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Papers of the Sixty-Seventh Annual Session

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In 1992 The West Virginia Academy of Science recognizes two Public School Teachers in West Virginia for their outstanding efforts in the teaching of science and for the preparation of young people to become scientists.

This year the award goes to:

Darlene Boyles, Fairmont Senior High School, and
Ed Keller, III, Mountainview Elementary School, Morgantown.

We wish to thank Dr. John Chisler and Mrs. Karla Scoggins for their assistance in the set-up of these numbers.

The Papers of the 1992 Meeting

Biology Section

A Fishery Survey of Middle Island Creek, Ohio River Drainage, West Virginia

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Abstract

Twenty-five fish population surveys were conducted in the Middle Island Creek drainage basin from 1980 through 1985. A total of 6,148 specimens representing 57 fish species was collected. The most common species by total percent occurrence were *Luxilus chrysocephalus* (88%), *Hypentelium nigricans* (88%), *Moxostoma erythrurum* (88%), *Pimephales notatus* (84%), and *Micropterus dolomieu* (80%). The most abundant species were *L. chrysocephalus* (17.8%), *M. erythrurum* (13.1%), *P. notatus* (7.7%), *Campostoma anomalum* (4.3%), and *H. nigracans* (4.3%). Gamefish species, which primarily include *Esox masquinongy, Micropterus dolomieu, M. punctulatus, Ictalurus punctatus,* and *Pylodictis olivaris*, comprised 4% to 50% (average 24%) of the standing crop per survey. Age and growth analysis for *M. dolomieu*

and *M. punctulatus* indicated a rate comparable to other West Virginia streams. Data from the survey are compared to existing information.

Introduction

Published fishery data for Middle Island Creek are scant. Such ichthyofaunal information is found only in Schwartz (1959), Miles (1978), Lee et al. (1980), and certain taxonomic species reviews (e.g., Lachner and Jenkins 1971, Tsai and Raney 1974). An examination of existing records, including the above investigations, indicates that the majority of the data for the drainage emanates from the unpublished fishery collections of the Wildlife Resources Section of the West Virginia Division of Natural Resources (WVWR; formerly the Conservation Commission). Unfortunately, most WVWR information is not readily available because it is summarized in Departmental documents or Dingell-Johnson Federal Aid reports (Cincotta et al. 1986). Although no comprehensive ichthyofaunal survey has been conducted in the drainage, the WVWR report by Menendez and Robinson (1964) provides a fair description of the ichthyofauna (50 species) and sport fishery. Apparently Menendez and Robinson's data (Vari, pers. comm.), a single 1932 collection of fishes by C. L. Hubbs and M. L. Trautman (Creighton, pers. comm.), and unpublished WVWR information from the 1950's (Humphries, pers. comm.), are the basis of the records depicted in Lee et. al. (1980).

This survey, which is part of a continuing statewide effort to inventory fishes and monitor gamefish populations, was funded by the Dingell/Johnson Federal Aid Project F-10-R. The purpose of this report is to summarize the fishery information collected during this study and compare it, when possible, to the database presented in Menendez and Robinson (1964). A secondary objective is to provide a checklist of fishes for the Middle Island Creek drainage. The data will be utilized to develop a successful fishery program in the subject drainage.

Study Area

The Middle Island Creek Drainage basin is located in northwestern West Virginia within Pleasants, Tyler, Doddridge, and Wetzel counties (Figure 1). Approximately 71% of the basin is forestland, 9% cropland, and 15% pastureland (Embree et. al. 1983). The basin drains 145,925 ha (1458 km^2) and is roughly elliptical in shape with the major axis oriented in a northwest-southeast direction; it has a length of 57.9 km and a maximum width of approximately 39 km. The topography of the basin is typical of the Appalachia Plateau physiogeographic province. It is a deeply eroded plateau characterized by steep hills and ridges and very narrow valleys and flood plains. The creek has a total fall of 54.9 m over its 123.1 km course for an average gradient of 0.73 m/km. As indicated by its gradient throughout most of its length, this is a slow-flowing, meandering stream characterized by short riffles and long, deep pools ranging from 9.1 to 45.7 m in width and up to 3.2 km in length. The lower 20.3 km are inundated by the Willow Island pool of the Ohio River. The mean average discharge at Little, Tyler County, is 18.1 m^3/s (Embree et. al. 1983).

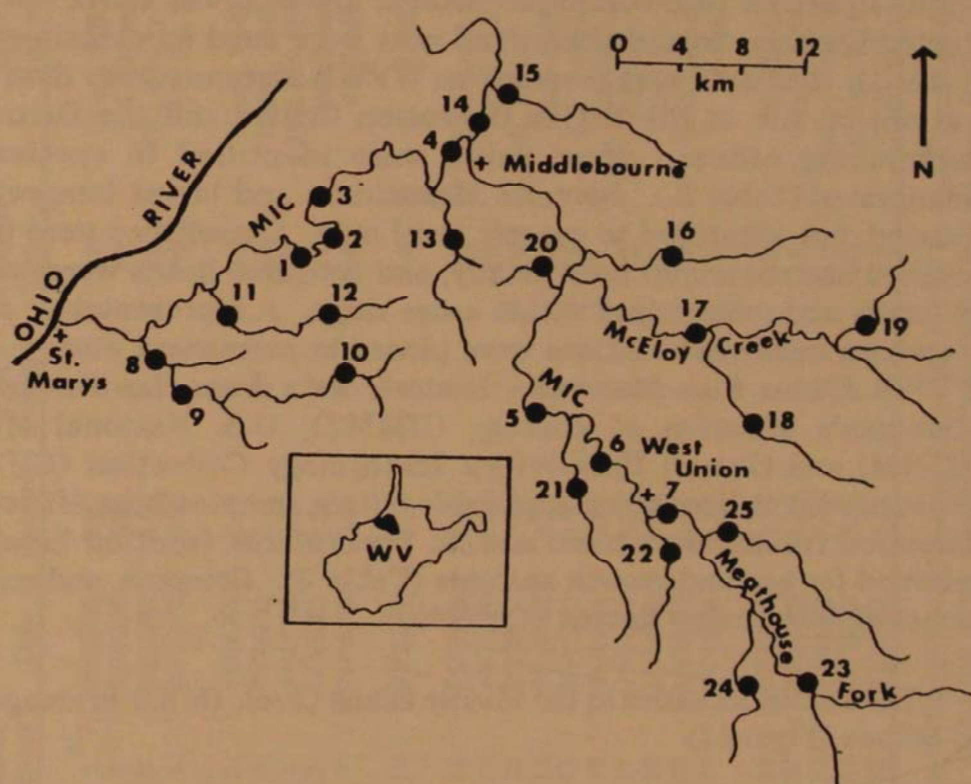

Figure 1. Middle Island Creek (MIC) drainage indicating the fish sampling localities. Insert shows the drainage location in West Virginia.

The Middle Island Creek drainage basin contains 204 km of fishable high quality streams. A high quality stream is defined as one that is over 8.1 km in length with desirable gamefish populations and public utilization thereof (Potesta, 1986). There are ten major tributaries of Middle Island Creek that are considered by the WVWR as high quality streams. These streams and drainage areas are McKim (96.6 km^2), Sancho (57.0 km^2), Point Pleasant (156.2 km^2), Indian (83.1 km^2), McElroy (274.0 km^2), Arnolds (89.9 km^2), Bluestone (39.4 km^2), Buckeye (100.0 km^2), and Meathouse Fork (178.2 km^2) creeks.

Methods and Materials

This survey was conducted from 1980 to 1985. Fishes were usually collected by electrofishing with a 220 AC generator and utilizing the West Virginia parallel wire technique (Holton and Sullivan 1954); backpack electroshockers, boat shocker, and nets were used on certain surveys (Table 1). Raw data were recorded on WVWR stream survey data forms and are on file at the Elkins Operation Center and the District VI Parkersburg offices. Most fishes were identified to species, and enumerated (Table 2.). Juvenile *Moxostoma* and larval lamprey were counted, but identified to generic level only. Gamefishes were usually weighed and measured individually, and nongame fishes were weighed by family and summarized within a size range. A representative sample of species from most stations were placed in permanent storage at the WVWR Elkins Fish Museum. Historic data from the University of Michigan's Museum of Zoology (UMMZ), U.S. National Museum (USNM) and Cornell University's Ichthyology Collection (CU) were reviewed and utilized when applicable. Scale samples from *Micropterus dolomieu* (smallmouth bass) and *M. punctulatus* (spotted bass) were retained for age and growth analysis (Table 3). Common and scientific names of fishes follow Robins et al (1991).

The station localities in the Middle Island Creek (MIC) drainage were as follows (Figure 1).

1 - 5) MIC, Tyler Co.

6 - 7) MIC, Doddridge Co.

8 - 10) McKim Cr., Pleasants Co.

18) Flint Run, Doddridge Co.

19) Talkington Fk., Doddridge Co.

Table 1. Summary of fish population data collected from streams in the Middle Island Creek drainage, 1980-1985.

Stream	Station Number	Date	Hectare	Type Survey*	Number Species	Major** Sport Species	Percent Gamefish Weight	Total Number	Total Weight Kg	Kg per Hectare
Middle Island Cr.	1	09/05/85	0.42	A	29	Drum, SpB, SmB	15	710	81.3	193.6
Middle Island Cr.	2	09/05/85	0.29	A	19	ChC, Drum, SpB	19	210	64.5	222.4
Middle Island Cr.	3	10/16/81	3.90	B	13	FIC, Musky, Drum	36	28	63.1	***
Middle Island Cr.	4	08/10/83	0.37	C	30	SpB, RB, SmB	-	246	Weights not taken	Weights not taken
Middle Island Cr.	5	09/10/85	1.10	A	24	Drum, SpB, ChC	14	466	90.5	82.3
Middle Island Cr.	6	08/05/81	0.27	B	13	Musky, SpB, ChC	36	52	19.1	***
Middle Island Cr.	7	09/10/85	0.54	A	22	SpB, RB, Hyb Sunf	20	608	36.8	68.1
McKim Cr.	8	08/06/85	0.21	A	22	SpB, Drum, RB	41	226	12.6	59.8
McKim Cr.	9	08/08/80	0.06	D	14	RB, SmB, SpB	-	176	Weights not taken	Weights not taken
McKim Cr.	10	07/23/82	0.06	A	10	None	-	249	Weights not taken	Weights not taken
Sugar Cr.	11	08/29/84	0.22	A	19	SmB, LmB, G Sunf	25	256	9.4	42.9
Sugar Cr.	12	06/23/83	0.06	A	16	SmB, BG, RB	15	160	10.3	172.4
Sancho Cr.	13	06/23/83	0.08	A	20	SmB, L SunF, Hyb Sunf	4	355	14.4	180.3
Point Pleasant Cr.	14	08/03/83	0.19	A	23	SmB, SpB, RB	19	132	7.7	40.3
Elk Fk.	15	08/03/83	0.05	A	22	RB, SmB, L Sunf	47	188	2.0	40.8
Indian Cr.	16	08/04/81	0.25	A	21	RB, SmB, SpB	27	540	19.5	77.8
McElroy Cr.	17	09/11/81	0.25	A	19	RB, SmB, SpB	20	219	7.2	28.8
Flint Run	18	10/03/83	0.06	A	20	SmB, Rb, SpB	14	165	10.8	179.9
Talkington Fk.	19	10/03/83	0.04	C	17	SmB, G Sunf, RB	11	285	2.0	49.9
Unnamed Trib.	20	06/11/81	>.01	D	5	None	-	25	Weights not taken	Weights not taken
Arnolds Cr.	21	07/15/83	0.16	B	25	RB, YBhd, SpB	19	337	16.1	100.6
Bluestone Cr.	22	07/15/83	0.03	C	13	SmB, RB, BG	50	73	1.1	36.3
Meathouse Fk.	23	07/01/83	0.56	A	16	Musky, SmB, Hyb Sunf	40	109	20.5	***
Toms. Fk.	24	07/01/83	0.45	A	20	Musky, WCr, SpB	22	129	14.4	***
Buckeye Cr.	25	07/23/82	0.14	A	19	SmB, SpB, YBhd	16	214	15.9	113.4

* A = AC parallel wire electrofishing; B = AC boat electrofishing; C = AC backpack electrofishing; D = Throw net and/or 10 foot seine
** Major sportfish abbreviations are: Drum = freshwater drum; SpB = Spotted Bass; SmB = Smallmouth Bass; ChC = Channel Catfish; FIC = Flathead catfish; Musky = Muskellunge; RB = rockbass; Hyb Sunf = Sunfish; LmB = Largemouth Bass; G Sunf = Green Sunfish; L Sunf = Longear Sunfish; BG = bluegill; YBhd = Yellow Bullhead; WCr = White Crappie
*** Collection efficiency too low to estimate standing crop (i.e., due to high flows or turbid conditions)

11 -12)	Sugar Cr., Tyler Co.	20)	Unnamed Trib., Wheelers Run, Tyler Co.
13)	Sancho Cr., Tyler Co.	21)	Arnolds Cr., Doddridge Co.
14)	Pt. Pleasants Cr., Tyler Co.	22)	Bluestone Cr., Doddridge Co.
15)	Elk Fk. Cr., Tyler Co.	23)	Meathouse Fk., Doddridge Co.
16)	Indian Cr., Tyler Co.	24)	Toms Fk., Doddridge Co.
17)	McElroy Cr., Tyler Co.	25)	Buckeye Cr., Doddridge Co.

Detailed locality data are available from the authors and will be provided upon request.

Results and Discussion

A total of 6148 specimens representing at least 57 species and 12 families was collected in this survey (Table 2). Based on Hocutt et. al. (1986), 56 species of the 57 collected are considered native to the upper Ohio River drainage. *Cyprinus carpio* (common carp) was introduced from the Old World.

The six most common species by total percent occurrence were *Luxilus chrysocephalus* (striped shiner, 88%), *Hypentelium nigricans* (northern hog sucker, 88%), *Moxostoma erythrurum* (golden redhorse, 88%), *Pimephales notatus* (bluntnose minnow, 84%), *Micropterus dolumieu* (80%), *Ambloplites rupestris* (rockbass, 76%), and *Micropterus punctulatus* (72%) (Table 4). The most abundant species were *L. chrysocephalus* (17.8%), *M. erythrurum* (13.1%), *P. notatus* (7.7%), *Campostoma anomalum* (central stoneroller minnow, 4.3%), and *H. nigricans* (4.3%). The following species were collected at only one station: *Notemigonus crysoleucas* (golden shiner), *Phoxinus erythrogaster* (southern redbelly dace), *Rhinichthys atratulus* (blacknose dace), *Ictiobus*

Table 2. Part A. Fishes taken from Middle Island Creek drainage with numbers, total percent occurrence, and total abundance noted.

SPECIES	STATIONS 1	2	3	4	5	6	7	8	9	10	11	12	13
Ichthyomyzon sp. (larva)	-	-	-	-	-	1	-	-	-	-	-	-	-
Lepisosteus osseus	1	-	-	-	1	-	-	-	-	-	-	-	-
Dorosoma cepedianum	53	19	1	-	21	3	-	3	-	-	-	-	-
Esox masquinongy	-	-	1	-	1	1	1	-	-	-	-	-	-
Campostoma anomalum	82	-	-	13	-	-	1	1	9	42	-	17	25
Cyprinella spiloptera	14	-	-	11	-	-	-	-	-	-	-	-	-
C. whipplei	-	-	-	23	-	-	-	-	-	-	-	-	-
Cyprinus carpio	11	9	13	-	28	7	-	1	-	-	-	-	-
Luxilus chrysocephalus	8	-	-	14	7	-	106	67	124	59	15	28	74
Lythrurus umbratilis	-	-	-	-	-	-	-	4	-	-	-	1	2
Nocomis micropogon	-	-	-	-	-	-	-	1	-	-	-	-	-
Notemigonus crysoleucas	-	-	-	-	-	-	-	-	-	-	-	-	-
Notropis atherinoides	-	-	-	5	-	-	-	-	-	-	21	-	-
N. buccatus	5	-	-	8	-	-	9	-	1	37	16	9	9
N. photogenis	67	-	-	3	9	-	15	-	-	-	-	-	1
N. rubellus	-	-	-	5	-	-	-	1	-	-	-	-	-
N. stramineus	-	-	-	17	-	-	-	-	-	-	2	-	1
N. volucellus	43	1	-	24	2	-	3	-	-	-	-	-	-
Phoxinus erythrogaster	-	-	-	-	-	-	-	-	-	-	-	-	-
Pimephales notatus	16	-	-	15	1	-	12	20	19	48	9	19	93
Rhinichthys atratulus	-	-	-	-	-	-	-	-	-	-	-	-	-
Semotilus atromaculatus	-	-	-	-	-	-	-	-	3	28	-	2	13
Carpiodes cyprinus	-	-	1	-	-	-	-	-	-	-	-	-	-
Catostomus commersoni	-	-	-	-	-	-	-	-	2	17	16	9	10
Hypentelium nigricans	71	5	-	3	1	2	57	7	1	11	3	1	18
Ictiobus cyprinellus	-	-	1	-	-	-	-	-	-	-	-	-	-

Table 2. Part A continued.

SPECIES	STATIONS 1	2	3	4	5	6	7	8	9	10	11	12	13
Minytrema melanops	-	-	-	-	-	-	2	-	-	-	1	-	-
Moxostoma anisurum	2	1	1	2	1	4	-	1	-	-	-	-	1
M. carinatum	2	9	-	-	1	-	-	-	-	-	-	-	-
M. duquesnei	-	1	-	-	-	-	1	1	5	-	2	4	12
M. erythrurum	3	3	1	3	3	18	1	3	-	4	1	46	77
M. macrolepidotum	14	14	-	1	1	-	-	-	-	-	-	-	-
M. sp.	182	90	-	-	239	-	225	51	-	-	131	1	-
Ameiurus melas	-	-	-	-	-	-	-	-	-	-	-	-	-
A. natalis	-	-	-	-	-	-	-	-	-	-	1	-	-
Ictalurus punctatus	11	13	-	-	4	1	-	-	-	-	-	-	-
Noturus flavus	8	-	-	2	-	-	-	-	-	-	-	-	-
Noturus miurus	-	-	-	1	-	-	-	-	-	-	-	-	-
Pylodictis olivaris	3	4	1	-	2	1	-	-	-	-	-	-	-
Percopsis omiscomaycus	-	-	-	-	53	-	9	-	-	-	-	-	-
Labidesthes sicculus	-	-	-	4	-	-	13	-	-	-	-	-	-
Ambloplites rupestris	4	1	-	1	6	-	11	11	4	-	1	2	-
Lepomis cyanellus	2	-	-	-	-	-	8	3	-	-	5	4	3
L. hybrid	1	-	-	-	9	2	22	6	-	-	-	-	1
L. macrochirus	-	-	3	1	12	5	-	9	-	-	6	6	-
L. megalotis	3	1	1	1	20	-	53	8	-	-	1	1	5
L. sp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Micropterus dolomieu	18	6	-	1	-	-	2	5	1	-	6	9	2
M. punctulatus	20	13	1	15	29	6	39	13	1	-	5	-	-
M. salmoides	-	-	-	-	-	-	-	-	-	-	2	1	-
Pomoxis annularis	1	-	1	-	-	1	1	-	-	-	-	-	-
Ammocrypta pellucida	-	-	-	6	-	-	-	-	-	-	-	-	-

Table 2. Part A continued.

SPECIES	STATIONS 1	2	3	4	5	6	7	8	9	10	11	12	13
Etheostoma blennioides	20	2	-	24	-	-	-	-	3	-	-	-	-
E. caeruleum	-	-	-	-	-	-	-	-	1	1	-	-	-
E. flabellare	-	-	-	1	-	-	-	-	-	-	-	-	1
E. nigrum	-	-	-	12	-	-	-	-	1	-	-	-	-
E. zonale	4	-	-	19	-	-	-	-	-	-	-	-	-
Percina caprodes	21	5	-	9	4	-	13	1	1	-	4	-	3
P. maculata	1	2	-	3	6	-	4	8	-	2	-	-	4
Aplodinotus grunniens	19	11	2	-	5	-	-	1	-	-	-	-	-
TOTAL SPECIMENS	710	210	28	247	466	52	608	226	176	249	248	160	355
TOTAL SPECIES	29	19	13	30	23	12	21	22	15	11	19	16	18

Table 2. Part B. Fishes taken from Middle Island Creek drainage with numbers, total percent occurrence, and total abundance noted.

SPECIES	STATIONS 14	15	16	17	18	19	20	21	22	23	24	25	TOTAL	TOTAL % OC	% REL. AB.
Ichthyomyzon sp. (larva)	-	-	-	1	-	-	-	-	-	-	-	-	2	9	<1
Lepisosteus osseus	2	1	-	-	-	-	-	-	-	-	-	-	5	16	<1
Dorosoma cepedianum	-	-	-	-	-	-	-	-	-	-	-	-	100	24	1.6
Esox masquinongy	-	-	-	-	-	-	-	-	-	3	1	-	8	24	<1
Campostoma anomalum	4	18	9	3	2	26	-	6	8	-	-	-	266	64	4.3
Cyprinella spiloptera	6	4	-	-	-	-	-	-	-	-	-	-	35	16	1.0
C. whipplei	-	-	-	-	-	-	-	-	-	-	-	-	23	4	<1
Cyprinus carpio	-	-	-	-	-	-	-	2	-	1	-	1	73	36	1.2
Luxilus chrysocephalus	4	29	189	79	40	98	11	97	7	10	22	4	1092	88	17.8
Lythrurus umbratilis	-	-	3	-	-	-	-	20	-	2	-	-	32	24	1.0
Nocomis micropogon	-	-	3	2	-	-	-	-	-	-	-	-	6	12	<1
Notemigonus crysoleucas	-	-	-	-	-	-	-	-	-	-	2	-	2	4	<1
Notropis atherinoides	10	-	-	-	-	-	-	-	-	-	-	-	36	12	1.0
N. buccatus	3	10	3	-	2	5	-	-	4	-	-	-	121	56	2.0
N. photogenis	7	-	9	6	6	-	-	29	-	1	-	5	158	48	2.6
N. rubellus	-	15	2	9	-	4	-	7	-	-	-	-	43	28	1.0
N. stramineus	1	11	-	-	10	3	-	1	-	-	-	-	46	32	1.0
N. volucellus	2	29	-	-	-	-	-	-	-	-	-	-	104	28	1.7
Phoxinus erythrogaster	-	-	-	-	-	-	2	-	-	-	-	-	2	8	<1
Pimephales notatus	5	11	38	26	14	90	-	24	9	3	1	2	475	84	7.7
Rhinichthys atratulus	-	-	-	-	-	-	9	-	-	-	-	-	9	4	<1
Semotilus atromaculatus	-	3	1	2	1	16	2	7	18	-	-	2	98	52	1.6
Carpiodes cyprinus	-	-	-	-	-	-	-	-	-	-	-	-	1	4	<1
Catostomus commersoni	-	1	3	1	3	3	-	5	1	-	2	1	74	56	1.2
Hypentelium nigricans	13	12	21	13	1	9	-	10	2	-	1	1	263	88	4.3
Ictiobus cyprinellus	-	-	-	-	-	-	-	-	-	-	-	-	1	4	<1

Table 2. Part B continued.

