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BATS OF CAMP DAWSON, WEST VIRGINIA: RELATIVE ABUNDANCE, HABITAT USE, AND PERIODS OF ACTIVITY

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ABSTRACT

Six species of bats ($n = 91$) were caught at Camp Dawson Collective Training Area, Preston County, West Virginia in June 2002 (63 net nights). Netting was completed in upland and bottomland habitats. The northern long-eared bat (*Myotis septentrionalis*) was caught disproportionately often ($n = 47$). Proportionately more individuals of this species were caught in upland than bottomland habitats, but the proportion of upland and bottomland sites that produced this species was similar. Big brown (*Eptesicus fuscus*; $n = 17$) and eastern red (*Lasiurus borealis*; $n = 16$) bats were caught in proportions similar to chance. No reproductive female eastern red bats were caught. A single eastern small-footed bat (*Myotis leibii*) was caught. Seven little brown bats (*Myotis lucifugus)* and three eastern pipistrelles (*Pipistrellus subflavus*) were caught. Collectively, more bats of all species were caught earlier in the evening than late, but individually, the eastern red bat was the only species where catch over time was disproportionate. MacArthur's diversity index indicated that 2.9 species were equally represented in the catch in all habitats, while 2.4 species were equally represented in uplands and 3.6 species in bottomlands. All species of bats likely to be caught were caught, except possibly the endangered Indian bat, and relative abundance of species was congruent with expectations. The catch was indicative of the woodland habitats present. Although not caught during summer sampling, hoary and silver-haired bats are likely present as migrants in spring and autumn.

INTRODUCTION

Twelve species of bats are typically considered to occur in West Virginia: little brown bat (*Myotis lucifugus*), northern long-eared bat, (*Myotis septentrionalis*), Indiana bat, (*Myotis sodalis*), eastern small-footed bat (*Myotis leibii*), big brown bat (*Eptesicus fuscus*), evening bat (*Nycticeius humeralis*), eastern pipistrelle (*Pipistrellus subflavus*), eastern red bat (*Lasiurus borealis*), hoary bat (*Lasiurus cinereus*), silver-haired bat (*Lasionycteris noctivagans*), Rafinesque's big-eared bat (*Corynorhinus rafinesquii*), and Townsend's big-eared bat (*Corynorhinus townsendii*; Harvey et al., 1999; Whitaker and Hamilton, 1998). In addition, the gray bat (*Myotis grisescens*) has once been documented in the state (Stihler and Brack, 1992).

The caves of West Virginia have long been known as an important resource for bats and several studies have concentrated on bats in caves (Reese, 1934; Davis, 1966; Dotson, 1977; Stihler and Brack, 1992), although occasional studies have concentrated on a single species, such as the endangered Indiana bat (Stihler, in press) or endangered Virginia big-eared bat (Sample and Whitmore, 1993), and in the case of Stihler (in press) a single species at a single location. Although Brack et al. (2002) provided a summary of bats caught within West Virginia over a period of several years, little distributional information was provided.

The purpose of this paper is to provide documentation of the species of bats caught on the 4,125-acre (1,670 ha) Camp Dawson Collective Training Area (CDCTA), located in central Preston County, West Virginia, their relative abundance, the type of habitat they used, and periods of activity.

MATERIALS AND METHODS

Study Area.—The project site is in the Allegheny (Appalachian) Plateau physiographic province of northern West Virginia. Elevations are 600 - 1000 m above sea level and average annual rainfall is 89 - 102 cm. Geologic strata consist of Mississippian and Pennsylvanian sandstones, shales, and coal. Running water has carved dendritic drainage patterns, creating steep rugged terrain, typical of the Allegheny Plateau.

Over the years, land now within CDCTA has sustained a variety of uses, which have influenced forest composition and produced a mosaic of habitats, including upland forest, disturbed riparian zones, reclaimed strip mines, and developed areas. Forests range from regenerating (stocked, sapling, and pole timber) to mature stands. Generally, stands on CDCTA are understocked because of recent harvests and the presence of non-commercial growing stock.

Forests on CDCTA are characteristic of the Mixed Mesophytic forest described by Braun (1950) for the Allegheny Plateau, except American chestnut (*Castanea dentata*) and southern pines, such as Virginia (*Pinus virginiana*) and shortleaf (*P. echinata*), are absent. Undisturbed upper slopes and ridge tops are dominated by red maple (*Acer rubrum*) and several species of oak, including white (*Quercus alba*), chestnut (*Q. montana*), black (*Q. velutina*), and northern red (*Q. rubra*). Some upland areas, especially in Pringle Run drainage, were mined and now have black locust (*Robinia pseudo-acacia*), and white pine (*P. strobus*). Forests on less disturbed mesic coves and steep slopes are dominated by tuliptree (*Liriodendron tulipifera*), sugar maple (*A. sacchrum*), American beech (*Fagus grandifolia*), sweet birch (*Betula lenta*), and northern red and white oaks. Forests in the steepest areas are dominated by hemlock (*Tsuga canadensis*), yellow birch (*B. alleghaniensis*), sweet birch, and white pine, with a dense rhododendron (*Rhododendron* spp.) understory. Lower slopes and floodplains of the Cheat River are disturbed. Some areas have no riparian woodlands, and when present, it is in varying stages of succession, dominated by American sycamore (*Platanus occidentalis*), sweetgum (*Liquidambar styraciflua*), sweet birch, tuliptree, and northern red oak.

Bat capture.—Bats were netted at seven upland and eight bottomland sites. Mist net sites were chosen to provide broad coverage across the Camp. Nets were generally placed in areas used as travel corridors for bats, including streams, trails, and infrequently used roads (Brown and Brack, 2003). Nets were variable in length and were stacked two to three nets high (5.2 - 7.8 m) high. Sites were typically netted for two nights with two net sets. Nets were tended for 5 or more hours per night, from dusk until approximately 0200 h. Netting was completed from 14 to 28 June 2002. Weather was seasonal.

Bats were identified to species and the sex, reproductive condition, age, weight, length of right forearm, and time and location/net site of capture were recorded.

Data Analysis.—Chi square analysis was used to compare captures of various groups, such as uplands and bottomlands, males and females, and times of capture. Bat capture was divided into 5 hourly time frames, starting with 2100 to 2200 h and ending with 0101 to 0200 (net down), to analyze periods of activity. A species diversity index (SDI) was calculated: SDI = $1/\Sigma P_i^2$ (MacArthur, 1972), where P_i is the proportion of each species caught.

RESULTS

Ninety-one bats of six species were caught (Table 1) over 63 net nights. The catch was not spread evenly among species ($X^2 = 94.47$; $\alpha = 0.005$); eastern red and big brown bats were caught in proportions similar to chance. The northern long-eared bat accounted for nearly 51.6% of the catch and the eastern small-footed bat only 1.1%.

At least one bat was caught at each site, 10 sites (67%) produced at least five bats, and two or more species were caught at nine sites (60%). Northern long-eared bats were caught at 10 sites and eastern red and big brown bats were each caught at nine sites. The eastern small-footed bat was caught at only one site, while little brown bats and eastern pipistrelles were each caught at two sites. The SDI indicated that 2.9 species were equally represented in the catch in all habitats, while 2.4 species were equally represented in uplands and 3.6 species in bottomlands.

No juveniles were caught, as it was generally too early in the season for young to be volant. Adult males accounted for 57% and adult females 40% of the catch. The catch by sex was not significantly different than random for all species combined, or for individual species, except the eastern red bat (Table 1). The single adult female eastern red bat caught was not reproductive.

Three upland sites caught the most bats: 15, 12, and 11 bats. The site that caught the most species of bats (n = 4) was also an upland site. Sixty-five bats were caught at seven upland sites (9.3 bats/net site), which is significantly more ($X^2 = 22.42$; $\alpha = 0.005$; Table 2) than the catch of 26 bats at eight bottomland sites (3.2 bats/net site). Upland sites, on average, caught 2.7 species while bottomland sites caught 1.8 species on average.

Forty-seven northern long-eared bats were caught at 10 upland and bottomland sites (Table 2). Although the frequency at which the species was caught in upland and bottomland sites was similar, the numbers of northern long-eared bats in these two types of habitat was different (Table 2). The frequency of capture in upland versus bottomland sites was similar for all other species, and the rate of capture of each species in the two habitats was similar, although collectively, significantly more bats were caught in upland habitats.

Bats of all species combined were caught more frequently early in the evening, generally before 2300 h, than late ($X^2 = 22.79$; $\alpha = 0.005$). In bottomlands the catch was even more skewed towards earlier times ($X^2 = 25.92$; $\alpha = 0.005$), while in uplands the catch was similar across hourly periods of capture. In contrast, the northern long-eared bat, the species most frequently caught, was equally active during all periods in both upland and bottomlands, as was the big brown bat. The eastern red bat displayed a bimodal period of activity (dusk to 2200h, and 0001 to 00100 h) when upland and bottomland habitats were considered together ($X^2 = 15.88$; $\alpha = 0.01$).

DISCUSSION

Although 13 species of bats have been recorded from West Virginia, only six were found at Camp Dawson Collective Training Area, Preston County in June 2002. No endangered Indiana bats, Virginia big-eared bats, or gray bats were caught, although Indiana bats hibernate in a cave within 16 km of CDCTA. The Virginia big-eared bat is strongly associated with caves, a resource not present on CDCTA. Only two live gray bats, found during winter hibernation, are recorded from the state (Stihler and Brack, 1992). Hoary and silver-haired bats are most likely to be caught as migrants, not during mid-summer. Rafinesque's big-eared bat is rare in southern parts of West Virginia, but is unknown from areas farther north. Although West Virginia is considered within the range of the evening bat by many authors, its distribution in Mid-Atlantic States is probably best described as east of the Appalachian Mountains. Thus, our survey captured all species likely to be present in the project area. Of the species not found, the Indiana bat probably had the greatest likelihood of being present. However, Stihler (in press) suggests the possibility that during summer, Indiana bats from this area move farther west where it is warmer.

The species diversity was greater in bottomland habitats, although significantly more bats were caught in upland habitats. MacArthur's index, or reciprocal of the Simpson (1949) index, includes elements of both the number of species and abundance, without emphasizing either. All species (except the eastern small-footed bat) were caught in, and used, both habitats, although activity is apparently greater in upland habitats. The greater diversity in bottomlands may represent use of this habitat for foraging and drinking, travel, or a combination of causes.

The northern long-eared bat was the most frequently netted species. This bat is a common component of the woodland chiropterafauna of much of the eastern United States. Summer maternity colonies are usually under sloughing bark or in cracks of trees (Lacki and Schwierjohann 2001). Stihler (In press) indicated it was a common component of the bat capture at Fernow Experimental Forest, Tucker County. The northern long-eared bat was more common in upland habitats, but similar proportions of upland and bottomland sites produced this species. It was active from dusk until nets were closed. In Indiana, Brack and Whitaker (2001) reported that this species was active throughout the night, that it was more abundant at non-riparian sites than expected, and that the species was caught at similar proportions of upland and riparian sites. The northern long-eared bat probably forages in upland habitats. It apparently gleans at least part of the time while foraging, as determined from food habits (Brack and Whitaker, 2001; 2004) and light-tagging studies (LaVal et al., 1977).

The capture of big brown bats was similar during sampling periods and in upland and bottomland habitats, is consistent with the observation that the species is a generalist in the type of habitats frequented. In Indiana, the species was caught in similar frequencies in upland and riparian habitats, but disproportionately often in dusk to midnight samples (Brack, 1985). In Michigan, catch of this species was much more frequent in the first half of the night (Brack et al., 1984). On CDCTA, capture of adult males and females was similar, whereas in Pennsylvania, females were more common than males at lower elevations (Brack et al., 2002). On Hoosier National Forest in south-central Indiana, males were more commonly caught than females (Brack et al., 2004). The big brown bat is a frequent resident of man-made structures, and apparently a generalist in the type of habitats frequented, though it apparently specializes to some degree on heavily chitinized insects like beetles.

No reproductive female eastern red bats were caught. The dominance of male eastern red bats in the region has been attributed to migratory patterns (LaVal and LaVal, 1979). However, recent studies suggest that sexual disparities may be related to differing energetic and roosting needs (Brack et. al, 2002; Cryan et al., 2000; Ford et al., 2001). In West Virginia, Virginia, and Pennsylvania, Brack et al. (2002) found an inverse relationship between reproductive females of several species of bats, including the eastern red bat in West Virginia, and elevation. Higher elevations are cooler, wetter, and have more variable temperatures. In the Black Hills of South Dakota, Cryan et al. (2000) found a positive correlation between higher latitudes (and colder mean monthly temperatures) and male populations of several species of bats. Ford et al. (2001), looking at museum specimens, found that in the Appalachian Highlands where mean monthly temperature in June fell below 28.5°C, male eastern red bats dominate.

On CDCTA, the catch of eastern red bats was similar in uplands and bottomlands, both in terms of the proportion of sites and numbers of individuals. In Indiana, eastern red bats were caught at similar proportions of upland and riparian sites, but significantly more individuals were caught at riparian sites (Brack, 1985). On CDCTA, the catch of eastern red bats was bimodal over sampling periods. In southern Michigan, (Brack et al., 1984), Clermont County, Ohio (Brack and Finni, 1987), and on Crane Division, Naval Surface Warfare Center in central Indiana (Brack and Whitaker, 2004), the catch was similar throughout the night.

Although the little brown bat is one of the most widespread species in North America, its abundance varies considerably from locality to locality. It was caught at only two locations on CDCTA, once each in upland and bottomland habitats. It often roosts in buildings and feeding is often associated with aquatic habitats where it apparently feeds on flying insects that have aquatic larva.

The eastern pipistrelle is similarly widespread, with abundance varying considerably across the range. This species sometimes forms small maternity colonies in buildings, but most colonies are located in clusters of dead or living leaves (Veilleux et al., 2003). Proximity of summer and winter habitat is apparently necessary. In Indiana, the species is uncommon north of the Wisconsin glacial limit (Brack and Mumford, 1984). This apparently is because a close geographic association of winter hibernacula and summer habitat is important (Whitaker and Hamilton, 1998).

The capture of a single male eastern small-footed bat is unique, but not extraordinary. Most information on the species relates to winter occurrences and use of hibernacula. Virtually no information is available on summer ecology. Although the species is credited with emerging early in the evening, the individual in this study was caught at 0145 h.

