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Macroinvertebrate assemblages of surface mine wetlands of Southwest Virginia, USA

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Abstract—The focus of this study was to investigate the macroinvertebrate community in surface mine wetlands. Nine wetlands were sampled for macroinvertebrates from July 1993 through May 1994. These sites represented a range of physical, chemical, and biological parameters. Macroinvertebrates were found in all sites; a total of 14 orders, 40 families, and 70 genera were identified in the samples. Insects were the most common invertebrates, and most functional feeding groups were represented. Predators dominated with 63% of the taxa, followed by the collector/gathers with 20%, shredders 14%, and scrapers 3%. Sites differed in the number of taxa inhabiting them. Richness ranged from 10 genera to 52. The lowest richness was found in two seasonal wetlands that were dry for the majority of the year. A permanently flooded site with no water quality problems and a dense growth of aquatic plants had the highest richness.

Keywords: macroinvertebrate assemblages; surface mine wetlands; wetland faunas.

1 Introduction

Although macroinvertebrates are a major component of wetland faunas, research on the details of their abundance, distribution, and functioning in wetland habitats has only recently been initiated. Most macroinvertebrate studies have focused on lotic (stream) ecosystems. Krieger (Krieger, 1992) and Rosenberg and Danks (Rosenberg, 1987) suggest several reasons for the lack of research on macroinvertebrates in lentic systems: (1) attention to control and/or eradication of a few pest insect species, (2) a perception that macroinvertebrates are economically trivial, and (3) difficulties encountered in identification and sampling. Research has begun to increase as the role of aquatic insects in the food web and nutrient cycle is identified (Murkin, 1988).

Wetlands on surface mines have been identified as novel wetland resources. Prior to passage of the Surface Mining Control and Reclamation Act of 1977 (USA PL 95-87), mines were abandoned after coal was removed. In this situation, new landforms replace natural topography. Water is retained in small depressions, due to severe compaction, and in sediment, which limits infiltration. With time, these areas are colonized by hydrophytes, and detritus accumulates, which can influence wetland functions. Part of the litter biomass provides energy resources for macroinvertebrates.

Several studies have investigated macroinvertebrates of wetlands created by human disturbance (Barnes, 1983; Fowler, 1985; Street, 1979). However, wetlands of contour mines in the Allegheny Plateau region of the state of Virginia have not been studied. These sites are unique because they are located along long, narrow surface mine benches, occur at elevations higher than typical riverine wetlands, and are individually small, but they exhibit a high density. The objective of this research was to determine what macroinvertebrates utilize these unusual ecosystems. Goals of the current study were (1) to determine if macroinvertebrates are a component of accidental wetlands on surface mine benches of Southwest Virginia, (2) to identify the structure of this macroinvertebrate community, (3) to characterize the macroinvertebrate community response to disturbance, e. g., drawdown, and (4) to estimate the potential of macroinvertebrates to colonize wetlands constructed for reclamation of surface mines.

2 Methods

Macroinvertebrates were collected from nine wetlands located on three surface mine benches. The study sites were part of a larger project investigating the ecological services provided by surface mine wetlands of contour mine benches (Atkinson, 1994). The sites represented a variety of physical parameters (Table 1). Sites were small, with an average size of 0. 06 ha, ranging from 0. 01 ha to 0. 17 ha. Mean age of the wetlands was 17 years——the youngest was 9 years and the oldest 26. The depth of the wetlands was recorded for each site. Since the wetlands varied in depths, some of the sites were seasonal or dry during one or more sampling periods.

Water chemistry parameters varied between sites (Table 1). High conductivity, metals concentrations, and sulfate concentration indicated stressed sites. Four species of *Typha* spp. macrophytes dominated different wetlands (Table 2). *Typha* was dominant in four sites, *Scirpus cyperanus* in three sites, *Sparganium americanum* in one site, and the aquatic *Myriophyllum* spp. in the final site.