SPECIES	STATIONS 14	15	16	17	18	19	20	21	22	23	24	25	TOTAL	TOTAL % OC	% REL. AB.
Minytrema melanops	-	-	-	-	1	-	-	-	-	-	7	1	12	20	<1
Moxostoma anisurum	4	-	-	2	-	-	-	-	-	6	4	-	29	48	1.0
M. carinatum	-	-	-	-	-	-	-	-	-	-	-	-	12	12	<1
M. duquesnei	-	3	-	1	16	-	-	2	-	-	-	1	49	48	<1
M. erythrurum	31	5	186	52	46	4	-	38	-	60	51	170	806	88	13.1
M. macrolepidotum	3	-	-	-	-	-	-	-	-	-	-	-	33	20	1.0
M. sp.	-	-	-	-	3	10	-	1	-	-	-	-	933	40	15.2
Ameiurus melas	-	-	-	-	-	-	-	-	-	-	1	-	1	4	<1
A. natalis	-	-	-	-	1	-	-	2	-	-	-	2	6	16	<1
Ictalurus punctatus	-	-	-	-	-	-	-	-	-	-	-	-	29	16	1.0
Noturus flavus	-	-	-	-	-	-	-	-	-	-	-	-	10	8	<1
Noturus miurus	-	-	-	-	-	-	-	-	-	-	-	-	1	4	<1
Pylodictis olivaris	-	-	-	-	-	-	-	-	-	1	-	-	12	24	<1
Percopsis omiscomaycus	1	-	-	-	-	-	-	8	-	-	10	-	81	20	1.3
Labidesthes sicculus	-	-	-	-	-	-	-	-	-	-	1	-	18	12	<1
Ambloplites rupestris	8	7	10	6	5	1	-	11	7	4	-	2	102	76	1.7
Lepomis cyanellus	1	1	11	1	-	2	-	7	-	1	6	3	58	60	1.0
L. hybrid	-	-	4	-	-	-	-	2	-	7	1	1	56	44	1.0
L. macrochirus	-	-	1	-	-	-	-	-	1	2	2	1	49	48	1.0
L. megalotis	-	6	19	-	-	3	-	11	-	2	7	2	144	68	2.3
L. sp.	-	-	-	-	-	-	-	-	2	-	-	-	2	4	<1
Micropterus dolomieu	8	11	13	6	5	4	-	5	7	5	1	6	121	80	2.0
M. punctulatus	3	-	9	5	2	-	-	10	-	1	6	6	184	72	3.0
M. salmoides	1	-	-	-	1	-	-	-	-	-	-	-	5	16	<1
Pomoxis annularis	-	-	-	-	-	-	-	-	-	-	2	-	6	20	<1
Ammocrypta pellucida	-	-	-	-	-	-	-	-	-	-	-	-	6	4	<1

Table 2. Part B continued.

SPECIES	14	15	16	17	18	STATIONS 19	20	21	22	23	24	25	TOTAL	TOTAL % OC	% REL. AB.
Etheostoma blennioides	-	2	-	-	2	-	-	3	-	-	-	-	56	28	1.0
E. caeruleum	-	-	-	-	-	-	-	-	-	-	-	-	2	8	<1
E. flabellare	-	-	-	-	-	1	1	-	2	-	-	-	6	20	<1
E. nigrum	-	-	-	-	2	1	-	-	5	-	-	-	21	20	<1
E. zonale	-	-	-	-	2	-	-	1	-	-	-	-	26	16	<1
Percina caprodes	2	3	5	1	-	-	-	1	-	-	-	-	73	56	1.2
P. maculata	13	3	1	3	-	5	-	27	-	-	1	3	86	64	1.4
Aplodinotus grunniens	-	-	-	-	-	-	-	-	-	-	-	-	38	20	1.0
TOTAL SPECIMENS	132	185	540	219	165	285	25	337	73	109	129	214	6148		
TOTAL SPECIES	22	21	20	19	20	17	5	24	12	15	19	18	460		

cyprinellus (bigmouth buffalo), *Ameiurus melas* (black bullhead), *Noturus miurus* (brindled madtom), and *Ammocrypta pellucida* (eastern sand darter).

Other records of fishes are known from the Middle Island Creek drainage, but were not collected in this study. Museum records include *Ichthyomyzon bdellium* (Ohio lamprey; WVWR-83, 388), *Lampetra appendix* (American brook lamprey; Cincotta et al. 1986), *L. aepyptera* (least brook lamprey; UMMZ 108291), *Lepomis gulosus* (warmouth; USNM 243799), and *Hiodon alosoides* (goldeye; USNM 177345). A record of the *Ichthyomyzon greeleyi* (mountain brook lamprey; USNM 170972) by Schwartz (1959) is discounted here, as his Middle Island Creek specimen was redetermined as the *I. bdellium* by Jenkins (pers. comm). Stauffer (pers. comm.) recently collected *Percina phoxocephala* (slenderhead darter) in Middle Island Creek and has confirmed museum records of *Notropis amblops* (bigeye chub) and *Carpiodes carpio* (river carpsucker) from the drainage. *Esox lucius* (northern pike), *Morone chrysops* (white bass), *Pomoxis nigromaculatus* (black crappie), and *Stizostedion canadense* (sauger) have been confirmed from the drainage by one of the authors (SFM). Additionally, WVWR has stocked *Salvelinus fontinalis* (brook trout), *Oncorhynchus mykiss* (rainbow trout), and *Salomo trutta* (brown trout) into Conaway Run Lake and between 1977-81 stocked *Esox lucius* X *E. masquinongy* (tiger musky) during June into the backwaters of Middle Island Creek. *Rhinichthys cataractae* (longnose dace) and *Lepomis gibbosus* (pumpkinseed) were listed in the surveys of Menendez and Robinson (1964). The *L. gibbosus* information is believed valid due to verifiable records from nearby waters (WVWR unpubl. data). However, the *R. cataractae* data are questioned due to a lack of habitat and the significant distance between Middle Island Creek and the nearest confirmed records from a Hancock County stream (Barnes et al. 1985) and the Elk River of the lower Kanawha River (WVWR unpubl. data). Thus, this survey and the data above increase the known fish fauna of Middle Island Creek to 71 species.

Of the 71 species known from the basin, 21 are considered sportfishes (WVWR unpublished data). The four most important gamefish species, which are widely distributed in the drainage, are *Esox masquinongy* (muskellunge), *Micropterous dolomieu*, *M. punctulatus*, and *Ambloplites rupestris*. *Ictalurus punctatus* and *Pylodictis olivaris* (flathead catfish) are sought by anglers primarily in the main stem Middle Island Creek and at the mouths of major tributaries. *Morone chrysops*, *Pomoxis nigromaculatus*, *P. annularis* (white crappie), and *Micropterus salmoides* are also important species harvested, but are mainly restricted to the Ohio

River backwater portion of Middle Island Creek. Even though crappie fishing opportunity is limited, the current state record *Pomoxis* (species undetermined) was caught from Meathouse Fork in 1971 (WVWR unpublished data); this fish was 50.2 cm in length and weighed 1.84 kg. The four *Lepomis* species known to the watershed are not actively fished for by anglers.

Menendez and Robinson (1964) theorized from their Middle Island Creek surveys that if a station population contained a 25% gamefish standing crop (i.e., weight composition as reported in kg/ha), then it was rated as good or average. Apparently they utilized these surveys as a standard for their evaluation of 244 northeastern West Virginia localities, because of this drainage's reputation for excellent water quality and fishing. The standing stocks of gamefish populations in this study ranged from 4% to 50% and averaged 24% (Table 1).

Standing stock standards regarding black bass populations (*Micropterus dolomieu, M. salmoides, M. punctulatus*) were also summarized by Menendez and Robinson (1964). They indicated that good or average bass populations existed when weights comprised at least 15% of the total sample. Their work reported for the drainage an average standing crop of 14% for bass. During the present study the average for the entire watershed was 11%, however, the main channel Middle Island Creek's black bass weights averaged appreciably lower at 6% (range 1% to 11%). According to Menendez and Robinson's criteria, good black bass populations are found in Bluestone Creek, Elk Fork, McKim Creek, Sugar Creek, and Meathouse Fork (Table 1).

Age and growth data for *Micropterus dolomieu* and *M. punctulatus* in Middle Island Creek drainage are presented in Table 3. According to Hess (1977), growth rates relative to the main stem are above average for *dolomieu* and below average for *punctulatus* in West Virginia streams. Age and growth data for fishes collected from tributaries indicate *dolomieu* growth as average, while growth rates for *punctulatus* are below average.

During the period 1969 through 1989, 463 legal sized *Esox masquinongy* were caught from Middle Island Creek drainage and registered with the West Virginia Husky Musky Club. The main channel Middle Island Creek leads the state in the number of *E. masquinongy* registered, which represents 17% of all recorded catches. During the same period, 76 muskellunge catches were registered from Middle Island

Table 3. Age and growth data for smallmouth bass (A) and spotted bass (B) collected from Middle Island Creek and its major tributaries (number of fish in parenthesis, lengths in cm). Statewide average is from Hess (1977)

Streams	Calculated Lengths at Each Annulus					
	I	II	III	IV	V	VI
(A)						
Middle Island Creek	9.9 (15)	17.5 (15)	22.9 (9)	28.5 (1)		
Sugar Creek	9.4 (9)	16.0 (7)	22.4 (6)	29.2 (2)		
Sancho Creek	7.6 (1)	15.2 (1)				
Point Pleasant Creek	9.9 (5)	14.2 (5)	16.3 (3)			
Elk Fork	9.1(3)	16.8 (2)	20.1 (1)	23.1 (1)		
Indian Creek	10.9 (13)	15.2 (9)	20.8 (2)			
McElroy Creek	8.6 (5)	13.2 (3)	19.6 (2)	20.8 (1)		
Arnolds Creek	9.9 (3)	14.0 (3)	18.0 (2)	19.8 (2)		
Bluestone Creek	9.1 (3)	17.8 (2)	21.8 (1)			
Meathouse Fork	8.9 (3)	16.0 (3)	25.4 (3)	30.7 (3)	34.8 (2)	39.6 (2)
Buckeye Creek	10.7 (6)	16.0 (4)	20.1 (3)	22.4 (2)	24.4 (1)	
Tributary Average	9.4 (51)	15.2 (39)	20.8 (23)	25.4 (11)	31.2 (3)	39.6 (2)
Drainage Average	9.5 (66)	15.6 (120)	20.7 (32)	24.9 (12)	31.2 (3)	39.6 (2)
Statewide Average	8.6	15.2	20.3	25.9	32.8	38.1
(B)						
Middle Island Creek	9.1 (43)	15.5 (43)	20.1 (31)	23.4 (13)	27.2 (4)	30.5 (2)
Sugar Creek	6.4 (2)	19.6 (1)	19.8 (1)			
Point Pleasant Creek	8.6 (2)	15.0 (2)	19.3 (1)	22.1 (1)	28.5 (1)	
Indian Creek	6.9 (9)	12.7 (7)	17.3 (3)	21.8 (1)		
McElroy Creek	7.9 (4)	13.5 (4)	18.0 (1)	21.3 (1)		
Arnolds Creek	8.1 (4)	13.0 (4)	17.6 (2)	22.1 (2)	23.4 (2)	24.9 (2)
Meathouse Fork	8.4 (1)	14.7 (1)	19.3 (1)	21.3 (1)	26.7 (1)	
Toms Fork	10.4 (5)	16.0 (2)	21.3 (1)	24.6 (1)	27.2 (1)	
Buckeye Creek	8.4 (6)	15.2 (5)	18.5 (4)	21.8 (2)	25.2 (1)	
Tributary Average	8.1 (33)	14.2 (26)	18.5 (14)	22.1 (9)	25.7 (6)	24.9 (2)
Drainage Average	8.2 (76)	15.0 (69)	19.0 (45)	22.3 (22)	26.4 (10)	27.7 (6)
Statewide Average	9.4	15.5	21.3	26.4	29.9	33.8

Creek's tributaries. The most important tributary was McElroy Creek (65 recorded), with the remaining 11 fish coming from Indian Creek, Meathouse Fork and Toms Fork. Miles (1978) summarized the life history of this species in West Virginia based on Middle Island Creek data. He indicated that adults were heavily exploited by fishermen and showed extensive upstream and downstream movements.

The drainage basin contains an excellent non-game and/or forage fishery. Sucker species comprised the highest percentage of weight in most surveys. Weight compositions for the sucker family ranged from 14% to 86% and averaged 50%, while the minnow family ranged from 0% to 53% and averaged 14% (Table 1). *Ammocrypta pellucida* was the only nongame species collected that is currently under consideration as an endangered species by the U.S. Fish and Wildlife Service pursuant to the Endangered Species Act (Fed. Reg. 1989). However, Cincotta (1990) does not list this darter as a species of special concern at the state level, because it is not considered in jeopardy in West Virginia.

Recommendations for fishery management in the drainage should be restricted to habitat and water quality protection. Major problems facing the watershed are directly related to the oil and gas industry. Currently, this industry is experiencing a recession and no problems are expected within the immediate future. Minor problems with siltation and domestic pollution are expected to persist until stronger legislation is enacted to protect aquatic resources within West Virginia. Data collected during this study suggest there is not an over utilization of any game species. The current fishing regulations appear adequate for the protection of the drainage's sportfishery resources.

Acknowledgments

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Literature Cited

1. Barnes, M. B., D. L. Rice, and T. E. Linkous. 1985. New locality records of the longnose dace, *Rhinichthys cataractae* (Cyprinidae), in the upper Ohio River valley. Oh. Acad. Sci. 85:135-136.

2. Cincotta, D. A. 1990. Fishes. Pages vi - x, 1 - 34. *In* Vertebrate Species of Concern in West Virginia. W. V. Dept. Nat. Resour., Wildl. Resour. Div., Charleston. 105 pp.

3. Cincotta, D. A., R. L. Miles, M. E. Hoeft, and G. E. Lewis. 1986. Discovery of *Noturus eleutherus, Noturus stigmosus*, and *Percina peltata* in West Virginia, with discussion of other additions and records of fishes. Brimleyana 12:101-121.

4. Embree, W. N., E. A. Friel, T. A. Ehlke, and S. M. Ward. 1983. Water resources data, West Virginia, water year 1982. U.S. Geol. Surv. (WV-82-1). Charleston. 342 pp.

5. Federal Register. 1989. Endangered and threatened wildlife and plants: Review of vertebrate wildlife, U.S. Dept. of Interior, Fish Wildl. Service 450 (180):37958-37967.

6. Hall, J. H. 1977. Comprehensive survey of the Middle Island Creek Basin, Volume I. WV. Dept. Nat. Resour., Div. Water Resour. 107 pp.

7. Hess, L. J. 1977. Compendium of game fish age and growth data for West Virginia. WV. Dept. Nat. Resour., Charleston. Federal Aid Project F-23-R, Study III-2. 91 pp.

8. Hocutt, C. H., R. E. Jenkins, and J. R. Stauffer, Jr. 1986. Zoogeography of the fishes of the central Appalachians and central Atlantic coastal plain. Pages 161-211, *In* C. H. Hocutt and E. O. Wiley, editors. The Zoogeography of North American freshwater fishes. John Wiley and Sons, NY. 866 pp.

9. Holton, G. D., and C. R. Sullivan. 1954. West Virginia's electrical fish-collecting methods. Prog. Fish. Cult. 16:10-18.

10. Lachner, E. A., and R. E. Jenkins. 1971. Systematics, distribution, and evolution of the chub genus *Nocomis* Girard (Pisces, Cypinidae) of eastern United States, with descriptions of new species. Smithson. Contrib. Zool. 85:1-97.

11. Lee, D. S., C. R. Gilbert, C. H. Hocutt, R. E. Jenkins, D. E. McAllister, and J. R. Stauffer, Jr. 1980. Atlas of North American Freshwater Fishes. N. C. State Mus. Nat. Hist., Raleigh. 854 pp.

12. Menendez, R., and D. W. Robinson. 1964. Stream survey of District I (Northwest) West Virginia. WV. Dept. Nat. Resour., Div. Game and Fish, Charleston. Fed Aid Proj. F-10-R-(1-6). 60 pp.

13. Miles, R. M. 1978. A life history study of muskellunge in West Virginia. Amer. Fish. Soc. Spec. Publ. 11:140-145.

14. Potesta, R. R. 1986. West Virginia high quality streams. 5th edition. W. V. Dept. Nat. Resour. Div., Charleston. 45 pp.

15. Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1991. A list of common and scientific names of fishes from the United States and Canada. 5th edition. Amer. Fish. Soc. Spec. Publ. 20.

16. Schwartz, F. J. 1959. Records of the Allegheny brook lamprey *Ichthyomyzon greeleyi* Hubbs and Trautman, from West Virginia with comments on its occurrence with *Lampetra aepyptera* (Abbott). Oh. Jour. Sci. 59(4):4 pp.

17. Tsai, C., and E. C. Raney. 1974. Systematics of the banded darter, *Etheostoma zonale*. (Pisces: Percidae). Copeia 1974(1):1-24.

Botany Section

Updates on the Vascular Flora of West Virginia. VIII.

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Abstract

On-going studies at the West Virginia University Herbarium (W Va) have uncovered two species of vascular plants as new or noteworthy additions to the flora of West Virginia according to Strausbaugh and Core (1978). Unless otherwise noted, the nomenclature and distribution information follows Fernald (1950).

The new species are as follows:

POACEAE. *Sporobolus neglectus* Nash. Mingo County: Allison W. Cusick 29257. September 25, 1990. We are in the midst of the range of this taxon. It is therefore to be expected.

ASTERACEAE. *Astranthium integrifolium* (Michx.) Nutt. Barbour County: Eleanor Bush s.n., May 26, 1991, and Barbour County: Charles Baer s.n., June 2, 1991. We are just off the northeastern edge of the range of this species. Therefore, it can be expected and is a range extension for this taxon.

Literature Cited

1. Fernald, M. L. 1950. Gray's Manual of Botany, 8th edition. American Book Co., New York. 1632 pp.

2. Strausbaugh, P. D., and E. L. Core. 1978. Flora of West Virginia, 2nd edition. Seneca Books. Grantsville, WV. 1079 pp.

Chemistry/ Biochemistry Section

Characterization of Argon/Methane Plasma Chemistry Relevant to the Deposition of Diamond Films

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Abstract

Mass spectrometry and optical spectroscopy experiments permit the characterization of argon/methane glow discharge plasmas. These investigations demonstrate the relationship between the plasma chemistry and the percent dilution of a CH_4/H_2 mixture with argon. Results from these investigations provide an understanding of the influence of argon dilution on plasma temperature dependent changes in the chemistry of these plasmas.

Introduction

Diamond is essentially a lattice of sp^3 hybridized carbon atoms. Because of technologically useful properties, i.e., thermal conductivity, electrical resistivity, IR transparency, and durability, diamond thin films and their fabrication are the subject of extensive investigation (1). Much of the research effort focuses on the development of techniques permitting the growth of high quality diamond thin films on a variety of surfaces for use in optics, optoelectronics, and microelectronics (2). Plasma vapor deposition employing flame, microwave, inductively-coupled, or glow discharge plasmas uniquely permits diamond film growth even on temperature sensitive substrates not amenable to other growth methods. Plasma vapor deposition currently relies on the empirical determination of appropriate plasma operating conditions. Because plasma operating parameters profoundly influence the processes that control the growth rate and determine the quality of the deposited diamond film, this empirical determination fails to yield the reliable and reproducible production of high quality films that is essential for the desired applications (1). Realization of the full potential of plasma-based diamond thin film deposition requires a better understanding of the underlying plasma chemistry.

Diamond thin film growth arises from the reaction of CH_X radicals with sp^3 hybridized carbon sites on the bulk surface. Controllable populations of free H atoms and CH_X radicals are critical to the growth of high quality diamond films (3). The role of the H atoms is to protect the sp^3 hybridized carbon sites until CH_X radicals displace them and add to the lattice. In plasma vapor deposition of diamond films, plasma chemistry produces the reactive H and CH_X species. The plasma also provides energetic electrons or ions that bombard the growing film, enhance the mobility of species toward active growth sites, and preclude the need to otherwise heat the substrate.

As previously mentioned, the operating parameters of the plasma determine the plasma chemistry responsible for film growth. The two most important plasma operating parameters are the partial pressures of reactant gases and the operating power coupled into the plasma (4). This research focuses on the relationship between the partial pressures of the reactant gases in the plasma, the energy content of the plasma, and the population of the CH_3 ions in the plasma. Once the relationship between the partial pressure of the gases and the ionic species produced in the plasma is determined, one will be better prepared to determine the conditions at which the population of CH_3 radicals in the plasma reach a maximum. The use of these optimized conditions will bring about increased quality and growth rate of the diamond thin films.