In summary, all species of bats likely to be caught on CDCTA were caught there, except possibly the endangered Indian bat, and relative abundance of species was congruent with expectations. The catch was indicative of woodland habitats on CDCTA. Although not caught during summer sampling, hoary and silver-haired bats are likely present as migrants in spring and autumn. The Indiana bat, although not captured, may yet be present, or as woodlands mature, may colonize the area. It is unlikely endangered gray or Virginian big-eared bats will be found on CDCTA.

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Table 1. Bat capture at Camp Dawson Collective Training Area by species and sex, and percent each species is of total. A Chi Square test of equality of catch by sex for each species is provided.

Species	Male	Female	Escaped	Total	%	X^2	Sig. α
N. Long-eared	22	24	1	47	51.6	0.09	No
Little Brown	4	3	0	7	7.7	N/A	-
E. Small-footed	1	0	0	1	1.1	N/A	-
E. Red	14	1	1	16	17.6	11.27	0.005
Big Brown	9	8	0	17	18.7	0.06	No
E. Pipistrelle	2	1	0	3	3.3	N/A	-
TOTALS	**52**	**37**	**2**	**91**	**100.0**	**2.53**	**No**

Table 2. Number of upland and bottomland sites where each species was caught on Camp Dawson Collective Training Area, and numbers of bats of each species caught in upland and bottomland sites. A Chi Square test of equality of catch is provided for sites and numbers of individuals.

	No. Sites				**No Bats**			
	Upl.	**Btm.**	X^2	**Sig. α**	**Upl.**	**Btm.**	X^2	**Sig. α**
N. Long-eared	7	3	2.12	No	41	6	31.08	0.005
Little Brown	1	1	N/A	-	5	2	N/A	-
E. Small-footed	1	0	N/A	-	1	0	N/A	-
E. red	4	5	0.02	No	11	5	1.53	No
Big Brown	5	4	0.29	No	6	11	0.88	No
E. Pipistrelle	1	1	N/A	No	1	2	N/A	-
TOTALS	19	14	1.58	No	65	26	22.42	0.005

FALL AND WINTER DIET OF THE FISHER (*MARTES PENNANTI*) IN WEST VIRGINIA AND MARYLAND

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ABSTRACT

We examined the fall and winter diet of fishers (*Martes pennanti*) in West Virginia and Maryland by analyzing the contents of 30 gastrointestinal tracts. Food items included 10 mammal species, four bird species, one gastropod species, and two types of vegetation. White-tailed deer (*Odocoileus virginianus*) was the most frequent dietary component. Medium-sized mammals such as raccoon (*Procyon lotor*) and small mammals such as *Peromyscus* spp. also were major dietary components, although small mammals occurred less frequently than reported elsewhere. Diet overlap between sexes was considerable (C_1 = 0.87) and differences between sexes in the occurrence of major food groups (small mammals, medium-sized mammals, large mammals, birds, and fruit) were not significant (<= 0.52). Fishers in the region had a diverse diet and apparently scavenged during fall and winter more frequently than reported in other studies. Frequent use of seasonally or locally abundant food sources such as carrion suggest that fishers in the central Appalachians can compensate for the low availability of important prey such as snowshoe hare (*Lepus americanus*) and porcupine (*Erethizon dorsatum*).

INTRODUCTION

The historic distribution of the fisher in eastern North America included mountainous regions as far south as North Carolina and Tennessee. The fisher became extirpated throughout central and southern Appalachian portions of their distribution by the early 1900s because of extensive timber harvest and unregulated trapping (Powell 1993). Several fisher reintroduction efforts have been conducted the central and southern Appalachians. In 1969, fishers were reintroduced in West Virginia and, subsequently, the population expanded into western Maryland (Cottrell 1978, Pack and Cromer 1981). During 1994-1998, 189 fishers were reintroduced in northcentral and northwestern Pennsylvania (e.g., Dzialak et al. 2001). More recently, 40 fishers were reintroduced on the Cumberland Plateau in Tennessee (B. Anderson, TWRA, pers. comm.). Although it would be premature to judge the outcome of fisher reintroduction in Tennessee, populations in Pennsylvania, West Virginia and Maryland apparently are well established and expanding into adjacent regions such as southeastern New York and western Virginia, respectively (R. Farrar, Virginia Department of Inland Game and Fisheries, pers. comm.).

Effective management and conservation of fisher populations require an understanding of their feeding ecology and how it may vary regionally. Throughout most of the fisher's historic central and southern Appalachian distribution, two species identified as important prey in other regions – snowshoe hare and porcupine (Powell 1993) – are absent. In West Virginia and Maryland, snowshoe hares are present at high elevation but uncommon. Similarly, porcupines are uncommon in western Maryland and occur in northeastern West Virginia only as occasional/accidental residents (M. Ford, USDA Forest Service, pers. comm.). There have been no formal studies on fishers in this region, so the ecology and conservation status of the population remains poorly documented. A better understanding of the ecology of fishers in West Virginia and Maryland, including their food habits, would benefit their management and conservation and would have implications for management and recovery of fisher populations in other portions of the east. Herein, we document the fall and winter diet of fishers in West Virginia and Maryland.

METHODS

We collected fisher carcasses from Grant, Randolph, and Tucker Counties in eastern West Virginia, and Garret County in western Maryland. These counties are in the Allegheny Mountain and the Ridge and Valley physiographic regions. The area is largely forested with elevations of 73-1524 m (Core 1966). Historically, red spruce (*Picea rubens*) at high elevation and American chestnut (*Castanea dentata*) at lower elevation occurred throughout much of the region (Stephenson 1993). At present, northern hardwoods including maple (*Acer* spp.), beech (*Fagus* sp.) and birch (*Betula* spp.) on mesic sites, and oak (*Quercus* spp.), hickory (*Carya* spp.) and pine (*Pinus* spp.) on xeric sites, interspersed with small-scale agricultural clearings, characterize the region's flora (Strausbaugh and Core 1978). Mean annual temperature is 10.0-12.0 °C, and mean annual precipitation is 91.0-168.0 cm (Strausbaugh and Core 1978).

The West Virginia Division of Natural Resources and the Maryland Department of Natural Resources provided skinned carcasses of fishers ($n = 16$ and $n = 14$, respectively) that were trapped during legal seasons or incidentally killed during Nov 1997 - Mar 2003. Gastrointestinal (GI) tracts were removed from carcasses, soaked in 10% formalin for 24 h, and preserved in 65% ethanol. We identified all distinguishable components of GI tract contents macroscopically to the finest taxonomic level possible by comparison with reference collections and keys (Adorjan and Kolenosky 1969, Korschgen 1980, Stains 1958). When necessary, we made microscopic comparisons (American Optical Corporation, Southbridge, MA, 01550, and Zeiss, Thornwood, NY 10594) based on hair pigmentation, length, and scale patterns (Giuliano et al. 1989, Short 1978). We expressed results as percent occurrence of items found in GI tracts (Martin 1994, Powell et al. 1997, Zielinski et al. 1999). For analysis, we partitioned contents of GI tracts into groups that included large mammals (> 10 kg), medium sized mammals (1.0-10.0 kg), small mammals (< 1 kg), birds, and fruit. We quantified dietary overlap between sexes by standardizing the data and using Morisita's index (C_I; Morisita 1959). Morisita's index varies from 0 to 1 representing no overlap to complete overlap, respectively. We used Fisher's exact test to evaluate differences in the occurrence of food groups between sexes. We identified plant material likely ingested incidentally using keys (Martin and Barkley 1961, Schopmeyer 1974), reference collections, and by consulting dendrologists.

RESULTS

Food items included 10 mammal species, four bird species, one gastropod species, and two types of vegetation (Table 1). White-tailed deer was the most frequent dietary component (Table 1). Small mammals occurred frequently in the diet of females, and medium-sized mammals and birds occurred frequently in the diet of males (Table 2). Nonetheless, diet overlap between sexes was considerable ($C_I =$ 0.87), and differences in the occurrence of food groups between sexes were not significant ($\alpha =$ 0.52). Eighteen of 30 GI tracts contained vegetation that was probably ingested incidentally with food items. A broad assemblage of taxa characteristic of mixed mesophytic and northern hardwood forest occurred in 15 GI tracts (*Rosaceae*, birch sp., maple sp., cherry sp., spruce [*Picea* sp.], blueberry [*Vaccinium* sp.], eastern white pine [*P. strobus*], eastern hemlock [*Tsuga canadensis*], yellow-poplar [*Liriodendron tulipifera*]). Grasses and other non-woody taxa (*Gramineae, Apiacae*, *Bromus* sp., *Poa* sp.) occurred in six GI tracts. Mosses (*Musci*, *Lycopodium*) occurred in two GI tracts. Unidentified bone fragments and flesh occurred in 19 GI tracts, and fisher hair occurred in 15 GI tracts. All GI tracts contained identifiable material other than fisher hair.

DISCUSSION

Frequent scavenging?

Previous research on the feeding ecology of fishers demonstrated that the fisher is an opportunistic predator with a diverse diet (deVos 1952, Clem 1977, Kuehn 1989, Martin 1994), it readily scavenges (Kelly 1977, Powell 1993, Powell and Zielinski 1994), and its diet varies regionally (Grenfell and Fasenfest 1979, Raine 1987, Zielinski et al. 1999, Van Why and Giuliano 2001). Powell (1993) and Martin (1994) determined that, throughout the fisher's distribution, white-tailed deer, porcupine, and snowshoe hare were the most frequent mammalian components of the diet. Snowshoe hare and porcupine did not occur in our analysis. Snowshoe hares are present in the region and porcupines appear to be reestablishing in western Maryland, but overall the availability of these species as prey during fall and winter apparently was limited. In contrast, white-tailed deer was the most frequent dietary component in this study, occurring at a frequency higher than reported in other studies. Generally, large ungulates (primarily white-tailed deer in eastern North America) are available to fishers as carrion and occur in their diet at frequencies < 25% (Powell 1993, Martin 1994, Van Why and Giuliano 2001, Zielinski et al. 1999), but in West Virginia and Maryland nearly 47% of fisher carcasses contained deer. Here, sources of deer carrion probably included road-kills or parts discarded by hunters – in these states firearms deer hunting season begins in November, and most fishers in this study (*n* = 27) were recovered shortly after this source of deer carrion became available. This high frequency of deer may have reflected high seasonal availability as well as compensation for other prey species that were less available such as snowshoe hare and porcupine (Kuehn 1989, Zielinski et al. 1999).

In addition to deer, medium-sized mammals such as raccoon, cottontail rabbit (*Sylvilagus* spp.), and Virginia opossum (*Didelphis virginianus*) occurred frequently in the diet of fishers, especially males. Fishers undoubtedly kill individuals of these species occasionally, but they also scavenge carcasses of these species when available. Some medium-sized mammals such as raccoons and Virginia opossums are struck frequently by vehicles and may be available as carrion in this manner. We found insect larvae (decomposers; *Hydrophilidae* and *Muscidae*), apparently ingested secondarily, in four GI tracts that also contained large quantities of raccoon or Virginia opossum (also deer). This suggests that medium-sized mammals, like large mammals, were consumed by fishers as carrion in some instances. If so, considering deer, raccoon, and Virginia opossum, carrion may have occurred at a frequency ~ 50% during fall and winter in West Virginia and Maryland. In one instance, the GI tract of a fisher that had been struck by a vehicle contained Virginia opossum, *Muscidae*, and American crow. Was this fisher foraging near a highway where roadkilled Virginia opossum and scavenging American crows are frequently seen, before being struck by a vehicle itself? Seasonal abundance and frequent use of carrion by fishers in this region could be a contributing factor in the apparent expansion of their distribution if improved physical condition in winter enhances reproductive success. Fishers have obligate delayed implantation; generally, they give birth and mate in late March and early April, respectively. The embryo implants in February so active pregnancy is a brief period in late winter (Powell 1993).

Birds, small mammals, and vegetation

Birds occurred in the diet at a slightly higher frequency than has typically been reported (Martin 1994). Throughout the fisher's distribution, passerines generally comprise the majority of avian prey (Martin 1994). This was the case in West Virginia and Maryland where three common resident species, two unidentified passerines, and a domestic chicken (*Gallus domesticus*) occurred in the diet (Table 1). Small mammals were consumed frequently by female fishers but, considering both sexes, small mammals were less important than reported elsewhere (Brown and Will 1979, Zielinski et al. 1999). Generally, a diverse small mammal assemblage is reported in the diet (Coulter 1966, Raine 1987, Arthur et al. 1989, Van Why and Giuliano 2001), but we recorded eight occurrences of small mammals representing just three genera (*Peromyscus*, *Sciurus*, and *Tamiastriatus*).

Fruit and other vegetation can be a considerable seasonal component of the diet (Arthur et al. 1989, Kelly 1977, Zielinski et al. 1999). In this study, apple (*Malus* spp.) and cherry fruit seemed to have been consumed intentionally by fishers, whereas other plants likely were ingested incidentally. Based on visual inspection, apple and cherry when present comprised ~ 80% of the stomach contents, whereas other vegetation types consistently comprised ~ 10% of the contents. We suspect that the importance of fruit or other vegetation as a dietary component will reflect seasonal availability, as is the case in other portions of the fisher's distribution (Powell and Zielinski 1994).

Implications for fisher management and recovery

Discussing fisher management or recovery implications given these data requires that we first ask: to what extent did trap bait influence these results? Neither state mandates surrender of fisher carcasses so, unfortunately, detailed information on the circumstances associated with each carcass was unavailable. Trappers in the region seeking to capture fishers generally use cubby sets that frequently include bait and foothold traps. These sets are baited primarily with unfurred flesh, usually beaver (*Castor canadensis*). We estimate that about 10 of the carcasses we examined were captured in cubby sets based on communications with regional furbearer biologists. The rest of our sample were shot, roadkilled, or incidentally trapped in sets for other furbearers that typically include a lure and visual stimulus instead of bait. Some researchers contend that trap bait is a legitimate seasonal component of the diet for opportunistic carnivores in managed settings (Kelly 1977, Powell and Zeilinski 1994). Nonetheless, trap bait and its potential to introduce bias is a consideration in any furbearer food habits study that uses carcasses, and readers should consider this when evaluating our results. Two facts give us cause to suggest that these results provide a reasonable representation of fisher feeding ecology in the region and that possible inclusion of trap bait did not diminish the value or interpretation of the data set. The type of bait nearly exclusively used in the region (beaver) did not occur in the results. Also, we found unfurred flesh that, based on visual inspection, comprised ~ 80% of the stomach contents in only one fisher and we considered this material unidentified in the methodology. This issue underscores the value of acquiring detailed information on the specific circumstances associated with the capture of fishers and other furbearers in the region. Reducing bias in furbearer food habits studies should be a management objective because it would improve the accuracy of data upon which management decisions might be made.

