge from 364 to 436 µmhos/cm. Morgan Creek was well oxygenated and the pH within normal limits (range) at all sites. On Day 39, following 2.3 cm of rainfall, turbidities of 5.5, 162, and 66 nephelometric turbidity units (NTU) were recorded at the HWY54, AbWWTP and BeWWTP sites, respectively. For non-storm sampling dates, turbidity was usually less than 10 NTU (median = 4.5) for all sites.

The experiment was terminated on Day 39 because the leaf pack in one cage from the HWY54 site had lost 99 percent of its initial mass Leaf packs averaged 85.4±9.2 (SE), 39.0±5.7 and 7.6±1/1 percent weight loss at the HWY54, AbWWTP and BeWWTP sites, respectively. Differences in survival (organism density) alone accounted for the additional leaf pack mass at the AbWWTP and BeWWTP sites ($F_{0.05(1),2,6} = 0.609$) .

No mortalities fo *P. dorsata* occurred at the Hwy54 site until Day 37 when one dead larva was recorded (Figure 3). In contrast, cumulative percent mortalities for *P. dorsata* reached 36.7±14.5 and 23.4±3.4 by Day 7 at the AbWWTP and BeWWTP sites. Fifty percent mortalities were reached on Day 29 for the AbWWTP

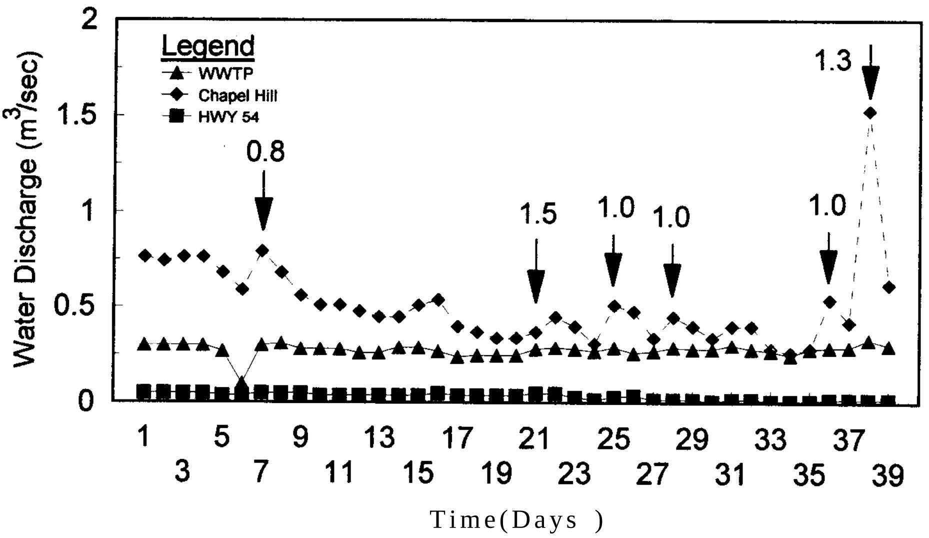

Figure 2. Daily mean water discharge (m^3/sec) for the Highway 54 (HWY54) and Chapel Hill gauges in Morgan Creek, Orange County, North Carolina The Mason Farm Wastewater Treatment Plant (WWTP) discharge is for water inflow to the facility. Arrows (→) indicate rainfall at the Mason Farm WWmP rain gauge ≥ 0.5 cm/day.