Experimental

The DC glow discharge employed in these experiments is powered by a fast programmable voltage amplifier (OPS-3500, Kepco, Flushing, NY) that operates at 800 to 1300 V and 1 to 5 mA. The cathode, a 13 mm long and 2 mm diameter rod of spectrographic grade graphite (National Carbon, Parma, OH), is mounted on a 13 mm dia. direct insertion probe

(5). This probe is inserted into the discharge chamber through a ball valve (A & N, Inglis, FL) mounted on a 70 mm conflat flange (MDC, Hayward, CA). A stainless steel six-way high-vacuum cross (MDC, Hayward, CA) having 70 mm conflat flanges is employed as the discharge chamber. This chamber is equipped with two suprasil (Heraus Quartz, Duluth, GA) optical view ports mounted perpendicular to the probe axis to permit optical probing of the plasma. A steel plate with a 0.5 mm aperture inserted into arm of the cross opposite the probe is employed as the mass spectrometric sampling orifice. Pumping is provided through this aperture by the mass spectrometer vacuum system. Pressure in the discharge chamber is monitored by a thermocouple pressure gauge (Teledyne-Hastings, Hampton, VA). An electronic grade mixture of 5% CH_4 in H_2 (Matheson, Philadelphia, PA) is diluted with Research Grade Ar (WV Welding, Morgantown, WV) to yield the desired gas mixture for individual experiments. The mixture ratio is determined by admitting a set pressure of the methane/hydrogen gas and then diluting to a final pressure with Ar.

The optical spectroscopy system is based on a 0.64 m monochromator (ISA, Edison, NJ) equipped with a RU-928 photomultiplier tube. Atomic Emission (AES) measurements are made by focusing the image of the discharge plasma onto the entrance slit of the monochromator. The signal from the photomultiplier is acquired in synchronization with monochromator scanning controlled by a PC-Based Spectrometer Operating System (ISA, Edison, NJ). For Atomic Absorption (AAS) measurements, 811.5 nm radiation from an argon filled hollow cathode lamp modulated at 3000kHz by a chopper (EG&G PARC, Princeton, NJ) is passed through the glow discharge and imaged onto the entrance slit of the monochromator. The signal from the photomultiplier tube is preamplified (MIT, Boulder, CO) then processed by a Lock-in Amplifier (EG&G PARC, Princeton, NJ) tuned to the modulation frequency and displayed on a 100 MHz bandpass digital oscilloscope (Tektronix, Beaverton, OR).

Mass Spectrometric measurements are made with a triple-quadrupole mass spectrometer (Extrel, Pittsburgh, PA) operating in the Q3 MS mode. This mass spectrometer has been modified to permit monitoring of glow discharge plasmas. The EI/CI ion source is removed from the triple quadrupole mass spectrometer. A bessel-box energy analyzer (Extrel, Pittsburgh, PA) is mounted in the place of the ion source. The front flange of the mass spectrometer vacuum chamber is modified to accept the discharge chamber described above. Data are acquired from the output of the continuous dynode electron multiplier (Galileo Electro-Optics, Sturbridge, MA) through a preamplifier (MIT, Boulder, CO) with a PC-Based Mass Spectrometer Operating System (Teknivent, St. Louis, MO).

Results and Discussion

The dilution of a 5% CH_4/H_2 mixture with argon was investigated. The rationale for using a mixture of only 5% CH_4 in H_2 is that although the formation of diamond film is facilitated by a large population of CH_X radical species, the homogeneous nucleation of radical species, attendant to large radical populations, hinders the formation of quality films. From the mass spectrometric investigations into the chemistry of methane glow discharges (6), the effect of increasing CH_4 pressure is known to be increased production of larger hydrogenation species through nucleation. Since the important species in diamond deposition are the monocarbon radicals, CH_X, it is understandable that low relative concentrations of

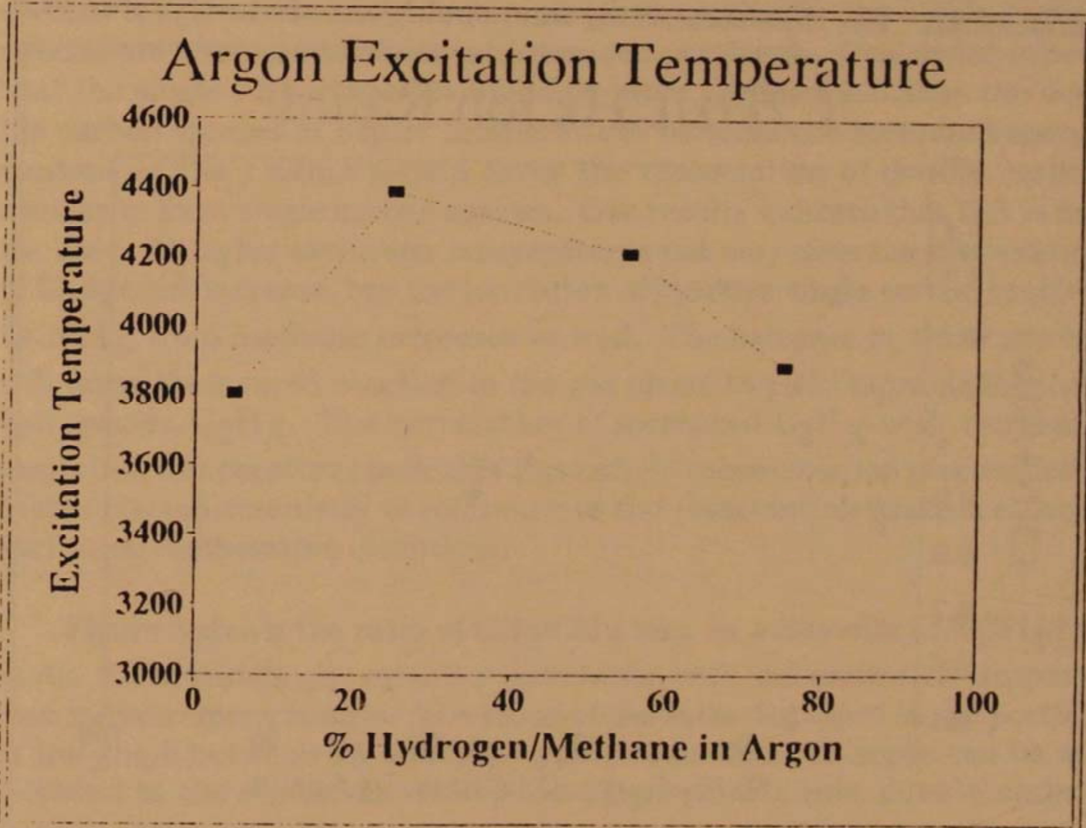

Figure 1. The variation of argon excitation temperature with the percent dilution of the argon plasma with a hydrogen/methane mixture. The excitation temperatures obtained by optical spectroscopy can be used as a measure of the energy content of the glow discharge plasma.

CH_4 are employed to prevent their loss by aggregation. This plasma gas will then be diluted with differing amounts of Ar to study the impact of this dilution on the relative plasma energy content and on the populations of ionic species present in the plasma.

The energy content of the plasma was estimated from measurements of argon excitation temperatures by optical spectroscopy. The argon excitation temperatures were determined from the relative intensities of a series of transitions in the wavelength range from 425 - 435 nm (7). $\log(I\lambda/gA)$ is a linear function of the excitation energy, E, with a slope equal to $-.625/T_{exc}$. The variable I is the intensity of the signal, λ stands for the wavelength of emission signal, g is a statistical weighting factor, and A is the Einstein coefficient for spontaneous emission between the two states. A plot of the T_{exc} determined by this method as a function of the discharge gas composition, Figure 1, provides us with a measure in the relative change in plasma energy content as a function of plasma gas composition. The data concerning ion populations are interpreted with

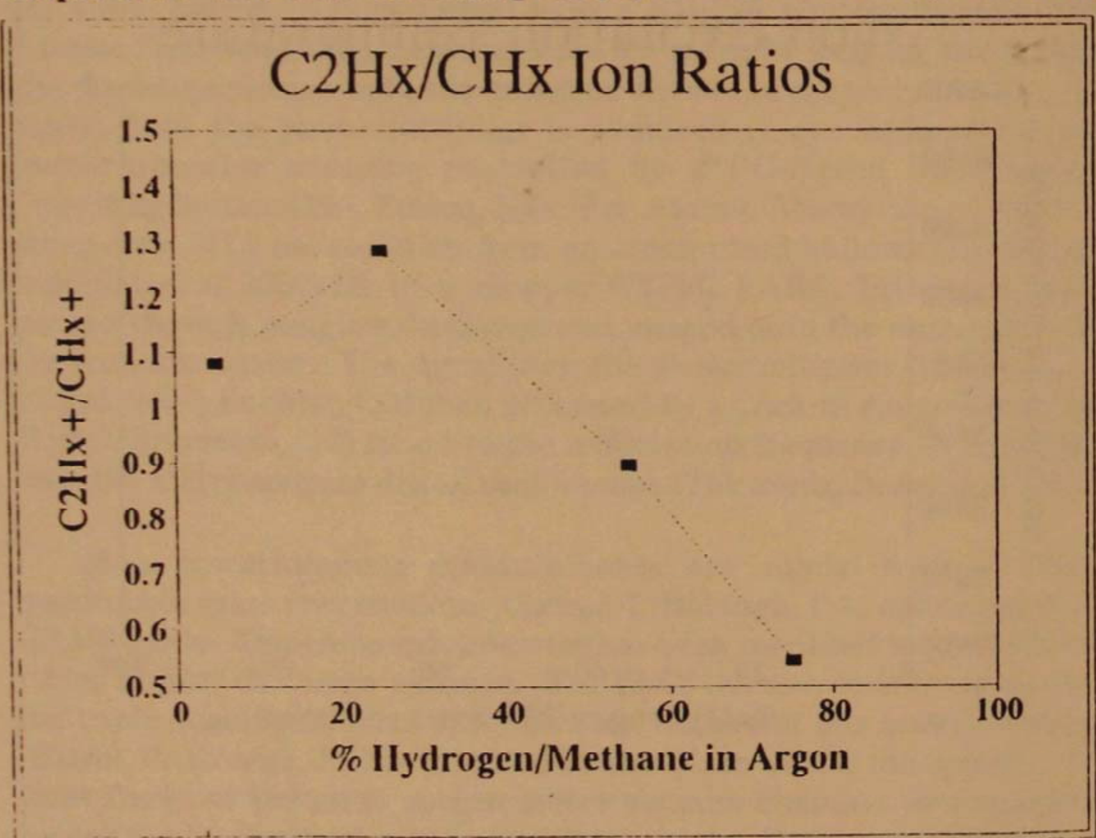

Figure 2. The variation of the ratio of the double carbon species to the single carbon species present in the plasma with the percent dilution of argon with a hydrogen/methane mixture. The results displayed correlate with the results displayed in Figure 1.

respect to this experimentally determined change in plasma energy content.

The ratio of C_2H_X/CH_X species as a function of $\%CH_4/H_2$ in Ar can be seen in Figure 2. The C_2H_X represents the total mass spectrometry signal arising from those species that contain two carbon atoms, C_2, C_2H, C_2H_2, C_2H_3, and C_2H_4; whereas, CH_X represents the total mass spectroscopy signal arising from those species that contain one carbon atom, C, CH, CH_2, CH_3, and CH_4. The ratio increases to a maximum value at around 25% CH_4/H_2 then begins to fall off at a steady rate. Interestingly, this trend is similar to the trend for the influence of discharge gas composition on excitation temperature, Figure 1. Although, this similarity suggests a relationship between the ratio of C_2 species to C_1 species and the excitation temperature of argon, the nature of the relationship is counterintuitive. A comparison of Figures 1 and 2 shows that the double carbon species are favored at higher temperatures, whereas the single carbon species are more predominant at lower temperatures. One would expect that the single carbon species would be more predominant than the double carbon species at higher temperatures because the increased energy content of the plasma should favor the dissociation of double carbon species to form single carbon species. Our results indicate that this is not the case. At higher excitation temperatures not only does the dissociation of C_2 species increase, but the formation of reactive single carbon species, i.e., CH_3, from methane increases as well. The increase in these species will favor their rapid reaction in the gas phase to yield more double carbon species, C_2H_X. The correlation of increased C_2H_X with increased excitation temperatures indicates this radical recombination process dominates plasma chemistry in reference to the dissociation process at high excitation temperature conditions.

Figure 3 shows the ratio of CH_3/CH_4 ions as a function of $\%CH_4/H_2$ in Ar. These results also exhibit a correlation with the excitation temperature measurement results. The trend of the ratio displayed in the portion of the graph between 5% and 25% hydrogen/methane in argon can be attributed to the recombination of the CH_3 radicals into double carbon species. Here, the temperature of the plasma is increasing, and a large number of CH_3 radicals are produced. However, these radicals have a high rate of reactivity, and are quickly destroyed due to recombination as discussed in the previous paragraph. In the portion of the graph between 25% and 50% hydrogen/methane in argon, the temperature of the plasma is decreasing with increased % CH_4/H_2, and yet the CH_3/CH_4 ratio is

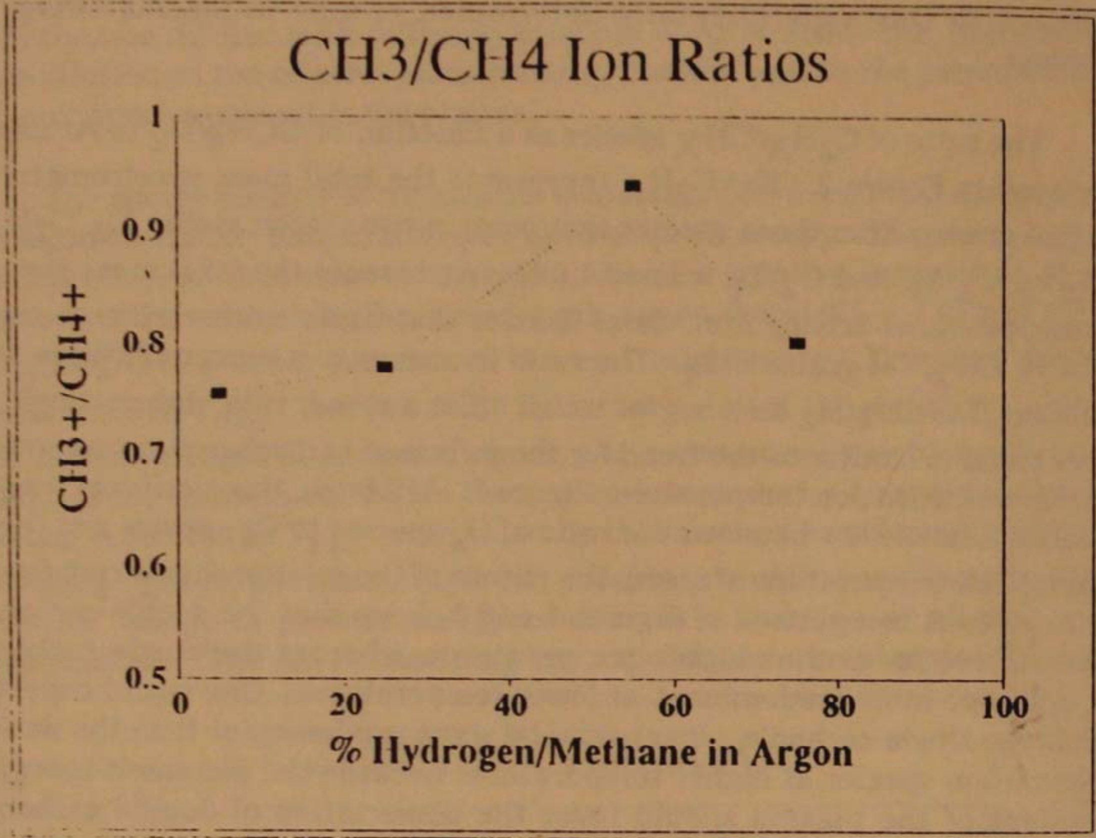

Figure 3. The variation of the ratio of CH_3^+ to CH_4^+ present in the plasma with the percent dilution of an argon plasma with a hydrogen/methane mixture.

increasing. This can be explained by the fact that the loss of CH_3 to recombination reactions is decreasing. The ratio results displayed in the portion of the graph between 50% and 75% hydrogen/methane in argon correlates well with the temperature of the plasma. Here the temperature is decreasing, and the formation of the CH_3 radicals is decreased as expected. It is interesting to note that the ratio of CH_3/CH_4 is at about the same value at 75% dilution of Ar with CH_4/H_2 as at 10%. If one looks back to Figure 1, one would see this same occurrence, thus strengthening the observation that the production of CH_3 radicals is related to the temperature of the plasma.

The ratio of CH_2 species to CH_3 species was also investigated. The plot of the CH_2/CH_3 ion ratios versus % CH_4/H_2 in Ar can be seen in Figure 4. It has been demonstrated that the introduction of methane into

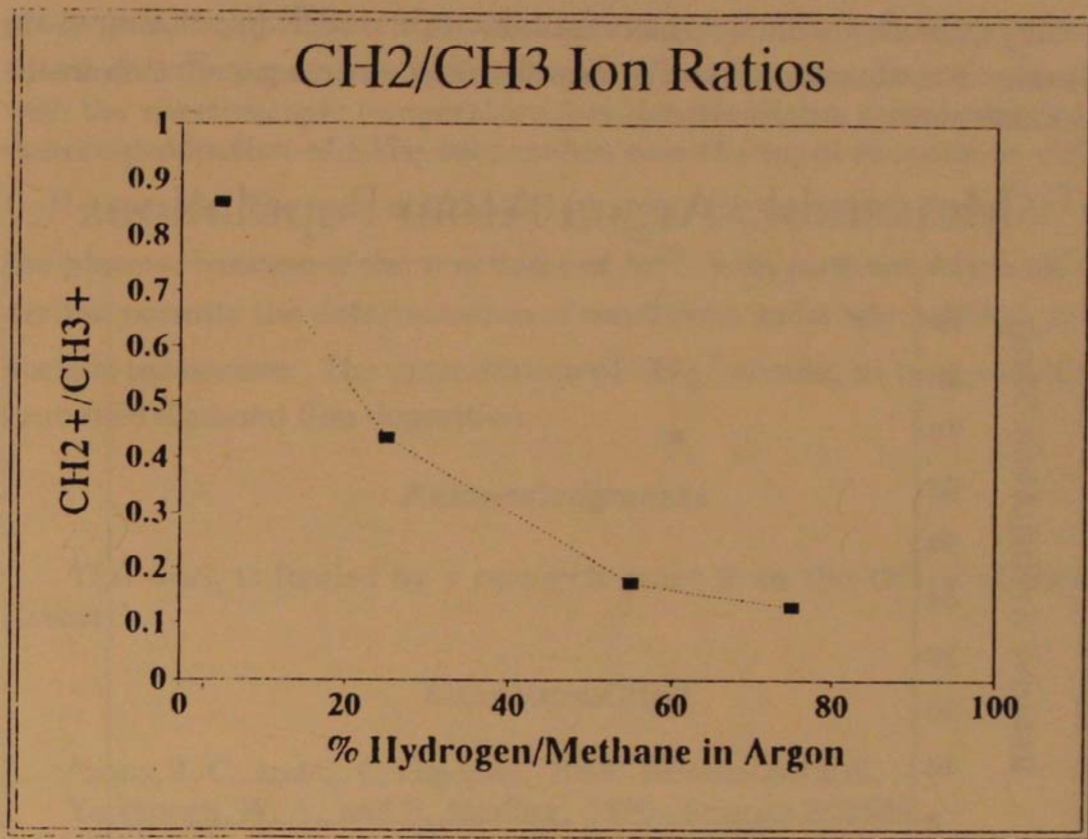

Figure 4. The variation of the ratio of CH_2^+ to CH_3^+ present in the plasma with the percent dilution of an argon plasma with a hydrogen/methane mixture.

Ar supported glow discharges reactively quenches the argon metastable atom population (Ar^m) (8). The behavior of CH_2 can be understood when these quenching reactions between methane and argon metastable atoms are considered. These reactions (9) are as follows:

$$Ar^m + CH_4 \longrightarrow CH_2 + 2H + Ar \quad (1)$$

$$\longrightarrow CH + H_2 + H + Ar \quad (2)$$

$$\longrightarrow CH_3 = H + Ar \quad (3)$$

$$\longrightarrow CH_2 + H_2 + Ar \quad (4)$$

The individual contributions of reactions (2)-(4) to the total reaction of argon metastable atoms with methane are unknown at this time; however, the contribution of reaction (1) to the total is well documented at 65% (9).

Since reaction (1) is the dominant reaction, it follows that the production of CH_2 radicals should be synchronized with the Ar^m population in the plasma. For this reason the metastable argon atom population in the methane plasma was measured.

