INTEGRATING RIPARIAN RESTORATION TO PROMOTE WILDLIFE HABITAT WITH NATURAL STREAM CHANNEL DESIGN ON MINE LAND HABITATS[1]

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Abstract. The role of natural streams and associated riparian habitat in structuring vertebrate communities is an important wildlife management issue in human-impacted environments. Many studies have illustrated the value of healthy riparian ecosystems in providing basic habitat requirements for a broad array of vertebrate taxa. In regions where coal mining is widespread and vital to state and local economies, it is important to address the effects of different mining practices on riparian ecosystems. Two major negative impacts of mining on natural streams and stream corridors is the alteration of physical characteristics of the stream itself and fragmentation of riparian habitat. Natural stream channel design has become a popular means of mitigating for impacts to stream channel structure; however, less emphasis has been placed on the science of creating riparian corridors to connect riparian areas fragmented by human impacts such as mining. This paper provides a background and review of literature regarding the importance of riparian ecosystems to vertebrates, the effects of mining on vertebrate populations in riparian habitats, and the use of natural stream design in riparian restoration. We provide suggestions and recommendations on how to manage riparian corridors on mine lands and outline a research agenda on wildlife in relationship to riparian corridors on mine land sites.

Additional Key Words: amphibians, birds, mammals, reptiles.

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Introduction

Riparian areas provide numerous important and valuable ecosystem services and ecological functions. Riparian areas provide bank stability; regulate water, nutrient and sediment flows; provide habitat for wildlife, fish, and plants; serve as landscape corridors by connecting habitats for organisms; and regulate water temperature (Palone and Todd 1997, National Research Council 2002). Riparian areas are important for maintaining downstream water quality and on-site wildlife habitat. Providing wildlife habitat and connecting habitats is equally if not more important than water quality issues on lands that have been impacted by surface mining (Chamblin 2002, Ammer 2003). Water quality in streams originating from lands that have been strip mined for coal is often poor and riparian buffers will probably not help to improve the water quality. Indeed, over 10,000 km of streams have been impacted by acid mine drainage in Maryland, Ohio, Pennsylvania, and West Virginia (U.S. Environmental Protection Agency 1995).

Numerous attempts have been made to define riparian areas (*See* Ilhardt et al. 2000 for a review). While almost all definitions consider the unique vegetated ecosystems that parallel a stream channel, some also include the actual aquatic ecosystem in addition to the vegetated ecosystem (Naiman et al. 1993). For purposes of this paper we will follow the definition of Ilhardt et al. (2000): Riparian areas are three-dimensional ecotones of interaction that include terrestrial and aquatic ecosystems, that extend down into the groundwater, up above the canopy, outward across the floodplain, up the near-slopes that drain to the water, laterally into the terrestrial ecosystem, and along the water course at a variable width. This definition is broad but recognizes the ecosystem services provided by riparian zones and also considers the in-stream fauna and habitat.

Geomorphic and hydrologic processes are highly altered due to surface mining including mountain top mining and associated valley fills and surface mining for coal and other mineral resources. Activities such as mountain top mining remove all visible traces of the existing stream channel and the existing riparian vegetation. Following mining, we are basically left with a clean template with which to create streams. Natural stream channel design has been proposed as a means to restore natural stream channel function on some stream channels on mined lands. Natural stream channel stability can be achieved by allowing the river to develop a stable dimension, pattern, and profile so that channel features are maintained over time and so that the stream neither aggrades nor degrades (Rosgen 1996). However, the art and science of natural stream channel design is still in its infancy, and has not been readily applied to mine land restoration projects. Moreover, riparian restoration in general has lagged behind fluvial processes as it relates to natural stream restoration in the eastern U.S.

Most created stream channels on mined lands are relatively straight, overly wide, and heavily armored with riprap. The philosophy of natural stream channel design is to take advantage of the physics of water movement to allow a stream to be active and dynamic but maintain the overall channel stability (Rosgen 1996). Planting of appropriate vegetation in the proper locations is an important component in the maintenance of natural stream channels and will provide appropriate travel corridors and habitats for wildlife.

This paper seeks to link wildlife management, riparian restoration, streams designed using natural stream channel principles, and mine land habitats. Our objectives are to provide a general overview of the importance of riparian corridors to wildlife, evaluate the impacts of mining on vertebrate populations, develop strategies for incorporating riparian restoration with natural stream channel design on mined lands, and outline a research agenda for wildlife populations on riparian zones in mine land habitats.

