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Fish response to discharge events from a power plant cooling reservoir in a river affected by acid mine drainage and thermal influences

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Fish response to discharge events from a power plant cooling reservoir in a river affected by acid mine drainage and thermal influences.

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Abstract

Fish response to discharge events from a power plant cooling reservoir in a river affected by acid mine drainage and thermal influences.

Cara Chowning Hoar

Lotic systems are affected by a variety of stressors that can directly or indirectly influence fish behavior and movement. Of considerable interest are the impacts of impoundments and thermal enrichment upon fish populations. The fish community of the Stony River, WV is exposed to a variety of potential stressors. In the summer, a discharge from a power plant cooling reservoir located on the Stony River can result in large increases in discharge and temperature can potentially exceed fish thermal tolerance levels of some species. Further, Stony River is affected by mining affected tributaries that contribute heavy metals to the system while over treatment of this water leads to pH surges and high levels of ammonia. To study the influence of reservoir discharges upon fish populations we evaluated community composition and movement of fish prior to and following discharges from Mount Storm Lake along a thermal gradient and in relation to mining affected inputs. Radio telemetry was used to monitor larger (>65 g) smallmouth bass (*Micropterus dolomieu*) movements and parallel wire electrofishing was used to define fish community composition. The fish community, before and after discharge events, did not differ, but community structure varied with mining affected inputs. Radio telemetry data suggests that bass movement was induced by increased discharge and bass avoided areas of high conductivity associated with effectively treated acid mine drainage (AMD). The observed thermal increases associated with reservoir discharges have minimal effects on fish movement and community composition presently found in the Stony River. Yet fish movement and limited community composition are influenced by the presence of mining affected tributaries. Although effective treatment of AMD reduces the negative influence on fish communities, elevated specific conductivity associated with these inputs is still likely degrading miles of streams and rivers throughout the Mid-Atlantic Region of the United States.

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Figure 2. Temperature regime for the 2004 study period at each site, A) Site 1, B) Site 2, C) Site 3, and D) Site 4, sampled for the electrofishing surveys. Shaded areas and solid straight lines represent the critical thermal maximum (CTmax) for the dominant species found at each site: Site 1—smallmouth bass, [1] 36.9°C (Smale and Rabeni 1995), Site 2—central stoneroller, [2] 28.8-37.7°C (Changon and Hlohowskyj 1989, Mundahl 1990), and Site 4—central stoneroller and creek chub, [3] 35.7°C (Smale and Rabeni 1995)

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Chapter 1: Introduction

Natural and anthropogenic disturbances in lotic systems can have varied effects on the aquatic biota. Well-adapted species take advantage of these conditions where other species are negatively affected (Ross and Baker 1983, Meffe 1984, Turner et al. 1994, Fernandes 1997). The negative influence of disturbances ranges from minor shifts in habitat use (Todd and Rabeni 1989, Brown et al. 2001, David and Closs 2002) to more severe effects, such as reduced abundance and altered community structure (Matthews 1986, Paller et al. 1992).

Increased discharge, elevated temperatures, and mining affected inputs are disturbances that can negatively affect fish communities. Reduced fish abundance and altered community structure are a result of changes caused by these disturbances. The fish community response to these disturbances is dependent on many factors, including fish species, size, and age (Chapman and Kramer 1991, Pearson et al. 1992, Hayes 1995). In addition, the severity of the disturbance is likely an important influence on the response of the fish community (Nislow et al. 2002). This review focuses on the effects of discharge, elevated temperature, and acid mine drainage on fish abundance, community structure, and movements.

Discharge

Discharge is an important factor structuring fish assemblages and behavior. Discharge has variable influences on fish communities and individual species. In some cases, flood conditions have minor influences or are advantageous to some species. Minor influences result in utilization of varied habitats during flood conditions (Matthews 1986). Changes in habitat use can occur with the use of velocity refuge. These refuge areas occur in a variety of forms; backwaters (Brown et al. 2001), flooded riparian zones (David and Closs 2002), boulders or logjams (Todd and Rabeni 1989), deep pools (Matthews et al. 1994), or eddies (David and Closs

2002). In addition, fish have been observed taking advantage of high discharge for reproduction (Fernandes 1997, Parkinson et al. 1999), dispersal to new locations (Fernandes 1997), and exploitation of newly available food sources (Ross and Baker 1983, Turner et al. 1994).

Flood conditions negatively influence fish communities by reducing abundance, decreasing species diversity, and altering community structure (Matthews 1986, Paller et al. 1992). These changes can be immediate (Harrell 1978, Jowett and Richardson 1994, Paller et al. 1992, Nislow et al. 2002) or delayed (Elwood and Waters 1969). The severity of the decline of fish abundance is closely linked to the magnitude of the flood (Nislow et al. 2002). The higher discharge conditions increase the possibility of individuals being displaced (Heggenes and Traaen 1988). Floods that alter instream habitat possibly make the habitat less suitable for the previous fish community (Roghair et al. 2002), thereby reducing diversity, abundance, and altering community structure.

The extent flood conditions negatively effect fish communities is dependent on size, age, and life history traits of the fish (Chapman and Kramer 1991, Pearson et al. 1992, Hayes 1995). Varied life histories lead to some species being adapted to flood conditions while floods negatively affect maladaptive species (Harrell 1978, Meffe 1984, Matthews et al. 1994). Adults often survive floods and remain in a given stream reach (Gerking 1950, John 1964). Juveniles are more susceptible to the negative effects of high discharge conditions (Schlosser 1985, Heggenes and Traaen 1988, Nislow et al. 2002), likely due to their relatively weaker swimming ability. Amongst juvenile fish, there are contrasting observations concerning the effects of fish size on survival during flood conditions. One result is larger fish are more susceptible to mortality due to inability to occupy habitat that provides physical velocity barriers (Angermeier and Karr 1984, Pearsons et al. 1992). In contrast, Uphoff (1989) and Logan (1985) found that smaller individuals experienced higher mortality during increased flow.

Temperature

Temperature is an important ecological resource for fish communities (Magnuson et al. 1979). Fish have a range of temperatures in which normal physiological function occurs. When temperature tolerances are exceeded, physiological functions become impaired, potentially resulting in death (Fry 1947). There are few occurrences of natural heat death due to several reasons. First, fishes are able to increase their upper tolerance levels (Davies 1973). Second, temperature increases often result in increased movement, enabling fish to flee undesirable conditions. Third, the upper tolerance level of most North American fishes is above the ambient temperature in natural systems (Mundahl 1990). However, alterations to natural thermal regimes may increase temperatures to lethal levels or above tolerable levels.

Temperature increases below lethal levels may still negatively influence the fish community. Increased growth and metabolic function are characteristics of increased temperatures (Whitledge et al. 2002). Initial temperature increases contribute to increased growth and metabolic function. Once temperatures reach or exceed tolerance levels, growth and metabolic function declines rapidly (Jobling 1997). Temperature increases unfavorable for growth could lead to declines in their condition, size, and ultimately, population density.

Water temperature is an important influence in fish physiology, distribution, and lifestyle. Temperature is critical to spawning and reproduction, being the primary determinant of spawning time (Graham and Orth 1986). Temperature changes are an important cue to trigger spawning activities in many fishes (Jobling 1995). Some fish spawn in the fall, cued by decreasing temperatures. Many other species spawn in the spring, prompted by warmer temperatures. Temperature increases may induce early gonad development and potentially premature egg deposition (Jobling 1995). Alteration to the natural thermal regime possibly influences fish community structure by influencing reproductive behavior of some species.

In a system where temperatures can exceed or reach tolerance levels, fish may seek thermal refuge. In a heterogeneous environment, fish will change their location to minimize the influence of temperature increases, known as behavioral thermoregulation (Magnuson et al. 1979). Behavioral thermoregulation allows fish to decrease metabolic function by moving to cooler water (Reynolds and Casterlin 1979). Fish may seek necessary thermal refuge in a variety of habitats when temperatures exceed their tolerance levels (Neill and Magnuson 1974). Fish change position in streams (Matthews et al. 1994), lakes with thermal stratification (Brandt et al. 1980), and in response to artificial thermal effluent (Benda 1975, Neill and Magnuson 1974).

Temperature is a major influence on fish distribution, acting as an important habitat parameter (Magnuson et al. 1979). Fish species are divided into thermal guilds (e.g. coldwater, coolwater, warmwater) based on temperature tolerances (Magnuson et al. 1979, Eaton et al. 1995). A prolonged temperature increase can cause shifts from coldwater fish communities, such as salmonids, to cool- and warmwater species, such as centrachids (Eaton et al. 1995). The thermal regime of an aquatic system will ultimately dictate the fish species present (Sowa and Rabeni 1995).

Acid Mine Drainage

In central Appalachia, a common problem in aquatic systems is acid mine drainage (AMD). Acid mine drainage is created when high sulfate coal is removed and water is able to interact with bacteria, oxygen, and pyrites to create a solution of low pH, high sulfates and dissolved metals (Herlichy et al. 1999). Heavy metals can be toxic to aquatic life; the toxicity of these metals depends on their concentrations and pH. The decreased pH associated with AMD inputs increases the solubility of potentially toxic metals, therefore increasing the toxicity to fish (Tiwary 2001). The presence of AMD in a lotic system leads to severe chemical degradation (Woodward et al. 1997), which impairs the aquatic biota. The influence of AMD on aquatic biota can be curtailed with treatment of affected inputs. Treatment of AMD results in increased pH, therefore reducing toxic metal solubility (Tiwary 2001). Although the impairment may be reduced by treatment, elevated metal and ion concentrations associated with these inputs may have sublethal effects on fish communities.

Acid mine drainage can cause direct impairment on the fish communities through influences including heavy metal toxicity (Barry et al. 2000, Lydersen et al. 2002) and disruption of ion regulation (Beaumont et al. 2000) or indirectly reduce the benthic macroinvertebrates (Scullion and Edwards 1980). The fish community is often closely linked to the benthic macroinvertebrate community (Freund 2004), which serves as prey. Fish abundance, species richness, and diversity are generally reduced downstream of AMD inputs (Woodward et al. 1997, Freund 2004). These effects on fish communities may be reduced through treatment of AMD inputs (Freund 2004). The increased pH after treatment allows for acid-sensitive benthic macroinvertebrates to persist, restoring a valuable food source to fish.

Other indirect influences of AMD on fish communities include reduced dispersal through avoidance behavior (Woodward et al. 1997), reducing the source of potential colonizing individuals (Gore and Milner 1990), or creating a chemical barrier through which dispersal is limited to periods of relatively good water quality (Schlosser 1995). Often, AMD produces a severe degradation of habitat quality (Herlichy et al. 1999, Williams et al. 1999). Treatment of AMD decreases the influence of these inputs on water quality (Tiwary 2001), yet these inputs possibly continue to influence fish movements. Treatment of AMD increases pH, but dissolved ions and metals are still elevated, resulting in high specific conductivity, which is highly associated with mine drainage (Gray 1996). Fish have been observed experiencing hyperactivity when exposed to sublethal concentrations of metals (Ellgaard et al. 1978). Avoidance behavior is detected in areas of elevated specific conductivity (Hartwell et al. 1987a, 1987b) and high movement rates and avoidance of high metal concentrations have been suggested as an indicator of habitat degradation (Winker et al. 1995).

Understanding fish behavior during disturbances and alterations to their habitat has important management implications, since stressors can have a variety of influences on the fish community. Floods can reduce fish abundance and alter community structure (Matthews 1986) or influence fish movements (Hubert 1981). Temperature changes can alter fish distribution and species composition (Eaton et al. 1995) or cause individuals to seek thermal refuge (Neill and Magnuson 1974). The presence of AMD reduces abundance, species richness, and diversity (Freund 2004, Woodward et al. 1997). In addition, fishes may increase movement rates (Scarfe et al. 1983) and exhibit avoidance behavior in response to AMD inputs (Woodward et al. 1997). To understand the influence of these potential stressors on a fish community, it is important to understand how fish respond to these environmental conditions.

Electrofishing Surveys and Telemetry

Electrofishing surveys are useful in determining the abundance and composition of fish communities. Therefore, electrofishing surveys can be utilized to study the influence of discharge, temperature, and AMD on fish abundance, species diversity, and richness. The current understanding of high discharge events comes from the comparison of fish community structure before and after flood events (i.e. Matthews 1986, Jowett and Richardson 1994).

Electrofishing surveys provide information on abundance and species compositions in response to these events, but do not account for the behavioral response of fishes to these potential stressors. To study behavioral responses requires integration of other techniques. The combined use of electrofishing surveys and telemetry provides response on the community level as well as behavioral responses.