Taxa ingested incidentally or as food items included species characteristic of mixed mesophytic and northern hardwood forest (yellow-poplar, eastern hemlock, blueberry sp.), habitat generalists (Virginia opossum, raccoon, American crow), species that have close associations with transitional habitats (Eastern meadowlark, *Apiacae*, *Gramineae*, *Bromus* sp.), and domestic species (domestic cat [*Felis catus*], domestic chicken). This diverse diet suggests that their foraging habitats were varied, and does not support the notion that fishers are generally restricted to boreomontane habitats. Perhaps the apparent low availability of snowshoe hare and porcupine reflected use of lower elevation transitional habitats by fishers rather than hare or porcupine abundance. If so, it seems probable that sufficient habitat and prey exist in portions of their eastern distribution where the fisher remains extirpated, such as eastern Kentucky, southwestern Virginia, or western North Carolina, to support recolonization or efforts in their reintroduction. We suggest that, from a biological perspective, the region best suited to support reintroduction is eastern Kentucky. Hagmeier (1956) and Graham and Graham (1994) excluded Kentucky from the fisher's historic distribution, depicting Kentucky's northern and eastern borders as precisely delimiting the southernmost extent of the fisher's historic eastern distribution. Dzialak (2003) considered this unlikely, and cited Imlay (1793), Hagmeier (1956), Webb (1974), Hall (1981), Douglas and Strickland (1987), Powell (1993), and Gibilisco (1994) as likely evidence for the presence of fishers in pre-settlement Kentucky. Forest habitat in eastern Kentucky is extensive, the endangered northern flying squirrel (*Glaucomys sabrinus fuscus* or *G. s. coloratus*) – a potential prey species of the fisher – is absent, and the region supports a large reintroduced elk herd that could contribute to the success of reintroduction efforts as a source of carrion. Regardless, given their predatory habits, recovery in Kentucky would be a sociocultural issue rather that a biological one

(Dzialak 2003). Future research should investigate the demographic structure of the population in West Virginia and Maryland and identify habitats critical to reproductive segments. This population may provide an opportunity to examine associations between fishers and sympatric northern flying squirrel (*G. s. fuscus*) populations. Data characterizing the interaction between fishers and *G. s. fuscus* would be necessary before considering fisher reintroductions in Southern Appalachian habitats where *G. s. coloratus* populations occur. Northern flying squirrel abundance in West Virginia and Virginia seems to have increased concurrently with the expansion of the fisher's distribution in the region (M. Ford, pers. comm.). This is consistent with our suggestion that fishers in the central Appalachians may not restrict their foraging to boreomontane habitats. If this is the case, research addressing fisher ecology in spring and summer, with emphasis on determining edge habitat use and rate of predation on passerine nests would be warranted.

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Table 1. Percent occurrence of food items identified in gastrointestinal tracts of fishers (*Martes pennanti*; *n* = 30) from West Virginia and Maryland, Nov 1997- Mar 2003.

Food Item	Males (*n* = 18)	Females (*n* = 12)	Both (*n* = 30)
White-tailed deer (*Odocoileus virginianus*)	44.4 (8)[a]	50.0 (6)	46.7 (14)
Avian[b]	27.8 (5)	16.7 (2)	23.3 (7)
Peromyscus spp.	11.1 (2)	25.0 (3)	16.7 (5)
Fruit (*Malus* spp., *Prunus* spp.)	16.7 (3)	8.3 (1)	13.3 (4)
Raccoon (*Procyon lotor*)	11.1 (2)	8.3(1)	10.0 (3)
Sylvilagus spp.	5.5(1)	16.7 (2)	10.0 (3)
Woodchuck (*Marmota monax*)	11.1 (2)	0.0(0)	6.7 (2)
Red squirrel (*Tamiastriatus hudsonicus*)	5.5(1)	8.3(1)	6.7 (2)
Virginia opossum (*Didelphis virginianus*)	11.1 (2)	0.0(0)	6.7 (2)
Sciurus spp.	0.0(0)	8.3(1)	3.3 (1)
Muskrat (*Ondatra zibethicus*)	5.5 (1)	0.0 (0)	3.3 (1)
Domestic cat (*Felis catus*)	5.5(1)	0.0(0)	3.3 (1)
Invertebrates[c]	5.5(1)	0.0(0)	3.3 (1)

[a] Parentheses indicate number of occurrences.

[b] Hairy woodpecker (*Picoides villosus*), American crow (*Corvus brachyrhychnos*), eastern meadowlark (*Sturnella magna*), domestic chicken (*Gallus domesticus*), and two unidentified passerines.

[c] *Gastropoda* (*Geophila* – land snail).

Table 2. Percent occurrence of food groups identified in gastrointestinal tracts of fishers (*Martes pennanti*; *n* = 30) from West Virginia and Maryland, Nov 1997- Mar 2003.

Food Group	Males (*n* = 18)	Females (*n* = 12)	Both (*n* = 30)
Large mammals[a]	44.4 (8)	50.0 (6)	46.7 (14)
Medium mammals[b]	50.0 (9)	25.0 (3)	40.0 (12)
Small mammals[c]	16.7 (3)	41.7 (5)	26.7 (8)
Avian[d]	27.8 (5)	16.7 (2)	23.3 (7)
Fruit[e]	16.7 (3)	8.3 (1)	13.3 (4)

[a] White-tailed deer (*Odocoileus virginianus*).

[b] Raccoon (*Procyon lotor*), *Sylvilagus* spp., woodchuck (*Marmota monax*), muskrat (*Ondatra zibethicus*), Virginia opossum (*Didelphis virginianus*), domestic cat (*Felis catus*).

[c] *Peromyscus* spp., red squirrel (*Tamiastriatus hudsonicus*), *Sciurus* spp.

[d] Hairy woodpecker (*Picoides villosus*), American crow (*Corvus brachyrhychnos*), eastern meadowlark (*Sturnella magna*), domestic chicken (*Gallus domesticus*), and two unidentified passerines.

[e] Apple (*Malus* spp.), cherry (*Prunus* spp.).

ANALYSIS OF STRUCTURE EVOLUTION WITHIN THE SLOAN DIGITAL SKY SURVEY QUASAR CATALOG

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ABSTRACT

Quasars are among the most powerful, yet least understood, astronomical objects in the universe. To develop a greater understanding of quasar properties, we have undertaken an examination of the second edition of the Sloan Digital Sky Survey Quasar Catalog, which contains data on more than 16,000 quasars. We use the pointwise dimension - an easily applied fractal statistic that computes the scaling of objects around a specified position - to quantify environmental correlations found within the distribution of these quasars. We find that on scales beyond 30 megaparsecs, quasar distributions evolve significantly throughout multiple redshift epochs, corresponding to billions of years of time. We also find that the evolution is magnitude dependent: quasars of intermediate luminosities show the most evolution over time, while bright and faint quasars show little to no structure evolution. It is therefore crucial that structure formation models address not only the smallest astronomical scales (where gravity is most dominant), but significantly larger scales as well.

INTRODUCTION

The study of large-scale distributions is an area of observational cosmology that has grown significantly over the past few decades. Numerous surveys since the 1970s have collected information on various parts of the sky for a wide range of astronomical objects. Properties such as magnitudes, diameters, emission line strengths, positions, and redshifts are among the most popular. The natures of these surveys vary widely, from shallow wide field surveys (e.g. de Lapparent et al. 1986) to deep narrow field "pencil beam" surveys (e.g. Broadhurst et al. 1990). These efforts have contributed not only to cosmography, but also to the mapping of the local velocity field of the Universe. One of the most important findings of these studies is non-homogeneous clustering on various distance scales. Astronomers find not only clusters of galaxies (containing tens or hundreds of galaxies) and superclusters (clusters of clusters), but also voids, which are areas with little galactic activity. Large surveys have been conducted to quantify the observed clustering, the nature of dark matter, the value of the cosmological density parameter and the tracers of galaxy formation and evolution. Among the most recent of these surveys have been the Two-degree Field (2dF) Galaxy Redshift Survey, the Two Micron All Sky Survey (2MASS), and the Sloan Digital Sky Survey (SDSS), which will ultimately catalog hundreds of millions of astronomical objects, and have already contributed significant information to galactic research.

The differing types of galaxies have been a primary focus of this research. Elliptical galaxies have smooth and rounded contours and contain little gas and dust, and lack both a disk and spiral structure. Additionally, the density of stars in elliptical galaxies drops smoothly with increasing radius. Spiral galaxies resemble flattened disks with internal spiral structure. Spirals contain young stars, gas, and dust; a central bulge comprised of older stars; and a surrounding halo (Silk 1989). This halo, made largely of dark matter, causes a spiral galaxy's rotation curve to remain relatively constant with radius as its luminosity declines. While a spiral galaxy appears to concentrate its mass toward a luminous center, its mass actually extends evenly from its center to its edge (Freeman 2001).

While elliptical galaxies amount to approximately 20% of all observed galaxies, they dominate the denser regions of the universe (Silk 1989). Rarely does one find isolated elliptical galaxies. Several hypotheses exist to explain this phenomenon. One states that interactions between galaxies cause internal motion of the galaxies' constituent stars; if these stars initially existed in a flattened disk, this motion will cause the galaxy to thicken into an elliptical shape (Davies 2001). Since such interactions occur most often within rich clusters, this hypothesis proves useful in explaining why ellipticals frequent the universe's denser regions (Silk 1989). Similarly, ellipticals may result from the merger of two spiral galaxies (Hernquist 1993). When two spiral galaxies collide, the large gravitational forces between them disturb the orbits of each galaxy's stars. Such mergers also cause the gas and dust in each gas-rich spiral galaxy to vanish as the tidal forces increase; the gas and dust either gain energy and are expelled into the intergalactic medium, or lose energy and fall towards the galaxy's center. These processes explain the lack of structure and of gas and dust in elliptical galaxies. Additionally, while elliptical galaxies crowd rich clusters, spiral galaxies tend to be spread throughout the universe in a less clustered fashion (Dressler 1980).

These types of galaxies are used to trace structure in the local universe. In order to probe larger scales, we turn our attention to quasi-stellar objects, or quasars, originally described as "star-like objects with large redshifts" (Osmar 2001). Our understanding of quasars has changed greatly since their discovery in the 1960s. The first breakthrough came when astronomers identified a quasar's emission lines as high-redshift hydrogen and oxygen lines. If such redshifts result from cosmic expansion, then it follows from Hubble's law that quasars must originate 1 or 2 billion years following the Big Bang. Given the great distances of these objects implied by their high redshifts, quasars must emit an incredible amount of energy. In addition, Smith and Hoffleit (1963) demonstrated that, since quasars' brightnesses change very rapidly (sometimes within days), they must be relatively small—light-days to light-months in diameter. Because of quasars' small sizes and large luminosities, astronomers believe that supermassive black holes (10^6 to 10^9 solar masses) at the centers of early galaxies fuel these extremely luminous objects. Because quasar distributions can be used to probe cosmological parameters such as the cosmological constant, baryon density, and quasar lifetimes (e.g. Popowski et al. 1998; Haiman and Hui 2001; Martini and Weinberg 2001; Yahata et al. 2005), quantification of the distributions is crucial.

Fractals: The Mathematics and Use within Astronomy

The universe has structure on a range of scales, from galaxy pairs to clusters to superclusters. The small-scale and large-scale structures exhibit a remarkable degree of similarity. The self-similar behavior of galaxy clustering suggests that the concept of fractal geometry may apply (Mandelbrot 1983; Peebles 1993). Several types of fractal analyses have been applied to large-scale structure description, but the pointwise dimension is particularly useful for the analysis of galactic and quasar environments. It also has the distinction of being conceptually simple and easy to apply to two- and three-dimensional galaxy catalogs. However, we must first understand this nontraditional mathematics.

One distinguishes a fractal from other shapes by whether that shape exhibits a characteristic length. A characteristic length is a customary, interpretable length of that shape. Any smooth shape, such as a circle or square, has an easily defined characteristic length (e.g. radius or height.) However, non-geometric objects (such as animals) may also exhibit characteristic lengths because one can easily express them in geometric terms. Mandelbrot popularized the word 'fractal' to categorize shapes or other entities that lack a characteristic shape (see Mandelbrot 1983).

Figure 1 illustrates a common representation of a fractal. Known as the Koch curve, this fractal exhibits self-similarity—that is, its basic shape is recursive on ever-smaller scales. As one magnifies a section of the Koch curve, one will notice the same shapes repeating themselves. This is a necessary condition of having no characteristic shape.

Fractals also have the property of having non-integer dimensions. To understand this, a brief overview of the concept of dimension is in order. We identify the "dimension" of an object by how many directions of freedom it requires to plot a point on that object. For example, a line requires one dimension (length), a plane or spherical surface requires two dimensions, (longitude and latitude), and space requires three (longitude, latitude, and height). To plot a specific point at a specific time also requires a time-dimension. From everyday experience, these conditions hold; however, the concreteness

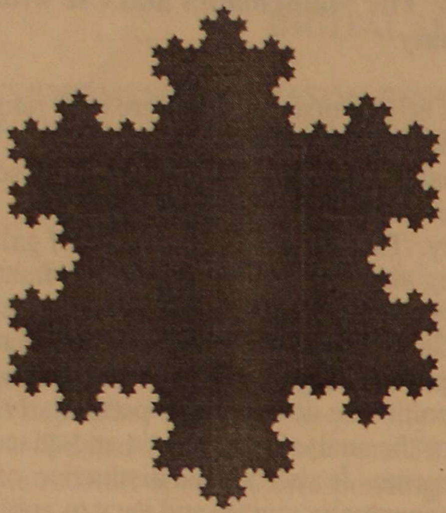

Figure 1: The Koch curve: an example of a fractal.

of such an analysis failed when the mathematician Peano described a curve, known as the Peano curve, the limit of which could nonetheless completely cover a square. It thus becomes possible to plot a point on a two dimensional surface with one dimension: one's position on the Peano curve.