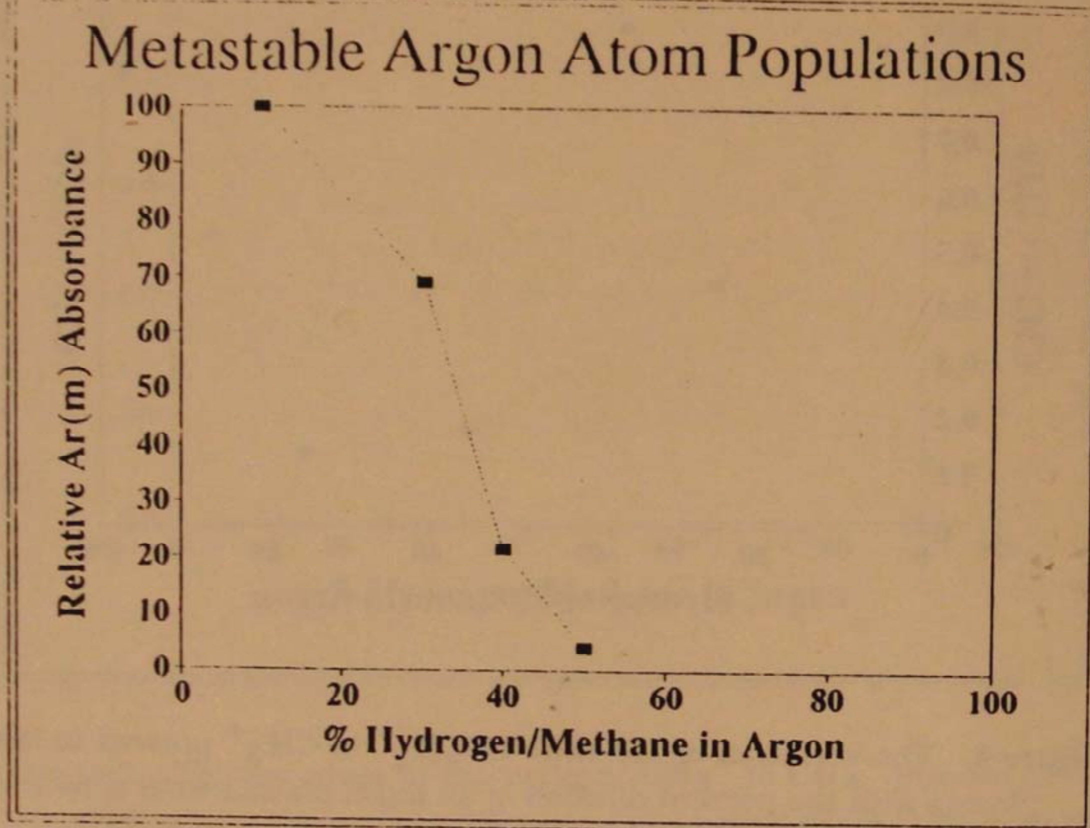

Figure 5. The variation of the metastable argon atom population of the plasma with the percent dilution of the argon plasma with a hydrogen/methane mixture.

Atomic Absorption Spectrometry was employed to measure the relative Ar^m absorbance at 811.5 nm as a function of %CH_4/H_2 in Ar, Figure 5. This graph clearly shows the metastable population decreasing sharply with increasing percentage of CH_4/H_2 mixture in the plasma. This trend mirrors that observed for CH_2/CH_3. This confirms the influence of Ar^m on the CH_2 population in the plasma.

Summary

The distribution of input gases into the plasma has a dramatic effect on the temperature and the Ar^m population of the plasma. Both of these effects are important because it has been shown in this research that the production of carbon ions in the plasma is dependent on both the temperature and Ar^m population in the plasma. Gas phase condensation tracks with the spectroscopic temperature, because the higher temperatures favor the production of CH_X species but also the rapid reaction to yield C_2H_X species. The ratio of CH_2/CH_3 tracks with the population of Ar^* in the plasma, because of the reaction s of Ar^m with methane. This information permits the determination of conditions under which CH_3^+ production maximizes. The optimization of CH_3^+ should, in turn, result in improved diamond film deposition.

Acknowledgments

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Literature Cited

1. Angus, J. C., and C. C. Hayman. 1988. Science 241:913.
   Yarbrough, W. A., and R. Messier. 1990. Science 247:688.

2. Bachmann, P. K., and R. Messier. 1989. Chemical and Engineering News 67:24.

3. Chu, C. J., M. P. D'Evelyn, R. H. Hauge, and J. L. Margrave. 1990. J. Mater. Res. 5:2405.
   Martin, L. R., and M. W. Hill. 1990. J. Mat. Sci. Lett. 9:621.
   Harris, S. J., and L.R. Martin. 1990. J. Mater. Res. 5:2313.

4. Deshpandey, C., and R. F. Burnshah. 1988. Thin Solid Films 163:131.

5. King, F. L., and W. W. Harrison. 1989. Int. J. Mass Spectrom. and Ion Proc. 89:171.

6. Smolinsky, G., and M. J. Vasile. 1975. Int., J. Mass. Spectrom. Ion Phys. 16:137.

7. Mermet, J. M. 1987. In Inductively Coupled Plasma Emission Spectroscopy - Part 2. Chapter 10. John Wiley & Sons, Inc. 353-386.

8. Smith, R. L., D. Serxner, and K. R. Hess. 1989. 61:1103.

9. Balamuta, J., M. F. Golde, and Y. Ho. 1983. J. Chem. Phys. 79:2822.

Geochemistry of a Carbonate-Depositing Stream and Spring in Mineral County, West Virginia

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Abstract

An unnamed tributary to New Creek in Mineral County issues from a small spring on the west slope of New Creek Mountain, and calcium carbonate has precipitated as travertine-marl deposits in its bed. New Creek Mountain is underlain by steeply dipping rock of the western limb of the Wills Mountain anticline, and bedding dip exceeds topographic slope. The spring results from ground water overflowing an underground dam formed by a low-permeability bed within the upper part of the Devonian Helderberg Group of rocks. The stream flows for approximately 230 m while descending about 60 m. Over this length, there are both gaining and losing reaches as some of the water is diverted underground through relatively permeable beds of the Oriskany sandstone or by underflow in the alluvium to be once again forced to the surface by less permeable layers of the bedrock. Water samples were taken at five locations along the small stream and from New Creek and analyzed for the major inorganic constitutents. Waters are relatively typical karst waters, of a calcium carbonate composition with an additional moderate sulfate content. All samples from the spring and the spring run were found to be highly supersaturated with respect to calcite. Loss of calcium carbonate through precipitation does not begin until the water has flowed 30 m below the spring to an area of increased stream turbulence, and then continues to the junction with New Creek, at degrees of supersaturation in excess of ten times saturation with respect to calcite. Water analysis data and analyses of travertine and marl from the stream bed indicate that the material precipitating is a low-magnesian calcite. In the 200-m length of stream over which precipitation occurs, the stream looses 10% to 15% of its dissolved calcium and bicarbonate, but little or none of the other ions present.

Introduction

Travertine-depositing springs and streams have evoked interest in the scientific literature for some time as being somewhat unusual features of the landscape. Recently Janet Herman and David Hubbard (1990a) compiled a volume of articles concentrating on the Valley and Ridge province of Virginia, but also discussing some other areas. One of these articles describes a spring in West Virginia (Kite and Allamong, 1990), emphasizing the sedimentological and stratigraphic aspects of the deposit; the chemical aspects of the water and deposition of the material are briefly discussed. The present study was undertaken to further explore the hydrochemical aspects of this spring.

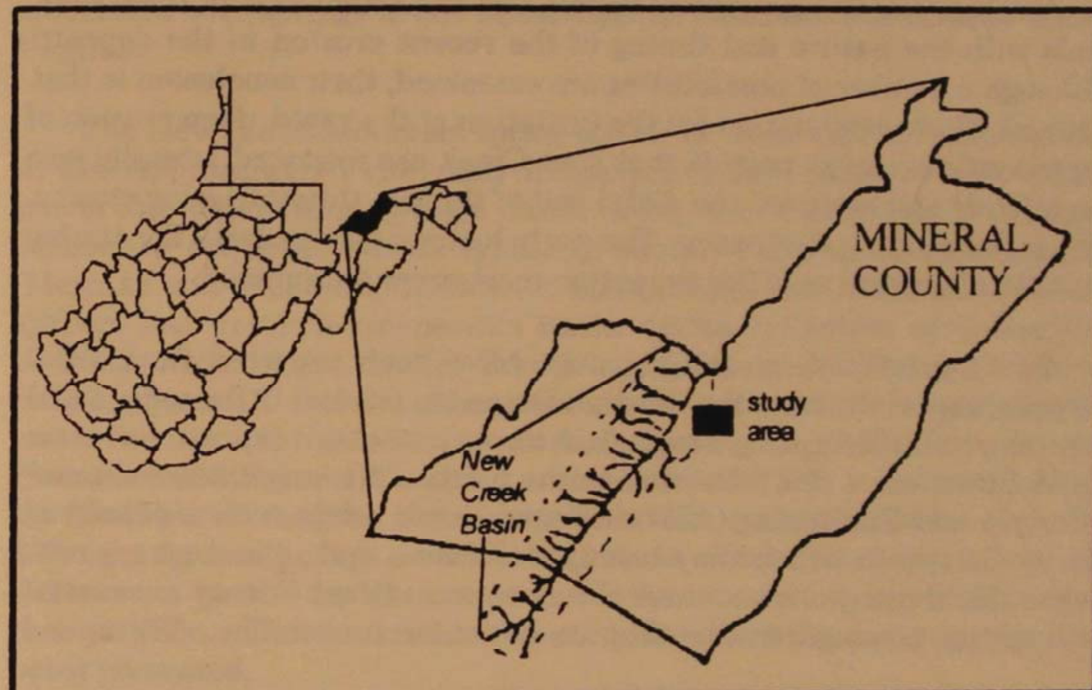

Figure 1. Location map of study area (after Kite and Allamong, 1990).

This travertine-depositing spring issues from vertical to slightly overturned rocks of Devonian age and is located on New Creek Mountain in the Valley and Ridge Province of West Virginia, approximately 4 km south of Keyser, Mineral County (figure 1). The spring and stream are located within a drainage basin whose surface drainage divide encompasses approximately 0.26 km^3 of the west slope of the mountain. The small, unnamed stream flows in a channel about a half meter wide for 230 meters into New Creek. The surface stream heads in an area underlain by Silurian clastic rocks, but the majority of the basin is underlain by Silurian Tonoloway Limestone and Devonian Helderberg Group of limestones and chert. The lowermost portion of the basin is underlain by the Devonian Oriskany sandstone.

sinkholes developed in the Tonoloway Limestone. The water resurfaces from the upper part of the Helderberg Group, about where shaly beds typically occur (Reger, 1924). Apparently these shaly beds form an underground dam which stops or retards the westward flow of ground water and forces some or all of the flow to the surface.

Kite and Allamong's (1990) discussion of the area deals primarily with the nature of the alluvial and colluvial sediments and structure of the fan developed in the spring run valley. An important part of their work deals with the nature and timing of the recent erosion of the deposit. Although a number of possibilities are examined, their conclusion is that the most likely explanation for the initiation of the rapid, deep erosion of the travertine-marl deposit is that New Creek has migrated laterally into the hillside and removed the distal end of the fan, thus initiating erosion that is progressing upstream. The early history, particularly the timing and rate of deposition of the travertine-marl, are not examined.

Few travertine-depositing springs have been reported from West Virginia, especially from the Silurian-Devonian terrain. Allamong (1991) mentions another spring-associated travertine-marl deposit on New Creek Mountain a short distance to the north of the one discussed here. Gillespie and Clendening (1964) have published a report on a deposit in Hardy County in which they briefly describe a spring and spring run. Reger (1924) mentions two marl occurrences in Grant County associated with springs issuing from the Silurian-Devonian limestones. Tilton and

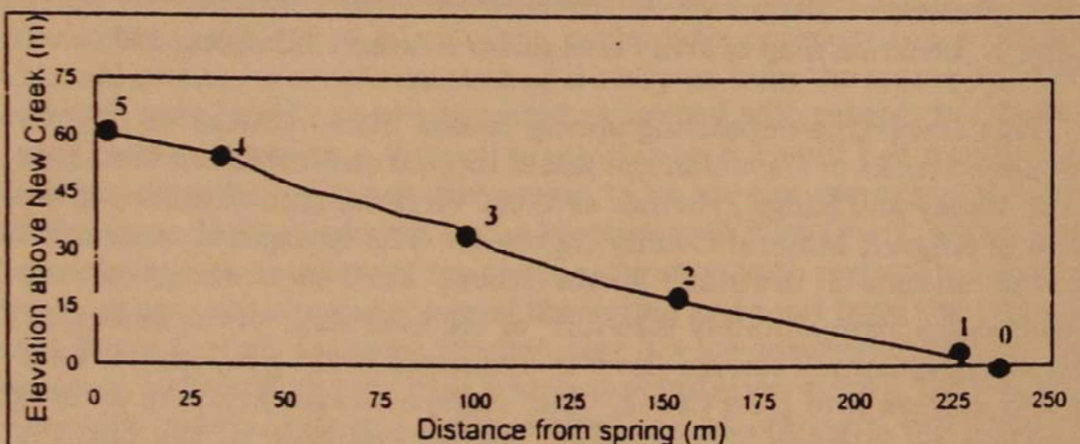

Figure 2. Stream profile of the unnamed tributary to New Creek. The spring is on the left at location 5, New Creek is at location 0. Note locations 3 and 4 in higher gradient portions. Based on map in Figure 3 of Kite and Allamong (1990); no vertical exaggeration.

others (1927) illustrate and briefly describe the travertine deposit at Bubbling Spring in Hampshire County along the Cacapon River, also from Silurian-Devonian limestones. Grimsley (1916) mentions marl deposits with travertine in Jefferson and Berkeley counties, but does not associate these with springs but rather with surface water leaching the underlying Cambrian-Ordovician limestones. Hutton, Miller, and Conrad (1968) associate a marl deposit in Jefferson County with many limestone springs draining into the area. Small marl-travertine deposits are also associated with springs in the Mississippian limestones in eastern West Virginia.

The New Creek Mountain spring differs in some aspects from others in the Appalachian Valley and Ridge province. Most of the other travertine-depositing springs issue from the Cambrian-Ordovician carbonate sequence which typically contains appreciable dolomite (Herman and Hubbard, 1990b). Consequently, the water from these springs has calcium-magnesium molar ratios reflective of dolomitic bedrock; for instance, Hoffer-French and Herman (1989) report ratios ranging from 1.17 to 1.85. Also, most of the streams flow in a relatively low-relief terrain; the "stream cascade" figured by Hoffer-French and Herman (1990, figure 11) with an average slope of 18% is less steep than the "flat" portions of the New Creek Mountain spring run with a slope of 20% (see figure 2). It is possible that these characteristics may create differences in the hydrochemistry of the waters or in the mineral precipitation. This is a continuing study for which the early results are being presented.

Materials and Methods

The spring and stream were sampled twice and analytical results reported by Kite and Allamong (1990), and subsequently sampled on three occasions in the present study (table 1). On the first trip, the spring itself (station 5), the spring run at its junction with New Creek (station 1), and New Creek (station 0) were sampled. Several sampling stations were later added to provide more detail. Station 4 is at the top of a mound of marl and travertine, just before the stream bed becomes steep; station 3 is at a small waterfall over a bedrock ledge, and station 2 is in the middle of the gentlest slope along the spring run. The spring itself was sampled at the same location on each trip even though the beginning of flow was not always at the same place. The location of first appearance of water on the surface changes with flow; this is probably due to the nature of the underground dam mentioned above. The station at the downstream end

Table 1. Results from all water samples taken. The 1988 samples are taken from Kite and Allamong (1990), the remainder were collected for the present study. Station 0 is New Creek; remaining stations proceed sequentially upstream along the spring run, with station 5 being the spring.

Station	Date	pH	T °C	SpC µS/cm	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO_3 mg/L	NO_3 mg/L	SO_4 mg/L	Cl mg/L	Flow L/min	SI_C	SI_D	$\log P_{CO_2}$ atm	Ca/Mg	%err
5	880100	7.5		588	108	12.2			344				68	0.40	-0.02	-2.06	5.4	
1	880100	8.1		547	94	11.7			300				60	0.89	0.49	-2.72	4.9	
5	880700	8.1		686	116	16.4			338				42	1.01	0.64	-2.67	4.3	
1	880700	8.2		547	103	11.3			259				6	0.96	0.53	-2.88	5.5	
5	910728	7.91	15.4	780	126	14.2	2.3	3.2	353	4.9	95	3.3	12.1	0.94	0.55	-2.43	5.4	1.9
1	910728	8.10	18.2	640	101	11.8	1.9	1.6	273	0.9	72	3.8	3.8	0.98	0.62	-2.71	5.2	0.3
0	910728	8.33	20.3	420	51	8.7	4.1	2.0	143	1.3	56	7.5		0.71	0.44	-3.20	3.6	3.3
5	911212	7.71	9.8	760	123	15.6	2.5	1.2	345	5.3	91	1.9	4.5	0.64	0.24	-2.28	4.8	0.2
4	911212	8.10	8.7	760	123	15.2		2.0	346	4.9	93	2.4	5.2	1.01	0.61	-2.67	4.9	0.6
3	911212	8.22	7.9	740	119	16.0	2.5	2.9	336	4.4	95	1.4	7.3	1.09	0.70	-2.81	4.5	0.3
2	911212	8.06	7.2	710	114	13.7		2.3	311	4.9	96	2.4	3.6	0.88	0.46	-2.68	5.1	0.9
1	911212	7.91	6.6	670	109	14.7	2.7	2.4	297	4.4	97	2.4	4.0	0.68	0.29	-2.55	4.5	0.7
0	911212	8.20	5.2	380	43	6.8	4.2	1.8	104	5.3	48	14.3	13500	0.15	-0.21	-3.29	3.9	3.5
5	920316	7.59	9.3	710	117	8.7			335	7.1	47	2.6	70	0.49	-0.02	-2.17	8.2	1.2
4	920316	7.94	8.0	695	116	8.7			332	7.5	48	2.6	150	0.81	0.30	-2.53	8.1	1.0
3	920316	8.32	6.7	690	115	8.7			328	7.1	46	2.9	120	1.17	0.65	-2.92	8.0	1.5
2	920316	8.39	5.1	660	110	9.1			316	6.2	47	2.9	120	1.18	0.67	-3.01	7.4	1.3
1	920316	8.29	4.6	620	108	9.1			308	6.2	50	2.9	80	1.05	0.55	-2.92	7.2	0.9
0	920316	7.70	6.1	200	20	3.0			46	5.3	23	8.4	96000	-0.98	-1.36	-3.13	4.0	1.6

Notes: The saturation index (SI) of a mineral is the log of the saturation ratio, which is the ratio of the actual amount of solution products of the mineral determined from analysis to the amount that would be present in a saturated solution. This value at saturation is 0.0; negative values indicate undersaturation; positive values indicate supersaturation. The subscript indicates the mineral; "C" is calcite, "D" is dolomite.

The theoretical partial pressure of carbon dioxide (P_{CO_2}) indicates the content of carbon dioxide of an atmosphere which would be in equilibrium with the water analyzed.

%err is the discrepancy between the sum of all cations and the sum of all anions, expressed as a percentage of the total of all ions.

of the spring run is at the base of a small waterfall just above New Creek. Figure 2 shows the locations of the sampling stations along the profile of the stream.

Temperature and pH were measured in the field using a Hach One pH meter with the standard electrode which has a built-in electronic thermometer; pH calibration was with both pH 7 and pH 4 buffers equilibrated to the sample water temperature. Specific conductance was also measured in the field with a Beckman Solu-Bridge (Type RB-5) conductivity meter, and corrected with a curve developed with conductivity standards. Measurements were taken in the stream at the same location as the sample. Flow measurements were performed by use of various techniques. Where possible measurement was made by timing the filling of a calibrated container. If that was not possible, stream cross-sections were measured and velocity determination made with a General Oceanics current velocity meter where flow was deep and fast enough or with surface floats when the meter could not be used. Because of inaccuracies inherent in such methods and because of significant underflow in the stream channel, discharge measurements may be in error by as much as one third.

Sampling progressed in the upstream direction to avoid disturbing the subsequent sampling locations. Two samples were collected at each site in plastic bottles; one sample was filtered in the field through a 0.45µ cellulose membrane filter and the other was left unfiltered.

A standard alkalinity titration, with 0.02N sulfuric acid and using the inflection point method for determining the end-point, was performed on part of the unfiltered sample, and was converted to the bicarbonate value assuming that all alkalinity was bicarbonate. Additional analyses were performed on the unfiltered sample: sulfate by the turbimetric method, chloride by the mercury titration-diphenylcarbazone indicator method, and nitrate by the cadmium reduction method. The alkalinity titration and nitrate analysis were performed within 12 hours of collection, and chloride and sulfate analysis within one week of collection.

The filtered sample was acidified with nitric acid immediately on returning to the laboratory and allowed to stand for 24 hours or more to redissolve any metals adsorbed onto the bottle surface. Analyses for the cations were then performed on that sample; calcium and magnesium determinations were by the EDTA titration method, sodium was done with an ion-specific electrode and potassium by the tetraborate turbimetric method. Strontium analyses were by inductively coupled plasma spectrometry (ICP).

Accuracy for alkalinity and calcium analysis is ±1%; accuracy for chloride, magnesium, nitrate and sulfate analysis is ±5% or better, depending on concentration. Accuracy of the sodium and potassium analysis is questionable; however, the results were consistent within the data set and concentrations of these constituents are not significant for the purposes of this study.

The saturation index (log of saturation ratio) of the water with respect to calcite (SI_C) and dolomite (SI_D) and the equilibrium partial pressure of carbon dioxide (P_{CO_2}) were calculated by a modified version of the computer program originally written by Roger Jacobson (Jacobson and Langmuir, 1972) and updated with those more-recent thermodynamic constants which were available; the constants used are those compiled by White (1988). This program also provides an error estimate for the chemical analysis by calculating the discrepancy in the cation-anion balance.

A sample of the travertine-marl was analyzed for calcium, magnesium, and strontium content by placing the sample in 1:1 nitric acid and allowing it to digest for 15 days, and then applying the same laboratory analysis used for the water samples.

Results

The waters in this system are calcium bicarbonate waters with a small sulfate and magnesium component. Ca/Mg molar ratios are typical of other Appalachian *limestone* karst waters. The spring ratios are in the range of 5 to 10, although New Creek itself is lower than that, possibly reflecting a larger input from a terrain underlain by dolomitic rocks. The pH values range from about 7.5 to 8.5 (figure 4), which is usual for unpolluted karst waters. Sodium, potassium, chloride, and nitrate components are always low, and are not significant in this discussion. Strontium analysis was done on the sample from station 3 for March 1992, with a result of 1.13 mg/L.