There are generally two types of underwater telemetry: ultrasonic and radio. Although telemetry studies can be expensive, they are the most practical in gathering information on fish movements in response to environmental variables. After initial surgical or tag attachment procedures, telemetry is less invasive for data collection than other methods (Winter 1983). Following initial implantation, recovery from surgery is relatively short and tracking has little influence on fish behavior (Martinelli et al. 1998).

The choice between ultrasonic and radio telemetry is based on the study area (Winter 1983). Ultrasonic telemetry was developed for underwater use due to low frequency and long wave signal (Winter 1983). These characteristics make it more suitable for high conductivity waters such as saltwater or deep water. However, the signal is negatively affected by a variety of environmental conditions, such as a thermocline, algae, and turbulent water. Individual ultrasonic transmitters are distinguished by different pulse rates, thereby reducing the number of distinguishable individuals. Radio telemetry was originally developed for terrestrial studies, but was modified for aquatic use. Radio transmitters are most effective in shallow, low conductivity water (Winter 1983). Algae, thermoclines, and turbulent waters do not affect radio signals. Radio receivers do not have to come in contact with the water, enabling a greater area to be sampled in a shorter period of time. Radio signals can be reflected by a variety of objects, such as metals, trees, or boulders. The presence of these obstacles makes precise locations difficult, yet this can be reduced with experience. These characteristics make radio telemetry the more appropriate method for a study in a high gradient, rocky stream.

Radio transmitters are attached to the fish through surgical implantation, gastric implantation, or externally. External attachment of transmitters is not possible in streams, due to drag, imbalance, and possible entanglement. Gastric implantation of transmitters is not favorable due to alterations in feeding and loss of tags through regurgitation. Surgically implanted transmitters have a long retention time and have little or no influence on fish movement and behavior (Winter 1983). Further, the recovery time for surgical implantation is reduced compared to gastric implantation (Martinelli et al. 1998).

Originally, telemetry was limited to larger fishes for short periods of time. Advances in technology have allowed the development of smaller, more powerful transmitters. This enables telemetry to be used on smaller fish for longer periods of time (Winter 1983). These advances have made telemetry of stream fishes possible. The use of radio telemetry in conjunction with electrofishing surveys provides information on fish community structure and fish movement in response to potential stressors, such as increased discharge, temperature fluctuations, and AMD inputs.

Objective and Summary

The objective of this study was to determine the effects of increased discharge, elevated temperature, and mining affected inputs on fish abundance, species composition, and movement. These disturbances can be detrimental to fish assemblages, by reducing fish abundances and altering species composition. In addition, these disturbances could influence fish movements. Electrofishing surveys were conducted before and after discharge events. Sites were chosen based upon the thermal gradient and location of mining affected tributaries. These collections evaluated the influence of temperature and mining inputs on fish abundance and species composition. In addition, radio telemetry studies were conducted on smallmouth bass (*Micropterus dolomieu*) during two summers to evaluate the effects of these environmental parameters on their movement. This study will provide information on fish response to three potential stressors (i.e. increased discharge, elevated temperature, and mining affected inputs) located in a single lotic system.

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Chapter 2: Fish response to discharge events from a power plant cooling reservoir in a river affected by acid mine drainage and thermal influences

Introduction

Stream systems have naturally fluctuating temperatures, and temperature is an important factor influencing fish physiology, lifestyle, and distribution. Alterations to the natural temperature regime act as a potential stressor to individuals and fish communities. Temperature influences individual fish by altering metabolic rate (Whitledge et al. 2002), feeding behavior (Logan et al. 1991), reproduction (Graham and Orth 1986), and growth (Wrenn 1980). The most dramatic effect of elevated temperature is death (Fry 1947), but there are few accounts of natural heat death in aquatic systems. Several observations explain the low number of natural heat deaths. First, fish are able to increase their tolerance of high temperature (Davies 1973). Second, high temperatures induce increased activity, enabling fish to flee the high temperatures. Third, the upper tolerance level of most North American fishes is above the ambient temperature in natural systems (Mundahl 1990).

Temperature increases ultimately affect the fish community inhabiting the aquatic system. In a system influenced by thermal industrial effluents, temperatures can possibly exceed tolerance levels, serving as a potential stressor to fish communities. Section 316(a) of the federal Clean Water Act regulates the temperatures of these industrial effluents (USEPA 1974). The temperature of the discharge must support the protection and propagation of balanced indigenous populations in the water where the discharge occurs. Variances are awarded, allowing temperatures to exceed "natural temperatures," when owners of the discharge provide proof that the waters receiving the discharge can support a balanced indigenous population (USEPA 1974).

Increases in water temperature may alter the local fish community structure. Thermal tolerance levels vary; coldwater species have the lowest tolerance levels of any fish group (Eaton et al. 1995). As temperatures in lotic environments increase, there is a shift from coldwater species, such as salmonids, to cool and warmwater species, like centrachids (Eaton et al. 1995). In addition to alterations in community structure, temperature fluctuations have been shown to cause fishes to change positions in a variety of habitats. Fish change position in streams (Matthews et al. 1994), lakes with thermal stratification (Brandt et al. 1980), and in response to artificial thermal effluent (Neill and Magnuson 1974). Smallmouth bass (*Micropterus dolomieu*) have been found to seek seasonal thermal refuge in Jacks Fork River, Missouri (Peterson and Rabeni 1996). In the presence of heated effluents, fish will typically seek thermal refuge when cool water sources are available (Neill and Magnuson 1974).

The flow regime of lotic systems is a potential stressor on aquatic communities. These flow regimes are often driven by climatic events, such as precipitation and snowmelt. High discharge events may reduce abundance and alter community structure (Matthews 1986), but these effects are variable. The highly unpredictable flow regime associated with regulated rivers and streams can intensify these effects (Bain et al. 1988). These events may result in declines in fish density, either immediate (Harrell 1978, Jowett and Richardson 1989, Paller et al. 1992, Nislow et al. 2002) or delayed (Elwood and Waters 1969). High discharge events may have negative effects on some species, while others take advantage of high discharge to reproduce (Fernandes 1997, Parkinson et al. 1999), disperse to new locations (Fernandes 1997), or exploit newly available food sources (Ross and Baker 1983, Turner et al. 1994). Although high flow events may be utilized for various purposes, all individuals must seek refuge during extremely high discharge. Refuge areas occur in a variety of forms, including backwaters (Brown et al. 2001), flooded riparian zones (David and Closs 2002), boulders or log jams (Todd and Rabeni

1989), and deep pools (Matthews et al. 1994). These areas create shelter from high velocity water associated with high flow events.

A power plant cooling reservoir on a river can create a situation where fish are simultaneously exposed to elevated water temperature and increased discharge. Reservoir temperatures are warmer than the ambient river temperature; therefore, when the reservoir discharges, river temperature increases, potentially exceeding fish tolerance levels. The coupling of high discharge and elevated temperature could intensify the effects of these stressors on the fish community. Velocity refugia shield fish from high discharge, while continuing exposure to elevated temperature. Thermal refuge reduces exposure to elevated temperatures, but may not eliminate the effects of high discharge. Exposure to one stressor may be more detrimental than the other and refugia from both conditions may not overlap, thereby requiring individuals to "choose" one condition over the other. For example, smallmouth bass preference for an optimal temperature is overridden by a stronger preference for other variables, such as food (Bevelhimer and Adams 1991) or cover (Bevelhimer 1996).

A common problem associated with central Appalachian mountain streams is the presence of acid mine drainage (AMD). Acid mine drainage is created when high sulfate coal is removed and water is able to interact with bacteria, oxygen, and pyrites to create a solution of low pH, high sulfates and dissolved metals (Herlichy et al. 1999). Species richness, community composition, and abundance are reduced downstream of AMD inputs (Woodward et al. 1997, Freund 2004). Fish can be directly influenced by AMD inputs through heavy metal toxicity (Barry et al. 2000, Lydersen et al. 2002) and disruption of ion regulation (Beaumont et al. 2000), or indirectly with the reduction of benthic macroinvertebrate (Scullion and Edwards 1980). The fish community is often closely linked to the benthic macroinvertebrate community, which many fish utilize as prey (Freund 2004). Other indirect effects of AMD on fish communities are reduced dispersal through avoidance behavior (Woodward et al. 1997), reducing the source of potential colonizing individuals (Gore and Milner 1990), or creating a chemical barrier through which dispersal is limited to periods of relatively good water quality (Schlosser 1995). Often, AMD produces a severe degradation of habitat (Herlichy et al. 1999, Williams et al. 1999).

Some studies have focused on fish response to flows, temperature, or AMD, few if any have examined their interactive effects. Therefore, the objective of this study is to determine the effects of heated discharges from a power plant reservoir on fish abundance, species composition, and movement in a river partially affected by AMD. We evaluated fish abundance and species composition before and after discharges at four sites along the river, varying in temperature and conditions of mining affected tributaries. Smallmouth bass movement was evaluated to observe fish movements in response to thermal releases from a power plant cooling reservoir and to determine if movement in the mainstem is affected by mining influenced inputs.

Study Area

This study was conducted on the Stony River, a tributary of the North Branch of the Potomac River, located in Grant County, West Virginia (Figure 1). There are two impoundments along the Stony River: Stony River Reservoir and Mount Storm Lake. Mount Storm Lake is 486 hectares in size and was constructed for cooling capacity for the Mount Storm power plant. The dam at Mount Storm Lake does not function for flood control. It has no capacity to withhold water when the upstream Stony Reservoir discharges or when rainfall events increase the lake levels. It is a run-of-the-river dam structure. Water in the lake is warmer than ambient river water. Thus, when water is discharged from the lake to the Stony River it is the majority of flow, and river temperatures increase over ambient water temperature.

The study focused on a 13 km segment of river located downstream of Mount Storm Lake dam. This segment of the Stony River is influenced by thermal enrichment when Mount Storm Lake is discharging and mining activities in the watershed. During discharges from the lake temperatures are elevated over ambient temperatures throughout the 13 km segment. There is a mine effluent, Laurel Run mine outfall, approximately 2 km downstream of the Mount Storm Lake dam. These mine waters have effective treatment, resulting in neutral pH and high specific conductivity in the mainstem Stony River downstream of the input. In addition, two tributaries that are affected by mining activities, Fourmile Run and Laurel Run, are located 3.5 and 4.8 km downstream from the dam, respectively. Fourmile Run is a treated system, yet treatment is inconsistent. In the mainstem Stony River immediately downstream of Fourmile Run, pH fluctuates between 6.5 and 9.7, allowing metals to go in and out of solution and resulting in a large amount of precipitated metals. Laurel Run has no treatment for AMD, yet due to its small size (2 cfs) this tributary has little influence on the water quality of the mainstem Stony River.

Methods

To evaluate the possible influences of discharge, elevated temperature, and mining affected tributaries upon the fish community, a combination of fish surveys and radio telemetry were used in 2003 and 2004. Electrofishing surveys were conducted before and after discharges from Mount Storm Lake. Collections were made along the thermal gradient and near mining influenced inputs in the Stony River. These surveys were to examine the influences of mining affected inputs and discharge-related temperature increases on the fish community. The radio telemetry studies were designed to determine if movement in larger smallmouth bass (> 65 g) is influenced by the discharge events from Mount Storm Lake and to determine if the presence of mining affected tributaries affected smallmouth bass movement.

Electrofishing Survey

Four 150 m segments in the Stony River were chosen for fish sampling. These sites were distributed along the temperature (higher near dam) and mining affected (from tributaries) continuums present in the Stony River (Figure 1). Site 1 is located approximately 0.3 km downstream of the dam and is characterized by the highest temperatures during discharges from Mount Storm Lake. Site 2 is located immediately downstream of the Laurel Run mine outfall (approximately 2.0 km downstream of the dam). During base flow at this site fish are exposed to elevated specific conductivity, which becomes dilute during lake discharge events. Site 3 is located immediately downstream of Fourmile Run (approximately 3.6 km downstream of the dam). At this site, fish are exposed to degraded water quality (elevated metal and ion concentrations) associated with ineffective treatment of AMD. In addition, pH fluctuates in the Stony River mainstem from 6.5 to 9.5 due to inconsistencies in Fourmile Run water treatment. Site 4 is located approximately 12.9 km downstream from the dam. This site represented a background conditions for the river; temperature increases are minimal during discharge events and AMD impairment is nominal.