It is better to imagine a shape as made of similar segments of size "1/a". The number representing the number of segments this creates is denoted "a^D", where "D" is the shape's dimension. For example, a square sliced into four half-size squares is made up of 2^2 segments, where the exponent 2 represents the dimension of the shape (in this case, a square). This method enhances and generalizes the standard dimensional classification to non-integer dimensions. Applying this methodology to the Koch curve results in D=1.2618. To gain an intuitive understanding of this result, again consider the Koch curve in Figure 1. Because this curve is continuous yet nowhere differentiable, we expect it would be more complicated than a simple line, or greater than one dimensional. On the other hand, because this curve does not completely fill a surface, as the Peano curve does, we gain a sense that it is not as complicated as a two-dimensional surface. Thus we expect its dimension to fall somewhere between 1 and 2. Takayasu (1990) provides an excellent summary of fractal mathematics.

The specific methodology (discussed in Best et al. 1996) we apply for distribution studies is as follows: we can consider a function $N_{X_m}(r)$, which is a count of the number of data points within a distance r from a reference point x_m. It is found that, in a log-log representation, there is a scaling region over which a slope can be defined: within that scaling region, which is bounded by r_{min} and r_{max}, this slope d_{X_m} is interpreted as the pointwise dimension (PD) and is defined as

$$d_{\bar{x}_m} = \frac{\log(N_{\bar{x}_m}(r_{\max})) - \log(N_{\bar{x}_m}(r_{\min}))}{\log(r_{\max}) - \log(r_{\min})}$$

The PD technique can easily be applied to a catalog of quasars. For each quasar, we can plot a curve that gives the number of galaxies within some specified distance of that quasar. Calculating the fit to the curve quantifies the dimension of the curve. The dimension becomes a measure of the environment around a specified quasar. Furthermore, we can analyze structure separately on various scales, simply by limiting the distance range over which the slope is determined.

The Data: SDSS Quasar Catalog

The Sloan Digital Sky Survey (SDSS) constitutes the most comprehensive survey of the universe to date. The survey incorporates half of the northern celestial hemisphere and a smaller portion of the southern celestial hemisphere. In all, the survey will assemble data on the positions and absolute magnitudes of more than 100 million celestial objects, and the distances to more than one million galaxies and 100,000 quasars.

In an attempt to gain a more complete understanding of quasar properties, the following research employs the second edition of the SDSS Quasar Catalog (Schneider et al. 2003), which provides data on 16,713 quasars (16% of the total planned study). Figure 2 is a visual representation of the SDSS Quasar Catalog. We limit the absolute magnitude range M to between -22 and -30, and we limit the redshift range to between 0 and 5.41, based on the assumed cosmology and the assumed form of the quasar spectral energy distribution applied by the survey authors. We note that the

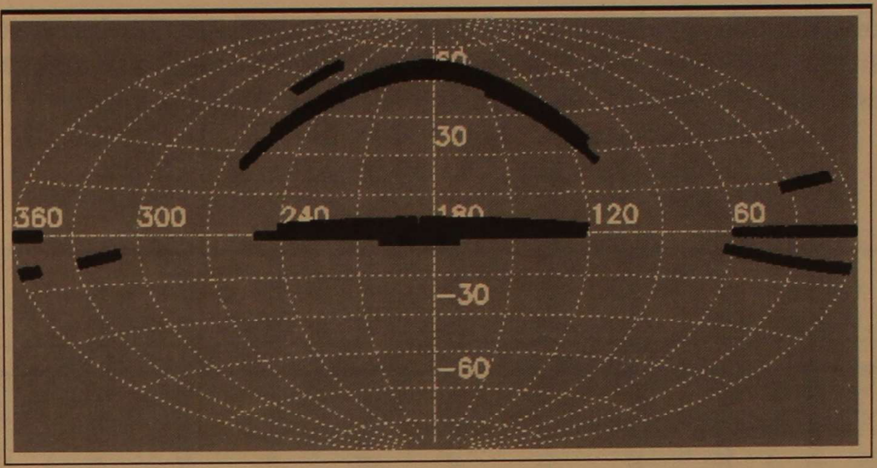

Figure 2: SDSS Quasar Catalog. The black areas indicate the distributions of quasars.

minimum redshift range for the catalog is 0.08, so our setting a lower redshift limit of 0 will not adversely affect our analyses.

ANALYSES

In all analyses, we consider how the clustering around a quasar changes as a function of the distance ("fitting range") from the quasar. We have chosen the following fitting ranges for all analyses: 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 150, 200, 300, 400, and 500 megaparsecs. Furthermore, we use redshift ranges (0-1, 1-2, 2-3) and magnitude ranges ($-24 < M < -22$, $-26 < M < -24$, $-28 < M < -26$, $-30 < M < -28$) when appropriate as part of targeted analyses. As we wish to study the evolution of structure, we utilize Kolmogorov-Smirnov (KS) tests, which are designed to study the probability that different samples are drawn from the same distribution. We define two datasets as dissimilar if their corresponding KS test returns a value such that the probability of the datasets being drawn from the same distribution is less than 1%. When reporting such results, we use a "Y" to denote a statistically similar dataset and an "N" to denote a dataset with a less than 1% probability of similarity. A dash means that a lack of data has prevented analysis.

For the first analysis, we compared different fitting ranges for quasars of the same magnitude, neglecting redshift information. In this way, we hope to study how evolution of structure depends on the large and the small scale environments for quasars. Table 1 presents these results, where the vertical axis lists the magnitude range of the quasars being analyzed (with 2422, for example, representing absolute magnitude ranges between $-24 < M < -22$), and the horizontal axis lists the fitting ranges being compared. The rows marked "NM" include all quasars (regardless of magnitude), while the remaining rows display the specified magnitude ranges. This allows us to examine not only magnitude specific trends, but also overall trends. The second set of analyses compares the same fitting ranges for quasars of the same magnitude across different redshift ranges. In this way, we can examine the redshift evolution of quasar distributions. Tables 2a, 2b, and 2c present these results, where the vertical axes list the magnitude range of the quasars being analyzed (with 2422, for example, representing absolute magnitude ranges between $-24 < M < -22$), and the horizontal axes list the fitting range. Again, the rows marked "NM" include all quasars (regardless of magnitude), while the remaining rows display the specified magnitude ranges. Finally, we performed cross-magnitude comparisons. More specifically, for a given fitting range (between 10 and 500 Mpc) and for a given redshift range (0.00 to 1.00, 1.00 to 2.00, 2.00 to 3.00, 3.00 to 4.00, and 4.00 to 5.00), we compared the environments of quasars with different magnitudes. We can study the luminosity dependence of quasar clustering in this manner. Tables 3a-3f display these comparisons.

Table 1: Comparisons of different fitting ranges for specified magnitudes. The horizontal axes represent the two environments (in Mpc) around each quasar studied. The vertical axis represents the magnitude range of the quasars studied. Y = statistically similar N = not statistically similar

NM = No magnitude constraint, 2422 = -24 < M < -22, 2624 = -26 < M < -24,
2826 = -28 < M < -26, 3028 = -30 < M < -28

	10-20	10-30	10-40	10-50	10-60	10-70	10-80	10-90	10-100	10-150	10-200	10-300	10-400	10-500
NM	N	N	N	N	N	N	N	N	N	N	N	N	N	N
2422	N	N	N	N	N	N	N	N	N	N	N	N	N	N
2624	N	N	N	N	N	N	N	N	N	N	N	N	N	N
2826	N	N	N	N	N	N	N	N	N	N	N	N	N	N
3028	N	N	N	N	N	N	N	N	N	N	N	N	N	N
		20-30	20-40	20-50	20-60	20-70	20-80	20-90	20-100	20-150	20-200	20-300	20-400	20-500
NM		N	N	N	N	N	N	N	N	N	N	N	N	N
2422		N	N	N	N	N	N	N	N	N	N	N	N	N
2624		N	N	N	N	N	N	N	N	N	N	N	N	N
2826		N	N	N	N	N	N	N	N	N	N	N	N	N
3028		Y	N	N	N	N	N	N	N	N	N	N	N	N
			30-40	30-50	30-60	30-70	30-80	30-90	30-100	30-150	30-200	30-300	30-400	30-500
NM			N	N	N	N	N	N	N	N	N	N	N	N
2422			N	N	N	N	N	N	N	N	N	N	N	N
2624			N	N	N	N	N	N	N	N	N	N	N	N
2826			N	N	N	N	N	N	N	N	N	N	N	N
3028			Y	N	N	N	N	N	N	N	N	N	N	N
				40-50	40-60	40-70	40-80	40-90	40-100	40-150	40-200	40-300	40-400	40-500
NM				N	N	N	N	N	N	N	N	N	N	N
2422				N	N	N	N	N	N	N	N	N	N	N
2624				N	N	N	N	N	N	N	N	N	N	N
2826				N	N	N	N	N	N	N	N	N	N	N
3028				Y	Y	Y	N	N	N	N	N	N	N	N
					50-60	50-70	50-80	50-90	50-100	50-150	50-200	50-300	50-400	50-500
NM					N	N	N	N	N	N	N	N	N	N
2422					N	N	N	N	N	N	N	N	N	N
2624					N	N	N	N	N	N	N	N	N	N
2826					N	N	N	N	N	N	N	N	N	N
3028					Y	Y	Y	N	N	N	N	N	N	N
						60-70	60-80	60-90	60-100	60-150	60-200	60-300	60-400	60-500
NM						N	N	N	N	N	N	N	N	N
2422						N	N	N	N	N	N	N	N	N
2624						N	N	N	N	N	N	N	N	N
2826						N	N	N	N	N	N	N	N	N
3028						Y	Y	Y	Y	N	N	N	N	N
							70-80	70-90	70-100	70-150	70-200	70-300	70-400	70-500
NM							N	N	N	N	N	N	N	N
2422							N	N	N	N	N	N	N	N
2624							N	N	N	N	N	N	N	N
2826							Y	N	N	N	N	N	N	N
3028							Y	Y	Y	N	N	N	N	N
								80-90	80-100	80-150	80-200	80-300	80-400	80-500
NM								N	N	N	N	N	N	N
2422								N	N	N	N	N	N	N
2624								N	N	N	N	N	N	N
2826								N	N	N	N	N	N	N
3028								Y	Y	N	N	N	N	N
									90-100	90-150	90-200	90-300	90-400	90-500
NM									N	N	N	N	N	N
2422									N	N	N	N	N	N
2624									N	N	N	N	N	N
2826									N	N	N	N	N	N
3028									Y	N	N	N	N	N
										100-150	100-200	100-300	100-400	100-500
NM										N	N	N	N	N
2422										N	N	N	N	N
2624										N	N	N	N	N
2826										N	N	N	N	N
3028										N	N	N	N	N

Tables 2a-c: Comparisons of quasar environments between specified redshift ranges. The horizontal axes represent the environment (in Mpc) around each quasar studied. The vertical axes represent the magnitude range of the quasars studied. Y = statistically similar N = not statistically similar

NM = No magnitude constraint, 2422 = -24 < M < -22, 2624 = -26 < M < -24,

2826 = -28 < M < -26, 3028 = -30 < M < -28

	10	20	30	40	50	60	70	80	90	100	150	200	300	400	500
NM	Y	Y	N	N	N	N	N	N	N	N	N	N	N	N	N
2422	N	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	N	N
2624	Y	Y	N	N	N	N	N	N	N	N	N	N	N	Y	N
2826	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
3028	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 2a: Comparison of quasar environments between z=0.00-1.00 and z=1.00-2.00

	10	20	30	40	50	60	70	80	90	100	150	200	300	400	500
NM	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N
2422	-	-	-	-	-	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
2624	Y	Y	Y	N	N	N	N	N	N	N	Y	Y	N	N	N
2826	Y	Y	N	N	N	N	N	N	N	N	Y	Y	Y	Y	Y
3028	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 2b: Comparison of quasar environments between z=0.00-1.00 and z=2.00-3.00

	10	20	30	40	50	60	70	80	90	100	150	200	300	400	500
NM	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N
2422	-	-	-	-	-	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
2624	Y	Y	N	N	N	N	N	N	N	N	N	N	N	N	N
2826	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N
3028	-	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Table 2c: Comparison of quasar environments between z=1.00-2.00 and z=2.00-3.00

Tables 3a-f: Comparisons of quasar environments between specified luminosity ranges. The horizontal axes represent the redshift range for each quasar. The vertical axes represent the environment (in Mpc) around each quasar studied. Y = statistically similar N = not statistically similar

	0.00-1.00	1.00-2.00	2.00-3.00	3.00-4.00	4.00-5.00
10	Y	N	-	-	-
20	N	Y	-	-	-
30	N	Y	-	-	-
40	N	Y	-	-	-
50	N	Y	-	-	-
60	N	Y	-	-	-
70	N	Y	-	-	-
80	N	Y	-	-	-
90	N	Y	-	-	-
100	N	Y	-	-	-
150	N	N	-	-	-
200	N	N	-	-	-
300	N	N	-	-	-
400	N	N	-	-	-
500	N	N	-	-	-

Table 3a: Luminosity dependence comparison:

-24 < M < -22 vs. -26 < M < -24

	0.00-1.00	1.00-2.00	2.00-3.00	3.00-4.00	4.00-5.00
10	Y	N	-	-	-
20	Y	Y	-	-	-
30	Y	Y	-	-	-
40	Y	Y	-	-	-
50	Y	Y	-	-	-
60	Y	Y	-	-	-
70	N	Y	-	-	-
80	N	Y	-	-	-
90	N	Y	-	-	-
100	N	N	-	-	-
150	N	N	-	-	-
200	N	N	-	-	-
300	Y	N	-	-	-
400	Y	N	-	-	-
500	Y	N	-	-	-

Table 3b: Luminosity dependence comparison:

-24 < M < -22 vs. -28 < M < -26

	0.00-1.00	1.00-2.00	2.00-3.00	3.00-4.00	4.00-5.00
10	-	Y	-	-	-
20	-	Y	-	-	-
30	-	Y	-	-	-
40	-	Y	-	-	-
50	-	Y	-	-	-
60	-	Y	-	-	-
70	-	Y	-	-	-
80	-	Y	-	-	-
90	-	Y	-	-	-
100	-	Y	-	-	-
150	-	Y	-	-	-
200	-	Y	-	-	-
300	-	Y	-	-	-
400	-	N	-	-	-
500	-	N	-	-	-

Table 3c: Luminosity dependence comparison:

-24 < M < -22 vs. -30 < M < -28

	0.00-1.00	1.00-2.00	2.00-3.00	3.00-4.00	4.00-5.00
10	Y	Y	Y	-	-
20	Y	Y	Y	-	-
30	N	N	Y	-	-
40	Y	N	Y	-	-
50	Y	N	Y	-	-
60	Y	Y	Y	Y	-
70	Y	N	Y	Y	-
80	Y	N	Y	Y	-
90	Y	N	Y	Y	-
100	Y	N	Y	Y	-
150	Y	N	Y	Y	-
200	Y	N	N	Y	-
300	Y	N	N	Y	-
400	Y	N	N	Y	-
500	Y	N	N	Y	-

Table 3d: Luminosity dependence comparison:

-26 < M < -24 vs. -28 < M < -26

	0.00-1.00	1.00-2.00	2.00-3.00	3.00-4.00	4.00-5.00
10	-	Y	-	-	-
20	-	Y	Y	-	-
30	-	Y	Y	-	-
40	-	Y	N	-	-
50	-	Y	N	-	-
60	-	Y	Y	Y	-
70	-	Y	Y	Y	-
80	-	Y	Y	Y	-
90	-	Y	Y	Y	-
100	-	Y	N	Y	-
150	-	Y	Y	Y	-
200	-	Y	Y	Y	-
300	-	Y	Y	Y	-
400	-	Y	N	Y	-
500	-	Y	N	Y	-

Table 3e: Luminosity dependence comparison:

-26 < M < -24 vs. -30 < M < -28

	0.00-1.00	1.00-2.00	2.00-3.00	3.00-4.00	4.00-5.00
10	-	Y	-	-	-
20	-	Y	Y	-	-
30	-	Y	Y	Y	-
40	-	Y	N	Y	-
50	-	Y	Y	Y	-
60	-	Y	Y	Y	-
70	-	Y	Y	Y	-
80	-	Y	N	Y	Y
90	-	Y	N	Y	Y
100	-	Y	N	Y	Y
150	-	Y	Y	Y	Y
200	-	Y	Y	Y	Y
300	-	Y	Y	Y	Y
400	-	Y	N	Y	Y
500	-	Y	N	Y	Y

Table 3f: Luminosity dependence comparison:

-28 < M < -26 vs. -30 < M < -28

DISCUSSION AND CONCLUSIONS

Table 1 shows a clear trend. Structure evolution seems to be affected not only on very small scales; large-scale evolution is apparent. When examining Tables 2a-c, one notes that if magnitudes are ignored, there seems to be an evolution of structure as a function of redshift. We note that while the results of Grazian et al. (2004) argue for a lack of evolution as a function of redshift, Stephens et al. (1997), La Franca et al. (1998), Bagla (1998), and Prociani et al. (2004) all argue for some sort of redshift evolution. Moreover, our result extends the physical scale of evolution beyond 100 Mpc.

While this trend holds generally when magnitude is considered, there are some very obvious exceptions. For instance, the brightest magnitude clusters ($-30 < M < -28$) show no apparent evolution of structure as a function of redshift. Interestingly, the faintest magnitude range ($-24 < M < -22$) shows the same trend, though not across all fitting ranges. The intermediate magnitude quasars show evolution over most of the fitting ranges. Tables 3a-f show a general lack of luminosity-based evolution of structure. In most instances, the environments of quasars of different magnitudes are not distinguishable. This agrees with the analogous galactic study conducted in Best et al. (1996). We do see some evolution in the intermediate magnitude ranges, most notably in Table 3d, which compares quasars of $-26 < M < -24$ to quasars of $-28 < M < -26$. While Croom et al. (2002) find a luminosity dependence (though weak) for quasar clustering evolution, our result extends the strength of the relationship.

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INCREASING EFFICIENCY WITHOUT DIMINISHING QUALITY OF STREAMSIDE DISSOLVED OXYGEN MEASUREMENTS

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ABSTRACT

The dissolved oxygen or "DO" levels found in streams and rivers are an important characteristic of the health of a watershed. Healthy levels are necessary for the survival of all forms of aquatic life, especially fish. Unfortunately, due to natural fluctuations in abiotic and biotic factors it is difficult to characterize. Many analytical techniques have been developed to measure DO. There is much debate over whether the chemical analysis of DO in the laboratory 24 hrs after sample collection is as appropriate as taking *in situ* streamside measurements. The stream in this study is Crooked Run located in northwestern Virginia. Six locations were chosen along Crooked Run. Streamside measurements were taken from February to April at each location using a DO meter. Two grab samples per location were also collected. One grab sample was stored on ice and the other at ambient temperatures for 24 hrs before measurement in order to investigate if there were differences between the two storage techniques. There were no significant differences between the *in situ* streamside DO measurements and measurements taken from grab samples after they were stored on ice for 24 hrs except at low DO concentrations. In contrast, samples stored at ambient temperatures gave significantly different readings from *in situ* measurements. These discoveries could be extremely useful for volunteer water monitoring organizations, saving them considerable time and money.

INTRODUCTION

According to Brooks et al. (1997), dissolved oxygen, or DO, "is one of the most important water quality characteristics in the aquatic environment." DO is the mass of oxygen contained in a volume of water. DO is influenced by temperature, biological activity, altitude, and aeration of water (Brooks et al. 1997). Oxygen is necessary for the survival of all forms of aquatic life, especially fish. Therefore, in order for warm water fish to remain healthy, a stream must maintain a DO of at least 5 mg L^{-1} (Davis 1968 and Pryde 1973). On the other hand if DO levels drop below 2 mg L^{-1}, anaerobic conditions can persist, and water will take on a foul odor due to sulfide compounds and will impair many ecosystem functions (Davis 1968). Levels of DO fluctuate naturally, changing from day to night. In addition to time of day, gradient (Prowse 2001), varying flow, and temperature all play a role in these natural fluctuations (Davis 1968).

The Appalachian Region is riddled with karst terrain, which can play a significant role in determining the quality of stream water in this region. According to Boyer and Pasquarell (1995, 1996), one third of the region's agricultural activities are located on karst geology. Many of the waters in these regions suffer poor water quality due to the large amounts of nitrates from agriculture percolating into ground water and running off into waterways (Boyer and Pasquarell 1995, 1996). If this amount of inorganic material is too high for a stream, the oxygen content could become low enough, due to excessive plant growth, to be detrimental to fish and other aquatic life (Davis 1968). One study related low DO levels in Virginia and Maryland's Piedmont waters to agricultural practices (Zipper et al. 2002). Other studies relate low DO findings to domestic and industrial wastewater (Joir et al. 1991). Findings such as these have spurred environmental groups to action by monitoring DO as a "key constituent" of water quality analysis (Greb 1995).

Many analytical techniques have been developed to measure DO. The Iodometric Method, or Winkler Method, of measuring DO is the most reliable and accurate method (Hewitt 1991). However, this method is time consuming and involves skilled technique. This method may also be difficult to conduct at some streamside locations (Austin 1998). Another disadvantage of the Winkler Method is the requirement that a fresh starch indicator be used for accurate readings (Austin 1998). Alternatively, the Membrane Oxygen Electrode Method can be used successfully both in the field and the laboratory, because it takes a direct measurement of DO from the water sample. However, these instruments can be very expensive. They also require careful handling, maintenance, and calibration (Hewitt 1991 and Austin 1998). As a result, many nonprofit volunteer water quality monitoring groups find it difficult to supply every volunteer with a membrane electrode meter. To alleviate the demand for so many meters, samples could be collected streamside for analysis in the laboratory if it could be demonstrated that brief sample storage under refrigeration does not affect DO readings.

Due to natural fluctuations that may affect DO measurement, there is much debate over delayed analysis of DO. According to Mancy (1971) and Patnaik (1997), DO samples should be analyzed immediately, in order to represent true environmental conditions. On the other hand, according to Sanders (1998) measurements can be taken accurately in the laboratory if a dark colored container is used, no air is trapped in the sample container, the sample is not agitated, and the sample is kept at 4° C for no more than 24 hrs. If these sample collection requirements are met and subsequent analysis in the laboratory could be conducted accurately in lieu of streamside analysis, water monitoring organizations would save considerable time and money.

This study was designed to test two hypotheses. The first null hypothesis predicted that there would be no measurable difference in DO for samples measured streamside as compared to those stored at ambient temperature and measured in the laboratory 24 hours after collection. The second null hypothesis predicted there would be no measurable differences in DO for samples measured streamside as compared to those stored on ice for 24 hours after collection.

MATERIALS AND METHODS

Study Site Description

The stream in this study is Crooked Run, which belongs to the Crooked Run watershed (30,322 acres) in Warren, Frederick, and Clarke counties in northwestern Virginia. This watershed empties into the Shenandoah River, which drains into the Potomac River at Harpers Ferry, which then eventually spills into the Chesapeake Bay.

The headwaters of Crooked Run flow from an overflow pipe in the Lake Frederick Dam. Six tributary streams and three springs contribute to the approximately eight-mile stretch of Crooked Run, which empties directly into the Shenandoah River at its mouth. In accordance to *Standard Methods for the Examination of Water and Wastewater* the sites were chosen based on their representation of the stream (American Public Health Association 1998). Six different sampling sites along the length of Crooked Run were chosen for this study. Detailed information on each stream site can be found in Figure 1 and in Table 1. Measurements and sample collection at each location were in accordance to *Standard Methods* (APHA 1998).

Sampling Techniques

Prior to data collection on each day calibration of the DO meter was performed using the procedures set forth in the membrane electrode meter's operational manual (WTW Multiline P4 Field Set, WTW, Florida, USA). Also, before heading to stream sites, twelve plastic bottles were labeled with date, site ID, and stream name. Of the two bottles per site, one of the bottles for each of the six sites read *sample for ice storage.* The other bottle for each of the six sites read *sample for ambient temperature storage.*

The six stream sites on Crooked Run were visited at the same time of day on February 23, March 1, March 5, March 8, March 15, March 20, March 29, and April 4, 2004 allowing for eight replications of the six sites. In addition to the variables of specific interest, the following variables were measured in the event that they influenced DO as well: current weather conditions, pH, water temperature, and air temperature. In addition, as suggested by

Mancy (1971) and the American Public Health Association (1998), flow conditions of the stream were noted and classed into one of three categories, low, normal, or high.

The following sample measurements and storage techniques were repeated at the same time and location on each sampling day. A circulator (Circulator, WTW, Florida, USA) was first placed on the membrane electrode meter's probe. The streamside DO measurements were taken in the middle of the stream and at mid-depth (American Public Health Association 1998), using standard procedures for the membrane electrode meter. Care was taken to submerge the circulator and half of the DO probe into the water. While the probe was measuring DO, two grab samples were collected as close to the probe as possible. The storage treatment to be collected first was randomly chosen. One of the collection bottles was placed into the water, the lid was opened underneath the water, and the bottle was slowly turned into the current until the bottle was upright. The bottle was then capped while it was still underwater. Before removing the bottle from the water, it was ensured that there were no air bubbles in the bottle (American Public Health Association 1998).

The sample to be stored on ice was placed into a cooler on crushed or cubed commercial ice (American Public Health Association 1998) for 24 hr storage. The sample to be stored at ambient temperature was placed into a different cooler without ice for 24 hr storage. Then the DO probe and circulator were removed from water, rinsed with distilled water and dried off with a paper towel.

Phase two of the study took place in the laboratory 24 hrs after samples were collected. The grab samples were measured for DO with the same membrane electrode meter used streamside. Each water sample was analyzed at the same time, 24 hrs after collection on each laboratory day. The following measuring techniques were repeated for all 12 water samples collected from the six stream sites. The sample from each pair to be measured first was randomly chosen. The sample was then placed on a stirrer/hotplate. Immediately after opening the collection bottle a magnetic stir bar was placed into the water sample with the stirrer set on the level 4.5. The DO probe was quickly placed into sample bottle until half of probe was in the sample. Temperature in degrees Celsius and DO in mg L^{-1} was then recorded. Lastly, the probe was removed from the sample, rinsed with distilled water, and wiped clean before analyzing the next water sample.

Analysis of the DO data showed that the concentrations at each of the sampling sites was normally distributed (Ennos 2000) according to the Gaussian function in the Microsoft Excel® package (version 2002). Since the DO data were normal, parametric tests could be used. Analysis of Variance (SAS, Inc.) was performed using a Generalized Linear Model (GLM) with Least Significant Difference to separate the difference between sampling techniques at each of the sites (SAS 1999; Der 2002).

RESULTS

At four of the six sites DO concentrations *in situ* were in the range of 10-12 mg L^{-1} (Figure 2). Two sites had measurements taken directly from the spring heads, Nineveh Spring at CR-02 and McKay Spring at CR-04, and these readings were substantially lower than those from the other sites ranging from 3 to 6 mg L^{-1} DO.

With the exception of one sample site (CR-07) there were significant differences in the mean levels of DO between the samples measured streamside and those stored at ambient temperatures (Figure 2). For three of the sites the mean DO levels were lower in the laboratory than streamside. For the two sites, characterized by low DO (CR-02 and CR-04), DO increased in the samples stored at ambient temperature for 24 hours.

When samples were stored on ice, the differences between the streamside measurement and the 24 hr measurement were not significant except for the two sample sites characterized by low DO concentrations (CR-02 and CR-04; Figure 3). These two sites showed increased DO concentrations compared to the streamside measurement as a result of being stored for 24 hours despite being stored on ice.

Mean temperature measurements ranged from 7.23 to 7.75°C for streamside measurements, from 2.15 to 2.82°C for samples stored on ice, and from 15.38 to 18.29°C for those stored at ambient temperature (Table 2).

Mean temperature measurements for the spring sites ranged from 11.93 to 12.61°C for streamside measurements, from 2.18 to 2.41°C for samples stored on ice, and from 16.42 to 16.76°C for those stored at ambient temperature.

DISCUSSION

The first null hypothesis predicted that there would be no measurable difference in DO at each study site for samples measured streamside as compared to those stored at ambient temperature and measured in the laboratory 24 hours after collection. The data, however, reveal statistically significant decreases in DO concentrations between streamside and stored samples for sites CR-01, CR-05, and CR-20 and statistically significant increases in DO concentrations at CR-02 and CR-04, therefore, the null hypothesis is rejected (Figure 2). The results demonstrate that DO cannot be accurately measured in the laboratory in most cases if stored at ambient temperatures for 24 hrs.