Macroinvertebrate samples were taken on four dates: July 1993, September 1993, March 1994, and May 1994. Three samples were taken on each date using a D-frame net for sweep samples. This technique was selected because it (1) allows sampling of both the water column and the top layer of sediment, (2) allows sampling of thick vegetation, (3) adequately samples microhabitats, (4) is nondestructive, and (5) compared to various other types of sampling methods, offers the best results for taxa richness and relative abundance in wetlands (Cheal, 1993). A 1. 0-mm mesh opening was selected to reduce clogging of the net. Samples were collected using a catch per unit effort (CPUE) technique. To standardize the sampling effort, a sample area of 0. 25 m^2 was swept. The size of the area was maintained by placing a 0. 25-m^2 frame on top of the water and moving the net throughout the area. Samples were preserved in a 10% formaldehyde solution. In the laboratory, samples were rinsed through a 1. 0-mm mesh sieve. The macroinvertebrates were then picked from the remaining material. Identification was taken to genus using keys from Merritt and Cummins (Merritt, 1984).

Table 1 Chemical and physical parameters of nine accidental wetlands located on the Powell River Project, Wise County, VA, July 1993 to May 1994

Site	pH	Cond, μMHO	Fe, mg/L	Mn, mg/L	SO_4, mg/L	Mg, mg/L	Hard($CaCO_3$), mg/L	Alk($CaCO_3$), mg/L	Area, ha	Distance to H_2O, m	Age yr	H_2O depth, m	H_2O flux, SD	H_2O perm
B1	6.58	469	0.5	1.7	229	24.4	180	55	0.04	*	20	0.7	1.9	Y
B2	6.27	988	5.7	4.7	927	84.8	618	59	0.2	3	20	0.7	0.8	Y
B3	4.99	932	0.1	3.2	723	88.1	533	56	0.08	37	20	0.6	1.8	N
L1	6.15	378	2.0	2.0	3	4.1	31	32	0.01	40	19	0.2	2.0	N
L2	6.34	714	0.2	0.5	329	36.4	243	34	0.06	71	18	0.9	0.4	Y
L3	6.23	103	0.8	0.5	9	5.7	37	42	0.02	*	16	0.4	2.8	Y
T1	6.15	150	2.3	0.7	2	4.2	36	33	0.05	61	12	0.2	3.0	N
T2	6.72	138	0.5	0.3	6	5.9	59	66	0.07	49	9	0.4	3.0	Y
T3	6.84	293	2.5	0.9	35	5.2	49	52	0.02	*	26	0.1	2.0	N
Powell River	7.54	349	0.1	0.1	158	17.4	171							

* No aquatic ecosystem apparent

Table 2 Vegetation parameters of nine surface mine wetlands, Wise County, VA, July 1993 to May 1994

Site	Plant richness, species	Plant biomass, g/m^2	Dominant species
B1	27	266	Spa Ame[a]
B2	9	881	Typ spp[b]
B3	29	328	Typ spp
L1	14	439	Sci Cyp[c]
L2	15	368	Typ spp
L3	14	624	Typ spp
T1	19	981	Sci Cyp
T2	23	319	Myr spp[d]
T3	31	493	Typ spp

[a] Spa Ame=*Sparganium americanum* [b] Typ spp=*Typha* spp

[c] Sci Cyp=*Scirpus cyperanus* [d] Myr spp=*Myriophyllum* spp

Macroinvertebrate richness was analyzed to identify differences between wetlands. Sites L1 and T3 were excluded form this analysis because they were flooded during the March 1994 sample, Hurlbert (Hurlbert, 1984) suggests that replicates within treatments are pseudo-replication. As such, the ANOVA test was performed with an inappropriate error term. To correct this problem, the interaction term (sample date * site) was substituted for sample error. Duncan's multiple comparison test was used to identify which sites were significantly different.

3 Results

All nine wetlands contained macroinvertebrates (Table 3). A total of 14 orders, 40 families, and 70 genera were identified in the samples. Insects were the most common invertebrates, and a few other macroinvertebrates were represented. The most common orders were Coleoptera (6 families, 26 genera), Dipera (8 families, most not identified to genera), Odonata (4 families, 13 genera), and Hemiptera (6 families, 7 genera). Annelidae was the only non-insect taxon that had great abundance. Several taxa——Ceratopogonidae, Chironomidae, Tabanidae, and Annelidae——were found in all sites. Additional species were found in all sites except the highly stressed sites (B2, L1, and T3 discussed below). These taxa are given in Table 4. Five sites, B1, B3, L3, T1, and T2, contained taxa that were unique to that one wetland. Site T2 had the greatest number of unique taxa with 5; site B2 had the next highest number with 3 unique taxa. Most functional feeding groups were represented. Predators were dominant with 63% of the taxa, followed by the collector/gathers with 20%, shredders 14%, and scrapers 3%.