Sites were sampled using AC current parallel wire electrofishing gear (Dominion Environmental, Richmond, VA) powered by a portable generator (2000 watts, Honda, Alpharetta, GA). Blocknets were placed at both ends of the sites prior to collections to prevent movement of fish out of the sampling site. Each site was sampled before and after two discharge events from Mount Storm Lake. The first was on 23 June 2004 (discharge 1) and the second was on 11 August 2004 (discharge 2). The time between discharges allowed for community recovery, if needed.

Before discharge fish samplings were made on 22 June 2004 for discharge 1 and 10 August 2004 for discharge 2. Upon collection, fish were identified to species, measured (total length), and given a fin clip to represent the collection site. Fin clips were used to determine if individuals remained in the sampling segment following discharge events. Fish were released in their original collection location. After all sites were sampled for the pre-discharge survey, water was released from Mount Storm Lake, simulating conditions in the Stony River when discharge events occur due to precipitation events. Water was released to reach a maximum discharge >130 cfs and to exceed base flow (<30 cfs) for a minimum of 12 hours. Once discharge in the Stony River returned to base flow (<30 cfs), the four sites were again sampled using the same methods as the pre-discharge survey. After discharge collections for discharge 1 and 2 were made on 24 June 2004 and 12 August 2004, respectively. The same information was collected from all fish and the presence of a fin clip was noted.

Radio Telemetry

Radio telemetry was used to monitor daily movement of 20 smallmouth bass in summer 2003 (August to September) and 27 smallmouth bass in summer 2004 (June to September). In 2004, there were slight variations in procedures from 2003 methods.

Radio Transmitters

In 2003, the radio transmitters (model F1420 Advanced Telemetry Systems, Inc., Isanti, MN) weighed 1.3g with external dimensions of 8x16x7 mm. In 2004, the radio transmitters (model F1430 Advanced Telemetry Systems, Inc., Isanti, MN) weighed 1.7 g with external dimensions of 9x17x7 mm. The tags were set to pulse at 35 ppm, giving a 28d warranty battery life and 56d battery capacity for the 1.3g transmitters and a 50d warranty battery life and 100d battery capacity for the 1.7g transmitters. Each tag had a unique frequency, which permitted identification of individual fish. Radio transmitters did not exceed 2% of the fish's total weight (Winter 1983, Bunnel et al. 1998).

Fish Capture

On 05-08 August 2003, smallmouth bass were collected from various locations in the Stony River using AC current parallel wires, and then transported to the surgery site in a 150-L container. On 25-30 June and 16 July 2004, smallmouth bass were angled from the Stony River and transported to the surgery site in 60.6-L containers. Collected fish were weighed to determine their suitability for the study. Minimum weight requirements for tagged fish were 65g in 2003 and 85g in 2004. At the surgery site, fish were held in 60.6-L containers until anesthetized for the surgical procedure. All holding and transport containers contained aerated ambient river water.

Surgical Procedures

All procedures followed animal care and use protocols developed by West Virginia University (ACUC #03-0604). Prior to the surgical procedure, fish were anesthetized individually. In 2003, fish were anesthetized with 120-mg/L clove oil solution at 20ºC (Anderson et al. 1997). In 2004, fish were anesthetized with 75-mg/L tricaine methanesulphonate at 18ºC. Anesthetic water bath temperature was maintained near capture temperature to avoid thermal stress (Jepsen et al. 2002). Upon losing equilibrium, fish were removed from the anesthesia bath, weighed, and measured (total length). The anesthetized fish was placed on water-saturated cotton, with a cloth placed over the head to ensure the gills stayed moist throughout the procedure. All instruments and radio transmitters were cleansed in

Nolvasan solution prior to each surgical procedure. The transmitter was placed in the body cavity through a 0.6-0.8 cm incision made mid-ventrally, posterior to the pelvic girdle. In 2003, the antenna exited the body cavity from the same incision. However in 2004, the external antenna was threaded through a hole located 1cm posterior from the incision and created with a curved hollow needle. All incisions were closed with monofilament nylon sutures using simple interrupted suture knots approximately 0.2 cm apart (Hart and Summerfelt 1975). Following surgical implantation, individuals were placed in a 60.6-L recovery tank until equilibrium returned.

Release Areas

Fish were released in areas of low velocity water at two locations along the Stony River: immediately downstream of Mount Storm Lake dam and downstream of the Laurel Run mine outfall (2.0 km downstream of the dam). In 2003, ten smallmouth bass were released in each location. In 2004, 17 smallmouth bass were released downstream of the dam and ten individuals were released downstream of the mine outfall. The Laurel Run mine outfall was used as a potential physio-chemical barrier, which allowed the evaluation of the outfall as a chemical impediment to fish movement. This was used rather than the other tributaries due to the more consistent treatment it receives as well as ease of accessibility.

Data Collection

Tracking of radio tagged fish was performed daily by two persons walking the study sections using two scanning receivers (Model R2000, Advanced Telemetry Systems, Inc. Isanti, MN), each programmed with half of the frequencies to eliminate the possibility of missed fish during the tracking surveys. Fish locations were determined by direction and signal strength. A GPS unit (Garmin GPS III Plus, Olathe, KS) was used to determine coordinates for the habitat in which the fish was located. Habitat characteristics, such as distance to cover, pool, riffle, or run, were observed and recorded at each fish location. Temperature, specific conductivity, pH, and dissolved oxygen were measured at each location using an YSI mutliprobe (model 650, YSI, Yellow Springs, OH).

Additional temperature and specific conductivity data was collected hourly from multiple points along the 13 km section of river using Hydrolab multi-probe (Hach Environmental, Loveland, CO). Discharge data was obtained from the USGS gauging station (#01595200) located on the Stony River 13 km downstream from Mount Storm Lake.

Analysis

In the electrofishing surveys, species composition similarity was determined using Morisita's similarity index. Morisita's similarity index is nonbiased with sample size and diversity (Wolda 1981). Morisita's index varies from 0 (no similarity) to 1.0 (complete similarity). These values were used to determine if species composition was similar before and after discharge events, among sites, and among discharges. Species composition similarity allowed combining results from the two discharge events and enabling statistical analysis of mean abundance. Mean abundance was compared between sites using one-way analysis of variance (ANOVA)

Continuously monitored parameters (i.e. discharge, temperature, and specific conductivity) in the river from 2003 and 2004 were compared using a two-tailed t-test. For the radio telemetry studies (2003 and 2004), groups of fish from each release location were analyzed separately due to the variation in environmental conditions at the respective release areas. Daily fish movement distances were determined using ArcView 3.2 Animal Movement Extension (Hooge and Eichenlaub 2000). Fish remaining in the same habitat unit were deemed to have a daily movement rate of zero. A constant was added to daily movement rate then log-transformed to approximate normality. Fish movement was measured in mean movement rate (log m/d). Fish movements were characterized by levels relative to the highest discharge for each tracking day, <30 cfs, 30-100 cfs, 100-180 cfs, and ≥180 cfs, hereafter referred to as discharge levels. During rapid increases in discharge, all movements during those discharge events were placed in the highest possible discharge level. Daily maximum river temperature was used to evaluate the influence of river temperature on fish movement rate. Specific conductivity was used to evaluate the influence of mining affected inputs on mean movement rate. This parameter was chosen due to tight correlation between high specific conductance and the presence of mine drainage inputs (Gray 1996). Backward step-wise multiple regression analysis was used to determine correlation between mean movement rate and environmental parameters. Duncan's multiple range test was used to determine differences among means. In all tests alpha was set at 0.05.

Results

Electrofishing Surveys

Mean river temperature was highest at site 1 (immediately downstream of the dam) and temperature decreased with distance from the dam. Specific conductivity increased at sites downstream from mining influenced tributaries (Table 1). The discharge events varied in maximum river temperature, maximum discharge, and duration of discharge (Table 2). At each of the four sites, species composition after the individual discharge event was similar to species composition before the discharge event (Table 3). Collections from discharge 2 yielded a species composition similar to that of discharge 1 (Table 3). Due to these similarities, the mean abundance values for each site were used for the remainder of the analysis.

Slight variations in species compositions were observed during the electrofishing surveys. These variations were due to the effects of discharge on the lake species present in the Stony River. Following discharge events, there was a loss of channel catfish (*Ictalurus punctatus*) from site 1 (both discharges) and largemouth bass (*Micropterus salmoides*) from site 2 (discharge 2, Table 4). The species composition varied between sites. Sites 1 and 4 were the most dissimilar (Table 5), with site 1 being dominated by smallmouth bass and site 4 being dominated by creek chub (*Semotilus atromaculatus*) and central stoneroller (*Campostoma anomalum*, Table 4). Sites 2 and 4 had the most similar species compositions between the sites (Table 5). Site 2 was dominated by central stonerollers (Table 4). River temperature at each site rarely or never exceeded the critical thermal maximum for dominant species collected at those sites (Figure 2).

The post-discharge mean total abundance was not significantly different from the pre-discharge abundance at any of the sites (Table 6). The mean total abundance between sites was significantly different, with no individuals being collected at site 3 during pre- or post-discharge collections (ANOVA, $df=3$, $F=10.05$, $p=0.0014$). Sites 3 and 4 had significantly lower total abundance than the site immediately downstream of Laurel Run mine outfall. The total abundance at Site 1 did not significantly vary from Site 4 (Figure 3).

Recapture rate of fin-clipped fish at each site following discharge was low. The mean recapture rates of fin clipped individuals at sites 1, 2, and 4 were 18.6, 20.2, and 0%, respectively (no individuals were collected at site 3). The low recapture rate is likely a result of low sampling efficiency, mortality, or individuals moving out of the sampling reach during the discharge.

Radio Telemetry

In 2003, fish were tracked for a 38d period with a maximum of 22 observations per fish. Most smallmouth bass locations (89.2%) were in pools within 5 m of boulder cover. During the tracking period discharge ranged from 10 cfs to 1225 cfs. Three high flow events resulted from water releases from Mount Storm Lake (Figure 4); all events were a result of precipitation events. Temperature immediately downstream from the dam ranged from 19.4 to 33.4°C with higher temperatures observed during discharges from Mount Storm Lake (Figure 4). Due to high mortality in summer 2003, only seven individuals were included in the analysis. Three individuals released immediately downstream of the dam and four individuals released downstream of Laurel Run mine outfall were included in the analysis.

In 2003, the mean movement rate of fish released immediately downstream from the lake was significantly related to individual fish ($F=6.27, p=0.0032$) and was not related to any other parameters, such as discharge, maximum river temperature, or the interaction of the two parameters. The mean movement rate of fish released immediately downstream from the mine outfall did not relate to discharge, temperature or specific conductivity. The mean movement rate was similar across all discharge levels (Figure 5). The mean movement rate did not significantly differ among individuals released immediately downstream of the dam and those released immediately downstream of the mine outfall (ANOVA, $F=0.34, p=0.5599$).

During the 2004 radio telemetry study, the environmental conditions of the Stony River downstream of Mount Storm Lake were significantly different than the conditions during summer 2003 (Table 7). The mean specific conductivity immediately downstream of the Laurel Run mine outfall was significantly lower in summer 2003 than summer 2004 (t-test; $t=11.41,$

$p<0.0001$). The mean maximum river temperature was significantly higher (t-test; $t=7.36, p<0.0001$) as was mean discharge (t-test; $t=9.31, p<0.0001$) in summer 2003 than summer 2004.

In 2004, fish were tracked for an 80d period with a maximum of 72 observations per fish. Most smallmouth bass locations (98.7%) were in pools other observations were with riffles and run. All observations were within 5m of boulder cover. During the tracking period discharge ranged from 6 cfs to 1850 cfs. Five high flow events resulted from water releases from Mount Storm Lake, one from a planned discharge for an electrofishing survey and four from precipitation events (Figure 4). Temperature immediately downstream from the dam ranged from 15.9 to 32.0°C, higher temperatures observed during discharges from Mount Storm Lake (Figure 4).

Mean movement rate of all fish significantly decreased following the initial dispersal from the release areas, which occurred during the first discharge following implantation (dam release area: $F=11.00, p<0.0001$; outfall release area: $F=4.49. p=0.004$). Therefore, the time period from radio transmitter implantation to immediately following the first discharge event was removed from analysis.

Three fish released downstream of the dam and one fish downstream of the mine outfall were lost early in the 2004 tracking period. These fish were likely lost due to mortality and were not included in the analysis. Six fish released immediately downstream of the dam moved upstream of the release area into a pool approximately 6 m in depth, where the water spills from the lake. Once entering this pool in their initial dispersal from the release area, these individuals remained in this location for the remainder of the tracking period. As a result, these fish were not exposed to the same high velocity water associated with discharge events found in the confines of the Stony River, therefore they were not included in analyses of fish movement rates.