The DO measurements for the four main channel sites (CR-01, CR-07, CR-05, and CR-20) may have decreased after 24-hr storage at the ambient temperatures because of biotic activity in warmer water, which also holds less oxygen. Prior to storage, average streamside temperature for the four main channel sites was 7.49°C. It can be speculated that DO decreased due to the average temperature increase of nearly 10°C over the 24-hr storage period that caused an increase in oxygen-consuming respiration by plant and animal life.

The second null hypothesis predicted there would be no measurable difference in DO for samples measured streamside as compared to those stored on ice for 24 hours after collection. However, there were significant increases in DO concentrations in two of the six sites, therefore, the null hypothesis must be rejected (Figure 3). The two sites that had increasing DO concentrations in both experiments were the spring sites which are characterized by low DO concentrations because they came directly from groundwater sources which usually have lower DO concentrations. The DO concentrations appear to increase as a result of storage both at ambient temperature and on ice. The cause of this increase is not clear but could be due to rapid influx of oxygen during the time of measurement as a result of the steep oxygen gradient.

Nevertheless, looking at the four main channel measurements with higher DO concentrations, the samples stored on ice for 24 hrs exhibited no significant difference from the measurements taken streamside (Figure 3). Thus, one could justify laboratory analysis of refrigerated samples in winter and when stream DO concentrations are more than 9 mg L^{-1}. Further testing must be done to determine if this is appropriate under other conditions. This result could be extremely useful to environmental groups, like watershed associations, who make use of citizen monitors because it would eliminate the need to supply expensive membrane electrode meters and training to every monitor. Collecting grab samples streamside and analyzing them in the laboratory could also reduce the amount of human error that can result from using the more time-consuming Iodometric Method and Winkler Method of measuring DO.

Furthermore, although there were statistically significant differences between some *in situ* measurements and some laboratory measurements, the numerical difference was relatively small (<1 mg L^{-1} in most cases). Many volunteer groups don't need high precision. They often just need to know if the DO is < 6, 6-8, or > 8 mg L^{-1}. So if precision were not an issue, then even ambient storage would be acceptable.

Further research is needed to determine why the spring sites had such a large increase in DO after 24 hr storage. Also, due to time limitations set on this study, these data were only collected from February to April. Further experimentation for more seasons could greatly improve our understanding of alternative sampling methods. DO concentrations are an important characteristic to consider when studying the health of a watershed, which is why affordable and effective sampling and storage techniques must be adopted that won't diminish the quality of the DO measurements. Future research into DO measurement techniques could be extremely useful for volunteer water monitoring organizations, saving them considerable time and money.

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TABLES

Table 1. Name, ID, and locations of the six sampling sites in the Crooked Run watershed.

Site Name	Site ID	Coordinates	
Headwaters of Crooked Run	CR-01	39° 2.495 N,	78° 9.462 W[a]
Nineveh Spring on Crooked Run	CR-02	39° 4.192 N,	78° 9.456 W
McKay Spring on Crooked Run	CR-04	38° 58.722 N,	78° 11.123 W
Above Molly Camel on Crooked Run	CR-07	39° 0.396 N,	78° 11.115 W
Crooked Run at Cabin Court	CR-05	39° 1.063N,	78° 3.103 W
Crooked Run at Country Club Road	CR-20	38° 57.393 N,	78° 11.138 W

[a] Coordinates recorded with a handheld Global Positioning System unit (Sportrack Pro, Magellan, Inc., California, USA)

Table 2. Seasonal mean water temperatures for streamside samples and grab samples stored for 24 hrs obtained from Crooked Run.

Site Name	Streamside (°C)	Sample stored on Ice (°C)	Sample stored at Ambient (°C)
Main Channel Sites			
CR-01	7.52	2.46	15.38
CR-07	7.23	2.15	17.06
CR-05	7.75	2.20	17.84
CR-20	7.47	2.82	18.29
Spring Sites			
CR-02	11.93	2.18	16.42
CR-04	12.61	2.41	16.76

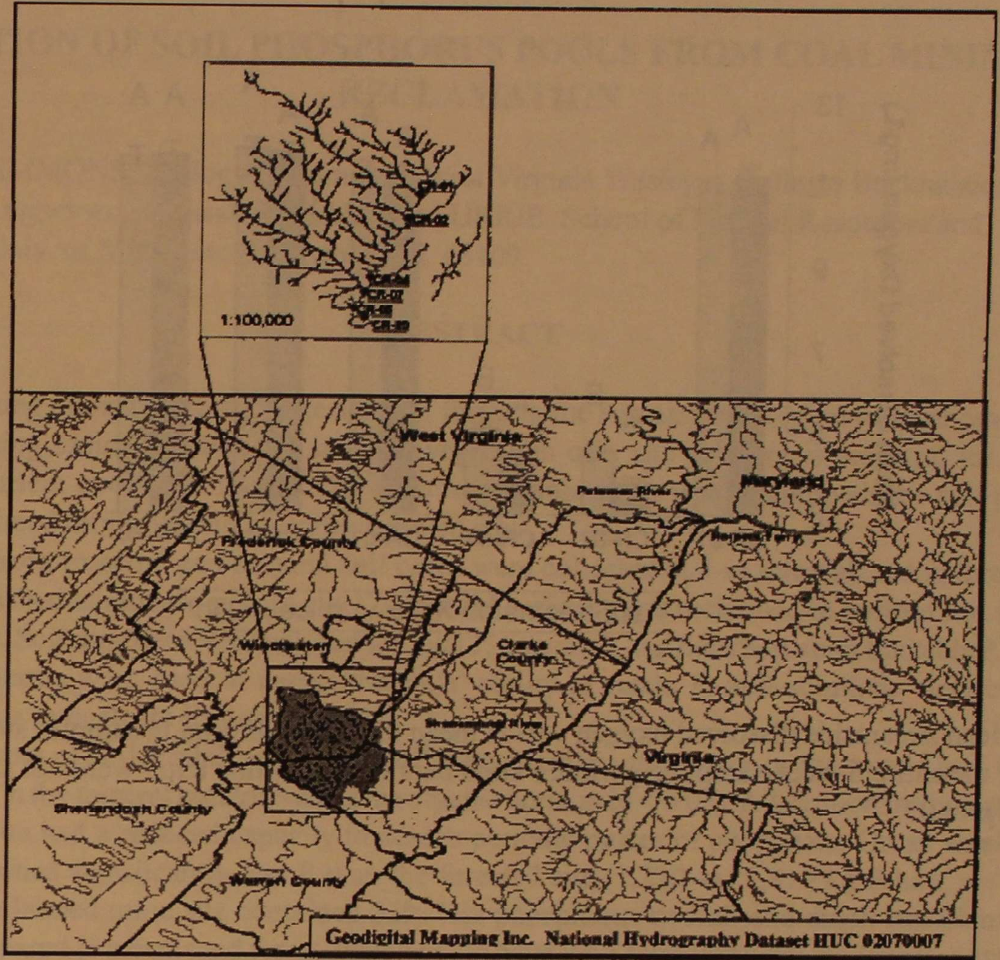

Figure 1. Map showing the location of Crooked Run and the six sampling sites.

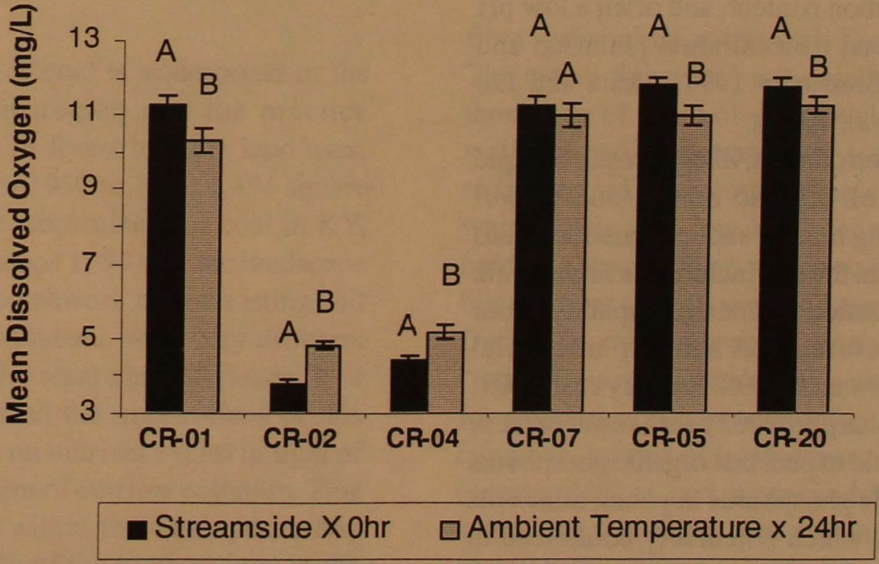

Figure 2. Mean streamside dissolved oxygen versus mean dissolved oxygen in samples stored at ambient temperatures for 24 hrs over the entire 6-week sampling period. Paired bars with the same letter were not significantly different at $p < 0.05$.

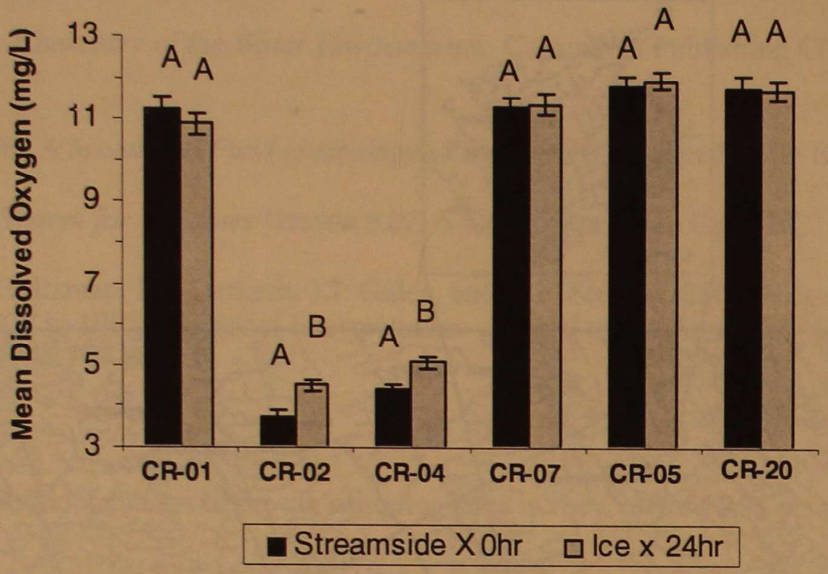

Figure 3. Mean streamside dissolved oxygen versus mean dissolved oxygen in samples stored on ice for 24 hrs over the entire 6-week sampling period. Paired bars with the same letter were not significantly different at $p<0.05$.

to have a high bulk density, little aggregate structure, low carbon content, and often a low pH or high toxic metal concentration (Johnson and Skousen 1995; Bradshaw 1997; Akala and Lal 2001; Ramsey et al. 2001).

The low carbon content, likely a result of rapid decomposition of organic matter due to soil disturbance during mining and reclamation, leads to other changes in the soil including a higher bulk density, lower cation exchange capacity, poor aggregate structure, and smaller microbial populations (Lyons et al. 1998; Ramsey et al. 2001; McDowell and Sharpley 2003). As a result of these changes one would expect that organic phosphorus and exchangeable phosphorus in young minesoils would be lower, which potentially could lead to reductions in net primary productivity. Indeed, P deficiency is cited as a common problem of minesoils that must be overcome in order to establish vegetation on a site (Plass and Vogel 1973; Thomas and Jansen 1985; Bradshaw 1997).

ALTERATION OF SOIL PHOSPHORUS POOLS FROM COAL MINING AND RECLAMATION

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ABSTRACT

Surface mining of coal converts large areas of forest in the Appalachian region to other land uses such as pasture. Mining radically alters the soil and vegetation of a site so there is potential for substantial alteration of nutrient pools and fluxes. The objective of this study was to compare the soil phosphorus pools of a reclaimed mine site and a nearby forested site.

Organic horizon material and mineral soil cores were collected at 3-m intervals along three transects that were established at random in a 14- to 17-year-old surface mine reclaimed to pasture and in a mature hardwood forest. Soil samples were analyzed for total P, organic P, and bicarbonate-extractable P. Phosphate adsorption isotherms were used to assess the soils' ability to retain P. Soil solutions were collected in tension lysimeters to evaluate soil solution P.

All three forms of soil P plus soil solution P were significantly lower in the mined soil than in the forested soil and in the mineral horizon versus the organic horizon ($p < 0.05$). Adsorption isotherms suggested that the mined site had a reduced capacity to adsorb periodic pulses of phosphate. On an areal basis, the mined site contained significantly less P than the forested site (1,230 vs. 1,810 kg P ha^{-1}; $p < 0.05$). In summary, the reclaimed mine site contained 32% less phosphorus overall and much less plant-available phosphorus compared to a managed forest, which could have long-term implications for plant nutrition and ecosystem development.

INTRODUCTION

Surface mining of coal is widespread in the central Appalachian region and the practice converts large areas of forest to other land uses, mainly pasture. From 1930 to 1980 1,454 square miles of forest were strip mined for coal in KY, WV, VA, and TN (Hopps 1994). At the landscape level the result is a patchwork of contrasting soil types supporting ecosystems with very different biological and geochemical characteristics. It is important to understand the implications of this large scale alteration on nutrient cycles in light of the nationwide problem of nutrient pollution. This is especially critical within the Chesapeake Bay watershed where 69% of the nutrient load to the Bay comes from the watersheds of the four main tributaries.

The soils that result from the mining and reclamation process are fundamentally different from undisturbed, native soils in a variety of ways. The native forest soil is typically the product of thousands of years of soil development and has well-defined horizons with a surface horizon characterized by a high organic matter content which leads to a low bulk density, high water-holding capacity, high cation exchange capacity, high nutrient content and good aggregate structure. During the mining process the native soil (called "topsoil") is removed, mixed, and piled to the side for a period of weeks to months. After mining is complete, a layer of homogeneous spoil material (overburden) is laid down and the "topsoil" is spread on top using heavy equipment. Thus, a typical minesoil has a 20- to 30-cm thick surface layer of mixed, compacted native soil material over a thicker homogeneous layer of spoil material (Doll 1988). Consequently young minesoils tend

The objectives of this study were to determine how conversion of forest to grassland via coal surface mining and reclamation affects P pools and P availability. We hypothesized that P pools would be reduced in the reclaimed mine soils as a result of the disturbance and the reduction in soil carbon. To accomplish this we compared the soil of a 14-17 year-old reclaimed mine watershed with the soil of a nearby forested watershed. Although reports of P availability in reclaimed minesoils abound (e.g., Plass and Vogel 1973; Barnhisel 1988; Bradshaw 1997), our study goes further by also examining organic P, P adsorption characteristics of the soils and concentrations of P in soil solutions.