Riparian Zones and Wildlife

Amphibians and Reptiles

The importance of riparian vegetation has been well documented for reptiles and amphibians. Critical microhabitats and climates are created in riparian zones and provide necessary living conditions for amphibians and preferable habitat for some reptiles. Plethodontids for example lack lungs and rely on cutaneous respiration, which restricts them to moist microhabitats (Feder 1983). Reptiles use riparian areas associated with aquatic habitats for foraging and nesting (Pauley et al. 2000).

Reptiles and amphibians are important links in the food chains of ecosystems and make up a large component of the total biomass. The biomass of salamanders at Hubbard Brook in New Hampshire was found to be higher than the biomass of birds during the peak of breeding season and equal to the biomass of mice and shrews (Burton and Likens 1975a). Spight (1967) found that densities of stream and streamside salamanders ranged from 0.43-1.42 salamanders per m^2

in North Carolina. They also determined that northern dusky salamanders (*Desmognathus fuscus*) produced 0.097-0.32 g of biomass per m^2 per year. Burton and Likens (1975b) described salamanders as a good energy source for predators because of their high protein content.

The use of riparian areas by herpetofauna has been well documented. McComb et al. (1993) found no difference in species richness in upland versus riparian sites in western Oregon, however the similarity between communities was less than 40%. Distinct assemblages occurred in riparian zones. McComb et al. (1993) also reported that the total number of amphibians captured declined as they moved away from the stream. This indicates the importance of streams and associated habitat on total amphibian biomass. MacCulloch and Bider (1975) found that two-lined salamanders (*Eurycea b. bislineata*) in Quebec were not always active in upland woodlands during the spring, summer, and fall, but remained active next to streams. They also determined that 75% of the individuals that survive the summer move less than 100 m from the stream. Waters et al. (2001) determined that in northwestern California riparian vegetation along small streams with confined reaches was less distinct, but an increase in the mean number of species in the herbaceous layer may have led to an increase in prey abundance. This in turn may have led to the increase in the number of vertebrates that were observed along reaches at least 2 m wide. A study of northern dusky salamanders in Preble County, Ohio observed that 24% of microhabitat used was wet leaves and woody debris such as logs and bark (Ashton 1975). This emphasizes the importance of the adjacent habitat in addition to in-stream habitat.

Riparian zones also act as corridors to the movement of reptiles and amphibians and help alleviated the effects of habitat fragmentation. Lowe and Bolger (2002) concluded that in New Hampshire population connectivity might buffer populations of spring salamander (*Gyrinophilus porphyriticus*) from disturbance. Gibbs (1998a) determined that woodland amphibians would attempt to cross open land by following streambeds. In Maine, DeMaynadier and Hunter (1999) determined that juvenile wood frogs (*Rana sylvatica*) and spotted salamanders (*Ambystoma maculatum*) used forests with a closed canopy for emigration and dispersal. Closed canopy around breeding sites was also thought to function as nursery habitat for individuals during their first season after metamorphosis. Species that undergo a large dispersal during migration may be sensitive to habitat fragmentation (Gibbs 1998b). Gibbs (1998b) thought that high dispersers may end migration in unsuitable habitat or may become stranded in open areas resulting in failure to be recruited into a breeding population. They concluded that landscape connectivity might be important in sustaining species such as the red-spotted newt (*Notophthalmus v. viridescens*).

Birds

The most extensive research of vertebrate populations in riparian areas has been conducted on avian fauna. Riparian vegetation covers only 1% of the western landscape of the United States, but more species of breeding birds are found in these riparian areas than the surrounding upland habitat (Knopf et al. 1988, Inman et al. 2002). Riparian habitat provides many benefits to avian populations. In fact, much of the current literature regarding avian populations in riparian habitat has shifted focus from questions of the value of riparian areas to questions of the appropriate width of riparian buffer strips left after disturbances (Darveau et al. 1995, Thurmond et al. 1995, Machtans et al. 1996, Hagar 1999, Whitaker and Montevecchi 1999).

Some of the primary benefits to avifauna of riparian areas are high vegetative density, complexity of the vertical canopy layers, and diversity in horizontal vegetative features (Anderson and Ohmart 1979, DeGraaf and Yamasaki 1999). Powell and Steidl (2002) suggest that vegetative features have more influence on avian habitat selection than any other environmental features. These authors found that breeding birds in riparian areas in Arizona selected nest sites with higher vegetative density and volume than randomly selected sampling locations. In Idaho, vegetative structure, life form, and soil moisture were correlated with breeding bird use of riparian areas (Douglas et al. 1992).