In fish released immediately downstream of the dam, 21% of the variation in movement was explained by a multiple regression model ($R^2=0.21, F=8.67, p<0.0001$). River temperature ($F=30.34, p<0.0001$) and discharge were positively correlated movement rates. The individual fish ($F=3.44, p=0.0014$) significantly contributed to the model, while the interaction of river temperature and discharge did not. Fish released immediately downstream of Mount Storm Lake had higher movement rates when discharge was between 30 and 100 cfs and greater than 180 cfs (Figure 6).

In fish released immediately downstream of the Laurel Run mine outfall, 35% of the variation in movement was explained by a multiple regression model ($R^2=0.35, F=18.67, p<0.0001$). Specific conductivity ($F=63.35, p<0.0001$) was negatively correlated to movement rate. However, river temperature ($F=6.03, p=0.0145$), discharge ($F=4.39, p=0.0368$) and the temperature-discharge interaction ($F=4.28, p=0.0393$) were positively correlated to movement rates. The individual fish ($F=19.95, p<0.0001$) significantly contributed to the model. Mean movement rates were lowest during the lowest discharge level, <30 cfs (Figure 6).

Fish released immediately downstream of the dam had restricted upstream movement due to the presence of the dam. In 2004, additional long movements did not follow the initial long distance dispersal from the dam release location. During 2004, downstream of the dam no individual exceeded a mean movement rate of 25 m/d and there was an overall mean movement rate of 8.00 +/- 1.96 m/d. Those fish released downstream of the mine outfall in 2004 had more observed fish locations upstream of the mine outfall (Figure 7) and no individual that moved upstream of the mine outfall had a mean movement rate that exceeded 25 m/d. For fish moving above the mine outfall the mean movement rate was 4.60 +/- 1.59 m/d.

In 2003, all individuals (n=4) released downstream of the mine outfall remained there (Figure 8). However, only three individuals maintained a position downstream of the mine outfall in 2004 (Figure 8). Two of these individuals lost their signals before the end of tracking and the third perished downstream of Fourmile Run. There was a significant difference in mean movement rates among years and fish final position (ANOVA, $F=25.07, p<0.0001$). All individuals that maintained position downstream of the mine outfall had mean movement rates that exceeded 60 m/d and had an overall movement rate of 78.78 +/- 40.69 m/d. In 2004, individuals released downstream of the dam and those released downstream of the mine outfall that had a final position above the mine outfall had significantly lower mean movement rates than individuals that remained downstream of the mine outfall (Figure 9). The mean movement rates of individuals that remained downstream of the mine outfall in 2004 were not significantly different from all 2003 individuals (Figure 9).

Discussion

The fish species currently found in the Stony River downstream of Mount Storm Lake appear uninfluenced by the observed increased water temperature associated with discharge events. The discharge temperatures from Mount Storm Lake do not exceed the critical thermal maximum (CTmax) of collected species (Hockett and Mundahl 1988, Mundahl 1990, Smale and Rabeni 1995). Fish species do not inhabit systems where temperatures would be detrimental (Eaton et al. 1995). The electrofishing surveys documented the fish community structure did not change following discharge events although less common lake species (channel catfish and largemouth bass) appeared to be flushed from the study reaches. Channel catfish in fluvial systems are generally associated with pool habitat (Jenkins and Burkhead 1993). Aadland

(1993) found that channel catfish were observed in medium- to deep-pools and these areas were relatively insensitive to changes in flow. However in the study reaches of the Stony River there are few medium- to deep-pool areas that could be used as velocity refuge for the channel catfish.

The electrofishing surveys showed that fish abundance and species composition of the Stony River is influenced by the presence of mining affected tributaries. The influence of these mining affected tributaries is variable. The treatment of the Laurel Run mine outfall results in neutral pH and elevated specific conductivity in the mainstem Stony River (downstream from the Laurel Run mine outfall). Potentially, these conditions alter the species composition, shifting from a population dominated by smallmouth bass directly downstream of the dam to a population dominated by central stoneroller. During this study, central stonerollers were not collected upstream of the Laurel Run mine outfall. However, individuals have been collected immediately downstream of the dam by Dominion Environmental during other surveys, indicating that this species is in low abundance upstream of the Laurel Run mine outfall. Higher elevated temperatures near the dam associated with Mount Storm Lake discharge are not a likely explanation for this shift; both species have a CTmax greater than temperatures found below the dam during this study (Changon and Hlohowskyj 1989, Mundahl 1990, Smale and Rabeni 1995).

Studies have shown that smallmouth bass can strongly affect the distribution and abundance of their prey (i.e. crayfish, Stein 1977). However in the Stony River, the reduced abundance of central stoneroller upstream of the Laurel Run mine outfall is not likely due to the presence of smallmouth bass. Central stoneroller were observed in pools despite the relatively high abundance of smallmouth bass (Matthews et al. 1987). Harvey et al. (1998) determined that smallmouth presence had little influence on central stoneroller distribution.

However, other biotic processes, such as food sources and grazing opportunities, are possibly driving the shift in species composition (Power et al. 1985). Crayfish are a preferred food item for smallmouth bass (Probst et al. 1984), yet they occur in low abundance in the Stony River (Horn 2005). When preferred food items are absent, smallmouth bass may seek alternative food sources such as fishes and insects (Probst et al. 1994). Insect densities are reduced downstream of Laurel Run mine outfall compared to densities immediately downstream of the dam (Dominion Environmental, unpublished data). In the Stony River, smallmouth bass diets are likely comprised of insects. These low insect densities likely decrease the possibility of smallmouth bass from inhabiting this portion of the river.

Grazing opportunities for central stoneroller are increased downstream of the Laurel Run mine outfall, possibly supporting the increased presence of the species. The input of treated AMD supports algal growth (Perrin et al. 1990), and there was an increased amount of algal growth observed downstream of the Laurel Run mine outfall. The increased algal growth possibly serves as a food source for the central stoneroller and algal growth has been shown to influence central stoneroller distribution (Power et al. 1985).

In addition to biotic processes, species tolerance levels to the water quality associated with Laurel Run mine outfall potentially influence the species composition of the Stony River. Central stoneroller is considered a tolerant species (Birge et al. 2000), thereby potentially tolerant to the water quality associated with the Laurel Run mine outfall. Smallmouth bass may have a decreased tolerance to mining influenced inputs (discussed later), potentially inducing avoidance and decreasing smallmouth bass abundance in this region.

Fish abundance and species composition are reduced downstream from Fourmile Run, where acid mine drainage is inconsistently treated and pH fluctuates from 6.5 to 9.7 in the mainstem Stony River. These fluctuating conditions indirectly influence the fish community by decreasing abundance and diversity of macroinvertebrates (Scullion and Edwards 1980), which are an important prey item for many fishes. The direct influences result from decreases in pH allowing for increased metal solubility, creating the possibility of metal toxicity on fish (Barry et al. 2000, Lydersen et al. 2002).

Although it appears that temperature is not influencing the current abundance and species composition of the Stony River, the thermal history and/or AMD history of this system have potentially reduced abundances or extirpated other species. The fantail darter (*Etheostoma flabellare*) and blacknose dace (*Rhinchthys atratulus*) were not collected during this study, but have been collected in low numbers in the Stony River (Dominion Environmental, unpublished data). The presence of these species in the Stony River is restricted to downstream of Mill Run, a healthy tributary approximately 11.3 km downstream of the dam. These species are abundant in Mill Run (Dominion Environmental, unpublished data) so Mill Run is potentially the source for these species in the Stony River downstream of its confluence. In addition, the white sucker (*Catostomus commersoni*) was not collected during this study, but has been collected in relative low numbers throughout the Stony River in 2001 through 2004 (Dominion Environmental, unpublished data).

These species, found in low abundances and/or restricted distributions in the Stony River, are found in the North Branch of the Potomac River. Blacknose dace and white sucker are the dominant species in the North Branch of the Potomac River within 16 km of the confluence of the Stony River (R. Morgan, Appalachian Environmental Lab, Frostburg, MD, unpublished data). The white sucker has a CTmax of 34.9°C (Smale and Rabeni 1995), which was never exceeded in the Stony River in October 2001 to October 2004 monitoring. But the maximum preferred temperature for the white sucker is much lower (27.1°C; Cincotta and Stauffer 1984). The blacknose dace has a CTmax of 31.9°C (Kowalksi et al. 1978), which is often exceeded upstream of Laurel Run mine outfall during summer discharges from Mount Storm Lake. The preferred temperature for blacknose dace is 24.6°C (Cincotta and Stauffer 1984). The lower preferred and tolerance temperatures of these species potentially explain their low abundance and/or limited distribution in the Stony River, despite being dominant species in the North Branch of the Potomac River (R. Morgan, Appalachian Environmental Lab, Frostburg, MD, unpublished data). The fantail darter has broad ranging CTmax (30.4 to 37.7°C), with the higher CTmax values being determined with extremely high acclimation temperatures (Ingersoll and Claussen 1994, Hlohowskyj and Wissing 1985, Mundahl 1990). This species has a preferred temperature range of 19.3 to 20.3°C (Ingersoll and Claussen 1984), much lower than the CTmax. Although the CTmax of this species can be much higher than temperatures associated with summer discharges from Mount Storm Lake, the fantail darter still has a reduced population and a limited distribution in the Stony River. The CTmax of the fantail darter is significantly reduced by the presence of sublethal concentrations of copper (Lydy and Wissing 1988). Elevated metal and ion concentrations associated with the mining-influenced tributaries may similarly decrease the CTmax of the fantail darter. Therefore the elevated temperature and the presence of these inputs may be limiting the distribution of the fantail darter in the Stony River.

In the Stony River downstream from Mount Storm Lake, upstream and downstream colonization sources are reduced or eliminated. The heated discharges from Mount Storm Lake potentially eliminated species from the region, but the presence of the lake reduces the possibility of colonization from upstream (Gore and Milner 1990). Mining affected inputs reduce populations and altered species composition (Woodward et al. 1997). The reduced population associated with AMD inputs eliminates colonization from downstream sources (Gore and Milner 1990). In the Stony River, these conditions potentially create a semi-isolated fish community adapted to the elevated discharge temperatures. Therefore, the presence of mining-related inputs and elevated temperatures may potentially be responsible for the reduction and limited distribution of the fantail darter, white sucker, and blacknose dace in the Stony River, despite their relatively high abundance in the North Branch of the Potomac River, and the extirpation of other species from the Stony River ecosystem.

Smallmouth bass movements have been evaluated during flood conditions and during increased temperatures, but few opportunities allow these two conditions to be studied simultaneously. Todd and Rabeni (1989) found that smallmouth bass movement was higher during seasons of frequent floods, but movement was not correlated with increased discharge. Summer 2003 had higher discharge (minimum 20 cfs) and higher movement, but the movement did not correlate with discharge level. In contrast, summer 2004 had lower discharge (minimum 6 cfs) and higher movement directly correlated with discharge level. Unlike 2003 and the Todd and Rabeni (1989) studies, water volume during the continually low discharge of 2004 likely limited smallmouth bass movement to higher flow conditions. Riffles have been observed to be barriers to movement of larger fishes (Matthews et al. 1994, Lonzarich et al. 1998). Prolonged low flow conditions may create barriers to smallmouth bass movements; other studies have shown that higher flow conditions elicit long distance movements by smallmouth bass. Hubert (1981) found that smallmouth bass were displaced 400-1000m downstream during extreme turbulence; these displacements were not observed in this study. However, long distance upstream and downstream movements were observed in response to mining affected tributaries.

In 2004, smallmouth bass movement did not exceed 25 m/d in areas exposed only to elevated temperatures, which is similar to normal discharge movements observed by Hubert (1981).

The effect of a flood on the fish community is influenced by the magnitude of the event (Nislow et al. 2002). Higher discharge conditions increase the possibility of individuals being displaced (Heggenes and Traaen 1988). However, in the 2004 study smallmouth bass were not displaced during extreme high flow events. Remnants of Hurricane Frances increased discharge from 20 cfs to >1800 cfs in less than 6 hours and smallmouth bass movement did not vary with this discharge event.

Smallmouth bass have been observed utilizing thermal refuge during seasonal changes in temperature. Many of these studies show smallmouth bass seeking warmer water during decreasing temperatures of the fall (e.g. Langhurst and Schoenike 1990, Peterson and Rabeni 1996). Smallmouth bass can tolerate relatively high temperatures. In Alabama, smallmouth bass experienced 87% survival when exposed to temperature near or above 35°C (Wrenn 1980). In Virginia, smallmouth bass were sampled in a river where temperatures reached 35°C (Stauffer et al. 1976). Fish may seek necessary thermal refuge when temperatures exceed their thermal tolerance (Neill and Magnuson 1974). In laboratory experiments, smallmouth bass have exhibited avoidance behavior in response to temperature increases. Avoidance temperatures range from 26 to 33°C, which is dependent on acclimation temperature (Cherry et al. 1975). During this study, discharge temperatures from Mount Storm Lake were within the avoidance temperature range for smallmouth bass with a maximum of 33.4°C.