METHODS

Site

The two study sites were located on Dans Mountain (N79° 02', W39° 40'), just south of Frostburg in western Maryland. The sites were selected based on similarity of soils (predisturbance), slope position, aspect and elevation. The first watershed (NEF) is a small (3.0 ha) forested subwatershed of Neff Run covered with mixed conifers and hardwoods at an elevation of 2,200 – 2,520 ft. and northwest aspect. The soil is classified as Cookport very stony silt loam. Most of the subwatershed was selectively logged in 1980 according to aerial photos (K. Kuers, personal communication). MAT is a 27.2-ha subwatershed of Matthews Creek, with an elevation of 2,540 – 2,740 and west aspect. Prior to 1981 MAT was covered with mixed conifer hardwood forest. Virtually all of MAT was clearcut in 1981 according to aerial photographs and permit records (K. Kuers, personal communication). These records also indicate that approximately one-half the area of MAT (12.5 ha) was surface mined for coal from 1981-1985. We refer to the reclaimed mine portion of the watershed as MAT-R. The upper portion of MAT-R was reclaimed to "pasture" in 1983 and the lower half in 1986 although since that time it has been managed as an ungrazed, periodically-mowed grassland. Reclamation included reapplying approximately 30 cm of topsoil that was scraped from the site, amending with fertilizer, and seeding with a mixture of grasses. The two watersheds, which are approximately 0.5 km apart, are described in more detail in Negley and Eshleman (2005).

Sampling

Three permanent, 100-m transects were established in both MAT-R and NEF at random locations and with orientations of either 0, 120, or 240 degrees. A surface soil and subsoil sample were collected from random locations within each 3-m-long segment along the length of each transect in August 1999 in NEF and in August 2000 in MAT-R. The Oe/Oa horizon was collected quantitatively using a 10 x 10 cm template in NEF. Similarly, at MAT-R we harvested quantitatively what appeared to be a thin Oe horizon (organic carbon content > 20%), but which subsequent analysis showed to be in some cases an organic-rich mineral (A1) horizon (organic carbon content < 20%). Therefore, the surface horizon at this site will be referred to as the Oe/A1 horizon. Mineral horizon material was collected quantitatively in both watersheds by taking two 5-cm diameter bulk density cores to a depth of 10 cm below the presumed organic horizons.

In 2001 tension lysimeters were installed in both watersheds within three randomly-located, permanent plots at depths of 10 cm (shallow) and 40 cm (deep). Three lysimeters at each depth were located in each plot for a total of 18 per watershed. Lysimeters were sampled once per month during the growing season of 2000 and 2001 by establishing a partial vacuum in the lysimeters, waiting 24 hours, and then removing the sample.

Analysis

Soil samples were weighed for bulk density and then sieved through a 2-mm mesh. The remaining analyses were conducted on the <2 mm fraction only. Soil pH (in 0.01 $CaCl_2$) and ammonium-acetate-extractable Fe, Al, and Ca were measured (Thomas 1982). Total C was determined using a CHN analyzer (Carlo-Erba, Inc.). Plant-available P was measured using a bicarbonate extraction and total and organic P by dry-ashing (Olsen and Sommers 1982). P adsorption was measured by adding 30 mL of extracting solution (0, 10, 30, 50, 70 and 90 mg P L^{-1}) to 3 g of soil, letting it equilibrate for 24 hours, and then vacuum filtering. The P adsorption procedure was conducted in triplicate on 12 randomly-selected samples from each horizon from MAT-R and NEF. Adsorption isotherms were calculated from these results. Carbon and phosphorus pools were calculated for each sampling location by multiplying the total C or total P concentration by the bulk density corrected for the mass of stones and then extrapolated to 30 cm depth.

Lysimeter samples were filtered (0.45 μm) and subsamples frozen until analysis for dissolved reactive P and total dissolved P (alkaline persulfate digestion). Dissolved organic P was calculated by difference (APHA 1995).

Statistics

A two-way ANOVA was used to identify site, horizon and interaction effects for the P fractions and soil physico-chemical characteristics. Horizon effects were not of concern for the phosphate adsorption data, so a simple t-test was used to examine differences between watersheds. A repeated measures ANOVA was used to test for site, horizon, and sampling date effects on lysimeter data. There were no significant date effects so data from all dates was pooled and analyzed with a two-way ANOVA. All statistical analyses were performed using SPSS v.13.0 (SPSS, Inc.) with an alpha of 0.05.

RESULTS

Because of the manipulation of the soil in MAT-R during the mining operation 14 to 17 years previously, the soil exhibited very little horizon development. A thin Oe/A1 horizon (mean thickness 0.9 cm) had formed in the years since reclamation, which was significantly thinner than the Oe/Oa horizon of NEF (6.4 cm; $p < 0.01$). Approximately 58% of the surface soil samples in MAT-R qualified as organic soil material indicating that the Oe horizon at this site was discontinuous. Compared to the forested NEF watershed, both horizons in the reclaimed mine site had a significantly higher pH but lower percent carbon (Table 1). Also the bulk densities of both horizons in MAT-R were significantly greater probably due to the lower organic matter content of these horizons.

The iron content (ammonium-acetate extractable) of the mined soil was significantly greater than that of the forested site ($p < 0.01$; Table 1). The higher metal concentration could be the result of the mixing in of subsoil material during the reclamation process which could include small amounts of iron minerals (like pyrite, FeS_2) that rapidly oxidize when exposed to air and water. The extractable aluminum and calcium concentrations of the two soils were not significantly different.

The two-way ANOVA for soil total P and organic P showed significant site, horizon, and interaction effects (Table 2). Both total P and organic P were significantly greater at NEF than at MAT-R (Table 2; Figure 1). Subsoil horizons contained only about half theconcentration of total P and organic P as the surface horizons. In contrast, there were no differences in organic P expressed as a percentage of total P between the two sites, only between horizons. The percent organic P averaged 71% in the surface horizons and 57% in the subsoil horizons at both sites.

Bicarbonate-extractable P, which represents the plant-available fraction, showed a similar pattern with significant differences by site, horizon, and interaction (Table 2). Bicarbonate-extractable P was significantly lower in MAT-R than in NEF. In its surface horizon MAT-R contained only 37% as much bicarbonate-extractable P and in the deeper horizon only 17% as much.

To determine if there were significant changes in the absolute amount of P in the soil column as a result of the mining and reclamation process we calculated the C and P pools at each site on an areal basis. The P pool was significantly smaller in MAT-R (1,230 kg P ha^{-1}) than in NEF (1,810 kg P ha^{-1}; Figure 2).

Table 1. Mean (standard deviation) characteristics of soil from an 18-yr-old selectively logged forest (NEF) and a 14- to 17-yr-old reclaimed coal mine (MAT-R). All sites were located within the Georges Creek watershed in western, MD. Two-way ANOVA results are presented at the bottom of each column. * and ** indicate that the effect was significant with $p < 0.05$ or 0.01, respectively; ns = not significant. N= 30 for each parameter in each watershed.

				Extractable Cations[b]		
	pH[a]	Bulk Density (g cm^{-3})	Total Carbon (%)	Fe (mg g^{-1})	Al (mg g^{-1})	Ca (mg g^{-1})
Surface Horizon[c]						
NEF	4.21[d]	0.032 (0.015)	32.9 (6.6)	1.1 (0.6)	0.88 (0.53)	2.3 (0.8)
MAT-R	5.59	0.128 (0.091)	15.5 (5.2)	2.2 (0.9)	1.04 (0.61)	2.4 (1.2)
Subsoil Horizons						
NEF	3.99	0.824 (0.201)	4.80 (2.9)	5.3 (1.8)	2.3 (1.2)	2.2 (0.9)
MAT-R	5.15	1.26 (0.152)	1.95 (0.3)	6.7 (2.8)	2.4 (1.7)	2.1 (0.9)
Significant effects						
watershed	**	**	**	**	ns	ns
horizon	**	**	**	**	*	ns
interaction	ns	**	**	ns	ns	ns

[a] pH measured in 0.01 $CaCl_2$.

[b] Fe, Al, and Ca extracted in 1N ammonium acetate (Thomas, 1982)

[c] In NEF the surface horizon was Oe/Oa; in MAT-R the surface horizon was a mix of Oe and A1 horizons

[d] pH values were back calculated from the mean H^+ concentrations; therefore standard deviations could not be calculated

Table 2. Mean (standard deviation) total, organic, and bicarbonate-extractable P from soils of a selectively-logged forest (NEF) and reclaimed mine (MAT-R) in western Maryland. Two-way ANOVA results are presented at the bottom of each column. * and ** indicate that the effect was significant with $p < 0.05$ or 0.01, respectively. ns = not significant.

	Total P (mg g^{-1})	Organic P (mg g^{-1})	Organic P[a] (%)	Extractable P (μg g^{-1})
Surface Horizon[b]				
NEF	2.50 (0.587)	1.81 (0.49)	69.8 (7.07)	129 (85.1)
MAT-R	0.371 (0.093)	0.29 (0.47)	74.0 (6.93)	48.0 (24.3)
Subsoil Horizon				
NEF	1.24 (0.758)	0.73 (0.51)	58.2 (10.4)	79.0 (42.0)
MAT-R	0.375 (0.165)	0.22 (0.11)	56.7 (13.6)	13.4 (11.5)
Significant effects				
watershed	**	**	ns	**
horizon	**	**	**	**
interaction	*	**	ns	**

[a] Organic P as a percentage of the total P

[b] In NEF the surface horizon was Oe/Oa; in MAT-R the surface horizon was a mix of Oe and A1 horizons.

In contrast to the P pool results and the dramatic difference in percent carbon between MAT-R and NEF, the total C pools were not different mainly because of the high bulk density of MAT-R soil which offset its lower carbon concentration. For both elements, the quantities in the mineral horizons exceeded those in the organic horizons by a factor of 10 or more because of the greater thickness and density of the former.

We also examined the capacity of the soil to retain P by using adsorption isotherms to calculate EPC_0. EPC_0 is the solution phosphate concentration at which phosphate is adsorbed and desorbed at the same rate. Graphically, it is the point at which the isotherm crosses the x-axis. Low EPC_0 values, which correspond to high retention capacity, mean that phosphate is adsorbed by soil particles at lower solution concentrations. The soil's ability to buffer against increases in soil solution P can be estimated from the slope of the isotherm at the point that it crosses the EPC_0 point. A steep slope means the soil's ability to adsorb additional P increases as soil solution P increases (i.e., that the density of adsorption sites increases).

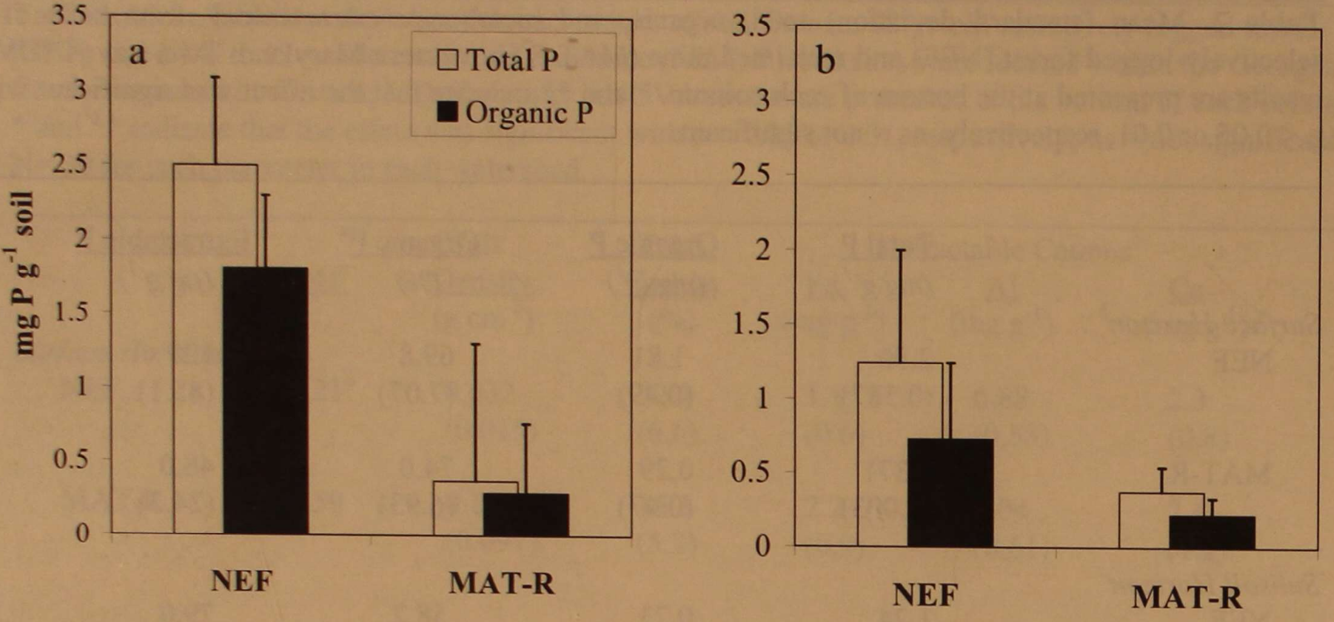


Figure 1. Total and organic P concentrations in (a) surface horizons and (b) subsoil horizons (0-10 cm) at the forested watershed (NEF) and the reclaimed mine watershed (MAT-R). Bars represent the mean of 30 replicate soil samples taken along three transects. Error bars show the standard deviation. Two-way ANOVA indicated significant watershed, horizon, and interaction effects (Table 2).