Table 3 Macroinvertebrate distribution of nine accidental wetlands located on the Powell River Project (PRP), Wise County, VA, July 1993 to May 1994

	Black creek			Low splint bench			Tyggart bench		
	B1	B2	B3	L1	L2	L3	T1	T2	T3
Coleoptera									
Chrysomelidae	12	1							
Dytiscidae									
Acilius spp.			1						
Aqabetes spp.			1						
Aqabus spp.			1	1		7		7	
Anodocheilus spp.							1		
Celina spp.	16	1	6		4	15	6	5	
Coptotomus spp.							3		
Cybister spp.							3	1	
Hydaticus spp.						1			
Hydrovatus spp.								1	
Ilybius spp.			1			1		5	
Laccophilus spp.	3		2				4	9	
Laccodytes spp.			7	1		1	14	2	
Uvarus spp.			4			2	5	2	
gen. spp. other			1		1	1		41	

Table 3 (Continued)

Gyrinidae									
Dineutus spp.	7	1				2			
Haliplidae									
Haliplus spp.								2	
Peltodytes spp.	1		1		5	14	75	5	1
Hydrophilidae									
Berosus spp.		1						1	
Enochrus spp.			2				8	3	
Paracymus spp.			4				2		
Tropisternus spp.			2			2	11	8	
Noteridae									
Hydrocanthus spp.			1				24	23	
Notomicrus spp.			1				19	12	
Suphisellus spp.							39	11	
Scirthidae									
Cyphon spp.			2				1		
Scirtes spp.			21		2	3	33	2	
Diptera									
Ceratopogonidae	150	248	22	125	915	168	24	110	18
Chaoboridae									
Chaoborus spp.	21					23		85	
Chironomidae	1802	208	36	11	1098	2337	46	231	36
Culicidae	4				21		1	10	
Stratiomyidae									
Odontomyia spp.	10	1	6		71	13	8	161	1
Syrphidae					2				
Tabanidae	6	3	3	5	6	8	14	28	1
Tipulidae									
Helius spp.			2	11	6	19	9	7	5
Ephemeroptera									
Baetidae									
Baetis spp.	23	1			90	15		53	
Caebudae									
Caenis spp.								7	
Hemiptera									
Belostomatidae									
Belostoma spp.								11	

Table 3 (Continued)

Corixidae									
Corisella spp.	2				2		108	51	
Gerridae									
Gerris spp.		1					2		
Nepidae									
Ranatra spp.	4							3	
Notonectidae									
Buenoa spp.	18		1		6	23	3	3	
Notonecta spp.	2				4	4		11	
Veliidae									
Paravelia spp.								1	
Lepidoptera									
Pyralidae							1	7	
Megaloptera									
Corydalidae									
Chauliodes spp.	1	1	3	12	12	5	17		14
Sialidae									
Sialis spp.	1	31	4						6
Odonata									
Aeshnidae									
Aeshna spp.	14	4	5	3	11	3	4	12	
Anax spp.	17	9	1		18	19	1	18	
Coenagrionidae									
Arqia spp.	7								
Chromaqrion spp.	73	17	2		29		10		
Enallaqma spp.	145	17	10		53	15	310		
Telebasis spp.	2								
Corduliidae									
Neurocordula spp.	1								
Lestidae									
Lestes spp.	53				13	117	1	104	
Libellulidae									
Lepthemis spp.					2			1	
Libellula spp.						1		1	
Macrodiplax spp.						1			
Miathyria spp.					4		127		
Pachydiplax spp.	10		1		124	5	11	21	
Trichoptera									

Table 3 (Continued)

Leptoceridae							3	7	
Limnephilidae	9				8		2	7	
Phrayganeidae	13		1	2	4	31	10	9	3
Polycentropodidae	1		1						
Annelidae	5	1	2	2	10	33	10	26	3
Collembola	1					1			
Gastropoda	16				5	5	12	3	1
Amphipoda							2	28	
Homoptera		2	1		13	2	79		
Ararina			2				5		
Total abundance	2450	547	162	173	2537	2897	665	1563	88
Total richness	33	17	36	10	28	33	38	52	10
Mean richness	12. 8	5. 3	7. 6	10	12. 6	12. 8	13	18. 3	10
Standard deviation	3. 7	2. 2	4. 7	0	3. 7	2. 3	4. 3	5. 1	0