The radio telemetry study suggests that smallmouth bass in the Stony River do not exhibit avoidance behavior or seek thermal refuge when temperatures increase. Smallmouth bass did not move out of the region influenced by elevated temperatures. In this region, there are a few extremely small coldwater inputs, and individuals were not observed near these known inputs during elevated temperatures of 2003 or 2004. Smallmouth bass have been observed selecting temperatures above their preferred temperatures in the presence of other important resources, such as food (Bevelhimer and Adams 1991) and cover (Bevelhimer 1996). In the Stony River, when temperatures are elevated during discharges from Mount Storm Lake, availability of other resources may be more important than temperature avoidance.

Thermal conditions experienced by smallmouth bass in the stilling basin below Mount Storm Lake may differ from those in the Stony River, potentially altering their response to discharge. Therefore, six fish released immediately downstream of the dam were removed from analysis due to their upstream movement into a pool approximately 6 m in depth, where the water spills from the lake. During a discharge event from Mount Storm Lake (11 August 2004), the water in the pool became well mixed with temperatures ranging from 31.4 to 31.8°C at varied depths (ranging from 3 to 5 m; C. Hoar, West Virginia University, Morgantown, WV, personal communication). However during another discharge event (25 July 2004), the water temperature varied with depth (i.e. surface temperature=27.4°C and 5.5 m temperature=19.5°C; C. Hoar, West Virginia University, Morgantown, WV, personal communication). Although the pool during some discharge events is thoroughly mixed during some lake discharge events, groundwater seeps may serve as thermal refuge for smallmouth bass.

Smallmouth bass movement in relation to mining-related waters has not been evaluated by other studies. The radio telemetry studies showed that mining affected tributaries influenced smallmouth bass movements. The effects of mining affected tributaries on bass movement varied between years, apparently in response to the relative contributions the AMD tributaries provides to total river flow. These inputs had no influence in 2003, likely due to their decreased influence on the mainstem Stony River due to dilution from increased discharge. However, in 2004, smallmouth bass movements were influenced by the presence of mining affected tributaries. Discharge was significantly lower in 2004, allowing for an increased influence of these inputs on the water quality of the mainstem Stony River. In 2004, six of the nine fish released downstream of Laurel Run mine outfall moved upstream of the input. The movement upstream of the Laurel Run mine outfall was possibly avoidance of the elevated specific conductivity associated with this area or its effects on other biota.

Although most fish moved upstream of the input, fish remaining downstream of Laurel Run mine outfall exhibited higher movement rates than the other fish in the 2004 study. These increased movement rates are similar to fish occupying degraded habitat. Winker et al. (1995) found that in areas of low habitat quality fish moved more than in areas of high habitat quality. The water quality downstream of Laurel Run mine outfall is potentially degraded due to the elevated metal and ion concentrations. The increased movement of smallmouth bass in this region is possibly a result of the degraded water quality. Other fish species have been observed avoiding low concentrations of metal and ion combinations (Hartwell et al. 1987a, Hartwell et al. 1987b). Also, the presence of metals has elicited hyperactivity in some fish species (Scarfe et al. 1983). In nine seasonal water quality samples collected by Dominion Environmental from October 2001 to October 2004, Laurel Run mine outfall exceeded state warmwater criteria on two occasions each for dissolved aluminum and ammonia. The increased movement rates, in conjunction with upstream movement represents avoidance of the Laurel Run mine outfall and suggests this input influences smallmouth bass movement in the Stony River without creating a complete barrier to movement.

The more severely degraded input of Fourmile Run had increased detrimental influences on smallmouth bass movement. During nine seasonal water samples by Dominion Environmental, Fourmile Run exceeded state warmwater water quality standards seven times for dissolved aluminum and five times for ammonia. In 2004, of the individuals released downstream of Laurel Run mine outfall, four individuals had movements near the confluence of Fourmile Run. Three individuals moved downstream over several days until reaching Fourmile Run, whereupon reaching the confluence the individuals made a single upstream movement greater than 1.2 km. One individual made this upstream movement until remaining at a final location above the mine outfall, and the other two moved back to the release area downstream of the mine outfall. These behaviors indicate avoidance of the confluence of Fourmile Run. Dispersal will decrease with avoidance of this region by smallmouth bass (Woodward et al. 1997).

The fourth individual moved downstream of Fourmile Run during increased discharge, when pH was neutral in the mainstem Stony River (Dominion Environmental, unpublished data). This individual remained in this region for 7d until it perished downstream of Fourmile Run. The death of this individual coincided with a large overnight pH fluctuation in the mainstem Stony River below Fourmile Run, when pH increased from approximately 7 to 9.7 in 6 hours. This indicates that Fourmile Run potentially acts as a “semi-permeable” barrier. Dispersal is limited to periods of relatively good water quality (Schlosser 1995). The periods of good water quality develop during pH stabilizations associated with AMD treatment and discharges from Mount Storm Lake diluting Fourmile Run. The severe water quality degradation associated with Fourmile Run at best creates a movement barrier for smallmouth bass and possibly other species during pH fluctuations and base flow and at worst may cause mortality.

The ineffective treatment of the Fourmile Run leads to smallmouth bass avoidance of this input. The avoidance of Fourmile Run is likely a result of direct and indirect effects associated with the water quality in the mainstem Stony River downstream of Fourmile Run. Direct effects can occur through disruption of ion regulation (Beaumont et al. 2000) or metal toxicity (Barry et al. 2000, Lydersen et al. 2002). In addition, smallmouth bass avoidance of this region may be due to indirect influences such as decreased benthic macroinvertebrate densities (Scullion and Edwards 1980). The mainstem Stony River downstream of Fourmile Run has a large amount of metal precipitate. Metal precipitate often fills interstitial spaces making the substrate unstable and making the habitat unfit for benthic macroinvertebrates (Hoehn and Sizemore 1977).

Temperatures associated with discharges from Mount Storm Lake do not influence the abundance or species composition of the assemblages currently found in the Stony River. However, elevated temperatures and mining affected tributaries in the Stony River are potentially eliminating or reducing other species that might be found there and are found in the North Branch of the Potomac River watershed. The presence of mining affected inputs appears to be the greatest influence on the fish community in the region exposed to these inputs. It potentially overwhelms other impacts as has been shown in other aquatic systems (Woodward et al. 1997, Sloane and Norris 2003). Fourmile Run has an ineffective AMD treatment regime resulting in depleted fish community downstream of the input. Smallmouth bass movement is restricted to upstream of the input except during periods of “good water quality”. However, movement downstream of Fourmile Run may result in mortality due to fluctuations in AMD treatment especially during low flow conditions. The water quality degradation associated with the ineffective treatment severely impairs the fish community by reducing abundance (Freund 2004) and creating dispersal barriers (Woodward et al. 1997). Although, Laurel Run mine outfall generally has effective AMD treatment, the input still has negative influences on the fish community. The input does not act as a complete barrier to fish movement but smallmouth bass avoid this region, therefore altering species composition and potentially restricting movement. Although the effects of tributary inputs with effective AMD treatment are not as severe as those without it these inputs are likely still degrading miles of rivers and streams. The evidence of smallmouth bass avoidance of high specific conductivity suggests that even with treatment AMD inputs influence fish communities. Streams and rivers influenced by elevated specific conductivity may be limited to more tolerant fish species. In addition these water quality parameters may reduce macroinvertebrate densities, which would influence the fish community of those systems by altering food availability.

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Table 1. Mean river conditions at all four electrofishing survey sites in the Stony River downstream of Mount Storm Lake during summer 2004. Site 1 is closest to the dam and site 2 and 3 are immediately below the confluences of AMD-influenced tributaries. Ranges in parentheses.

	Parameter		
Site	Temperature (°C)	pH	Conductivity (μS/cm^3)
1	23.5 (15.9-32.0)	7.76 (6.75-8.26)	174 (158-195)
2	19.9 (12.7-30.4)	7.62 (6.77-8.24)	624 (195-1214)
3	19.9 (13.3-29.8)	8.49 (5.99-10.05)	867 (231-1916)
4	19.3 (13.0-27.1)	6.87 (5.86-8.65)	507 (220-903)

Table 2. Discharge and thermal characteristics of each sample site during the each planned discharge event in 2004. Duration is the number of hours when discharge exceeded 30 cfs. Discharge is the maximum discharge recorded at the USGS gauging station located 13 km downstream from Mount Storm Lake. Temperature is the mean temperature at each site with range in parentheses. Mean represents of the mean of both discharge events, with range in parentheses.

	Discharge 1	Discharge 2	Mean
Duration (h)	18	25	21.5
Maximum discharge (cfs)	214	133	173.5
Temperature (ºC)			
Site 1	29.1 (26.7-30.0)	30.9 (26.7-32.0)	30.0 (26.7-32.0)
Site 2	26.5 (20.8-28.7)	27.4 (20.7-30.4)	27.0 (20.7-30.4)
Site 3	25.9 (20.4-28.1)	27.6 (22.7-29.8)	26.8 (20.4-29.8)
Site 4	20.7 (17.4-22.3)	23.3 (20.0-28.2)	22.0 (17.4-28.2)

Table 3. Results of Morisita's similarity index comparing similarity in species composition at each site before and after discharge 1 and 2 and comparing mean species composition of discharge 1 with that of discharge 2 (1 vs. 2). Morisita's similarity index was not used in site 3 comparisons because no individuals were collected at this site. A value for site 4, discharge 2 was not calculated due to a low sample size. Morisita's similarity index, ranges from 0 (no similarity) to approximately 1.0 (complete similarity).

Site	Discharge 1	Discharge 2	1 vs. 2
1	0.97	0.96	0.91
2	1.01	0.96	1.01
3	--	--	--
4	0.96	--	1.10

Table 4. Catches and abundance of fishes during the electrofishing surveys at each site before and after discharge events (1 and 2). Values shown represent mean.

		Discharge 1		Discharge 2		Mean	
Site	Species	Before	After	Before	After	Before	After
1	*Micropterus dolomieu*	26	21	26	31	26	26
	Cyprinella spiloptera	1	1	19	10	10	6
	Ictalurus punctatus	6	0	1	0	4	0
	Lepomis cyanellus	0	0	1	0	1	0
	Total	**33**	**22**	**47**	**41**	**40**	**32**
2	*Micropterus dolomieu*	14	18	27	26	21	22
	Campostoma anomalum	24	23	56	26	40	25
	Cyprinella spiloptera	0	0	7	5	4	3
	Micropterus salmoides	0	0	0	1	0	1
	Total	**38**	**41**	**90**	**58**	**64**	**50**
3	**Total**	**0**	**0**	**0**	**0**	**0**	**0**
4	*Semotilus atromaculatus*	12	22	1	2	7	12
	Campostoma anomalum	12	10	1	1	7	6
	Micropterus dolomieu	2	0	0	0	1	0
	Lepomis cyanellus	1	0	0	0	1	0
	Etheostoma flabellare	0	1	0	0	0	1
	Cottus bairdi	0	1	0	0	0	1
	Total	**27**	**34**	**2**	**3**	**15**	**19**

Table 5. Comparison of Stony River species composition within a site before and after discharge events (main diagonal) and across site. Morisita's similarity index was not used in comparing site 3 because no individuals were collected at this site. Morisita's similarity index, ranges from 0 (no similarity) to 1.0 (complete similarity).

	Site			
Site	1	2	3	4
1	0.97	0.55	--	0.06
2		0.98	--	0.74
3			--	--
4				0.96

Table 6. Comparisons of mean fish abundance in Stony River sites before and after discharge events. The analysis of variance detected no significant differences in abundance following discharge from Mount Storm Lake.

	Mean Abundance		ANOVA results		
Site	Before	After	df	F-value	p-value
1	40	31.5	1	0.52	0.5461
2	64	49.5	1	0.28	0.6490
3	0	0	--	--	--
4	14.5	18.5	1	0.04	0.8540

Table 7. Summary of river conditions during radio telemetry studies carried out in the Stony River during summers of 2003 (August to September) and 2004 (June to September). Mean maximum daily temperature is determined using the continuous temperature data collected immediately downstream of the dam by Dominion Environmental's temperature loggers. Mean discharge is determined using the continuous discharge data obtained from the Stony River USGS gauging station (#01595200). Mean specific conductivity is determined using the continuous specific conductivity data collected downstream of the Laurel Run mine outfall. Each value represents mean ± 95% confidence interval.