Two complete sets of samples were taken, one in December 1991 and one in March 1992. Antecedent weather conditions were quite different for the two times; December 1991 was at the end of a two-year drought

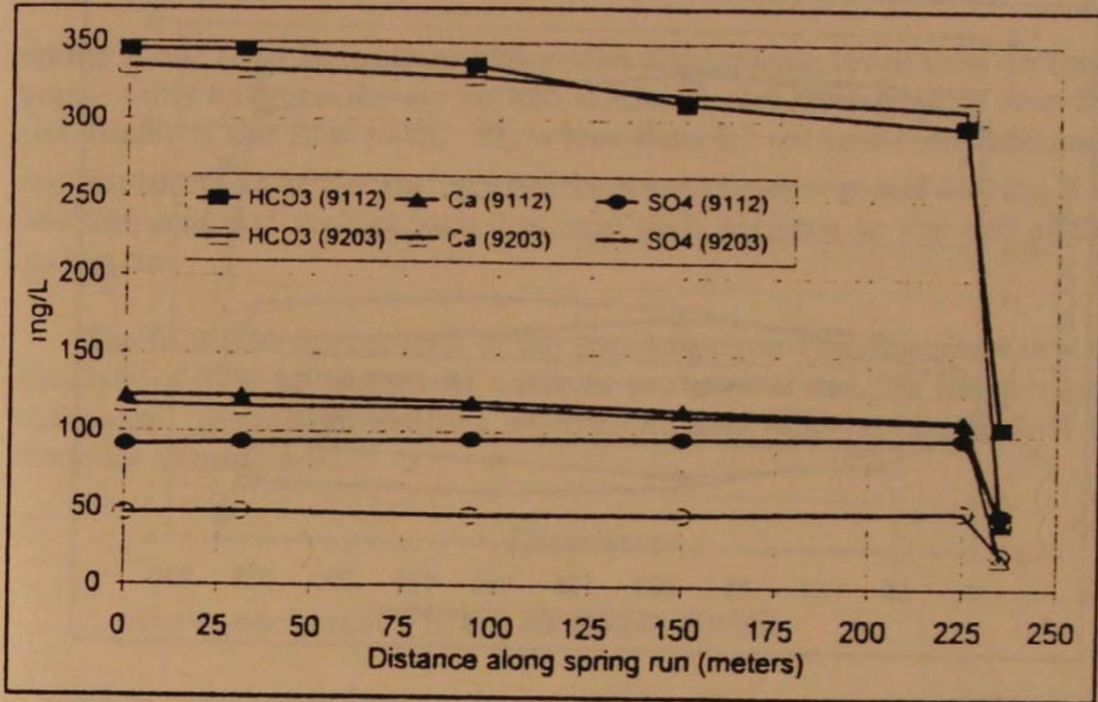

Figure 3. Concentration of the major ions in the water of the spring run and New Creek for the December 1991 and March 1992 samplings. The spring is on the left and New Creek on the right as in Figure 2. HCO_3 -- bicarbonate, Ca -- calcium, SO_4 -- sulfate.

whereas by March 1992 rains had resumed at slightly above normal amounts. Weather at the time of sample collection was approximately the same on both occasions. Spring discharge was more than ten times as high on the second date than on the first. A comparison between the two sets of samples (figure 3) shows that the important ions, calcium and bicarbonate, were nearly at the same concentration in the spring run samples, and changed in about the same way as the water progressed down the spring run. As the water flowed down the spring run, the calcium and bicarbonate content declined significantly. The loss begins at (or just below) station 4 and continues to the end. Sulfate concentration, also shown on figure 3, was quite different on the two occasions; it was nearly twice as high at the lower flow as at the higher flow. There was a small increase in concentration as the water progressed down the spring run, but the change did not exceed the probable analytical error, and so little significance can be attached to it at this time. Changes in the magnesium concentration are small and inconsistent, and may be due to analytical error.

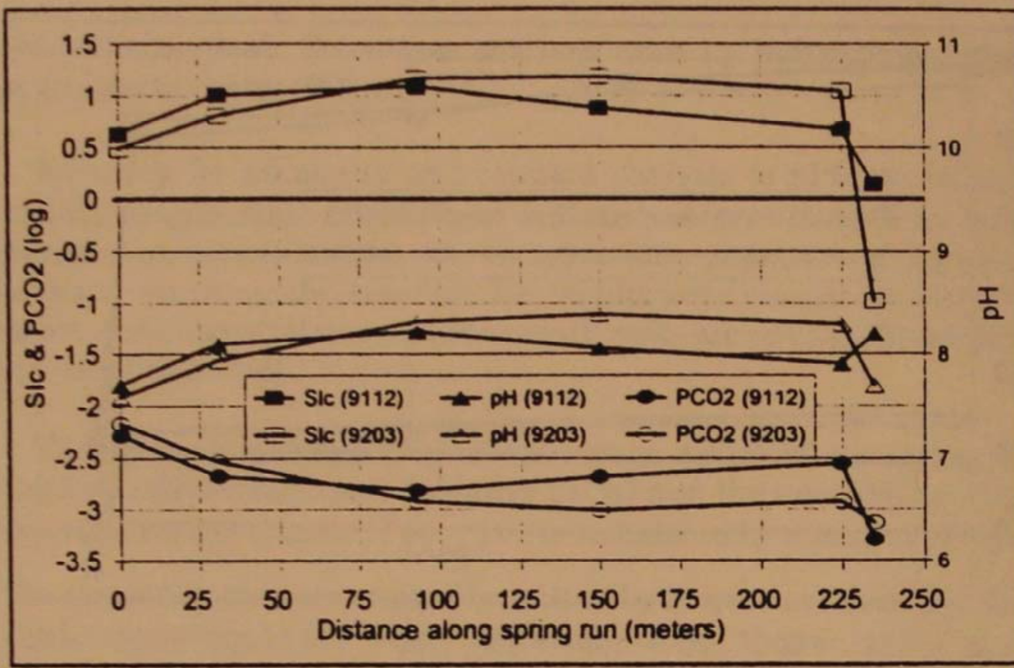

Figure 4. Saturation index with respect to calcite (SI_c), pH, and log of calculated equilibrium partial pressure of carbon dioxide (P_{CO_2}) in the water of the spring run and New Creek for the December 1991 and March 1992 samplings. The spring is on the left and New Creek on the right as in Figure 2.

The waters of the spring run were always supersaturated with respect to calcite and, with one exception, with dolomite. The saturation indices shown in table 1, are logs of the ratio of actual concentrations of the products of solution of a given mineral to the concentrations at saturation, so a positive value indicates supersaturation and a negative value indicates undersaturation. New Creek itself is undersaturated at high flow, and only slightly supersaturated with respect to calcite at the lower flow conditions of December 1991. At very low-flow conditions, in July 1991, New Creek was supersaturated with respect to both carbonate minerals. Also calculated is the theoretical partial pressure of carbon dioxide (P_{CO_2}) which would be in equilibrium with the water samples. P_{CO_2} for all the spring run samples is well in excess of the atmospheric value of $10^{-3.50}$ atm. P_{CO_2} for New Creek is lower, although still indicating a CO_2 concentration about twice atmospheric. The derived quantities, SI_c and log P_{CO_2} are illustrated in figure 4. The change in these parameters is fairly complex, but in general, P_{CO_2} begins at the spring about 15 to 20 times as high as the atmospheric level, then declines appreciably between the spring and station 3, and rises slightly over the remainder of the flow path. SI_c is less than 1.0 (or less than ten times supersaturation) at the spring, rises between the spring and station 3 at low flow and station 2 at high flow, and then declines to the end of the spring run.

The results of the analysis of the travertine-marl sample show that it consists of 70% by weight of calcium carbonate and 2% magnesium carbonate. Strontium content was 915 mg/kg. The remaining 28% is insoluble in nitric acid.

Discussion

Aqueous geochemistry of the carbonate system

Rain and snow falling on the top of New Creek Mountain infiltrates into the area underlain by the Tonoloway and lower part of the Helderberg limestones. As it passes through the soil it dissolves carbon dioxide from the soil atmosphere, which in this region may range between $10^{-3.50}$ and $10^{-2.00}$ atm (Rightmire, 1978). Calculated values of P_{CO_2} for the spring samples are considered to indicate a minimum carbon dioxide concentration for the soil air through which the infiltrating water passes; all these values fall into the regional range reported by Rightmire (1978). This carbon dioxide-charged water then circulates through the bedrock and reacts with the carbonate minerals, resulting in the dissolved components observed in the spring water. Given sufficient time, the water will reach saturation with respect to the minerals present in the rocks.

Once the water emerges from the bedrock environment to the surface, carbon dioxide concentrations in the overlying atmosphere will be much lower, and the water will equilibrate to those conditions by outgassing carbon dioxide. This involves the dissolved calcium and bicarbonate ions as well, resulting in precipitation of calcium carbonate through the following reaction:

$$Ca^{2+} + 2HCO_3^- \dashrightarrow CO_2\,(gas) + CaCO_3\,(solid) + H_2O$$

The reaction is written to indicate the action that is occurring in the spring run; the inverse form applies during infiltration and passage of the water through the bedrock. This reaction does not go to completion instantaneously. Figures 3 and 4 give an indication of the progression of the chemical reaction. The CO_2 outgassing almost immediately causes an increase in pH, which in turn results in an increase in the saturation of the water with respect to calcium carbonate. The response of log P_{CO_2}, pH, and SI_c in the spring run are apparent in the curves of figure 4.

Significant precipitation of calcite is not immediate, even though supersaturation exists. Other workers have found that a fairly high degree of supersaturation is required for calcite precipitation to begin; a commonly suggested value is eight times saturation ($SI_c = 0.90$) or greater. Jacobson and Usdowski (1975) find precipitation beginning at less than five times saturation ($SI_c = 0.70$), but note that it is not rapid until values of ten times saturation ($SI_c = 1.0$) are reached. Lorah and Herman (1990) find that little calcite precipitation occurs with less than five to nine times saturation ($0.70 < SI_c < 0.95$). Hoffer-French and Herman (1990) find that calcite precipitation is kinetically inhibited at less than five times saturation ($SI_c = 0.70$). Heller (1988) reports precipitation of travertine at five to seven times saturation ($0.67 < SI_c < 0.83$) with respect to calcite. In the spring run on New Creek Mountain, a value of at least ten times saturation ($SI_c = 1.00$) seems to be needed for significant calcite precipitation. Calcium and bicarbonate ion concentrations (see figure 3) do not decline until after the saturation index exceeds 1.00, at station 4 for December 1991, and station 3 for March 1992 (see figure 4). The saturation index then declines as calcite precipitation progresses.

Age of the travertine-marl deposit

It is possible to estimate a minimum age for a deposit formed by precipitation of mineral matter such as the travertine-marl deposit. One need only know the rate of deposition and the size of the deposit. There are some problems inherent in such a simplistic procedure, however; neither quantity is easy to determine. Determining the precipitation rate over time presents several difficulties. The discharge of the spring is not constant over the short term now, and has probably also had long-term variations. Of the data available (table 1), the March 1992 water analyses are the most likely to be representative of average present conditions. Using these data, the stream deposits approximately 1150 kg/yr (1124 kg/yr on the basis of bicarbonate loss and 1183 kg/yr on the basis of calcium loss) between the spring and New Creek.

In the literature examined for this study, the calcite-precipitating spring in Westerhof, Germany, studied by Jacobson and Usdowski (1975), is the only spring similar enough to the New Creek Mountain spring for comparison. That spring has a spring run slightly longer than the New Creek Mountain spring, an average discharge 3 to 5 times as high, and an average gradient about half as steep. Precipitation rates in the Westerhof spring run are about about 47 kg/yr/m while the New Creek Mountain stream deposits about 5 kg/yr/m. Two possibilities may explain the difference: 1- the gentler average gradient of the Westerhof stream, which causes slower flow velocities and more time for precipitation to occur as shown by nearly twice the loss of calcium and bicarbonate in the Westerhof stream, 2- the lower gradient of the Westerhof stream allows it to develop a wider stream channel and therefore a larger wetted perimeter, allowing the mineral precipitation to occur over a larger area (this is speculation; there are no channel widths given for the Westerhof stream in the paper). The amount of mineral precipitation of the New Creek Mountain spring then compares reasonably with that of the Westerhof spring.

The size of the deposit may be estimated from Kite and Allamong's (1990) data. They give an area for the deposit of 0.02 km^2 and an average thickness, determined by augering, of 1.0 m, for a volume of about 20,000 m^3. Assuming a density of 2 for the deposit and 58% (as determined by Kite and Allamong, 1990) as the $CaCO_3$ content, yields 2.3 X 10^{12} kg of $CaCO_3$ in the deposit. Using the $CaCO_3$ content determined from the sample discussed above, of 70%, yields a figure of 2.8 X 10^{12} kg of $CaCO_3$. This provides the likely range of the quantity of $CaCO_3$ currently in the deposit. As noted by Kite and Allamong (1990), there has been a great deal of recent, and probably older, erosion of the deposit, so the present amount is a minimum that has been deposited by the spring waters.

Using these estimated of deposit size and rate of deposition gives an approximate minimum age of 2.0 to 2.5 million years for the deposit. It must be remembered that denudational processes are also active at the site, so this estimate is actually is one of the residence time of the deposit, not of the initial activation of the spring. Reported residence times for surficial materials in the Appalachians are of the same order of magnitude, although typical estimates are generally lower; an upland Piedmont saprolite has been dated at about 1 million years by various methods (Mills and others, 1987, p. 20-21). Additional data are needed for better estimates of rates of the processes involved in deposition and denudation; perhaps further studies on the carbonate-depositing springs on New Creek Mountain and other, similar sites will resolve some of the questions regarding these rates.

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Literature Cited

1. Allamong, D. M. 1991. An investigation of colluvial and alluvial deposits in the New Creek valley of Mineral and Grant counties, West Virginia. Unpublished masters thesis, Department of Geology and Geography, West Virginia University, 144 pp.

2. Gillespie, W. H. and J. A. Clendening. 1964. An interesting marl deposit in Hardy County, West Virginia. West Virginia Academy of Science Proceedings 36:147-151.

3. Grimsley, G. P. 1916. Jefferson, Berkeley, and Morgan counties. West Virginia Geological Survey County Report, 644 pp.

4. Heller, S. A. 1988. Seasonal geochemistry of two tufa-depositing springs in southwestern Wisconsin. Geoscience Wisconsin 12:77-83.

5. Herman, J. S. and D. A. Hubbard, Jr., editors. 1990a. Travertine-marl: stream deposits in Virginia. Virginia Division of Mineral Resources Publication 101, 184 pp.

6. Herman, J. S. and D. A. Hubbard, Jr. 1990b. A comparative study of travertine-marl-depositing streams in Virginia. In Herman and Hubbard (1990a), pp. 43-64.

7. Hoffer-French, K. J. and J. S. Herman. 1989. Evaluation of hydrological and biological influences on CO_2 fluxes from a karst stream. Journal of Hydrology 108:189-212.

8. Hoffer-French, K. J. and J. S. Herman. 1990. A CO_2 outgassing model for Falling Spring Run, Augusta County, Virginia. In Herman and Hubbard (1990a), pp. 5-15.

9. Hutton, E. E. Jr., C. Miller and C. Conrad. 1968. A marl marsh natural area in eastern West Virginia. Castanea 33:241-245.

10. Jacobson, R. L. and D. Langmuir. 1972. An accurate method for calculating saturation levels of ground waters with respect to calcite and dolomite. Transactions of the Cave Research Group of Great Britain 14:104-108.

11. Jacobson, R. L. and E. Usdowski. 1975. Geochemical controls on a calcite precipitating spring. Contribution to Mineralogy and Petrology 51:65-74.

12. Kite, J. S. and D. M. Allamong. 1990. The morphology and stratigraphy of calcareous sediments in a small alluvial-colluvial fan, New Creek Mountain, Mineral County, West Virginia. In Herman and Hubbard (1990a), pp. 139-149.

13. Lorah, M. M. and J. S. Herman. 1990. Geochemical evolution and calcite precipitation rates in Falling Spring Creek, Virginia. In Herman and Hubbard (1990a), pp. 17-32.

14. Mills, H. H., G. R. Brakenridge, R. B. Jacobson, W. L. Newell, M. J. Pavich, and J. S. Pomeroy. 1987. Appalachian mountains and plateaus. In William F. Graf, editor. Geomorphic systems of North America. Boulder, Colorado: Geological Society of America, Centennial Special Volume 2, pp. 5-50.

15. Reger, D. B. 1924. Mineral and Grant counties. West Virginia Geological Survey County Report, 866 pp.

16. Rightmire, C. T. 1978. Seasonal variation in P_{CO_2} and ^{13}C content of soil atmosphere. Water Resources Research 14:691-692.

17. Tilton, J. L., W. F. Prouty, R. C. Tucker, and P. H. Price. 1927. Hampshire and Hardy counties. West Virginia Geological Survey County Report, 624 pp.

18. White, W. B. 1988. Geomorphology and hydrology of karst terrains. New York: Oxford University Press, 464 pp.

Ecology Section

A Survey of Hibernating Bats in Hellhole Cave, Pendleton County, WV

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Abstract

A survey of hibernating bats was conducted on 16 February 1991 at Hellhole Cave, Pendleton County, West Virginia. A total of 61,791 hibernating bats of 8 species were tallied. Species observed were: *Myotis lucifugus* (49,707), *M. grisescens* (2), *M. septentrionalis* (2), *M. sodalis* (5,470), *M. leibii* (2), *Pipistrellus subflavus* (417), *Eptesicus fuscus* (3), and *Plecotus townsendii virginianus* (6,188). These bats represent the largest known concentration of *P. t. virginianus*, the largest known concentrations of *M. lucifugus* and *M. sodalis* in West Virginia, and the first recent record of *M. grisescens* in the state. Also observed was one dead *Lasiurus borealis*. Three of these species, *M. sodalis*, *M. grisescens*, and *P. t. virginianus*, are federally endangered species; one species, *M. leibii*, is a candidate for federal listing (Category 2).

Introduction

Bats in West Virginia, being insectivorous, survive the harsh winter months when food (insects) and water are unavailable by migrating to areas of milder climate or by hibernating to reduce energy expenditures. In hibernation bats use body fat accumulated during late summer and autumn. In spring when insects are more abundant, hibernation is terminated, and the bats leave the cave. Caves are an important resource important for the survival of several species of bats in West Virginia (Reese 1934; Dotson 1977).

Species of bats vary in the microclimate conditions required for hibernation, and niches can best be defined in terms of temperature, relative humidity, and light (Twente 1955; Henshaw 1972). While some species, such as *Pipistrellus subflavus* (eastern pipistrelle), utilize a wide range of microclimate conditions (Brack and Twente 1985; WVDNR, unpub. data), other species, such as *Myotis sodalis* (Indiana bat) require more specific environmental parameters (Hall, 1962; Humphrey 1978). Gregarious species often concentrate in large numbers where conditions are favorable (Mohr 1972; Brady et al. 1983). Ideal hibernacula offer cold, stable temperatures and high relative humidity where bats can hibernate without disturbance. Hibernation is most efficient at lower temperatures, but temperatures at the hibernation site cannot fall below freezing or the bats will die.

Hellhole Cave, developed in Ordovician-age Lenoir Limestone, is located in Germany Valley, Pendleton County, West Virginia. Three karst windows at the bottom of a sinkhole open into the ceiling of a large room; the floor is over 50 meters below. Davies (1958) describes the cave and presents a map of approximately 660 meters of passage mapped in 1947; additional cave passage was discovered later and mapped (Medville et al. 1983). Accumulation of large quantities of water in the cave in November 1985 resulted in the opening of a new section of cave passage which had previously been blocked by mud and gravel (Bob Anderson, pers. comm.). Mapping of this new section has not been completed, but the passage has been explored to a depth of several hundred meters (Bob Anderson, pers. comm.).

The first comprehensive surveys for hibernating bats in Hellhole Cave were conducted from 1962 to 1964 (Hall 1972). At that time the cave contained the largest known concentrations of *M. sodalis* (N=500) and *M. lucifugus* (little brown bat) (N=20,000) in West Virginia. During subsequent surveys, Hall (1975) reported that the number of *M. sodalis* in the cave had increased to 1500, and he discovered approximately 500 *Plecotus townsendii virginianus* (Virginia big-eared bat) hibernating in the cave. Surveys conducted 22 February 1986 and 18 February 1988 (WVDNR, unpub. data) documented a continued increase in the numbers of both *M. sodalis* and *P. t. virginianus*; the population of *M. lucifugus* remained at approximately 20,000 individuals.

Hellhole Cave was declared critical habitat for *M. sodalis* by the U.S. Fish and Wildlife Service in 1967, and as critical habitat for *P. t. virginianus* in 1979. In July 1981 the entrances to Hellhole Cave were fenced by the U.S. Fish and Wildlife Service; the cave is closed 1 September to 15 May to protect hibernating bats.

Methods

The present survey was conducted on 16 February 1991. Nine survey crew members were divided into three survey teams; each team examined a different portion of the cave. This was the most complete bat survey conducted in the cave to date, and the only survey to include the new area opened in 1985. All bats were identified to species and tallied. Cluster size of all endangered bats species were noted; for *M. lucifugus*, cluster size was recorded only in the Bat Room where the major concentration of this species was found. Temperatures were taken using a Micronta 63-842 digital thermometer.

Results

A total of 61,791 hibernating bats of 8 species was observed including: 417 *P. subflavus*, 3 *Eptesicus fuscus* (big brown bat), 49,707 *M. lucifugus*, 2 *M. grisescens* (gray bat), 5,470 *M. sodalis*, 2 *M. septentrionalis* (northern long-eared bat), 2 *M. leibii* (small-footed myotis), and 6,188 *P. t. virginianus*. In addition, a dead specimen of *Lasiurus borealis* (red bat) was found on the cave floor. Three of the species observed are listed as federally endangered by the U.S. Fish and Wildlife Service: *M. grisescens* (Brady et al. 1982), *M. sodalis* (Brady et al. 1983), and *P. t. virginianus* (Bagley 1984). *M. leibii* is a candidate for federal listing (Category 2) (U.S. Fish and Wildlife Service 1991).

The 5,470 *M. sodalis* were grouped into 141 clusters; mean cluster size was 38.8 bats (Table 1). Mean cluster size for the 6,188 *P. t. virginianus* was 38.7 bats. A total of 16,832 *M. lucifugus* was observed in the Bat Room; these were distributed in 2,777 clusters with a mean cluster size of 6.1 individuals.