Table 4 Distribution of select taxa of nine surface mine wetlands, Wise County, VA, July 1993 to May 1994

All sites:	Diptera	Ceratopogonidae
		Chironomidae
		Tabanidae
	Annelidae	
All sites except B2, L1, and T3:		
	Coleoptera	Dytiscidae Celina
	Haliplidae	Peltodytes
	Diptera	Stratiomyidae
	Hemiptera	Notonectidae
	Odonata	Aeshnidae
		Aeshnidae
	Trichoptera	Phrayganiedae

The sites differed in the number of taxa inhabiting them. For individual sites, the richness ranged from 10 genera to 52. The lowest richness was found in two seasonal wetlands that were dry for the majority of the year; Diptera dominated the taxa in these sites. Site B2 had the third lowest richness, 17 taxa. These three sites (B2, L1 and Y3) are referred to above as the highly stressed sites. The greatest richness, 52 taxa, was found in site T2. The means and standard deviations by sample date are given in Fig. 1. The results of ANOVA indicate that the means are significantly different. Duncan's multiple comparison test shows that, at the $p < 0.05$ level, the mean richness of site T2 is significantly higher than the other sites and that sites B2 and B3 are significantly lower than all other sites.

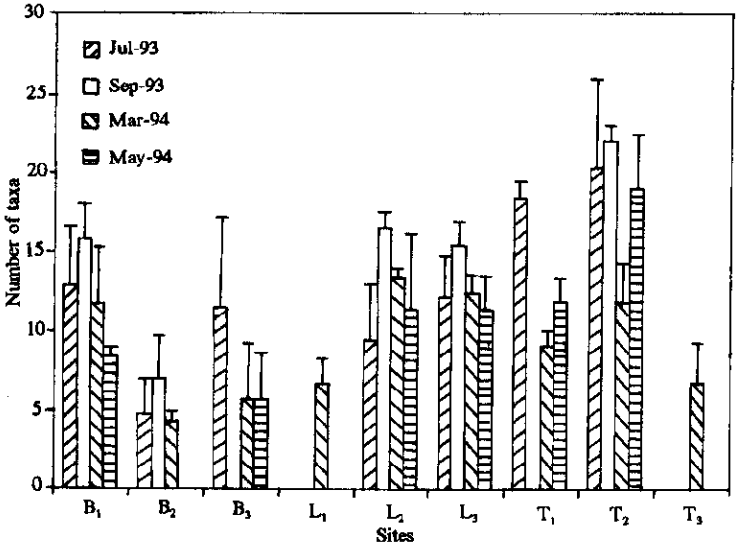

Fig. 1 Macroinvertebrate richness of nine surface mine wetlands, Wise County, VA July 1993 to May 1994. Error bars represent 1 *SD*

4 Discussion

4.1 Macroinvertebrate community

Macroinvertebrates inhabit wetlands on surface mine benches. This fact is relevant when considering the evolution of these wetlands. Surface mine wetlands are opportunistic ecosystems that form as a result of extreme landscape disturbance associated with surface mining. Environmental problems, such as erosion, sedimentation, and high metals concentrations, are associated with former mining sites, including some sites in this study (Table 1). Additionally, these wetlands are relatively young, with ages ranging from 10 to 30 years. Despite these problems, macroinvertebrates have become established at all the study sites. Comparison of the macroinvertebrate communities of the surface mine wetlands to reference sites was impossible. No reference sites existed because natural wetlands, which may have existed along floodplains, had been destroyed or had been impacted by sedimentation, and lentic wetlands located on mountain slopes did not exist. However, research into wetlands literature provided studies that offered information on macroinvertebrates of various wetland types.