Parameter	Year	
	2003	2004
Mean maximum daily temperature (°C)	30.3 ± 0.83	25.6 ± 0.97
Mean discharge (cfs)	105 ± 6.0	65 ± 5.8
Mean specific conductivity ($\mu S/cm^3$)	469 ± 21.3	624 ± 16.1

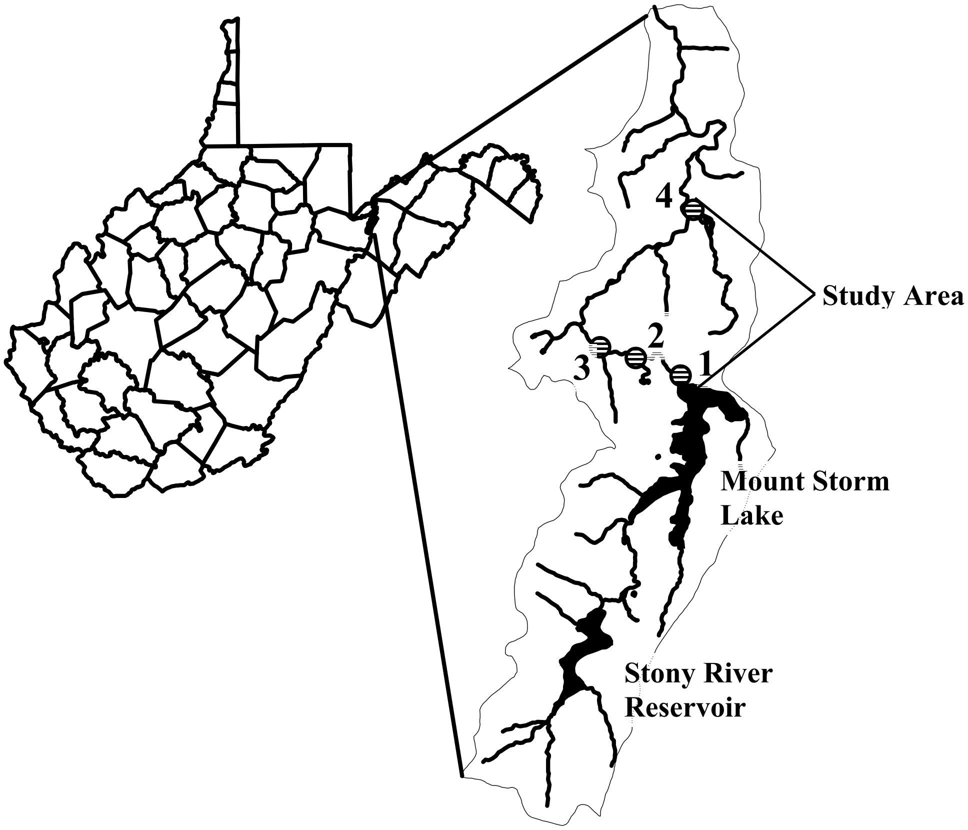


Figure 1. The study site was the Stony River between a cooling reservoir (Mount Storm Lake) and the confluence of the North Branch of the Potomac River. Focus was made on the 13 km immediately downstream of Mount Storm Lake. Four sites included in the species composition study are represented by numbers 1 to 4: Site 1 immediately downstream from Mount Storm Lake dam, Site 2 immediately downstream from Laurel Run mine outfall, Site 3 immediately downstream from Fourmile Run, and Site 4 is 12.9 km downstream from Mount Storm Lake dam.

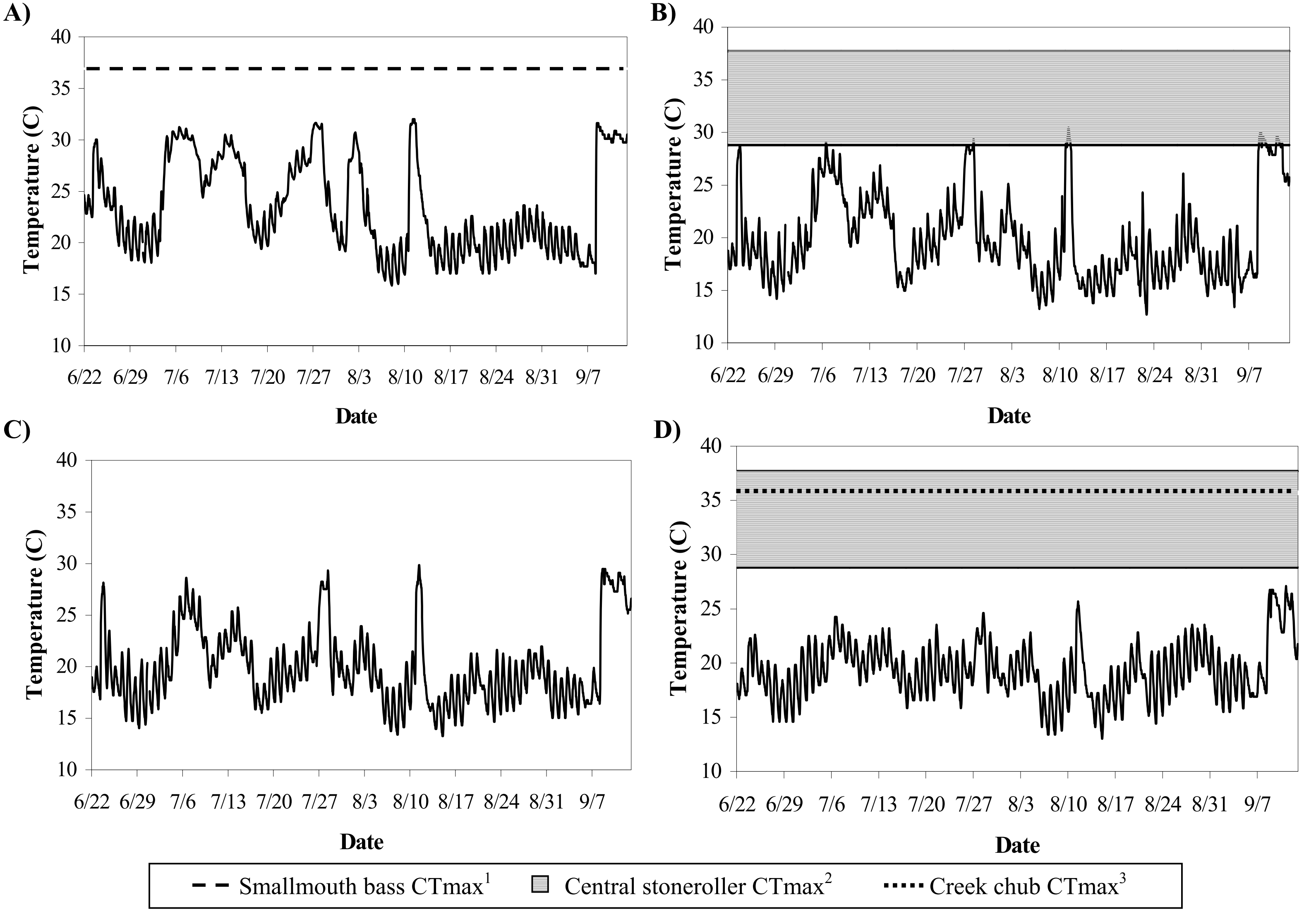


Figure 2. Temperature regime for the 2004 study period at each site, A) Site 1, B) Site 2, C) Site 3, and D) Site 4, sampled for the electrofishing surveys. Shaded areas and solid straight lines represent the critical thermal maximum (CTmax) for the dominant species found at each site: Site 1—smallmouth bass, [1] 36.9°C (Smale and Rabeni 1995), Site 2—central stoneroller, [2] 28.8-37.7°C (Changon and Hlohowskyj 1989, Mundahl 1990), and Site 4—central stoneroller and creek chub, [3] 35.7°C (Smale and Rabeni 1995)

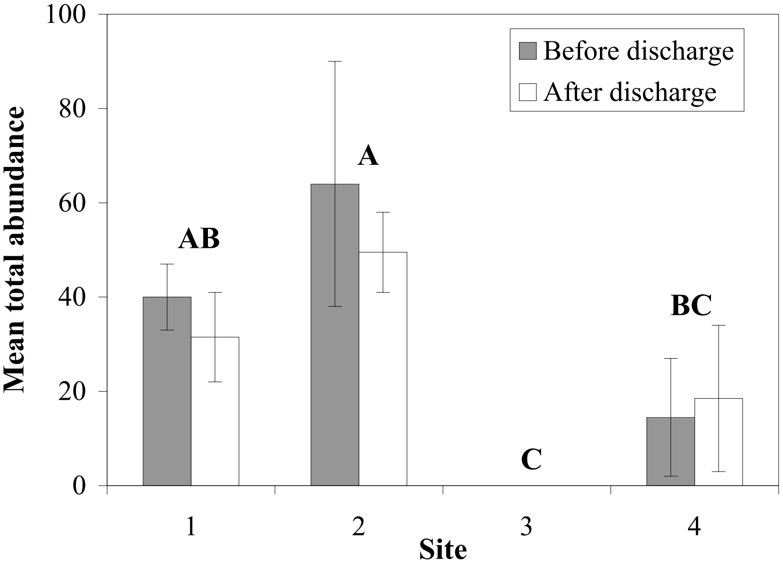


Figure 3. The mean total fish abundance (number per 150 m) at each site before and after discharge events. Error bars represent one standard error. Letters represent results of Duncan's multiple comparisons, differing letters represent significant differences in mean total abundance between sites (α = 0.05).

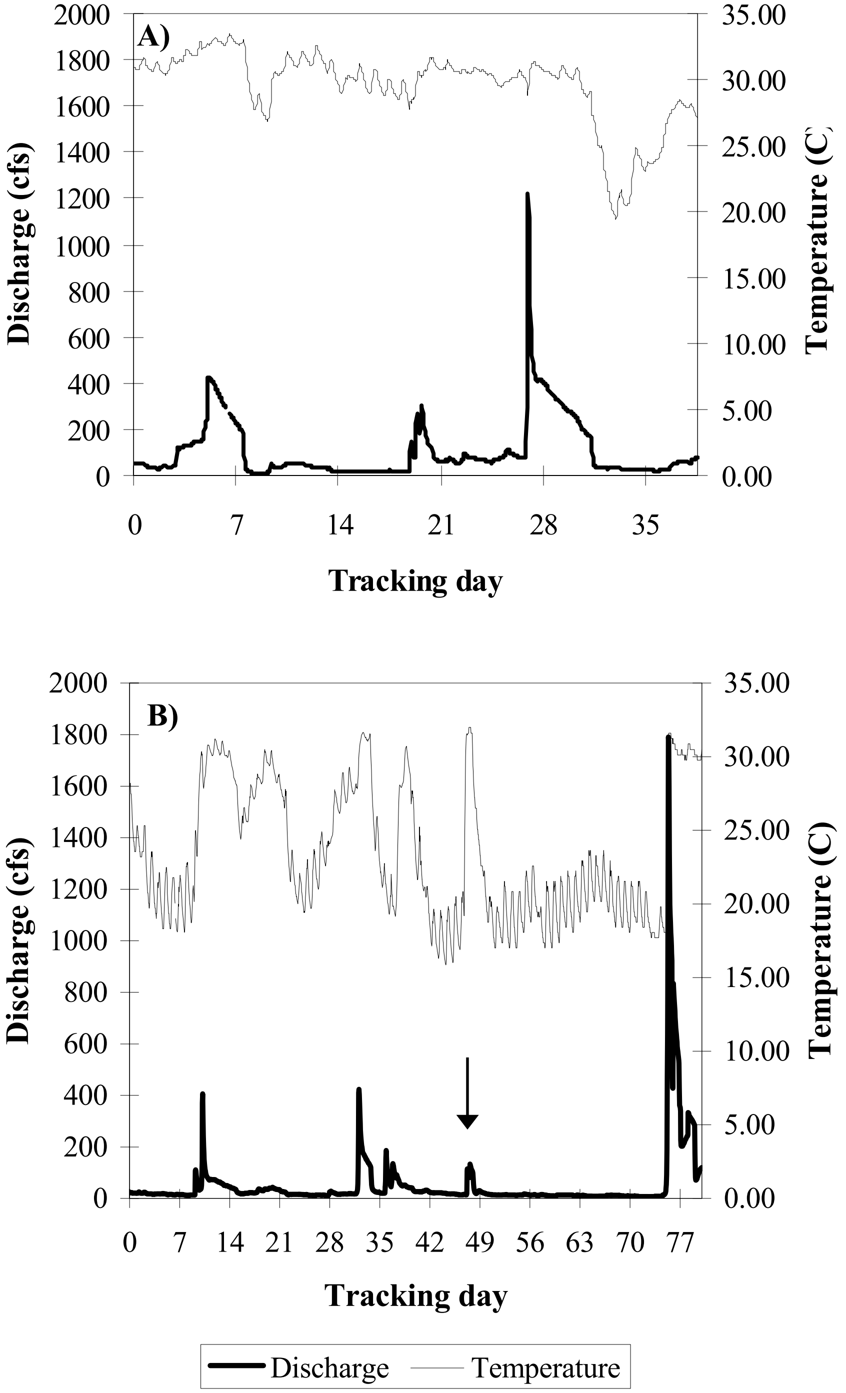


Figure 4. Discharge (cfs) in the Stony River recorded by the USGS gauging station 13 km downstream of Mount Storm Lake. Temperature (C) measured continuously at a location immediately downstream from the dam. A) August 8 to September 15, 2003 and B) June 24 to September 13, 2004. Arrow indicates planned discharge for the species composition survey on 12 August 2004. On September 8, 2004 (Tracking day 76) remnants of Hurricane Frances rapidly increased discharge.