Air temperatures at the sites where *P. t. virginianus* hibernated ranged from 1.6° C to 3.7° C; rock temperatures at these sites ranged from 0.6° C to 3.8° C. The highest temperatures were recorded at the site of the largest *Plecotus* concentration (N=4,410). Air temperatures at sites where *M. sodalis* hibernated ranged from 4.4° C to 6.9° C; temperature of the rock in these areas ranged from 4.5° C to 6.7° C. Air and rock temperatures at the location of one hibernating *M. leibii* were 2.6° C and 2.8° C, respectively.

Table 1. Number of clusters, mean cluster size, standard deviation, and range of cluster size for hibernating *M. lucifugus*, *M. sodalis*, and *P. t. virginianus* in Hellhole Cave, Pendleton County, West Virginia, 16 February 1991. Data for *M. lucifugus* are for the Bat Room only.

SPECIES	NUMBER OF CLUSTERS	MEAN CLUSTER SIZE	STANDARD DEVIATION	RANGE OF CLUSTER SIZE
M. lucifugus	2,777	6.1	6.20	1 to 380
M. sodalis	141	38.8	7.41	1 to 768
P. t. virginianus	160	38.7	5.40	1 to 750

The finding of two female *M. grisescens* in Hellhole Cave during the present survey represents the first known occurrence of this species in West Virginia. These two bats were found together in a small room containing 1,762 *M. lucifugus* and 15 *P. subflavus*. Since *M. grisescens* is a federally endangered species, no voucher specimens were collected. A camera was not available to photograph the animals. Handley (1956) reported one mandible from the Organ Cave system of West Virginia that could have been from *M. grisescens*, but the bone could not be positively identified.

Discussion

Hellhole Cave is the most important known bat hibernaculum in West Virginia. The cave contains significant populations of endangered bats: the only known occurrence of the *M. grisescens* in the state, the largest known concentration of *M. sodalis* in West Virginia (the next largest concentration numbers 210 bats (WVDNR, unpub. data)), and the largest known concentration of *P. t. virginianus* anywhere. The *P. t. virginianus* population in Hellhole Cave may be the largest concentration of any *Plecotus* species. Of the 84 caves known to harbor hibernating *M. lucifugus* in West Virginia, Hellhole Cave contains the majority of hibernating individuals; over 78% of the known population occurs in this one site.

More of the cave was surveyed in 1991 than in earlier surveys making it difficult to compare survey results, but the number of bats in the same areas of the cave have increased over previous survey numbers. *M. sodalis* and *P. t. virginianus* were found only in areas of the cave where they had been found previously, and the numbers of both species increased (*M. sodalis*, +6.0%; *P. t. virginianus*, +33.7%). The number of *M. lucifugus* in the Bat Room increased 58.8% from 10,597 in 1989 to the present 16,832. Part of the increase may be attributed to the winter closure of the cave and, for *Plecotus*, the protection of summer maternity caves in the vicinity of Hellhole Cave

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Literature Cited

1. Bagley, F.M. 1984. A recovery plan for the Ozark big-eared bat and the Virginia big-eared Bat. U.S. Fish and Wildlife Service. 56 pp.

2. Brack, V., Jr. and J.W. Twente. 1985. The duration of the period of hibernation in three species of vespertilionid bats I: Field studies. Can. J. Zool. 63:2952-2954.

3. Brady, J.T., T. Kunz, M.D. Tuttle, and D. Wilson. 1982. Gray bat recovery plan. U.S. Fish and Wildlife Service. 86 pp.

4. Brady, J.T., R.K. LaVal, T.H. Kunz, M.D. Tuttle, D.E. Wilson, and R.L. Clawson. 1983. Recovery plan for the Indiana bat (Revision). U.S. Fish and Wildlife Service. 83 pp.

5. Davies, W.E. 1958. Caverns of West Virginia. W.V. Geological and Economic Survey. Vol. XIX A. 330 pp.

6. Dotson, T.L. 1977. The status of bats in West Virginia. M.S. Thesis, Marshall Univ., Huntington, WV. 63 pp.

7. Hall, J.S. 1962. A life history and taxonomic study of the Indiana bat, *Myotis sodalis*. Reading (Pa.) Public Mus. and Art Gallery, Sci. Pub. No. 12. 68 pp.

8. Hall, J.S. 1972. The status of *Myotis sodalis*, the Indiana bat, in West Virginia. Unpub. report to WV Dept. Nat. Resour. 9 pp.

9. Hall, J.S. 1975. The status of the Indiana bat, *Myotis sodalis*, in the Monongahela National Forest. Unpub. report to U.S. Forest Service, Monongahela National Forest. 9 pp.

10. Handley, C.O. 1956. Bones of mammals from West Virginia caves. Am. Midl. Nat. 56:250-256.

11. Henshaw, R.E. 1972. Niche specificity and adaptability in cave bats. Natl. Speleological Soc., Bull. 34:61-70.

12. Humphrey, S.R. 1978. Status, winter habitat, and management of the endangered Indiana bat, *Myotis sodalis*. Florida Scientist 41:65-76.

13. Medville, D.M., G.R. Dasher, and E. Werner (Eds.). 1983. An Introduction to the caves of east-central West Virginia. Natl. Speleological Soc. Convention Guidebook No. 23. 146 pp.

14. Mohr, C.E. 1972. The status of threatened species of cave-dwelling bats. Natl. Speleological Soc., Bull. 34:33-47.

15. Reese, A.M. 1934. The fauna of West Virginia caves. WV Acad. Sci., Proc. 7:39-53.

16. Twente, J.W. 1955. Some aspects of habitat selection and other behavior of cavern-dwelling bats. Ecology 36:706-732.

17. U.S. Fish and Wildlife Service. 1991. Endangered and threatened wildlife and plants; animal candidate review for listing as endangered or threatened species, proposed rule. Federal Register 56:58804-58836.

Periphyton Community Structure of Wetlands Associated with the Ohio River

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Abstract

The community structure of periphyton assemblages of representative wetland types associated with the Ohio River was examined along with selected aspects of the physiochemical environment. Eight genera and thirteen species of diatoms were found to comprise the dominant periphyton representative of the wetlands. For most wetlands studied, periphyton species diversity was observed to decrease with successional progress of the plant community. A close association of dominant periphyton species with a narrow range of wetland depths and/or duration of flooding along with coefficients of similarity indicate that depth and/or duration of flooding were the most important factors influencing community structure. Low cell densities occurred in ephemeral wetlands that provided sporadic, good growing conditions. High densities occurred in enduring wetlands where growth of periphyton was maintained over relatively long periods of time. The wide range of periphyton densities in bodies of water of different depths and duration of inundation suggest that development time is an important factor affecting community structure in wetlands.

Introduction

A number of hypothesies have been presented to explain the mechanisms that generate differences in algal community structure. Some of these are based on the possibility of overlapping of succeeding algal populations (Moss, 1973), a patchy distribution of species (Richerson et al., 1970) or the continuous variations in environmental conditions (Grenny et al., 1973). Margalef (1968), using the information theory in the evaluation of species diversity in algal assemblages, postulated that species diversity will be low in eutrophic water and high in oligotrophic waters.

Low algal species diversity in eutrophic waters may result from an interaction with other organisms. This was reported by Brammer (1979) who demonstrated that competition for light between rooted submerged macrophytes and planktonic algae is frequently displayed when the aquatic environment for some reason is enriched with nutrients that benefit the growth of algae. Once established, submerged macrophytes inhibit algal growth by shading (Wetzel, 1975) which affects emergent vascular plants as well (Howard-Williams & Lentro, 1975). Allelopathic interference of macrophytes with the development of algal communities has also been reported (Weaks, 1988). Trace element limitation studies indicated the presence of a heat labile toxic substance(s) in certain habitats where specific macrophytes occur.

In the present study, periphyton community structure was examined and compared in five wetland classes associated with the Ohio River. Objectives of the study were: (1) to assess the potential for a relationship between periphyton community structure and wetland succession and (2) to identify the major causes of differences in periphyton assemblages among wetland types.

Methods

Wetland sites from Wayne, Cabell, Mason, and Jackson counties of West Virginia were chosen from aerial photographs and on-site visits. Sites selected were those representative of the most common wetland types of the Ohio River floodplain and do not include all the wetland diversity present in the area. U.S. Army Corps of Engineers navigation maps were used to establish wetland locations with respect to the Ohio River.

Periphyton community structure was studied using five wetland classes that included beginning and intermediate stages of succession. These classes were identified using the model of West and Evans (1982) showing sucessional trends in the lower Kanawha River floodplain. Several open water wetlands were selected for investigation because of the diversity of this wetland class in the region. Wooded wetlands, end points of succession, were not studied because no site was present in the study area.

Surface periphyton samples were taken with Catherwood diatometers using the methods described by Choi et al. (1992). The ephemeral nature of the shallow exposed wetlands restricted the sampling periods to May and June. Species diversity indices were established using the U.S. Environmental Protection Agency (1973) formula:

$$d = \frac{C}{N}\left(N \log_{10} N - \sum n_i \log_{10} n_i\right)$$

where C = 3.321928; N = total number of individuals; and n_i = total number of individuals in the ith species. Equitability was calculated as:

$$e = \frac{s'}{s}$$

where s = number of taxa in the sample and s' = the tabulated value.

In order to construct a stand classification based on periphytic diatom species alone, cluster analysis was applied to the data from the nine study sites using the method of Sokal and Sneath (1963). The value used to express the similarity between each pair of sampling stations was that of Sorensen (1948).

The coefficient of similarity was calculated as:

$$\frac{2w}{m+n}$$

where m= number of species in one sampling station; n= number of species in another sampling station; and w= number of species the two stations have in common.

Chlorophyll a was extracted and pigment concentrations were calculated according to the method of Parsons and Strickland (1963). Microclimate variables were evaluated on weekdays at each station except on days of heavy cloud or rain. Specific conductance, a measure of the concentration of dissolved ions, was determined using the LaMotte Multirange Conductivity Meter (Lind, 1974). The pH of water samples from each station was established using a Fisher Accument, Model 425, digital pH/ion meter. Turbidity was determined using the DRT-15, Series "A" portable battery operated turbidimeter by H. F. Instruments. Light intensity was established with a General Electric, Type 214, light meter. Light readings were taken 1 m above the water surface.

Results and Discussion

Physico-chemical data reflect the diversity of environmental conditions among the wetlands studied (Table 1). Turbidity ranged from

Table 1. Mean physical and chemical conditions of wetland classes.

Wetland class	Turbidity	pH (NTU)	Conductivity (umho/cm)	Light (lumens)
Open water (oxbow)	0.2	7.39	52.78	2690
Open water (drain)	1.6	7.33	72.80	5918
Seasonally flooded flat	2.6	7.19	345.80	1184
Vegatated open water (river slough)	12.0	7.00	136.50	1829
Shrub swamp	26.0	7.11	96.50	1076
Vegetated open water (sand and gravel pit)	12.0	7.00	96.50	6456
Shallow marsh	-	-	-	6476
Open water (artificial impoundment)	11.0	7.30	71.71	2582
Open Water (beaver pond)	4.0	7.34	98.30	3228

0.2 NTU in open water oxbows to 26.0 NTU for shrub swamps. Other open water wetlands (river sloughs, sand and gravel pits, and artificial impoundments) had much higher turbidity than most wetland classes. The pH was similar for all wetland classes and ranged from neutral (7.0) to slightly alkaline (7.4). Conductivity (umho/cm) was highest for seasonally flooded flats and river sloughs and lowest for open water (oxbow) wetlands. Light intensity (lum.) was generally higher for open water wetlands than for those vegetated with shrubs or trees (shrub swamps and seasonally flooded flats).

Table 2. Comparison of wetlands using selected biological varuables.

Wetland class	Cell Density (cells $cm^{-2}wk^{-1}$)	Chlorophyll a (mg $m^{-2}wk^{-1}$)	Mean diversity ($\bar{d}$)	Equitability
Open water (oxbow)	14,793	237.89	4.0	0.91
Open water (drain)	15,069	192.66	2.9	0.81
Seasonally flooded flat	418	14.15	2.8	0.79
Vegetated open water (river slough)	5,846	110.41	1.2	0.19*
Shrub swamp	1,277	196.22	2.5	0.80
Vegetated open water (sand and gravel pit)	13,672	119.08	0.2*	0.17*
Shallow marsh	24	12.72	0	0.33
Open water (artificial impoundment)	704	65.97	3.2	1.18
Open water (beaver pond)	20,818	227.08	2.9	0.05*

*Value indicates polluted water

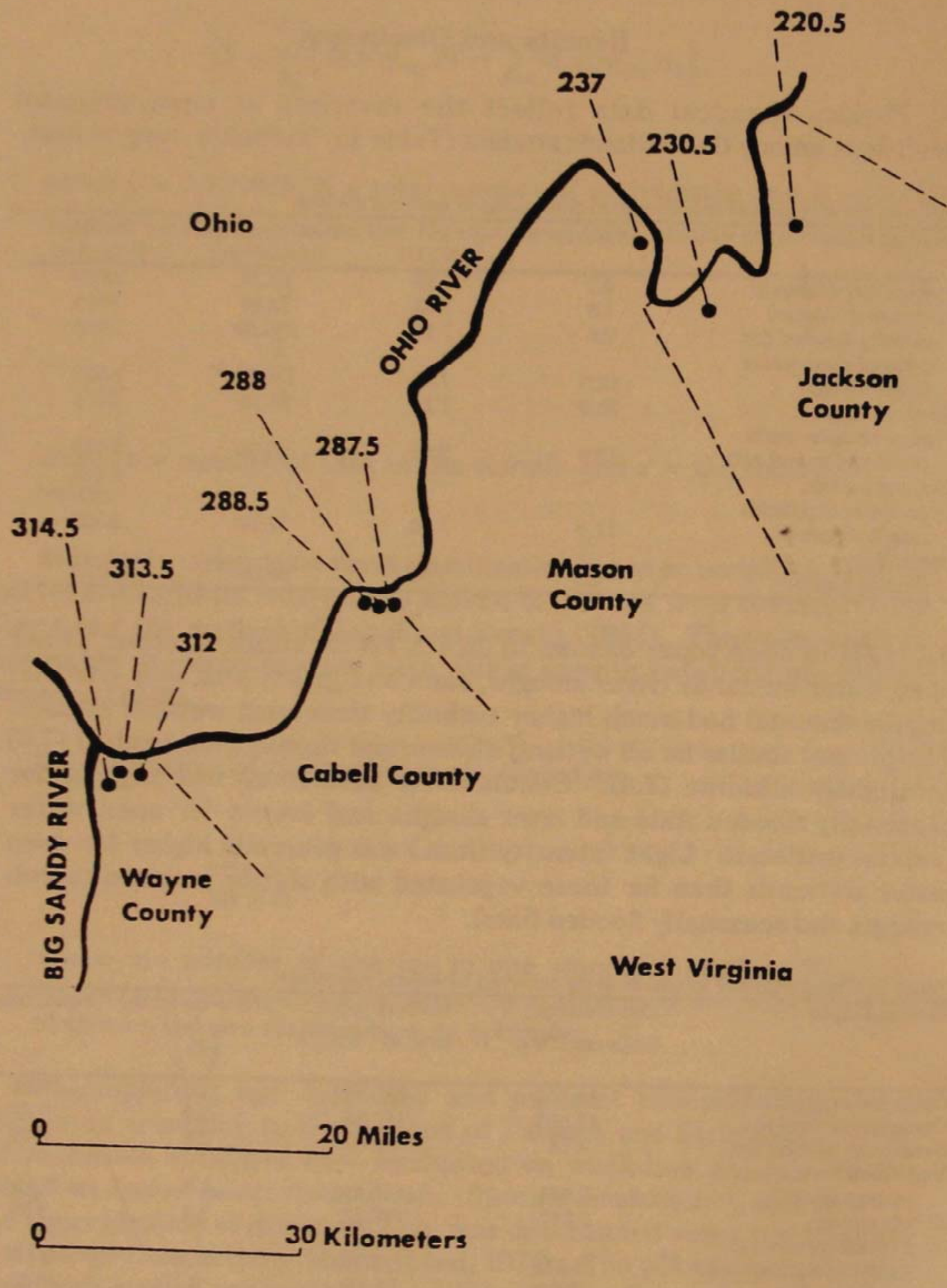

Figure 1. Map of sudy area.

Cell density (cells $cm^{-2}wk^{-1}$) was highest for open water wetlands (Table 2). For most wetland classes, chlorophyll a (mg m^{-2} wk^{-1}) appeared to be strongly related to cell density. Lowest chlorophyll a concentrations were for shallow marshes and seasonally flooded flats. Shrub swamps were exceptions, with one of the highest mean chlorophyll a levels, but a cell density of only 6 percent of that of open water beaver ponds.

Mean diversity $(\bar{d})$ ranged from 0 to 4.0 and was generally higher for the deep open water sites than for shallow wetlands (Table 2). For only two wetland types (shallow marshes; and vegetated open water, sand and gravel pits), was $\bar{d}$ less than 1. The equitability (e) value (0.17) for the latter wetland type fell within the range of polluted water (0- 0.3) (U.S. Environmental Protection Agency, 1973) as did sloughs and beaver ponds.

Eight genera and thirteen species of diatoms were found to comprise the dominant periphyton representatives of the wetlands investigated (Table 4). Of the dominant species, five were of the genus *Navicula*. Two species, *Navicula menisculus* v. *upsaliensis* (Grun.) Grun. and *Pinnularia subcapitata* Greg. v. *subcapitata* were dominants only of seasonally flooded flats; shallow wetlands characterized by low duration of flooding. *Navicula cryptocephala* Kutzing was dominant in marshes. One species, *Cyclotella ocellata* Pantocsek was a dominant only in the deepest wetlands studied.

Table 3. Coefficients of similarity between all possible pairings of representative wetlands for relative abundance of periphyton species. OX - oxbow, OWD - open water drain, SFF - seasonally flooded flat, RS - river slough, SS - shrub swamp, S&GP - sand and gravel pit, SM - shallow marsh, AI - artificial impoundment, OW - open water.

Wetland type	OX	OWD	SFF	RS	SS	S&GP	SM	AI
OX								
OWD	0.135							
SFF	0.194	0.200						
RS	0.175	0.174	0.214					
SS	0.025	0.217	0.136	0.115				
S&GP	0.097	0.300	0.211	0.130	0.235			
SM	0.074	0.063	0.067	0.053	0	0.100		
AI	0.114	0.125	0.174	0.259	0.143	0.167	0	
OW	0.156	0.147	0.242	0.162	0.129	0.107	0.042	0.121

Evidence of an influence of water depth and/or duration of flooding on periphyton community similarity was also found. A comparison of representative sampling stations (Fig. l) indicated that the vegetated open water wetland (sand and gravel pit) and an open water drain with a coefficient of similarity value of 0.300 had the highest degree of similarity

(Table 3). The second highest value (0.259) was for a river slough and artificial impoundment. In both instances the wetlands were flooded for long periods by water of considerable depth. The lowest values were for a shallow marsh and shrub swamp; and a shallow marsh and open water impoundment. Thus, these stations had the lowest degree of similarity or relatedness in respect to species composition. In both cases, the wetland pairs were flooded for disproportionate periods of time and depth of flooding was also quite dissimilar.

The model of West and Evans (1982) showing successional trends of vascular plants in the lower Kanawha River floodplain was used as the basis for relating periphyton species diversity to wetland class. Succession is deemed to be the responsible agent of change in wetlands where woody vegetation has grown to trees, where woody shrubs have invaded previously open wetlands and where floating or submerged vegetation has become established in open water (Larson et al. 1980). For most wetlands of the present study, periphyton species diversity was observed to decrease with successional progress of the plant community (Fig 2). Succession of a representative shallow marsh and a sand and gravel pit to a shrub swamps were exceptions to this trend. Duration and depth of flooding were substantially higher for the shrub swamp than for the shallow marsh (Table 4). In this successional step, the increased

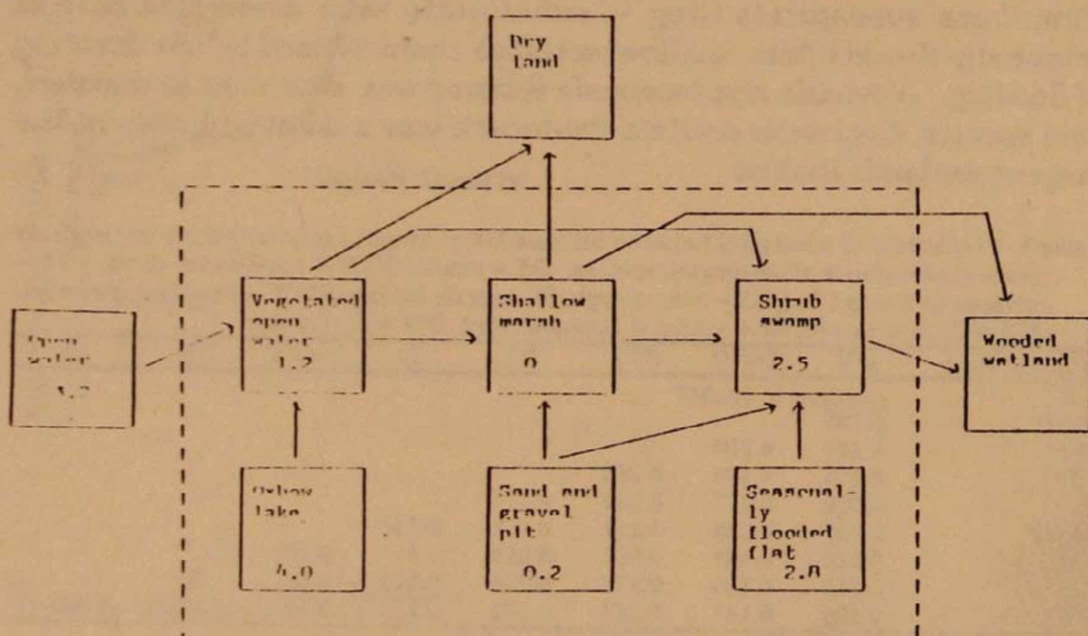

Figure 2. Relationship of periphyton species diversity to wetland succession. Values are species diversity of periphyton. The model of successional trends of wetlands is that of West and Evans (1982). Arrows depict successional trends.

periphyton species diversity of the shrub swamp would appear to have been influenced more by the duration and depth of flooding than the successional progress of the plant community. If succession alone had been the influencing factor, a decrease in species diversity rather than an increase would have been expected.