Structural complexity of ground litter is another important factor in breeding bird habitat that is provided in most riparian zones. In Washington, Steel et al. (1999) showed that woody debris piles associated with riparian-river corridors were used heavily by breeding birds as well as small mammals as shelter and aggregation areas of food resources like insects, seeds, and fungi. Riparian zones generally produce higher abundances of insects than upland areas (Borror et al. 1981, Whitaker et al. 2000). Since most breeding songbirds are insectivorous and feed their young insects during the early stages of development, riparian zones are often selected as breeding areas because of their high production rates of nutritious invertebrates (Holmes and Schultz 1988, Whitaker et al. 2000).

As previously mentioned, avian use of riparian areas has been well documented. Hehnke and Stone (1978) found that avian diversity was 71% higher in riparian areas than riprapped berms and 32% higher in riparian areas than agricultural lands along the Sacramento River in California. In northern Colorado, 82% of all annually breeding avian species occurred in riparian vegetation, and 51% of all bird species in southwestern states were completely dependent on riparian vegetation for breeding (Knopf et al. 1988). Riparian buffer strips provided habitat for forest generalist, forest interior, and riparian birds species in areas of intense clearcutting in boreal forests of Newfoundland (Darveau et al. 1995, Whitaker and Montevecchi 1999). Inman et al. (2002) found that most of the 54 bird species they sampled in Michigan preferred areas closest to water sources. These authors suggest that forested riparian wetlands provide critical breeding habitat for many avian species and especially rare or declining species.

In addition to providing valuable breeding habitat, riparian areas also serve an important function as movement corridors for avifauna. Machtans et al. (1996) found that riparian buffer strips were used more frequently by dispersing juveniles than adjacent clearcut areas in boreal mixed wood forests of Alberta, Canada. In Washington, the Lower Snake River and associated riparian habitat serves as an important stopover for migrating birds (Rocklage and Ratti 2000). A study of continuous riparian corridors and oases in southeast Arizona showed that conservation of all riparian habitat patches, regardless of size, is warranted for the protection of that area as a migration stopover for neotropical migrant birds (Skagen et al. 1998). Humple and Geupel (2002) found riparian areas associated with the Consumnes, San Joaquin, and Sacramento rivers in California's Central Valley to be more important migration corridors for neotropical migrant birds than the California coast during Autumn.

Mammals

Through examination of riparian areas in the last 20 years, ecologists have identified the need to conserve these areas as important terrestrial wildlife habitat (Darveau et al. 2001). Research on the importance of riparian areas for mammals is not extensive, but several studies have documented small mammal use and preference of riparian habitats (Doyle 1990, McComb et al. 1993, Osbourne 2002). Many small mammal species are endemic or have become restricted to riparian zones, and most large game mammals require access to riparian areas for vital water resources even if they do not spend the majority of their time in these areas (Odum 1978). In addition to water, many large and medium mammals use riparian buffer strips as travel corridors for foraging and migration.

Forested riparian areas generally provide a cooler, moister microclimate that is preferred by most insectivorous and many rodent species (Whitaker and Wrigley 1972, Linzey 1983, Owens 1984, Merritt 1987). Riparian areas also may provide better quality habitat than uplands because soils are more suitable for burrowing mammals and insect abundance is generally higher, providing a more abundant food source for insectivorous mammals (Borror et al. 1981, Doyle 1990). Greater structural complexity and vegetative production are other characteristics of riparian forests that influence mammalian use by providing more forage and cover (McComb et al. 1993, Cockle and Richardson 2003). Perhaps the most important advantage of riparian areas is that they generally provide a greater abundance of water resources than upland areas.

Mammals are important components of practically every ecosystem on earth because they contribute to the overall diversity of life forms and provide valuable functional diversity (Chew 1976, Carey and Johnson 1995, Osbourne 2002). Many small mammals are prey for avian, mammalian, and reptilian predators. In turn, mammalian predators maintain an important link in the food chain by preying upon mammalian, herpetofaunal, and avian species that could potentially outgrow carrying capacities (Fedriani et al. 2000). Additionally, many shrews and mice feed on insects, plants, seeds, fruits, and fungi that can potentially alter and dominate forest ecosystems (Platt and Blakely 1973, Chew 1976, Carey and Johnson 1995, Liebhold et al. 2000).