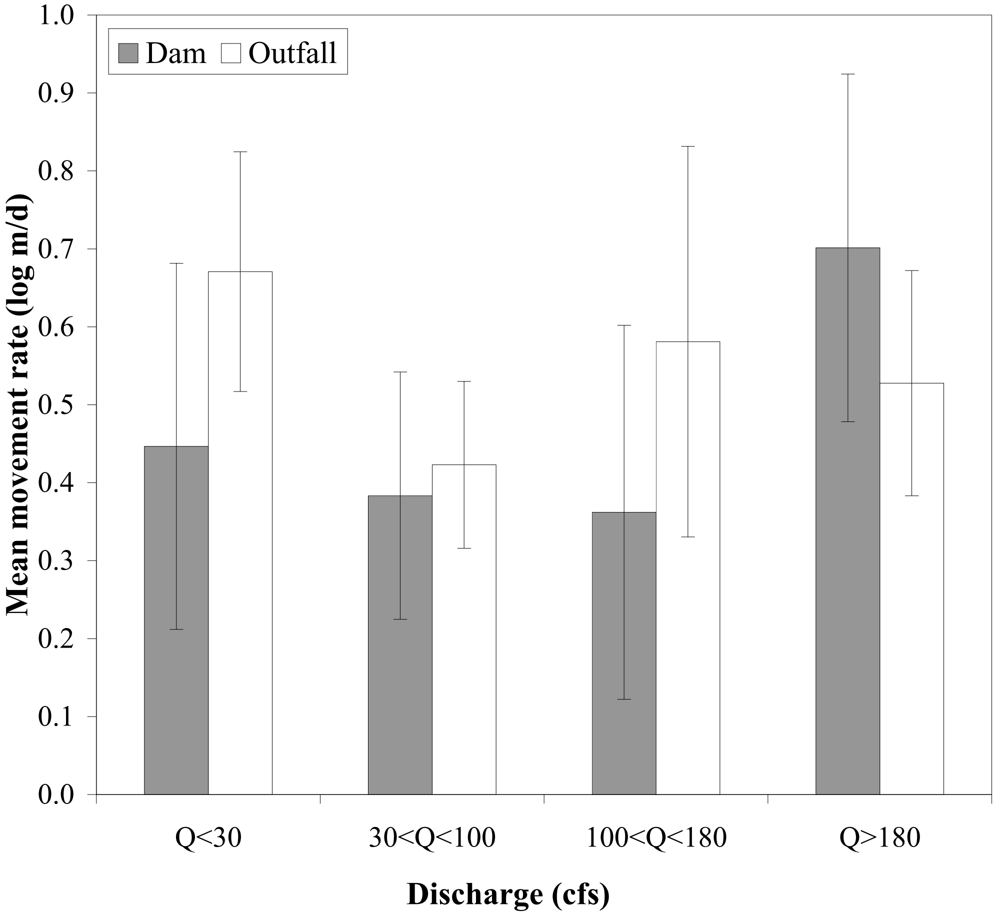


Figure 5. The mean movement rates (log m/d) for each discharge level for both release areas during summer 2003. Error bars represent one standard error.

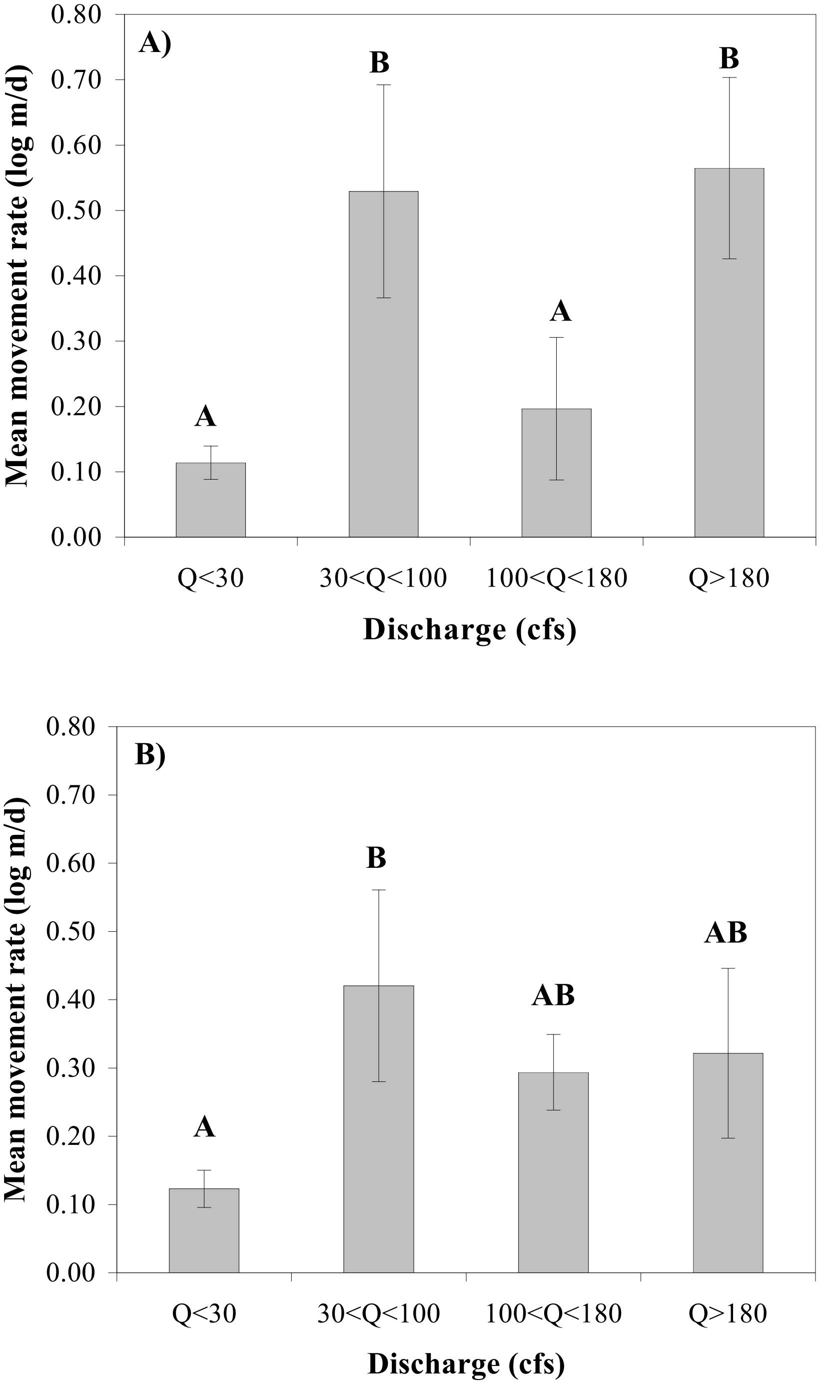


Figure 6. The mean movement rate (log m/d) of fish released in summer 2004 (A) immediately downstream of the dam and (B) immediately downstream of the Laurel Run mine outfall for each discharge category. Error bars represent one standard error and letters represent the result of Duncan's multiple comparisons.

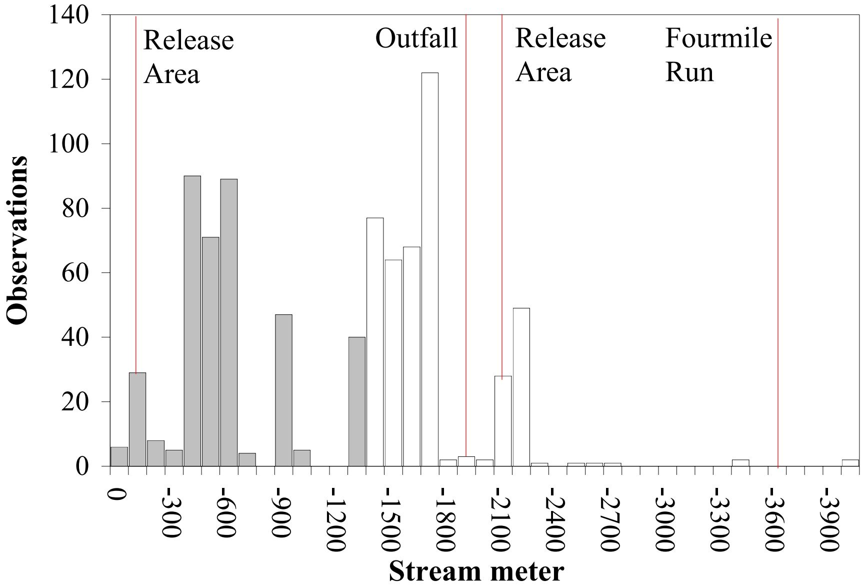
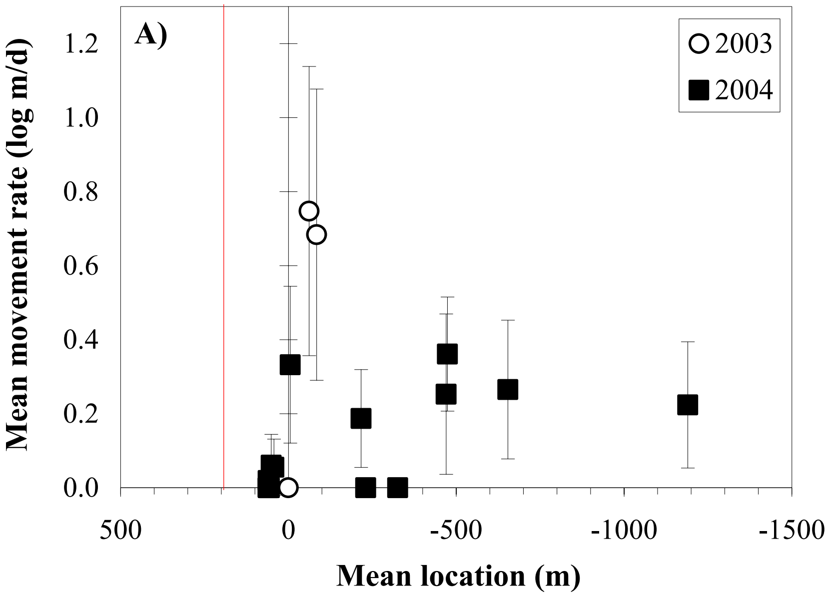


Figure 7. Frequency of observations of radio-tagged smallmouth bass by stream meter relative to release location in 2004. Fish released below the spillway were within 800 m downstream of release area (solid bars—▨) while fish released below the Laurel Run mine outfall moved above this source of high conductivity water (open bars—☐). Zero represents the spillway and negative number represent downstream position from the release area. Red lines represent various landmarks in the Stony River.