Bataille and Baldassarre (Bataille, 1993) investigated the macroinvertebrates of prairie potholes in Manitoba, Canada. These wetlands are probably similar to surface mine wetlands because they are shallow, contain dense hydrophytes, and the hydrology input is via precipitation or groundwater. In the prairie pothole research, three wetlands were studied. Using two sampling methods, Bataille and Baldassarre (Bataille, 1993) found 26 families of nektonic invertebrates and 50 families of emergent insects. In the present study, 40 families were identified. Of these, 34 families were aquatic insects. Magee *et al.* (Magee, 1993) studied the macroinvertebrates of two forested floodplain wetlands along the Mississippi River that were inundated by seasonal flooding. The sites were sampled with traps over a 2-year period, and 55 taxa were collected. The list of taxa was dominated by families other than aquatic insects. The only insects in the top 80% of frequency of occurrence were the Chironomidae. The taxa richness of this study was lower than the pothole study (Butaille, 1993), but still higher than the present study. Radar and Richardson (Radar, 1994) investigated the macroinvertebrates along a nutrient gradient in the Florida Everglades. Using a D-frame sweep net, 54 families of invertebrates were collected, and overall richness was similar to the floodplain sites (Magee, 1993), but higher than the current study. Aquatic insects in the everglades were represented by 27 families, compared to 36 families in the present study.

These studies (Bataille, 1993; Magee, 1993; Radar, 1994) suggested that the wetlands in the current study do not exhibit the macroinvertebrate taxonomic richness of natural wetlands. Water chemistry, age, and size of surface mine wetlands could explain these differences. Barnes (Barnes, 1983) investigated succession in 10 ball clay ponds of England. Similar to the wetlands in this study, these ponds were formed after mining operations had altered the landscape. In five pH-neutral ponds, 45 families were identified; whereas in the current study, 40 families were collected. These values suggest that, for similar wetland creation history , surface mine wetlands are not lacking in richness. Euliss *et al.* (Euliss, 1991) investigated agricultural rainwater evaporation ponds to determine their suitability for water-fowl habitat. These sites had high salt content, and the wetland plant and macroinvertebrates assemblages were species poor with only 15 macroinvertebrate families. In the current study, site B2 had poor water quality, and its macroinvertebrate community had 15 macroinvertebrate families.

Several studies have investigated wetlands associated with surface mining. Bosserman and Hill (Bossorman, 1985) investigated the impact of acid mine drainage on wetlands in Western Kentucky. Sites with acid mine drainage had fewer taxa and higher abundances than reference sites. This difference is related to water chemistry parameters. Sites with low pH, high sulfate concentration, and high metals concentration exhibited lower richness. Usis and Foote (Usis, 1991) investigated the effects of surface mining on a wetland Trichoptera, *Limnephilus indivisus*. The abundance of this species declined in a wetland after impacts from surface mining. Results of the study suggest that this decline is related to high conductivity and suspended solids. Fowler *et al.* (Fowler, 1985) studied the colonization of shallow ponds constructed as part of surface mine reclamation. Two-year old ponds had 36 families present, and the researchers propose that this richness would increase as the macrophyte community developed. The first two studies suggest that mining operations negatively impact aquatic systems. However, the last study shows that systems designed and constructed for reclamation provide ecologically beneficial habitat functions.

Data suggest that macroinvertebrate richness is influenced by water quality. Fig. 2 shows the richness values for the permanent sites. The seasonal sites were omitted to eliminate any hydrological effects. Site T2 had significantly higher richness than the other sites, and it had the lowest values for conductivity and metals and sulfate concentration. Conversely, site B2 had significantly lower richness and the highest water chemistry values. The other sites were intermediate to these two sites. However, the chemical parameters of site L3 appeared closer to T2 than any of the other sites, but the richness was lower. Fig. 3 shows this relationship. The difference in richness may be due to the difference in the dominant vegetation. Site T2 was dominated by an aquatic, *Myriophyllum* spp. , with high underwater surface area; whereas, site L3 was dominated by an emergent, *Typha* spp. , with low underwater surface area. Voits (Voits, 1976) found that the macroinvertebrate community is related to the dominant vegetation in an aquatic ecosystem. As the plant surface area increases, habitat diversity increases, thus enabling more macroinvertebrates to occupy the system.