Several studies have documented mammalian use and preference of riparian forest over associated upland forest. In the southwestern United States, Johnson and Lowe (1985) described the gradient from riparian to upland as a major influence in the structure of small mammal communities. In the Midwest, small mammal diversity was higher in channelized stream habitats than upland areas (Geier and Best 1980). Several studies in Oregon showed higher diversity of small mammals in riparian than upland habitats (Doyle 1990, McComb et al. 1993). Doyle (1990) found that species richness and total number of individuals was greater in riparian areas than uplands. In addition, the author showed that more adults in breeding condition and heavier individuals of most species occurred in riparian areas and that these areas often serve as population sources for many small mammal species. Population sources are areas where the reproduction rate is high enough that emigration of individuals to other areas is greater than immigration from outside the population (Pulliam 1988). In western Oregon, capture rates for small mammals were negatively correlated with distance from stream, and community similarity between streamside and upslope areas was <55% (McComb et al. 1993). More recently, Gomez and Anthony (1998) concluded that riparian areas provide important habitat for small mammals and protection and enhancement of these areas should be included in all wildlife management plans. Species richness and diversity were higher in riparian than upland grids in West Virginia indicating more species of small mammals were using riparian areas (Osbourne 2002).

Effects of Mining on Wildlife

Amphibians and Reptiles

Mining practices basically create large disturbances in habitats. Disturbance is generally negative on herpetofaunal communities. Pough et al. (1987) found that salamanders in New York were less abundant in recently disturbed forests compared to old growth deciduous forests. They determined that above ground activity was positively correlated with the density of vegetation in the understory and the depth of the leaf litter.

Increased acidity in habitats is one possible effect of mining. Acid from both natural and pollution sources have been shown to cause sub-lethal and lethal effects on amphibians (Dunson et al. 1992). Karns (1992) found that habitat acidity and amphibian breeding success were negatively related in peatlands of Minnesota. In hardwood-hemlock forests in the northeastern United States, Wyman and Jancola (1992) found negative correlations between habitat acidity and the density and species richness of amphibian communities. Beattie and Tyler-Jones (1992) determined that fertilization success and embryonic development in common frog (*Rana temporaria*) was inhibited in acidic breeding ponds in England. Middlekoop et al. (1999) found that streams affected by acid mine drainage had negative impacts on salamander populations. Frisbie and Wyman (1992) discovered that low pH in the soil affected the osmoregulatory performance of salamanders.

The removal of vegetation is another effect of mining. Plethodontids may be highly susceptible to forest canopy loss because of their dependence on cutaneous respiration (DeMaynadier and Hunter 1998). Percent cover explained best the observed abundances of larval two-lined and northern dusky salamanders in streams in south central Pennsylvania (Bast and Maret 1998). In northern Florida, lower numbers of anurans and lizards were observed in clearcuts compared to uncut forest stands (Enge and Marion 1986). In North Carolina, terrestrial salamanders were eliminated or reduced when mature forests were clearcut (Petranka et al.

1994). In Pennsylvania, salamander abundance was shown to increase with tree basal area (Ross et al. 2000). Bury (1983) determined that in Redwood National Park, California, logging had a long term effect on herpetofauna that was beneficial to a few species and detrimental to the majority of species that depend on forest cover. This study showed that old growth forests had more individuals, greater biomass, and a different species composition compared to logged sites. Coarse woody debris is also important for herpetofaunal communities. In western Oregon, abundances of clouded salamanders (*Aneides ferreus*) increased with the volume of coarse woody debris (Butts and McComb 2000). In riparian forests on Allegheny Plateau, mountain dusky salamanders (*Desmognathus ochrophaeus*) and red-backed salamander (*Plethodon cinereus*) were found more frequently under rocks and downed wood than leaf litter (Moore et al. 2001).

The removal of vegetation has negative effects in the associated streams. Streams in logged areas in western Oregon had smaller substrata due to increased sedimentation (Corn and Bury 1989). Spring salamanders in New Hampshire showed a negative association with increased embeddedness in streams (Lowe and Bolger 2002). Sediments from headwater streams can accumulate in lower gradient reaches downstream, degrading habitat (Murphy and Hall 1981). In western Oregon, the negative effects of sedimentation on Pacific giant salamanders (*Dicamptodon ensatus*) and Olympic salamanders (*Rhyacotriton olympicus*) were the greatest in low gradient streams (Corn and Bury 1989). Removal of streamside vegetation can also raise the water and soil temperature of streams and stream banks, which can negatively affect amphibians (Murphy and Hall 1981).