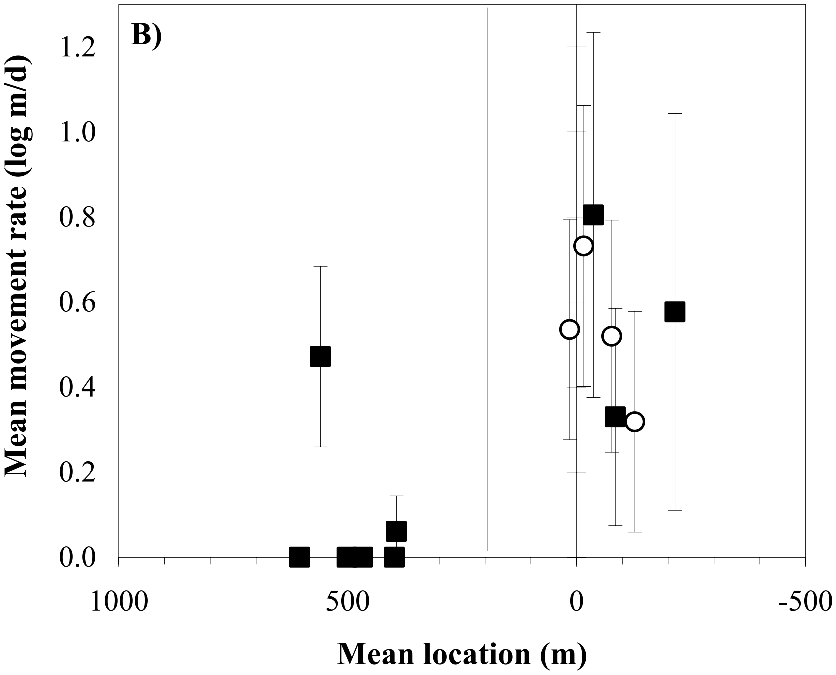


Figure 8. The mean location and mean movement rate (log m/d) of each fish in relation to the release area (x = 0), (A) immediately downstream of the dam and (B) downstream of Laurel Run mine outfall, following initial dispersal. Open circles represent fish released in summer 2003. Closed squares represent fish released in summer 2004. Positive numbers indicate upstream movement and negative numbers indicate downstream movement. Red lines represents key landmarks near each release area: (A) spillway pool and (B) Laurel Run mine outfall. The error bars represent 95% confidence intervals.

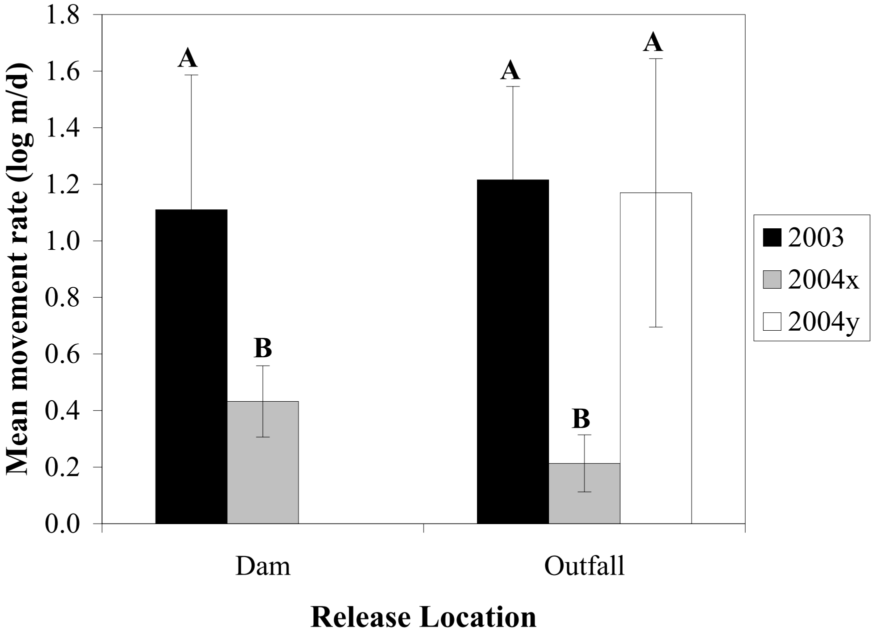


Figure 9. Mean movement rate of fish following initial dispersal from release area. Black bars represent fish released in summer 2003. Lighter colored bars represent fish released in summer 2004. Dam 2004x represent all individuals released downstream of the dam in summer 2004. Outfall 2004x represent individuals released downstream of the mine outfall in summer 2004 that moved upstream of the outfall. Outfall 2004y represent individuals released downstream of the mine outfall in summer 2004 that remained downstream of the outfall. Letters represent the results of Duncan's multiple range test different letter represent significant difference.

Curriculum Vitae
Cara C. Hoar

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Education:

2005. M.S. Wildlife and Fisheries Resources, Division of Forestry, West Virginia University, Morgantown, WV. GPA: 3.86

2000. B.S. Biological Sciences. Mary Washington College, Fredericksburg, VA.

Previous Employment:

Graduate Research Assistant, Wildlife and Fisheries Resources, Division of Forestry West Virginia University. 2003-present. Current research involves field investigation observing smallmouth bass movement and species composition in riverine system impacted by thermal discharges from a power plant cooling reservoir and acid mine drainage. Co-Advisors: Dr. Kyle Hartman, phone: (304) 293-2941 ext. 2494 and Dr. Patricia Mazik, phone: (304) 293-3497 ext. 2431.

Lab Technician Senior, Benthic Processes Lab, Department of Biological Science, Virginia Institute of Marine Science. 2000-2003. Assisted with field and laboratory work on a variety of projects, including the use of benthic fauna as environmental assessment for the construction of a bridge in Eastern Shore, VA. Focused attentions to infaunal species response to sediment disturbance processes in an energetic estuary: field and laboratory investigations. Other investigations included utilizing Arcview to display bottom composition of an energetic estuary. Employer: Dr. Linda Schaffner, phone: (804) 684-7366

Stream Assessment Intern, Culpeper Soil and Water Conservation District, Virginia Department of Conservation and Recreation. Spring 2000. Assisted in field work assessing the conditions of streams using characteristics such as bank erosion, inadequate buffer, fish barriers, animal access, etc. Compiled data into technical reports assessing overall stream conditions and pinpointing problem areas. Employer: Deborah Fisher

Undergraduate Research, Department of Biological Sciences, Mary Washington College. August 1999-April 2000. Conducted field collections and taxonomic identification of freshwater fishes for a study on the presence of the swamp darter in the upper York River basin. Advisor: Werner Wieland, phone: (540) 654-1426

Professional Experience:

Field work was conducted from May until August seven days a week in a mountainous area of West Virginia located two hours from office. Species composition studies were conducted utilizing parallel wire electrofishing equipment, equipment had to be carried to sites over steep terrain. Implanted Radio transmitters in smallmouth bass and white suckers. Fish were located daily along 3 mile stretch of river over steep and rough terrain, regardless of inclement weather.

Assisted fellow graduate students on other projects:

- Late night trapping surveys of crayfish and larval fish
- Field bioassay on crayfish and larval fish evaluating impacts of thermal pollution and acid mine drainage
- Late night beaver trapping for external radio tag attachment
- Freshwater benthic invertebrate collections in mountain stream
- Habitat survey of headwater trout streams
- Collection of fish using backpack and boat electrofishing equipment

Assisted on or acted as principal investigator on a total of 5 cruises, varying in location from estuarine rivers to Atlantic coast. The purpose of these cruises was for the collection of sediment and benthic faunal samples. Samples were collected using a Smith-Macintyre sediment grab, trawl, and oyster dredge.

Identified estuarine and marine benthic macroinvertebrate to species. Sediment analysis such as grain size, chlorophyll, and nitrogen and carbon composition.

Freshwater fish collections were made independently in the upper York River Basin, VA using backpack shocker. Acting as the principal investigator over 20 field collections was made.

Teaching and Mentoring Experience:

Graduate Teaching Assistant, West Virginia University, Department of Biological Science.
Supervisor: Pat Lutsie, phone: (304) 293-5201 ext 31546

- Introduction to Biology Laboratory (BIOL 115). Fall 2004.
- Introduction to Physiology Laboratory (BIOL 117). Spring 2005.

Co-mentor, VIMS Summer Intern Program, National Science Foundation Research Experience for Undergraduates. Summer 2001.

- Co-advised Ms. Patrice Longshaw, a Hampton University student, on a 10-week research project entitled, “Where in the world is the American Oyster?: A distribution study of suspension feeders in the York River”.

Outreach:

Carp Fest, Friends of the Deckers’ Creek. September 2004.

- Collected fish for a booth and attended a booth to demonstrate the current conditions and the potential conditions of aquatic communities in Deckers Creek, West Virginia.

Second Annual Student Colloquium of the Southern Division American Fisheries Society, West Virginia University. November 2003

- Volunteered on many aspects of the planning and running of the meeting, such as setting up, food preparation, raffles, and clean up.

College Buddy, Best Buddies Program, Mary Washington College. 1997-2000.

- Served as Board Member and College Buddy for a program that matches student volunteers with developmentally disabled peers in hopes of forming new friendships.

Pertinent Courses:

Introduction to Ecology
Genetics
Animal Ecology
Vertebrate Zoology
Anatomy of Chordates
Introduction to Mathematical Modeling
Botany
Biology of Fishes
Physiological Adaptations
Introduction to Fisheries Management
Spatial Analysis for Resource Management
Limnology
Advanced Wildlife Population Ecology
Quantitative Ecology
Fish Physiology
Advanced Ichthyology
Statistical Methods I
Statistical Methods II

Computer Skills:

MS Word
MS Excel
MS PowerPoint
Arcview 3.2, Animal movement extension
ArcMap 8.3
SAS 8.2
NtSYS
Program MARK

Oral and Written Communication:

Perform oral presentation annually pertaining to master's thesis project in graduate student seminar.

Perform oral presentations pertaining to class research projects, such as morphometrics and utilization of AIC for telemetry data analysis.

Constructed research progress reports annually (2003, 2004) for the USGS West Virginia Cooperative Fish and Wildlife Research Unit.

Professional Organizations:

American Fisheries Society
West Virginia Chapter American Fisheries Society
West Virginia University Student Subunit of the American Fisheries Society

Awards

Best Student Poster (second place)

"Investigation of fish response to discharge events in the Stony River, Grant County, West Virginia". Multi-Resource Management in West Virginia—Joint Meeting of the American Fisheries Society, the Society of American Foresters, and the Wildlife Society.

Certifications:

CPR certified
First Aid certified
SCUBA certification
Virginia Driver's Licenses

Paper and Poster Presentations:

C.C. Hoar, K.J. Hartman, and P.M. Mazik. 2005. Fish response to discharge events from a power plant cooling reservoir in a river influenced by acid mine drainage in Grant Co., WV (poster). Davis College Graduate Student

C.C. Hoar, K.J. Hartman, and P.M. Mazik. 2005. Investigation of fish response to discharge events in the Stony River, Grant County, West Virginia. Southern Division American Fisheries Society Spring Meeting. Virginia Beach, VA. February 10-13.

C.C. Hoar, K.J. Hartman, and P.M. Mazik. 2005. Investigation of fish response to discharge events in the Stony River, Grant County, West Virginia (poster). Multi-Resource Management in West Virginia—Joint Meeting of the American Fisheries Society, the Society of American Foresters, and the Wildlife Society. Flatwoods, WV. February 3-4.

C.C. Hoar, K.J. Hartman, and P.M. Mazik. 2004. Investigation of fish response to discharge events in the Stony River, Grant County, West Virginia (poster). Third Annual Student Colloquium of the Southern Division American Fisheries Society. Marineland, FL. November 2-4.

Hinchey, E.K., L.C. Schaffner, **C.C. Hoar**, L.P. Batte and B.W. Vogt. 2001. Infaunal species response to sediment disturbance processes in an energetic estuary: field and laboratory investigation. 16th Biennial Estuarine Research Federation Conference. St. Petersburg, FL. November 4-8.

Hoar, C.C. and W. Wieland. 2000. The presence of *Etheostoma fusiforme* in the upper York River basin. Association of Southeastern Biologists Annual Meeting. U. Tennessee—Chattanooga. Chattanooga, TN. April 6-10.

Publications/Technical Reports:

Hoar, C.C. and L.C. Schaffner. 2003. A study to evaluate the potential impacts of the Route 175 re-alignment on benthic living resources of Chincoteague Bay, Virginia. VDOT Project Number: 0175-001-V12, PE102, C502, B603, B606, PPMS: 1896. Prepared for Virginia Department of Transportation, Suffolk, Virginia.

Hinchey, E.K., L.C. Schaffner, **C.C. Hoar**, B.W. Vogt and L.P. Batte. 2005. Responses of estuarine benthic invertebrates to sediment burial: the importance of mobility and lifestyle. Hydrobiologia. In press.

Schaffner, L.C., C.F. Friedrichs, E.K. Hinchey, **C.C. Hoar**, T.M. Dellapenna, K. Dorgan, and S.A. Kuehl. 2005. Physical energy regimes and benthic subenvironments: A comparison of subestuaries of Chesapeake Bay. Estuaries. In prep.

References:

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