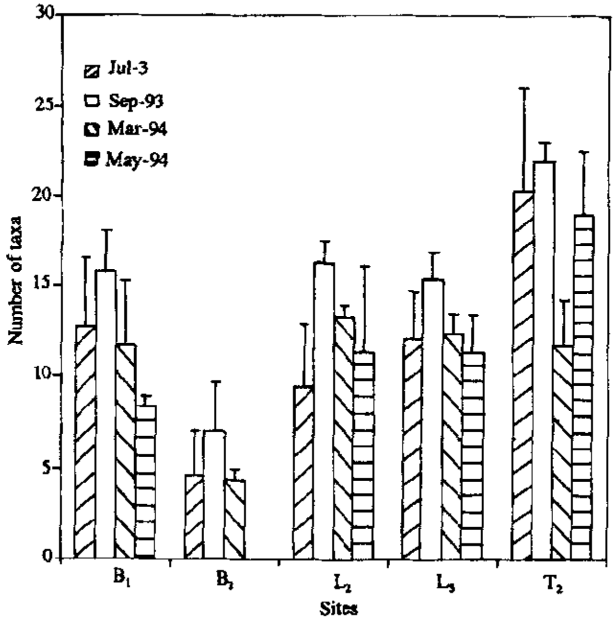

Fig. 2 Macroinvertebrate richness of five permanently flooded surfae mine wetlands, Wise County, VA, July 1993 to May 1994. Error bars represent 1 *SD*

4.2 Macroinvertebrate community response to disturbance

Wetlands are characterized by dynamic hydrologic regimes. Water fluctuation can be the driving force of macroinvertebrates of temporary waters (Neckles, 1990; Batzer, 1993; Bataille, 1993). Thus, in seasonal wetlands, the macroinvertebrate community is determined by the length and frequency of flooding (Ebert, 1987). Macroinvertebrates of temporary waters have developed strategies to withstand drought. Wiggins *et al.* (Wiggins, 1980) provide four methods for surviving dry periods: (1) permanent residents that have a resistant resting stage or diapause, (2) motile species that must oviposit in water, (3) motile

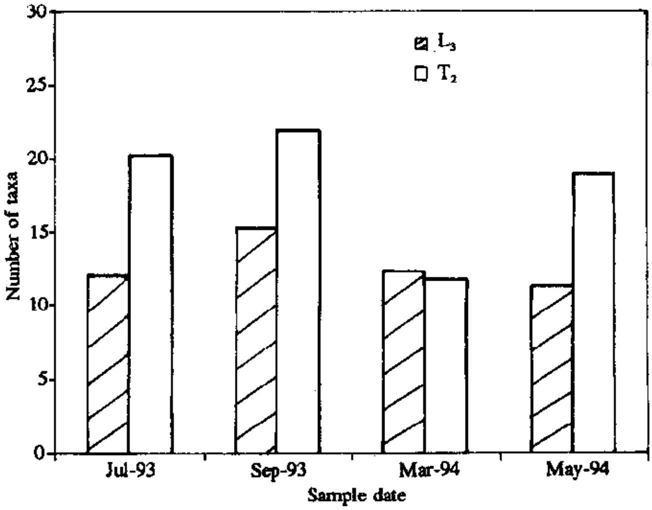

Fig. 3 Macroinvertebrate richness of two surface mine wetlands, Wise County, VA, July 1993 to May 1994

species in which oviposition is independent of water, and (4) motile species that migrate to permanent water then return to oviposit in the newly flooded basin.

Most of the macroinvertebrate sampling in this study was conducted during the extreme drought conditions of 1993. While seasonal drawdowns are common for this type of system (Williams, 1987), the 1993 drought provided an opportunity to quantify macroinvertebrate response to severe hydrologic disturbance. In this study, four of nine wetlands were dry during part of the year. All these sites contained macroinvertebrates after flooding. Two of the wetlands (T3 and L1) were inundated for only the March 1994 sample. The richness in these short-season wetlands was the lowest of all the sites sampled if the poor water quality sites B2 and B3 (Table 1) are not considered. This community structure is characteristic of seasonal wetlands——those that only have water present during the wet season. Seasonal wetlands typically have low diversity and high abundance (Neckles, 1990). Fig. 4 shows the richness of the five permanent sites (left side of X axis) and the four seasonal sites (right side of X axis) during the March 1994 sample when all sites were flooded.

Sites B2 and T1 were dry for only one sample period, September 1993. The overall richness for these two wetlands was second and third highest for this study. For the sites that became dry, the richness ranged from highest to lowest. The seasonal wetlands have characteristic low diversity, but the sites that dried for shorter periods had higher richness. Ebert and Balko (Ebert, 1987) suggested that, for temporary pools, richness increases with increasing frequency and duration of flooding. These wetlands may typically exhibit stable water levels, and only become dry during extreme years (1993 was the second driest year recorded).