The occurrence of dominant periphyton species within a narrow range of wetland depths and/or duration of flooding suggests that these are important factors influencing community structure. This is further supported by coefficients of similarity that pair wetlands of similar depths and duration of flooding. Low cell densities occurred in ephemeral wetlands that provided sporadic good growing conditions and high densities occurred in enduring wetlands where growth of periphyton was maintained over relatively long periods of time. McGaha and Steen (1974) reported that in streams a minimal flow time between 9 and 20 days is necessary for appreciable plankton to develop. In the present study, no attempt was made to establish development time of periphyton. However, the wide range of periphyton densities in bodies of water of different depths and duration of inundation indicate that development time is an important factor affecting community structure in wetlands.

Table 4. Tabular representation of major habitats of Ohio River wetlands. Distribution patterns for dominant species are shown along with information on duration and depth of flooding.

Species	Seasonally flooded flat	Shalllow marsh	Open water	Shrub swamp	Vegetated open water
Cyclotella ocellata Pantocsek.					X
Frustalia rhomboides v. *viridula* (Breb) Cl			X		
Gomphonema parvulum Kutz.				X	
Navicula capitata Ehr. v. *capitata*			X		
Navicula cryptocephala Kutzing		X			
Navicula elegans W. Sm. v. *elegans*			X		
Navicula menisculis v. *upsaliensis* (Grun.) Grun.	X				
Navicula rhynchocephalis v. *germanii* (Wallace) patr. comb. mov.			X		
Nitzschia dissipata (Kutz.) Grun			X		
Nitzschia palea (Kutz.) W. Sm.			X	X	X
Pinnularia subcapitata Greg. v. *subcapitata*	X				
Rhoicosphenia curvata (Kutz.) Grun.			X		
Synedra capitata Ehr. v. capitata		X	X		
Duration of flooding (months per year)	6-8	6-7	12	11-12	10-12
Depth of flooding (cm)	0-15	0-20	0-50	0-100	0-150

Literature Cited

1. Brammer, E. S. 1979. Exclusion of phytoplankton in the proximity of dominant water-soldier (*Stratiotes aloides*). Freshwater Biology 9:233- 249.

2. Choi, M.Y., C.K. Culp, T.E. Weaks and D.J. Webb. 1992. Artificial aeration as a factor influencing the periphytic algal community of Beech Fork Lake. Arch. Hydrobiol. 123(4):497- 511.

3. Grenny, W.J., D.A. Bella, and H.C. Curl. 1973. A theoretical approach to interspecific competition in plankton communities. Amer. Natur. 107:405- 425.

4. Howard-Williams, C. and G.M. Lenton. 1975. The role of the littoral zone in the functioning of a shallow tropical lake ecosystem. Freshwater Biol. 5:445- 459.

5. Larson, J.S., A.J. Mueller and W.P. MacConnell. 1980. A model of natural and man-induced changes in open freshwater wetlands on the Massachusetts coastal plain. J. App. Ecol. 17:667- 673.

6. Lind, O.T. 1974. Handbook of Common Methods in Limnology. C.V. Mosby, St. Louis, Missouri U.S.A., pp. 74- 77.

7. Margalef, R. 1968. Perspectives in Ecological Theory. University of Chicago Press, Chicago, Illinois U.S.A., 111 pp.

8. McGaha, Y.J. and J.P. Steen. 1974. The effects of variation in turbidity on cycles of planktonic and benthic organisms in flood control reservoirs of Northern Mississippi. Water Technology Interior Service, U.S. Department of Commerce.

9. Moss, B. 1973. Diversity in fresh-water phytoplankton. Amer. Mid. Nat. 90:341- 355.

10. Parsons, T.R. and J.D.H. Strickland. 1963. Discussion of spectrophotometric determination and marine plant pigments, with revised equations for ascertaining chlorophylls and carotenoids. J. Mar. Res. 21:155- 163.

11. Richerson, P., R. Armstrong, and C.R. Goldman. 1970. Contemporaneous disequilibrium, a new hypothesis to explain the paradox of the plankton. Proc. Nat'l Acad. Sci. 67:1710-1714.

12. Sokal, R.R. and P.H.A. Sneath. 1963. Principles of Numerical Taxonomy. M.W. Freeman Publishers, San Francisco, California U.S.A., 358 pp.

13. Sorensen, T. 1948. A method of establishing groups of equal amplitude in plant sociology based on similarity of species content and its application to analysis of the vegetation on Danish commons. Biol. Skr. (K. danske vidensk. Selsk. N.S.)5:1-34.

14. U. S. Environmental Protection Agency. 1973. Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents. Environmental Monitoring and Support Laboratory, Las Vegas, Nevada U.S.A., pp. 17-18.

15. Weaks, T.E. 1988. Allelopathic interference as a factor influencing the periphyton community of a freshwater marsh. Arch. Hydrobiol. 111(3):369-382.

16. West, B.K. and D.K. Evans. 1982. Flora and early secondary succession in wetlands of the lower Kanawa river floodplain. Symposium on Wetlands of the Unglaciated Appalachian Region, West Virginia University, Morgantown, West Virginia U.S.A., May 26-29, 1982, pp. 157-164.

17. Wetzel, R.G. 1975. Limnology. W.B. Saunders Pub., Philadelphia, Penn. U.S.A., pp. 1-743.

Response of *Juncus effusus* L. to Off Road Vehicle Disturbance in Wetlands of Northern Canaan Valley, West Virginia

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Abstract

Moderate Off Road Vehicle (ORV) traffic in wetlands of Canaan Valley selects for species that are tolerant of ORV disturbance, or can revegetate disturbed soils. *Juncus effusus* appears to be the emergent wetland species most tolerant of direct ORV disturbance in Canaan Valley. Resistance to ORV disturbance was evidenced by the ability of *J. effusus* to remain viable in repeatedly disturbed areas, apparently by assuming a low-growing form and retaining considerable root mass. *Juncus effusus* achieved greater biomass in an area recovering from past ORV disturbance than in any other area studied, mostly due to greater plant size. Greater growth in this area may be due to nutrient availability following soil disturbance, and the removal of potential competitors.

Introduction

Wetlands in Canaan Valley have an abundance and diversity of plant species unlike any other area in the southern Appalachians (Allard and Leonard, 1952; Fortney, 1975). Over the past twenty years, areas of northern Canaan Valley have seen an increase in Off Road Vehicle (ORV) traffic including motorcycles, three, and four-wheel vehicles. Repeated ORV use reduces plant cover and diversity (Slaughter, *et al*. 1990; Webb and Wilshire, 1983) stemming from physical abrasions and alterations of existing soil regimes (Ålcock and Symon, 1977; Gilbertson, 1983; Hinckley, *et al*, 1983). Susceptibility of plant forms to ORV disturbance appears to be greatest to least for woody dicots > herbaceous dicots > monocots.

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In tundra and taiga ecosystems, grasses, sedge, and rush species are often the first plants to revegetate ORV trails (Challinor & Gersper, 1973; Richard and Slaughter, 1973; Sparrow, *et al*, 1978). In Northern Canaan Valley the common rush *Juncus effusus* L. was one of the most abundant plants observed in emergent wetlands disturbed by ORV traffic. The purpose of this study was to compare *J. effusus* biomass, stem density, and stem weight in emergent wetlands subjected to varying degrees of damage and recovery from ORV disturbance. It was predicted that *J. effusus* colonizes ORV disturbed areas because it is resistant to repeated ORV traffic and maximizes growth following ORV disturbance.

STUDY AREA

Canaan Valley is located in the Allegheny Mountains of eastern West Virginia. The valley is approximately 22 kilometers long and 3-8 km wide. Canaan Valley is bordered by Canaan and Brown Mountain to the west, and Cabin Mountain to the east, which range to 1250 m peak elevation. This study focused on emergent wetlands north of Cortland Road where valley floor elevations ranged from 900-1000 meters. Expansive wetlands occur where the underlying bedrock is primarily Greenbrier limestone, and soils are humic, primarily muck and peat.

Emergent wetlands harboring *J. effusus* were studied at two sites. Sites were selected based on prior knowledge of recreational ORV use (site one) and the date and location of a previous race course (site two). Site one was a mixed emergent wetland with biomass of 22 species dominated by sedge (*Carex scoparia* Schkuhr, *C. lurida* Wahl., *C. angustior* Mack.), bluejoint (*Calamagrostis canadensis* (Michx.) Nutt.), and *J. effusus*. The disturbed area received moderate ORV traffic less than two months prior to this study. Site two was an emergent wetland with *J. effusus* accounting for >95% of the total plant biomass. Site two had been disturbed by an ORV race more than three years prior to study, but only a 2-m wide trail had been disturbed thereafter. The area recovering from past disturbance had some moss and bog goldenrod (*Solidago uliginosa* Nutt.), but *J. effusus* was the only plant present on the trail.

Materials and Methods

Vegetation was sampled in July 1991 using plot methods. At site one 10-m^2 grids were established in the recently disturbed area and in an adjacent relatively undisturbed reference area. Samples were collected by placing 0.25-m^2 hoops at 1.0 m intervals along randomly chosen grid lines. At site two hoops were tossed randomly in the ORV trail and the adjacent area recovering from past disturbance.

Vegetation within each hoop was photographed, and percent plant cover was determined in the laboratory using digital image analysis of photographs. Plants were harvested at ground level, returned to the lab, sorted to species, dried, and weighed to the nearest 0.01 g. *Juncus effusus* stem density and stem weight was measured when encountered in samples. Plant variables were compared between sites using Student's t-test ($p = 0.05$), and numbers reported are means with 95% confidence intervals.

Results and Discussion

Disturbance to the community at site one was moderate, with the exception of a few 1 to 5-m^2 patches where vegetation was absent. Mean percent plant cover was 91% in the reference area and 72% in the recently disturbed area, and differences were statistically significant (Figure 1). Disturbance occurred early in the growing season, as evidenced by recolonization of some disturbed soils with 2 to 10-cm shoots of spikerush (*Eleocharis obtusa* (Willd.) Schultes, and *E. acicularis* (L.) R. & S.). *Calamagrostis canadensis* encountered in the disturbed area was new growth from runners, a recolonization pattern similar to that reported for the genus in ORV disturbed tundra (Sparrows, *et al*, 1978).

Biomass of *J. effusus* was not significantly different in the disturbed versus reference area of site one, indicating that *J. effusus* was resistant to moderate ORV traffic. Mean stem density was similar, but stem weight was lower in the disturbed versus reference area (Figure 2). It appeared that larger stems were more susceptible to ORV damage than smaller stems.

After more than 3 years of recovery, plant cover at site two equaled that of the site one reference area, and exceeded that of the more recently disturbed area of site one (Figure 1). *Juncus effusus* stem density was generally greater at site two than at site one, evidence of the near monoculture at the site subjected to severe ORV disturbance in the past. Biomass of *J. effuses* in the recovery area of site two was greater than *J. effusus* biomass at all other sites, and exceeded the mean plant biomass of three other emergent wetlands in northern Canaan Valley (unpublished data).

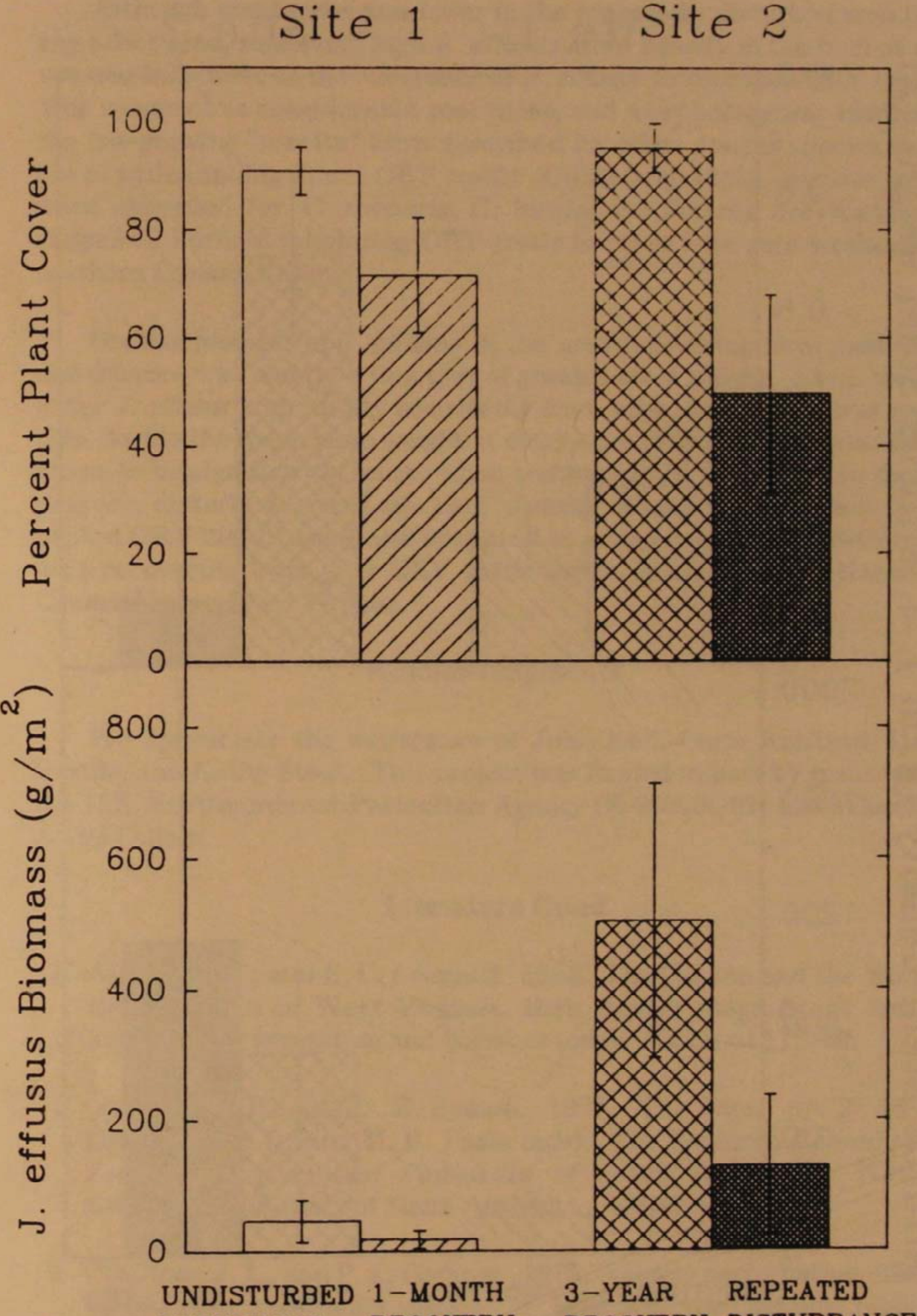

Figure 1. Mean percent plant cover and *Juncus effusus* biomass at study sites.

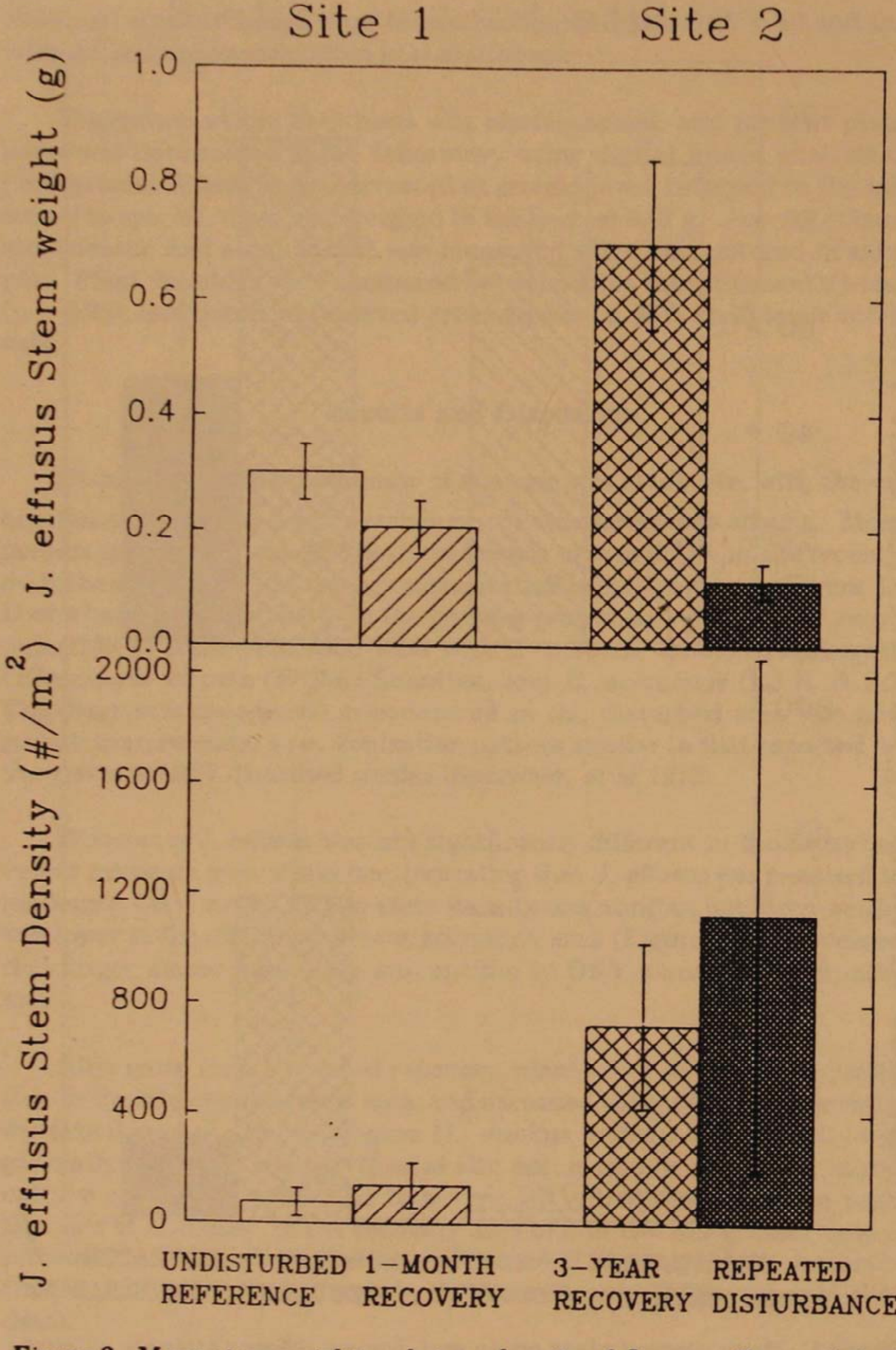

Figure 2. Mean stem weight and stem density of *Juncus effusus* at study sites.

Although plant cover was lower in the repeatedly disturbed area than any other area, relatively high *J. effusus* stem density in the trail at site two was indicative of the resistance of *J. effusus* to repeated ORV traffic. This species has considerable root mass, and morphology was similar to the low-growing "rosette" form described for other *Juncus* species capable of withstanding direct ORV traffic (Gilbertson, 1983). Similar forms were observed for *C. scoparia*, *C. lurida*, and *Juncus brevicaudatus* (Engelm.) Fernald inhabiting ORV trails in other emergent wetlands of northern Canaan Valley.

Greater biomass of *J. effusus* in the area recovering from past ORV disturbance was mostly a function of greater stem weight. Stem weight in the *J. effusus* community recovering from past disturbance was more than double the mean stem weight at other sites (Figure 2), We also found stems to be significantly longer when comparing the recovering to the repeatedly disturbed area of site two. *Juncus effusus* was resistant to repeated ORV disturbance, and appeared to achieve greatest growth in an area recovering from past ORV disturbance in emergent wetlands of Canaan Valley, West Virginia.

Acknowledgments

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Literature Cited

1. Allard, H. A., and E. C. Leonard. 1952. The Canaan and the Stoney River valleys of West Virginia, their former magnificent spruce forests, their vegetation and floristics today. Castanea 17:1-60.

2. Alcock, C. R., and D. E. Symon. 1977. The flora. pp. 25-44 in: Gilbertson, D. D., and M. R. Foale (eds). *The Southern Coorong and Lower Younghusband Peninsula of South Australia*. Nature Conservation Society of South Australia. Adelaide.

3. Challinor, J. L., and P. L. Gersper. 1975. Vehicle perturbation effects upon a tundra soil-plant system: II. Effects on the chemical regime. Soil Science Society America Proceedings 33:689-895.

4. Fortney, R. H. 1975. *The Vegetation of Canaan Valley, West Virginia, a taxonomic and ecological study.* Ph. D. Dissertation. West Virginia University, Morgantown. 210 p.

5. Gilbertson, D. D. 1983. The impact of off-road vehicles in the Coorong Dune and lake complex of South Australia. pp. 355-373 in: Webb, R. H., and H. G. Wilshire, eds. *Environmental Effects of Off Road Vehicle Use.* Springer-Verlag. New York.

6. Hinckley, B., R. Iverson, and B. Hallet. 1983. Accelerated water erosion in ORV-use areas. pp. 81-95 in: Webb, R. H., and H. G. Wilshire, eds. *Environmental Effects of Off Road Vehicle Use.* Springer-Verlag. New York.

7. Richard, W. E., and C. W. Slaughter. 1973. Thaw and erosion on vehicular trails in permafrost landscapes. Journal of Soil and Water Conservation 28:263-266.