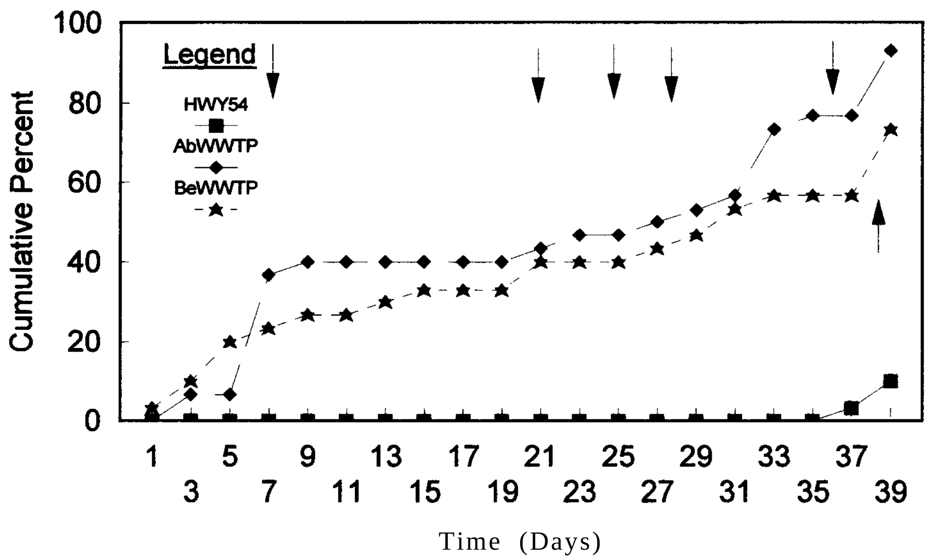

Figure 3. Mortality (cumulative percent) for *Pteronarcys dorsata* in cylinder cages near Highway 54 (HWY54), above the Mason Farm Wastewater Treatment Plant (AbWWTP), and below the Mason Farm WWTP (BeWWTP) in Morgan Creek, Orange County, North Carolina. Arrows (→) indicate rainfall at the Mason Farm WWTP rain gauge ≥ 0.5 cm/day.

site and on Day 31 for the BeWWTP sites, respectively. By Day 39, cumulative percent mortalities were 93.3±11.5, 73.3±6.7 and 10.0±3.3 at the AbWWTP, BeWWTP and HWY54 sites, respectively. Mortality of *P. dorsata* increased following rain storms on Days 7 and 38 at the AbWWTP and BeWWTP sites. Mortality curves for the AbWWTP and BeWWTP sites were not significantly different ($\chi^2_{0.05,1}$; $\chi^2_1 = 25.64$, $\chi^2_2 = 23.16$; $\chi^2_3 = 15.02$).

In situ toxicity studies with benthic macroinvertebrates have focused on organism response to experimental manipulation of water quality in streams (McCahon *et al.* 1989). In this study *P, dorsata* were placed in enclosures to record mortalities under ambient undeveloped and urban reaches of Morgan Creek. Test results revealed greater mortality in the urban reach of the creek. The difficulty in conducting enclosure studies is highlighted by the inability to position cylinder cages at sites with similar stream flow in Morgan Creek. Stream flow is minimal in summer (except following rain storms) and base flow is supplemented by the Mason Farm WWTP discharge to Morgan Creek. *P. dorsata* usually inhabit swift, clean creeks (McCaskill and Prins 1968). Nevertheless, survival was greatest at the HWY54 site where water flow was the least, suggesting the low flows were not deleterious to *P. dorsata.*

Cylinder cage studies demonstrated water quality was superior at the HWY54 site in Morgan Creek. Mortalities of *P. dorsata* occurred following rain storms at the AbWWTP and BeWWTP sites. One *P. dorsata* died on Day 37 and two on Day 39 in cylinder cages at the HWY54 site following rain storms. However, no peaks in storm hydrographs or turbidity were recorded at the HWY54 site following rain storms. Storm water was more turbid, deposited sand and silt, and had a higher specific conductance at the AbWWTP and BeWWTP sites. Fisher *et al.* (1995) determined that storm water from creeks receiving airport runoff was toxic to daphnia (*Daphnia magna*), in laboratory bioassays. However, the authors did not examine affects on benthic macroinvertebrates in the receiving waters. Surveys from the southeastern Piedmont have shown urban runoff decreases benthic macroinvertebrate species richness in streams (Mulholland and Lenat 1992). Although the cylinder cages were held above the stream bed to reduce interaction with the substrate, silt and sand were deposited in the cages at the AbWWTP and BeWWTP sites. Smothering of the *P. dorsata* by sand and silt may account for the greater mortalities at the AbWWTP and BeWWTP sites. It is also plausible that an unidentified toxicant in the storm water may be responsible. Urban storm water can contribute a number of pollutants to streams, particularly heavy metals, which may be toxic to invertebrates (Cole *et al.* 1984).

P. dorsata at the HWY54 site apparently exerted greater shredding (feeding) pressure on leaf packs. Because fewer *P. dorsata* survived at the AbWWTP and BeWWTP sites, leaf shredding was depressed. This sub-lethal indicator of toxicity has been reported elsewhere (McCahon *et al.* 1989; McCahon and Pascoe 1989). However, leaf pack depletion in the cylinder cages due to microbial, immigration of additional leaf shredders, or physical processes were not quantified (Reise 1980).

The HWY54 site is in a rural region of the watershed, which has little urbanization. The AbWWTP and BeWWTP sites are along an urban stretch of Morgan Creek which receives storm water runoff from public (university, roads and bridges), commercial and residential development. The BeWWTP site also receives municipal wastewater from the Mason Farm WWTP. Because of storm water discharge and siltation to the lower reaches of the creek, it is doubtful a relatively intolerant community of benthic macroinvertebrates can become established near the Mason Farm WWTP in Morgan Creek. Unless storm water is managed, limited habitat and diminished water quality will continue to restrict the distribution of intolerant benthic macroinvertebrate species in the urban stretch of Morgan Creek.

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