Resilience is the capacity of natural systems to absorb change without dramatic alteration (Holling, 1973). Surface mine wetlands in this study exhibited a range of hydrologic conditions during each sampling date. In spite of the variety of hydrologic responses to the 1993 drought, macroinvertebrate communities reestablished upon the return of flooded conditions. Thus, surface mine wetland macroinvertebrate communities demonstrated considerable resilience to severe drought (Fig. 5).

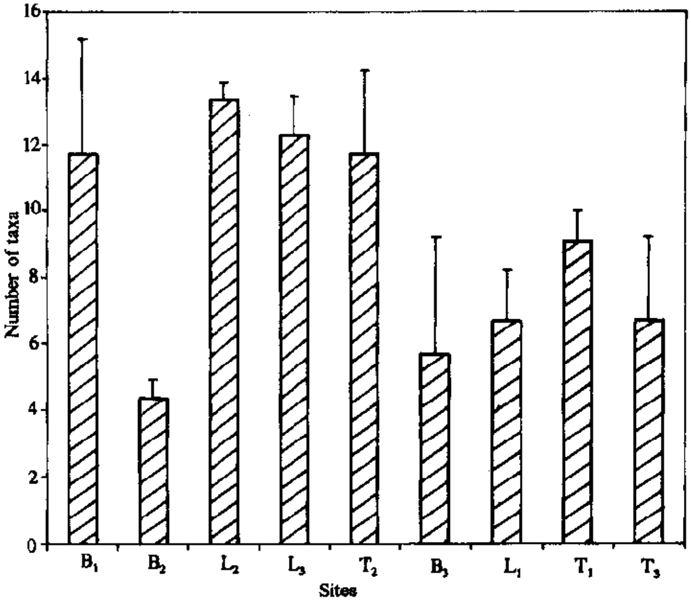

Fig. 4 Macroinvertebrate richness of nine surface mine wetlands, Wise County, VA March 1994. Sites are arranged on the X axis such that the five permanent sites are on the left side and the seasonal sites are graphed to the right

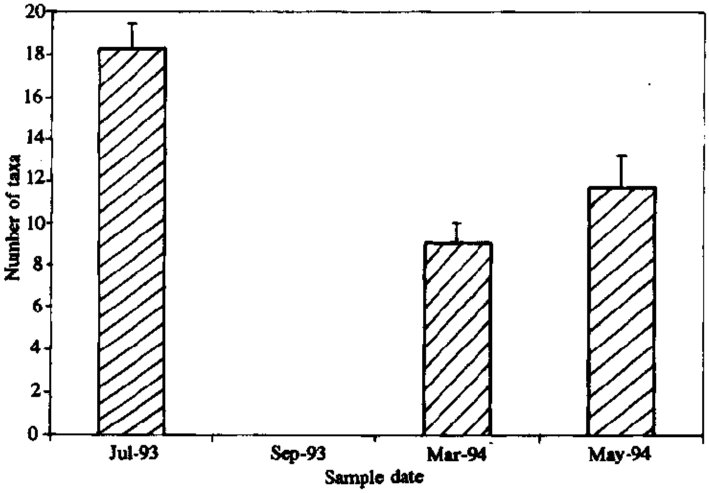

Fig. 5 Macroinvertebrate richness of one surface mine wetland, Wise County, VA, July 1993 to May 1994

4.3 Macroinvertebrate colonization of constructed wetlands

Surface mine wetlands provide a template for the design of created wetlands as a component of current surface mine reclamation (Atkinson, 1994). Created wetlands will provide ecological services to the post-mining landscape. Several studies have investigated macroinvertebrate colonization of constructed wetlands. Fowler *et al.* (Fowler, 1985) studied the colonization of surface mine sediment ponds in Eastern Tennessee. After 2 years, 36 families of macroinvertebrates were collected. With time, the researchers suggested that this richness will increase. Barnes (Barnes, 1983), in studies of the colonization of ball clay ponds, determined that initial colonization of neutral ponds was rapid. Short dispersal distances was suggested as the mechanism for quick colonization. The orders Coleoptera and Hemiptera were the earliest to colonize. As hydrophytes colonized and habitat complexity increased, the macroinvertebrate community shifted from algivores and predators toward epiphyton grazers and detritivores. Street and Titmus (Street, 1979) investigated colonization of 1- and 2-year old gravel pits. These ecosystems had rapid colonization the first year. During the second year, as hydrophytes developed, the populations of sites decreased in similarity. This differentiation was attributed to increased habitat complexity.