Birds

Studies on the effects on the aviafauna on active mine sites are conflicting. Chabwela (1982) found that as long as sufficient vegetation cover was available, bird communities were not affected by noise, dustfall, or traffic on aggregate mining sites in Southern Ontario. However, Allaire (1978) found that the density of singing males declined 39% on lands adjacent to active surface mines in eastern Kentucky. After mining activity ceased density began to rise again. Allaire (1978) believed that large dust clouds from blasting settled in the forest, greatly affecting ground-nesting birds and to some lesser extent mid-story and canopy nesting birds. Moreover, mine lands provide habitat for grasshopper sparrows (*Ammodramus savannarum*) and other grassland species that adjacent forested areas lack (Ammer 2003). These conflicting studies do not provide a clear picture to the effects of disturbances from active mine sites.

Mining can expose birds to possible contaminants. Mateo and Hoffman (2001) identified sediment contaminated by mining as a potential source for ingestion and subsequent lead poisoning. Myers et al. (1989) found that wood ducks (*Aix sponsa*), mottled ducks (*Anas fulvigula*), common moorhens (*Gallinula chloropus*), and double-crested cormorants (*Phalacrocorax auritus*) had elevated levels of radium-226 in their bone tissue at phosphate mines in Florida. However, the raised levels were not high enough to adversely affect populations. Meharg et al. (2002) found that white storks (*Ciconia ciconia*) ingested contaminants from a mining-sludge spill in southwestern Spain. Chick blood collected the following year showed genotoxic damage, which was evidence of the ingestion. Another potential source of contaminants is open pits from gold mining that contain sulfur (Tennesen 2001). These pits fill with rainwater, creating sulfuric acid, which can be lethal for migratory birds (Tennesen 2001). Mining can allow birds to become exposed to contaminants or higher levels of contaminants than they would find naturally in the environment.

Mining disturbs the vegetation of the area often creating earlier stages of succession. Karr (1968) found that the diversity of birds on strip-mined lands in east central Illinois increased with mixed successional habitats. In southern West Virginia, Crawford et al. (1978) found that the most bird species were found on unmined sites and sites mined 8 years earlier and the highest avian abundance was found on the site mined 9 years earlier. Brenner and Kelly (1981) found that the composition of bird communities changed with successional stages ranging from grassland to forest communities on reclaimed sites. Urbanek and Klimstra (1986) studied bird diversity on surface-mined lands in southern Illinois and concluded that habitat diversity and edge were the most important factors contributing to diversity of bird life. Mindell (1978) found that red-tailed hawks (*Buteo jamicensis*) selected natural or strip-mined edge and deciduous forest over natural open areas and strip-mined open areas. This may be due to a lack of perch sites since strip-mining methods prevent the selective saving of snags (Forren 1981). Reclaimed mining lands can provide new habitat and attract different species. Species compositions of communities can change when the habitat is altered. Wray et al. (1978) stated that some species that were not common in West Virginia are attracted by the new habitat created by reclaimed mine sites. Ingold (2002) reported that some uncommon grassland breeding birds were benefiting from a large reclaimed mine site in Ohio. Whitmore (1978) said that grassland bird species have benefited from reclaimed surface mines. Further evidence gathered by Piehler (1987) showed that grasshopper sparrows, savannah sparrows (*Passerculus sandwichensis*), and Henslow's sparrows (*Ammodramas henslowii*) were breeding on reclaimed surface mines in Pennsylvania. Bajema and Lima (2001) also found Henslow's sparrows using grasslands on reclaimed mining areas in southwestern Indiana. Changes in species composition may be undesirable if the goal of reclamation is to closely resemble natural conditions present before mining activities.