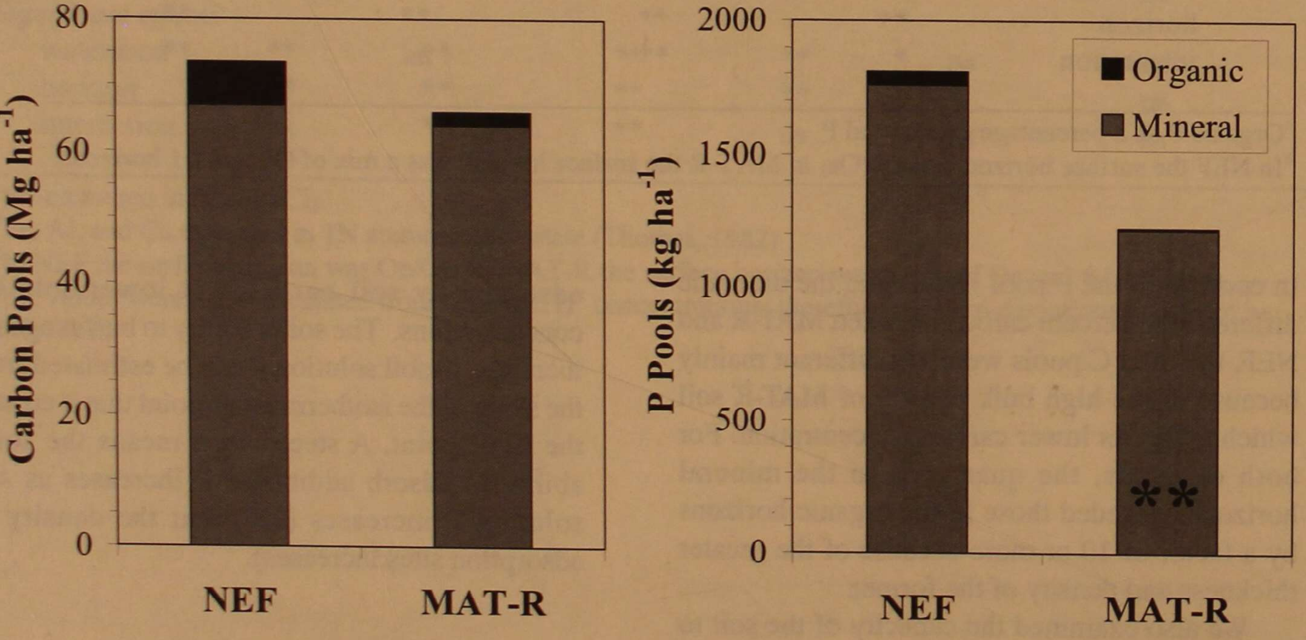


Figure 2. Total element pools per hectare in the forested watershed (NEF) and the reclaimed mine watershed (MAT-R) for (a) carbon and (b) phosphorus. The organic horizon in NEF was Oe/Oa, whereas in MAT-R it was a mixture of Oe and A1. Asterisks indicate a significant difference between the watersheds (t-test; $p < 0.01$).

The forested site's Oe/Oa horizon had a significantly greater EPC_0 than the reclaimed mine site's surface horizon (Table 3). This indicates that the forested Oe/Oa soil had a lower P retention capacity or, conversely, that a greater proportion of P remained in soil solution. Several researchers have demonstrated that the presence of organic matter tends to decrease P adsorption capacity of Fe and Al oxides through exclusion and competition. That is, organic molecules can adhere to mineral particles and block adsorption sites and organic acid anions can compete with phosphate ions for adsorption sites. In contrast, the reclaimed mine's surface horizon had a greater potential to retain P and we would therefore expect lower P concentrations in solution. However, because this horizon is so thin, the absolute capacity of this layer to adsorb phosphate will be limited.

At the same time the buffering capacity of the MAT-R surface horizon, as represented by the slope of the adsorption isotherm, was significantly lower than that of NEF. Thus, increases in soil solution P, such as might occur after plant senescence and leaf drop in autumn, will lead to relatively little P retention in the reclaimed mine soil. Instead, a large portion will remain in labile and solution phases where it may be leached to lower horizons. In contrast, the forested site's organic horizon will tend to retain more of these P pulses. In the mineral horizon there were no significant differences in the EPC_0 or slope between sites.

Soil solution P data exhibited a significant site and date effect but no effect of horizon (Figure 3). Both total dissolved P (TDP) and dissolved organic P (DOP) were significantly lower in MAT-R than in NEF. DOP contributed approximately 26 to 56% of the TDP.

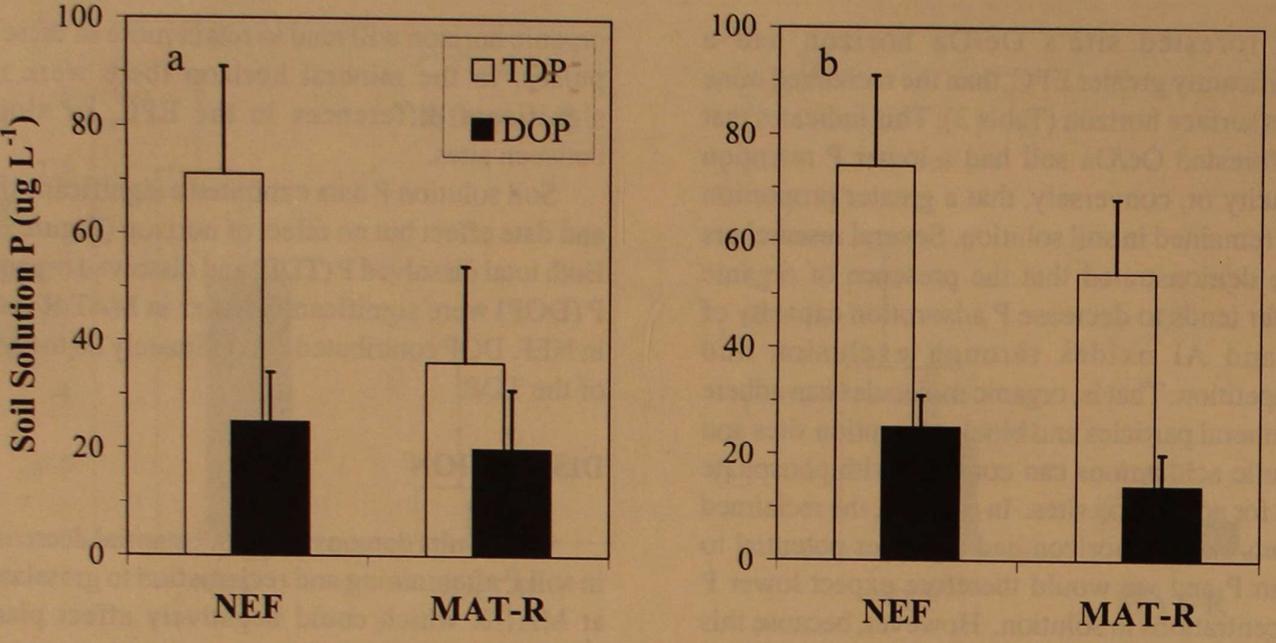
DISCUSSION

Our results demonstrate a substantial decrease in soil P after mining and reclamation to grassland at MAT-R which could negatively affect plant productivity. In particular plant growth rate may be negatively affected by the lower concentration of available P and soil solution P (Table 2; Figure 3). Whether or not plant production in MAT-R was actually limited by P, plants will need to allocate more resources to roots and mycorrhizal associations than those in NEF to obtain the same amount of P (Geisler et al. 2004). In a soil with low P concentration there is the potential for a negative feedback on the P cycle. Low soil P concentrations can lead to reduced uptake and consequently lower foliage P concentrations.

Table 3. EPC_0 (mg L^{-1}) and slope of phosphorus adsorption isotherms using equilibration solutions of 0, 10, 30, 50, 70 and 90 mg P L^{-1}. The mean and standard deviation of 12 replicate samples per watershed and horizon are presented. Asterisks indicate significant differences between watersheds ($p < 0.05$).

	EPC_0		Slope	
	Mean	SD	Mean	SD
Surface Horizon[a]				
NEF	3.20	(0.119)	2.12	(0.54)
MAT-R	0.158*	(0.68)	0.269*	(0.061)
Subsoil Horizon				
NEF	0.121	(0.113)	0.932	(0.517)
MAT-R	0.029	(0.021)	0.633	(0.262)

[a] In NEF the surface horizon was Oe/Oa; in MAT-R the surface horizon was a mix of Oe and A1 horizons.



This, in turn, can lead to lower concentrations of P in soil organic matter. If the C:P ratio is high enough it is possible that P can become limiting to microbial decomposers who will conserve it tightly at the expense of plant uptake (Gallardo and Schlesinger 1994; Cross and Schlesinger 1995). Thus, available P concentrations (bicarbonate-extractable and soil solution P) in such a soil will remain low until organic P has accumulated sufficiently to reduce the soil C:P ratio to the point that microorganisms are saturated. Adsorption isotherm results support this idea. The low EPC_0 values in the reclaimed mine site's soils suggests a P retention capacity that is not being realized and reflects a relatively low long-term soil solution concentration of P (Table 3; Figure 3). In contrast the Oe/Oa horizon in NEF does not adsorb as much P from soil solutions, leaving more available for plant uptake.

Furthermore, the lower concentration of total and organic P in MAT-R as well as the apparent small pool of adsorbed P means that the soil has a limited capacity to replenish the available P pool after plant uptake or after a minor disturbance like fire or harvesting. Over the long-term reduced plant growth and increased competition for P may affect succession by slowing it or by altering the species that can survive and compete there.

MAT-R soil has been changed in other ways as well. Compaction by heavy equipment and/or loss of organic matter increased the bulk density of the soil which was shown to decrease soil aeration and infiltration rate (Negley and Eshleman 2005). The organic horizon of MAT-R is very thin and discontinuous and does not serve as a nutrient reservoir for plants as the thick humus layer in NEF does. Physical and chemical limitations of minesoils such as these can limit the species of plants that can invade and establish themselves (Johnson and Skousen 1995). Visual inspection of the site showed an incomplete plant cover consisting mostly of perennial plants and virtually no tree species present. This suggests less than ideal growing conditions were present.

The reduction in total P concentration in soil horizons was mirrored by a reduction in total P per hectare. We can estimate the total amount of P lost from the reclaimed mine watershed if we assume that MAT-R soil prior to the disturbance was similar to the soil that exists currently in NEF. There is reason to accept this assumption. First, aerial photos and permits for the operation confirm the existence of mature hardwood forest on the site before 1980, meaning that a hardwood forest soil similar to that in NEF existed on the site and that it likely had some degree of horizon development. Second, the P pools in NEF are unlikely to have changed much during the past 14-17 years as the forest has recovered from the relatively minor disturbance of selective logging. P inputs from weathering and deposition are typically small and mostly offset by small leaching losses of P in highly conservative, aggrading forest systems (Newman 1995; Yanai 1998).

With the aforementioned assumption we estimate a net change of -580 kg P ha^{-1} in total soil P (Figure 2) based on the observed differences between the forested and reclaimed mine soil column. Reclamation records indicate that 90 kg P ha^{-1} of fertilizer was applied just before revegetation. That would mean a gross change of -670 kg P ha^{-1}, or -37%, due to the mining and reclamation process. At the ecosystem level the loss of P is probably even greater because of the removal of P in aboveground biomass (trees) prior to mining. It is unlikely that much of the P was lost during the 14-17 years of recovery because once vegetative growth was established, and the subsequent nutrient cycling through tissues and organic matter, P losses due to leaching would be minimal (Bradshaw 1997; Yanai 1998).

Rapid loss of P, as well as carbon, nitrogen, and other nutrients, during mining and reclamation could occur at several steps in the process although we know of no investigations of this process. Immediately after clearcutting the forest the cessation of plant uptake could lead to increased leaching losses. During mining when the native soil was removed and stored in spoil piles, decomposition of soil organic carbon would be stimulated with a concomitant loss of organic P. After replacement of the soil material and before establishment of vegetation, decomposition would again be stimulated by the disturbance, releasing organic P which would be rapidly leached without plant uptake to prevent it. Finally, erosional losses of bulk soil from spoil piles and unvegetated soil would contribute to the loss of P (Udawatta et al. 2004). P losses from all or some of these processes could be responsible for the observed decreases in soil P. During the 14 to 17 years since reclamation successional processes have been active at MAT-R. Akala and Lal (2001) documented changes in soil carbon in a chronosequence of reclaimed soils in Ohio. Soil organic carbon levels were low for the first 5 years and then C fixation by plants caused it to increase rapidly to nearly the pre-mining level by year 20. In a plot-level study in western Virginia soil carbon levels, which were initially low, returned to pre-mining levels after 16 years (Bendfeldt et al. 2001). Comparable rates of carbon accumulation were reported in an abandoned agricultural field chronosequence (Knops and Tilman 2000). A similar process may have occurred at MAT-R. In 2000 the C content of MAT-R was comparable to that of its pre-mining level; however, we do not know how far it was reduced immediately after reclamation.

Although C pools can be replenished in as little as 20 years, P accumulation is much slower. P accumulates through weathering and deposition at extremely low rates on the order of 1 to 2 kg ha^{-1} yr^{-1} (Newman 1995; Yanai 1998). Leaching losses of P in the eastern U.S. are on the order of 0.1 to 1.0 kg ha^{-1} yr^{-1} (Newman 1995; Yanai 1998). At these rates it would take over 300 years for the total P pool to return to its pre-mining level. Thus, in the short term P will remain in short supply. This underscores the importance of taking a long-term view in the design phase of the reclamation project. Decisions made regarding spoil materials used and configuration of those spoils will determine the long-term successional trajectory of the site (Chichester and Hauser 1991; Johnson and Skousen 1995).

If the results from this case study are typical of surface mines in Appalachia then we can expect mined watersheds to have much less P compared to surrounding forested ecosystems. Replenishment of that P from natural processes may take centuries and as such represents an enduring loss of this key nutrient. Nutrient management should be an integral part of ecosystem management but it is often overlooked in mining reclamation perhaps because reclamation, by definition, is a short term objective (Bradshaw 1997). A potential solution to this problem is amending the soil with fertilizer. However, additions of chemical fertilizers will be most effective 5 to 10 years after reclamation when the system's ability to retain phosphorus (via nutrient cycling) has been established. The fertilizer at our study site was applied when no vegetation was present and as a result much of the added P was probably leached or eroded from the system.

Another implication of this loss of P from terrestrial ecosystems is that some portion of that loss is translocated to the aquatic realm. At any given time, numerous surface mining operations are active in the Potomac River basin and could be acting as sources of P inputs to the river. Quantifying the size and significance of this source is not possible with current information, but it should be a priority for research in the next few years.

In summary, the reclaimed mine soil in this case study exhibited significantly smaller P pools (total, organic, soil solution, and adsorbed) and less available P than the forested soil. Furthermore the ability of the soil to retain P was reduced. It will likely take centuries for the P pool to recover to pre-disturbance levels. This underscores the importance of nutrient management as a part of ecosystem management.

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