In the current study, one constructed wetland was sampled in May 1995. The site was approximately 1-year old, had no hydrophytes growing, had been dry for several periods during the year, and had no epicenter for colonization for over 100m. However, four families were collected (Table 1). Similar to Barnes (Barnes, 1983), Coleoptera and Hemiptera were represented as the first taxa to colonize these sites. The other two taxa were Odonata and Diptera. These taxa have been found in new, isolated sites, and both are know to disperse widely (Sheldon, 1984). The colonization of this experimental site suggests that constructed wetlands will be inhabited quickly and that hydrophytes are not a prerequisite for colonization. The results of Barnes (Barnes, 1983) suggested that, as hydrophytes colonize and habitat complexity increases, macroinvertebrate richness will increase. By constructing wetlands in areas without water quality problems, macroinvertebrate communities similar to site T2 (Table 2) can be expected. Site T2 exhibited the greatest richness of all the wetlands sampled, and all the functional feeding groups were represented. It had permanent hydrology, moderate hydrology fluctuation, circumneutral pH, and low concentrations of metals. By constructing wetlands similar to site T2, macroinvertebrates may become established and contribute to wetland ecological services that will improve reclamation, such as nutrient cycling, trophic support, and energy transfer.

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References

Atkinson RB, Cairns JJr. Journal of Aquatic Ecosystem Health, 1994; 3:139

Barnes LE. Freshwater Biology. 1983; 13:561

Bataille KJ, Baldassarre GA. Wetlands, 1993; 13(4):260

Batzer DP, McGee M, Resh VH, Smith RR. Wetlands, 1993; 13(1):41

Bosserman RW, Hill PL. Wetlands and water management on mined lands (Ed. by Brooks RP, Samuel DE, Hill JB). School of Forest Resources, College of Agriculture, The Pennsylvania State University, State College, PA, 1985:287

Cheal F, Davis JA, Growns JE, Bradley JS, Whittles FH. Hydrobiologia, 1993; 257:47

Ebert TA, Balko ML. Archiv fur Hydrobiologie, 1987; 110:101

Euliss NH, Jarvis RL, Gilmer DS. Wetlands, 1991; 11(2):179

Fowler DK, Hill DM, Fowler LJ. Wetlands and water management on mined lands (Ed. by Brooks RP, Samuel DE, Hill JB). School of Forest Resources, College of Agriculture, The Pennsylvania State University, State College, PA, 1985:261

Holling CS. Annual Review of Ecology and Systematics. 1973, 4:1

Hurlbert SH. Ecological Monographs, 1984; 54(2):187

Krieger AK. Journal of Great Lakes Research, 1992; 18(4):634

Magee PA, Redrickson LH, Humburg DD. Wetlands, 1993; 13(4):304

Merritt RW, Cummins KW, eds. An introduction to the aquatic insects of North America. Kendal/Hunt Publishing Company, Dubuque, Iowa. 1984:722

Murkin HR, Wrubleski JA. The ecology and management of wetlands, Volume 1: Ecology of Wetlands, (Ed. by Hook DD and 12 others). London: Groom and Helm. 1988:239

Neckles HA, Murkin HR, Cooper JA. Freshwater Biology, 1990; 23:311

Radar RB, Richardson CJ. Wetlands, 1994; 14(2):134

Rosenberg DM, Danks HV. Aquatic insects of peatlands and marshes in Canada (Ed. by Rosenberg DM, Danks HV), Memoirs of the Entomological Society of Canada, 1987:140

Sheldon AL. The ecology of aquatic insects (Ed. by Resh VH,Rosenberg DM). New York: Praeger. 1984:401

Street M, Titmus F. Aquatic Insects, 1979; 1(4):233

Usis JD, Foote, BA. The Great Lakes Entomologist, 1991; 24(3):133

Voits DK. The American Midland Naturalist, 1976; 95(2):313

Williams DD. The ecology of temporary waters. London and Sydney: Croom Helm. 1987

Wiggins GB, Mackay RJ, Smith IM. Archive Hydrobiologie Supplement, 1980; 58:97

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