Mammals

Most of the research regarding mining effects on mammals has dealt with strip-mining effects on small mammal populations (DeCapita and Bookhout 1975, Sly 1976, Hansen and Warnock 1978, Urbanek and Klimstra 1986). There are many different mining techniques and the effects of various types of mining on wildlife can differ greatly, but the primary disturbance of any surface mining operation on mammalian populations is the severe disturbance to local vegetative communities (Chamblin 2002). Microhabitat characteristics are key to small mammal distribution, and communities may respond dramatically to changes in local food and cover availability caused by large-scale land use changes (DeGraaf and Yamasaki 1999). Another detrimental effect of mining on wildlife populations comes from acid mine drainage that contains heavy metals like iron and manganese. Over 17,600 km of streams in the United States have been affected by acid mine drainage, and the majority of those streams occur in the coal-mining regions of the Appalachian Mountains (Amrani 1987). Since small mammals are a major prey source for larger mammalian and avian predators, the accumulation of toxic chemicals in small mammals could indirectly have negative effects on top predators in addition to the effect of those chemicals directly on small mammal populations (Amrani 1987, O'Connor 1996).

We found little recent work on mammalian populations on mine land. Chamblin (2002) studied small mammal populations on reclaimed mountaintop mine/valley fill sites and found no difference in species richness between reclaimed mine habitat and control treatments of intact forest. This author found eastern chipmunk (*Tamias striatus*), woodland jumping mouse (*Napaeozapus insignis*), woodland vole (*Microtus pinetorum*), and northern short-tailed shrew (*Blarina brevicauda*) were more abundant on control plots, while *Peromyscus* spp., house mouse

(*Mus musculus*), southern bog lemming (*Synaptomys cooperi*), and masked shrew (*Sorex cinereus*) were more abundant on reclaimed treatments. The other species captured were equally abundant on control and reclaimed trapping areas, and the results gathered followed predictions. An interesting side project in Chamblin's (2002) research that arose from trapping the valley fill areas of these mine lands was the presence of state-listed Allegheny woodrats (West Virginia Division of Natural Resources 2002). Kirkland (1976) found species richness and overall abundance to be higher on intact forests (13 species) than reclaimed open-pit ore mines (7 species) in the Adirondack Mountains of New York. In Ohio, species richness was higher on unmined lands than previously mined areas and coal spoils (DeCapita and Bookhout 1975). Similarly, Voight and Glen-Lewin (1979) found more species on unmined than mined lands. These authors also found shorter breeding seasons for *Peromyscus* spp. on mined sites and speculated this was due to decreased amounts of food and adequate cover. In West Virginia, red fox (*Vulpes vulpes*) and gray fox (*Urocyon cinereoargenteus*) use of reclaimed mine lands varied seasonally with higher use in fall and winter than spring and summer (Yearsley and Samuel 1980). These authors speculated that fox use was dependant on small mammal numbers, but they did not test this hypothesis.

Several studies of small mammal succession on mined lands in the Midwest showed that more recently mined areas had higher overall abundance than areas that had been reclaimed earlier (Sly 1976, Hansen and Warnock 1978, Urbanek and Klimstra 1986). These studies also were consistent in showing that white-footed mouse (*Peromyscus leucopus*) was more abundant in forested than mined areas, and deer mouse (*P. maniculatus*) was more abundant in mined than adjacent forested areas.

Riparian Restoration on Mine Land Habitats

Mine lands may be ideal areas for implementing natural stream channel design and riparian restoration projects because earthwork should not be a limiting factor and mine lands generally have a surplus of large rocks that can be used for in stream structures. Moreover, mine land habitats are often devoid of trees and lack dispersal corridors for forest dwelling wildlife (Beier and Noss 1998). Riparian corridor restoration of mine land habitats in conjunction with natural stream channel design will increase their aesthetic appeal, improve on-site habitat for fish and wildlife, and improve dispersal and movement corridors for wildlife. This section is intended to provide recommendations on riparian corridor restoration for mined areas in the Appalachian Coalfield Region, which encompasses much of Alabama, Georgia, Kentucky, Maryland, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia (Environmental Protection Agency 2003).

Riparian buffers will serve as travel corridors or faunal movement corridors for a variety of wildlife species. Even if core reserve areas are relatively small (>6 km on a side), they will provide adequate habitat if connected by corridors (Noss 1992). The corridors themselves then serve as additional core habitat and as landscape linkages (Noss 1992). These linkages are extremely important in mine land areas which often were historically crossed by riparian zones.

We suggest that when possible strip corridors (> 12 m) are created rather than line corridors (< 12 m) (Forman and Godron 1986). The strip corridors are wide enough to have an interior and provide additional habitat for some edge sensitive species. However, even 12 m is too narrow for many species. A review by Semlitsch and Bodie (2003) indicated that corridors up to 300 m were optimal for some aquatic reptile and amphibian species. However, this is unrealistic in most situations and we recommend that whenever possible corridors are at least 15 m wide on each side of the stream.

In general, wider riparian buffers are more effective than narrower riparian buffers and forested riparian areas are more effective than grassed buffers in reducing sediment, nitrogen, and phosphorous from entering aquatic systems (Chesapeake Bay Program 1999). However, compacted soils like those on reclaimed mine lands reduce the effectiveness of riparian buffers for removing nutrients and sediment deposition rates (Schueler 1995). Even grasses, herbaceous vegetation, and shrubs are important for reducing runoff and provide beneficial habitat for some wildlife species. Overall, trees are better than either grasses or shrubs for bank stabilization, sediment and nutrient reduction, providing aquatic habitat, flood protection, and visual diversity (Tjaden and Weber 1999). In the Appalachian Coalfield Region we recommend that all travel corridors emphasize native shrubs and trees.

A diversity of woody species should be planted to provide adequate horizontal and vertical diversity and structure for wildlife. Species should be native and well adapted to the harsh environment that they will encounter on these sites. Moreover, plants will continue to grow and composition and structure will change over time due to ecological succession and geomorphic processes. For example, in some systems, water flow $\geq$125% of bankfull discharge is important in maintaining lateral channel migration, which is responsible for initiating ecological succession (Richter and Richter 2000). Another paper in this symposium (Fortney *In Press*) details the types of vegetation that can be used in riparian restoration on mine land sites.

Coarse woody debris (CWD) is a valuable structural component of riparian ecosystems, and the use of woody debris piles by small mammals (Carey and Johnson 1995, Steel et al. 1999, Osbourne and Anderson 2002), birds (Harmon et al. 1986, Steel et al. 1999, Lohr et al. 2002), and amphibians (Butts and McComb 2000, Young and Yahner 2003) in upland and riparian habitats has been documented. In riparian corridors, woody debris piles are often used to locate food resource and as refugia for cover and escaping predation (Steel et al. 1999).

Management of CWD in riparian zones has received much emphasis as increased pressure on these areas continues from human disturbance (Harmon et al. 1986, Carey and Johnson 1995, Steel et al. 1999, Osbourne and Anderson 2002). Carey and Johnson (1995) suggest that 15-20% CWD cover distributed throughout the forest floor is the minimum amount that would provide adequate cover for small mammals. These authors also suggest aerial tree removal, leaving standing dead trees intact, and retention of un-merchantable logs after logging as methods of protecting CWD resources for all riparian vertebrates. In West Virginia, CWD loadings of at least 8.86 m^3/ha were recommended to prevent loss of habitat quality for small mammals and other forest floor vertebrates (Osbourne and Anderson 2002). Bowman et al. (2000) found that southern red-backed voles (*Clethrionomys gapperi*) were more abundant in areas with the most decayed logs of 4 different classes. These results suggest that CWD should be established early and allowed to remain on sites long enough for logs to develop decayed sections for easy access and manipulation by vertebrates. Decayed logs are also more likely to provide forest floor vertebrates with valuable food resources like insects and fungi.

Once riparian corridors are created they need to be continually managed for wildlife populations. Most management on mine lands will probably involve curtailing human activities along these corridors to promote and maintain vegetation establishment and growth. The regulation of all terrain vehicles (ATVs) will be extremely important in the establishment of these areas. ATVs cause excessive erosion, contribute to soil compaction, and remove standing vegetation, which is counter to establishing riparian corridors. Therefore, activities such as this must be eliminated or reduced to ensure proper vegetation establishment and to ensure undisturbed corridors for wildlife passage. Another major disturbance of riparian corridors is cattle grazing (Chapman and Ribic 2002, Clary and Kinney 2002). Cattle should be excluded from riparian restoration areas using fencing or other methods. Long-term monitoring also should be implemented on riparian zones established on mine lands. Additional details are provided below in the research agenda section.

Research Agenda for Riparian Corridors on Mine Lands

During our literature search for this paper, few studies were found concerning vertebrate populations in riparian areas of mine lands. As mentioned earlier, a large body of research exists on the importance and use of riparian areas by vertebrate species, but most of the literature regarding vertebrate populations on mine lands was outdated and piecemeal. Below we present recommendations on important research ideas for vertebrate populations in riparian corridors of mined areas (Table 1).

Studies of amphibians and reptiles in riparian habitats have lagged behind studies of birds and mammals (Pauley et al. 2000). Long-term studies are needed to adequately monitor populations due to large natural population fluctuations (Pechmann et al. 1991). Most studies that have been conducted have been performed in the west and northwest with few in the Appalachian region (Pauley et al. 2000). Traditionally herpetofauna has received little attention from the public, professional ecologists, and land managers due to their lack of commercial value (Dunson et al. 1992). Only recently have ecological processes necessary for maintaining biodiversity received large amounts of attention. Also increasing numbers of reptiles and amphibians occurring in riparian habitats are being listed as endangered, threatened, or sensitive according federal, state, or agency mandates (Pauley et al. 2000). Adequate knowledge is needed to protect these species.

On mining lands, recolonization rates of reptiles and amphibians are not known. Individuals probably have to move from adjacent lands due to the large amount of disturbance to the vegetation and soils, leaving no refugia for species to endure disturbance until conditions are favorable. The best species composition of plants for herpetofauna is not known for reclamation. The more diversity in plants will most likely provide the best prey abundance and provide habitat for a greater variety of herpetofauna. The effects of mining on groundwater seeps may be important to amphibian populations. These are often used as overwintering sites due to their warmer temperatures (Ashton 1975). Stream substrate and soil profiles need to be examined on reclaimed lands to see if they are suitable for reptiles and amphibians. General population ecology studies of herpetofauna in the coal mining regions are necessary to know what goals should be set for reclamation efforts in resembling natural conditions.

Table 1. Table outlining a suggested research agenda for wildlife in riparian areas on mine lands.

Before Mining Activities	During Mining Activities	During Reclamation
Reptiles and Amphibians		
1. Population studies **a.** determine species present **b.** set reclamation goals **2.** Habitat studies **a.** determine key componets that should be targeted for reclamation	**1.** development of refugia for later recolinization **2.** could small islands be spared to later serve as population sources	**1.** Population studies **a.** recolonization rates **2.** Habitat studies **a.** soil and substrate profiles **b.** groundwater seeps **c.** vegetative diversity
Mammals		
1. Population studies **a.** determine current community structure **b.** look for disturbance sensitive species	**1.** Sampling around active mine lands to determine if individuals are relocating or suffering mortality	**1.** Population studies **a.** compare to premining conditions **b.** look for disturbance sensitive species
Birds		
1. Population studies **a.** determine species present **2.** Habitat studies **a.** feeding habitat **b.** nesting habitat **c.** vertical structure of vegetation	**1.** determine the effects of dust, noise, and disturbance on populations and behavior	**1.** Population studies **a.** compare to premining conditions **2.** Habitat studies **a.** feeding habitat comparisons **b.** nesting habitat comparisons **c.** vegetation comparisons of vertical structure

Most research on the value of riparian habitat in maintaining diversity and abundance of mammals has been conducted in the Pacific Northwest and arid desert regions of the southwest (Doyle 1990, McComb et al. 1993, Osbourne 2002). Extrapolating the results of studies conducted in habitat types differing in environmental setting, climate, and species assemblage to eastern forest environments could lead to errant assumptions (Osbourne 2002). In addition, making management recommendations about mammalian populations in riparian areas of mined lands without conducting research on the effects of the mining practices could be detrimental to the species being managed.

Most of the research that has been conducted on mammalian populations on mine lands has dealt with recolonization and succession of populations after reclamation. It would be valuable to know the effect of mining practices on mammal communities in riparian habitat surrounding the mine before, during, and after mining activities. If mining detrimentally affects sensitive species, then surveys conducted after reclamation of the area may not detect these species at all. This information also may be valuable in observing whether interspecific competition for habitat after reclamation has any effect on sensitive species. Basically, are *Peromyscus* spp. dominating areas that had a more diverse small mammal community before mining?

Riparian corridors on mine lands have the potential to be very important migration corridors for migrating bird populations. Machtans et al. (1996) evaluated riparian buffer strips as movement corridors in heavily impacted clearcut forest areas. These authors surveyed avian populations before and after treatments, and recommend this strategy because it provides data on patterns that would not be obtained from research conducted strictly on post-disturbance areas. Studies of avian movements in riparian corridors before and after the effects of mining would provide valuable information on the degree of disturbance caused to these corridors by mining activities. In fact, the idea of pre and post-disturbance sampling should be considered for all future wildlife studies on mine lands.

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