8. Slaughter, C. W., Racine, D. A. Walker, L. A. Johnson, and G. Abele. 1990. Use of off-road vehicles and mitigation effects in Alaska permafrost environments: a review. Environ. Mngt. 14:63-72.

9. Sparrow, B. D., F. B. Wooding, and E. H. Whiting. 1978. Environmental effects of off-road vehicle traffic on soils and vegetation of the Denali Highway of Alaska. Journal of Soil and Water Conservation 33:20-27.

10. Strausbaugh, P. D., and E. L. Core. 1970. *The Flora of West Virginia.* 2nd edition. Seneca Books, Grantsville, WV. 1079 pp.

11. Webb, R. H., and H. G. Wilshire, eds. 1983. *Environmental Effects of Off Road Vehicle Use.* Springer-Verlag. New York.

Mining/Geology Section

Hypothesis Testing and Model Comparisons of Trend Surfaces and Three-Dimensional Modeling Techniques Applied to Mapping Selected Roof Fall Characteristics in a West Virginia Coal Mine

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Abstract

Cost sensitive mine planning systems assume that the physical and economic conditions that will have the greatest impact on cost and coal quality can be predicted accurately enough to assist mine planners in making decisions. Several such factors, namely vertical height of mine opening, mine roof span in or adjacent to fall area, structure contour of maximum mine roof height, and height, from mine roof edge, to second and third rock break horizon of roof strata, extremely important parameters in forecasting potential ground control problems, were measured and mapped for 21 recent mine roof falls in a West Virginia coal mine. The coal mine is mining in a nine-foot, Upper Freeport seam. The major research and analysis tools used in the present study were polynomial-trend surface analyses, hypothesis testing and model comparisons of trend surfaces, and three-dimensional models generated from commercially available computer software, via the incremental drum plotter. The mean thickness of the vertical height of mine opening was 2.70 m.

Introduction

The stability of coal mining tunnel, entries, rooms, and associated openings plays a major role in the success of any major underground project. Hence, if the main access openings to a new coal mine become deformed and damaged by strata movement to the extent of requiring serious repairs, special problems may arise which will have an influence on ventilation, impairment to speed and reliability of transport systems as well as the direct and indirect costs involved with the repair program (Wells and Whittaker 1981).

The mechanical design of a roof support system is basically a matter of a working knowledge of statistics and dynamics, assuming that the imposed loads and mining conditions are known. However, in the Appalachian Coal Fields, the general conditions are known well enough to allow for the majority of mining techniques, to be furnished with standard and commercially available supports. Of course, these support systems and roof control procedures are equipped with suitable variants and options (Hutchinson 1981). The overall design of a mining system, which design incorporates not only size and capacity of the equipment to be used; but includes: equipment adaptability to the mining scheme; equipment versus human constraint, operation at the designed levels; and coordination of operation, maintenance and support design (Hutchinson 1981).

Hence, a multitude of factors must be considered in the successful underground operation. Cost-sensitive mine planning systems have been developed to help coal companies design underground mines that will recover coal reserves in the most profitable method. Information obtained from borehole logs, local mines, mining equipment manufacturers, and previous mining experience should be used in the mine planning process. Cost-sensitive mine planning assumes that the physical and economic conditions that will have the greatest impact on cost and coal quality can be predicted accurately enough to assist mine planners in making decisions. In the planning process, many maps, such as coal seam thickness, expected roof caving conditions, geologic lineaments, roof shale thickness, distance to the first sandstone, overburden thickness, underclay thickness, as well as a host of other factors, can be generated as overlays on each other to assist planners in selecting appropriate locations and orientations for the portal, mains, submains, and longwall panels.

Hence, the thrust of the present study is to examine the spatial distributions of vertical height of mine opening, mine roof span in or adjacent to fall area, structure contour of maximum mine roof height, and height to second and third rock break horizon of roof strata, as measured from the roofline, from a study of recent mine roof falls in a particular site in West Virginia. In addition, if spatially predictive relationships exist within the mine layout, a model of their characteristics can be plotted. If these relationships exist, they should prove useful in a cost-sensitive mine plan to avoid selected interactions of these parameters in planning room or main entry development.

Methods

The major research tools used in the present study are polynomial-trend surface analyses, hypothesis testing and model comparisons of trend surfaces, and three-dimensional models generated from commercially available computer software via the incremental plotter.

Polynomial Trend Surface Analyses and Model Comparisons

A trend is a statistically derived surface to explain variations in a given set of values, known as Z-values, that have a given geographic position, either regularly or irregularly distributed in the x-y plane. The surface is the representation of an equation using the least-squares criterion. This means that the generated surface will be fitted to the input data in such a way that the sum of the squared deviations between the data at their particular locations and the corresponding value of the computed surface are minimized. Thus, the least-squares criterion calls for the surface to be laid down in such a way that the sum of the squares of these discrepancies is as small as possible, as indicated by: $d^2 = E$, where $d^2 =$ deviation squared and $E =$ minimum value.

The basic reasoning behind minimizing the sum of squares of the deviations, and not minimizing the sum of the absolute magnitudes of the discrepancies, are: 1. It is extremely difficult to mathematically deal with the absolute discrepancies or deviations; while the treatment of the squared deviations provides the method of practical mathematical developments in the interpretation of the regression equation. 2. Useful and desirable statistical properties follow from using the least-squares criterion (McNeil, Kelly and McNeil 1976, Minium 1978, Rohatgi 1976).

The equation describing the surface can be linear (plane), quadratic (paraboloid), cubic (paraboloid with an additional point of inflection), to higher order degree surfaces. In general, the higher order of the surface, the more the residuals, or individual deviations, will be minimized and the more computation will be required. The higher-order trend surfaces may reflect the variation in Z-values more accurately if the study area is complex, but lower-order surfaces may be more useful in the isolation of local trends. The filtering mechanism allows the upper limit of variability to be determined by the order of the surface. The equation for a linear trend surface, for example, is:

$$Y = b_o + b_1X_1 + b_2X_2$$

where Y = dependent variable, b_o = constant value related to the mean of the observations, $b_1 b_2$ = coefficients, $X_1 X_2$ = geographic coordinates. This linear equation generates 3 unknowns and 3 equations are needed to determine a solution. These equations are:

$$(1) \quad \sum_{i=1}^{n} Y = b_o n + b_1 \sum_{i=1}^{n} X_1 + b_2 \sum_{i=1}^{n} X_2,$$

$$(2) \quad \sum_{i=1}^{n} X_1 Y = b_o \sum_{i=1}^{n} X_1 + b_1 \sum_{i=1}^{n} X_1^2 + b_2 \sum_{i=1}^{n} X_1 X_2, \text{ and}$$

$$(3) \quad \sum_{i=1}^{n} X_2 Y = b_o \sum_{i=1}^{n} X_2 + b_1 \sum_{i=1}^{n} X_1 X_2 + b_2 \sum_{i=1}^{n} X_2^2,$$

where n = number of observations or data collected. Solving these equations simultaneously will give the coefficients of the best-fitting linear surfaces, where best fit is defined by the least-square criterion. As the degree of the trend surface that is to be used increases, so does the number of equations that must be solved simultaneously.

The significance of a trend or regression may be tested by performing an analysis of variance, which deals with the separation of the total variance of a set of observations into components with defined sources of variation (Davis 1973). In trend surface analysis, the total variance in an independent variable may be divided into the trend itself, which is determined by regression analysis, and the residuals, or error vector. An analysis of variance table can be calculated (Table 1). By reducing the sum of squares, derived from the least-square criterion, an estimate of the variance can be computed by using the F-distribution (Davis 1973). The F-test, like a t-test, is a very robust test and relatively insensitive to violations of the assumptions of random selection of observations and normal distribution of the variables (Edwards 1972, Newman and Newman 1977). Newman and Fraas (1978) and Nunnally (1967) looked at a number of investigations that dealt with the F-distribution assumptions and their violation and summarized by suggesting that no appreciable effect on the accuracy of the F-test from skewed sample distribution occurred. In addition, if sample sizes are equal, heterogeneity of variance has a negligible effect.

Table 1. Typical Analysis of Variance Table for Polynomial Trend Surfaces.

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F Ratio
Regression	SS_{Reg}	m	MS_{Reg}	MS_{Reg}/MS_{Reg}
Residual	SS_{Reg}	n - m - 1	MS_{Reg}	
Total	SS_T	n - 1		

Note: In the table, m is the number of coefficients in the polynomial-trend surface equation, not including the constant term, b_0; and n is the number of valid data points used in the regression equation.

The F-test for significance of fit is a test of the null hypothesis that the partial regression coefficients are equal to zero and, hence, there is no regression. If the computed F-value exceeds the F-value having a probability of a set alpha level, (a = 0.01 to 0.05) the null hypothesis is rejected. In polynomial trend-surface analysis, it is customary for investigators to fit a series of successively higher degrees to the data without statistically testing the higher order's contribution in additional variance. Davis suggested that an analysis of variance table be expanded to analyze the contribution of the additional partial regression coefficients to give a measure of the appropriateness of each order equation. In regression work, the question often arises as to whether it was worthwhile to include certain terms associated with the order of the polynomial in the model. This question can be investigated by considering the extra portion of the regression sum of squares which arises due to the fact that the terms under consideration were in the model. If this extra sum of squares is significantly large, those terms should be included. However, if nonsignificant, they are judged unnecessary and should be deleted. For example,

$SS(b_1/bo)$ is the extra sum of squares owing to the B_1X_1 term was included in a model which otherwise only contained Bo. If the F-test indicated significance, the model should include the B_1X_1 term. The full versus restricted model principle implies that if the null hypothesis, were Ho : $B_1 = Q$ were true, and if this condition is imposed on the model, the result would be that contribution of the B_1X_1 term is zero. This is equivalent to discharging the B_1X_1 term from the model, resulting in the restricted model. Hence, the restricted model is the model which results when the specific null hypothesis, which is assumed true, is imposed or restricted on the full model. The full model is the model which contains all the terms of the lower and higher order polynomial coefficients being tested. The sum of squares of the null hypothesis (SS(Ho)) is equal to the difference of the regression sum of squares of the restricted model. Also, the degrees of freedom of the null hypothesis (df(Ho)) is simply the difference between the degrees of freedom of the full and restricted models.

Three-Dimensional Models

The three-dimensional plotting programs can be used via the incremental drum plotter to produce statistical surfaces of geographic units with assigned values of continuous data. There are a variety of options available to the user and these programs also produce their own diagnostic messages for common errors that the user may encounter. There are basically four programs under the three-dimensional plotting programs, each one designed to give either a completely different type of plot or flexibility in the presentation of its final form; these options are known as QUSMO, QUSMO2, QUCRS, and QUTAB (Sawan and Nash 1974).

Quick Smooth (QUSMO) produces a smoothed surface over an input data matrix and places the surface on a base or plane. This program performs a nine point quadratic interpolation between the input data points to give the plot a smooth appearance. QUSMO2, however, combines the features of QUSMO but allows for control over the size output, vertical scale, and read the data matrix from tape storage. QUSMO2, similar in function to the commercially available SURFACE II software (Sampson 1978), was used to produce the three-dimensional plot found in this study.

Quick Crosscut (QUCRS) also produces a smoothed surface over the input data as does QUSMO and QUSMO2. However, it does not put the interpolated surface on a plane. A base is drawn for the surface so that it can be visualized as if it was isolated in space.

Quick Tabular (QUTAB) produces a plot similar to a three-dimensional histogram. Each data point of the data matrix is assumed to be the center of a plotted cell and thus appears as many small squares at various levels. Since there is no interpolation between the input data points, the program produces a step-like surface. In addition, all four plotting routines have the option to view the surface from eight directions (north, south, east, west, northwest, northeast, southeast, southwest).

Results

One mine was selected for the study from West Virginia, Upper Freeport Coal Seam, to apply cost-sensitive mapping procedures with the combined use of trend surface analyses and three-dimensional modeling techniques. A total of 21 actual mine roof falls were measured and data concerning vertical height of mine opening, mine roof span in or adjacent to fall area, structure contour of maximum mine roof height, and height to second and third rock break horizon of roof strata, were collected. The

Table 2. ANOVA Table for Third Degree, Polynomial Trend Surface or Vertical Height of Mine Opening.

Source of Variation	SS	df_n/df_d	MS	F-Ratio	Prob. Sign.
Third Degree Regression	16.404465	9	1.822718	2.9931	0.0452 S*
Error (Residual)	6.698796	11	0.608982		
Total	23.103271	20			

$R^2_f = 0.7100$, $R^2_r = 0.0$

*Significant at 0.05 level.

majority of falls occurred in the entry or crosscut (52.4 percent) or in an intersection (47.6 percent). The means for each measured parameter were as follows: vertical height of mine opening (2.71 m), mine roof span (5.59 m), roof fall height above roof edge (2.86 m), height above roof edge to second rock break horizon (1.83 m), and third rock break horizon (0.653 m).

Table 3 - Summary of F-Ratios, Probability Levels, R^2 for Both the Full and Restricted Models, Degrees of Freedom-Numerator, Degrees of Freedom-Denominator, and Significance for Each Trend Surface for Associated Roof Fall Parameters.

Order of Trend Surface	R^2_f	R^2_r	df_n/df_d	F-Ratio	Prob.	Sgnfcnce.
VERTICAL HEIGHT OF MINE OPENING (N = 21)						
1	0.5438	0.0	2/18	10.7266	0.0009	S**
2	0.6019	0.0	5/15	4.5351	0.0102	S*
3	0.7100	0.0	9/11	2.9931	0.0452	S*
4	0.7778	0.0	14/6	1.5003	0.3218	NS
1 vs 2	0.6019	0.5438	3/15	0.7297	0.5501	NS
2 vs 3	0.7100	0.6019	4/11	1.0261	0.4361	NS
3 vs 4	0.7778	0.7100	5/6	0.3660	0.8552	NS
MINE ROOF SPAN IN OR ADJACENT TO FALL AREA (N = 21)						
1	0.3499	0.0	2/18	4.8439	0.0207	S*
2	0.5864	0.0	5/15	4.2539	0.0131	S*
3	0.6849	0.0	9/11	2.6570	0.0647	NS
4	0.8850	0.0	14/6	3.2995	0.0750	NS
1 vs 2	0.5864	0.3499	3/15	2.8597	0.0720	NS
2 vs 3	0.6849	0.5864	4/11	0.8598	0.5174	NS
3 vs 4	0.8850	0.6849	5/6	2.0889	0.1980	NS
STRUCTURE CONTOUR OF MAXIMUM MINE ROOF HEIGHT (N = 21)						
1	0.1769	0.0	2/18	1.9338	0.1735	NS
2	0.3102	0.0	5/15	1.3492	0.2975	NS
3	0.5564	0.0	9/11	1.5393	0.2465	NS
4	0.6898	0.0	14/6	0.9530	0.5641	NS
1 vs 2	0.3102	0.1769	3/15	0.9666	0.4342	NS
2 vs 3	0.5574	0.3102	4/11	1.5359	0.2588	NS
3 vs 4	0.6898	0.5574	5/6	0.5121	0.7602	NS
HEIGHT TO SECOND HORIZON OF ROOF STRATA (N = 19)						
1	0.1204	0.0	2/16	1.0955	0.3582	NS
2	0.1640	0.0	5/13	1.5102	0.7639	NS
3	0.6399	0.0	9/9	1.7774	0.2023	NS
4	0.9804	0.0	14/4	14.2723	0.0100	S**
1 vs 2	0.1640	0.1204	3/15	0.2260	0.8767	NS
2 vs 3	0.6399	0.1640	4/9	2.9740	0.0804	NS
3 vs 4	0.9804	0.6399	5/4	13.8767	0.0123	S**

Table 3. Continued.

Order of Trend	R^2_f	R^2_r	df_n/df_d	F-Ratio	Prob.	Sgnfcnce.
Surface						
1	0.0455	0.0	2/7	0.1669	0.8496	NS
2	0.3769	0.0	5/4	0.4840	0.7769	NS
1 vs 2	0.3769	0.0455	3/4	0.7093	0.5950	NS

NOTE: The symbols * denote statistical significance at 0.05 level, ** denote statistical significance at 0.01 level, both for a two-tailed, nondirectional test.

Each roof fall location was recorded and trend surface analyses, via SYMAP (Dougenik and Sheehan 1979) and a computer program suggested by Smith (1982), were performed. In addition, selected three-dimensional models were created. Tables 2 and 3 illustrate the result of the model comparisons and hypothesis testing of polynomial trend surfaces in predicting spatial distributions of selected mine roof fall characteristics. Table 2 is the hypothesis testing results, in standard analysis of variance (ANOVA) format, to determine if the third degree, polynomial trend surface for vertical height of mine opening is significant. The variance accounted for by the third-degree surface was 71.00 percent and this was found to be statistically significant (p=0.0452). Finally, Table 3 is a summary of the F-ratios, probability levels, R^2 for both the full and restricted models, degrees of freedom-numerator, degrees of freedom-denominator, and significance for each trend surface for the associated roof fall parameters. As evident from the table, the highest degree surface in predicting vertical height of mine opening over random variation was the third-order, however, it was shown not to be statistically better predictor than the lower surfaces (3 vs. 4 term was not significant, p = 0.8552). The second degree surface was shown to be significant (R^2 = 58.64 percent, p = 0.0131 over random variation, but was not significantly better predictor than the other surfaces. No significant polynomial trends were found for structure contour maximum mine roof height and height to third horizon of roof strata in mine roof. However, the fourth degree surface accounted for a significant amount of explained variance (p = 0.0100, R^2 = 98.04 percent) in predicting the spatial distribution of height to second rock break horizon, above the roof edge. This finding was consistent with the model comparisons with the other degree surfaces as was determined to be the best predictor.

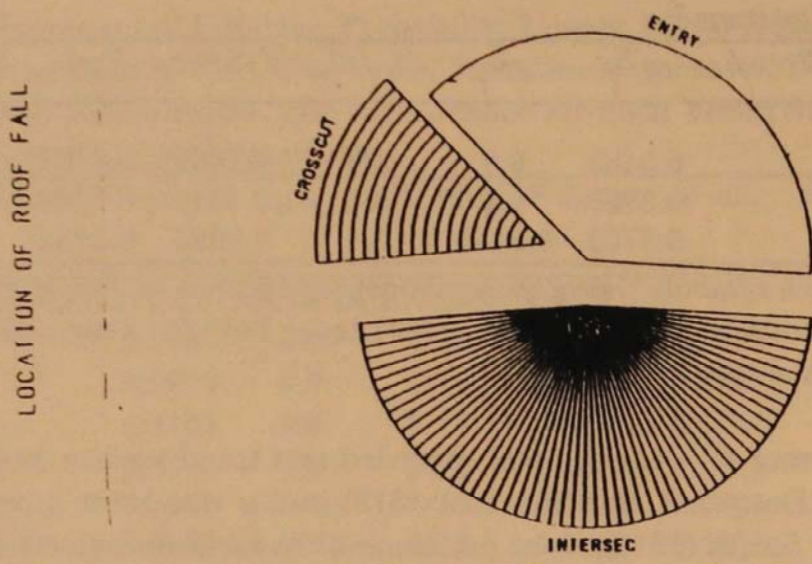

Figure 1. Graphically depicted distribution of location of mine roof falls used in the present study.

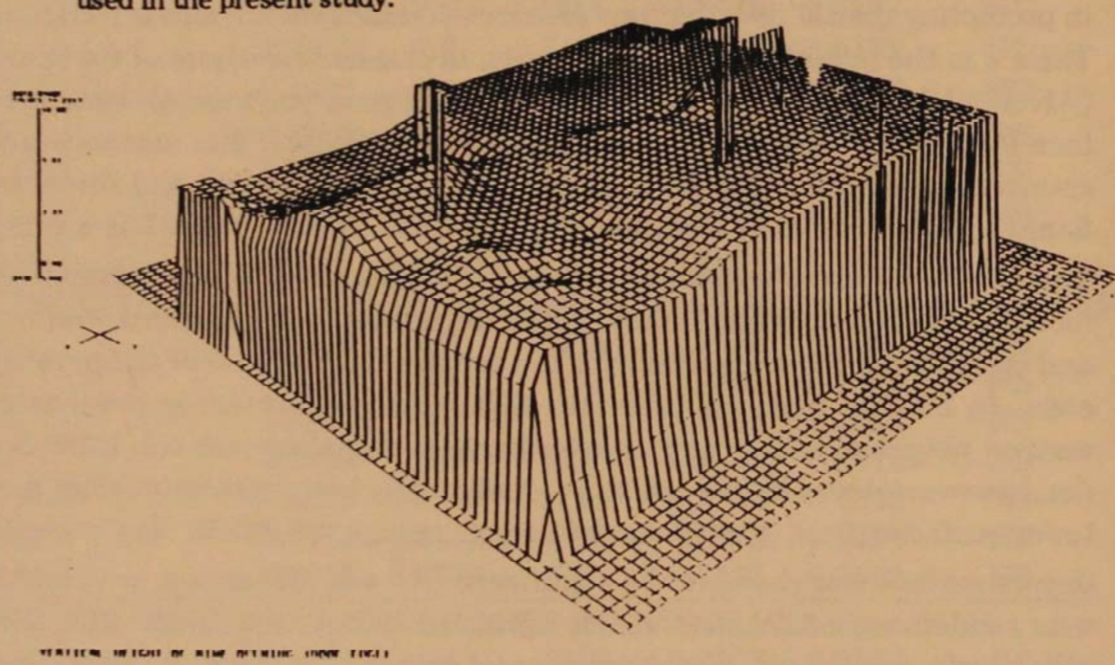

Figure 2. Three-dimensional model displaying spatial distribution of vertical height of mine opening from roof edge for the present mine layout, as viewed from the northeast direction.

The graphic displays of the three-dimensional plots for selected mine roof parameters can be found in Figures 2 through 5. Figure 2 illustrates the spatial distribution of vertical height of mine opening to roof edge, Figure 3 displays mine roof span in or adjacent to fall area, Figure 4 portrays height to second horizon of roof strata, and Figure 5 presents height to third rock break horizon, from roof edge, at roof strata.

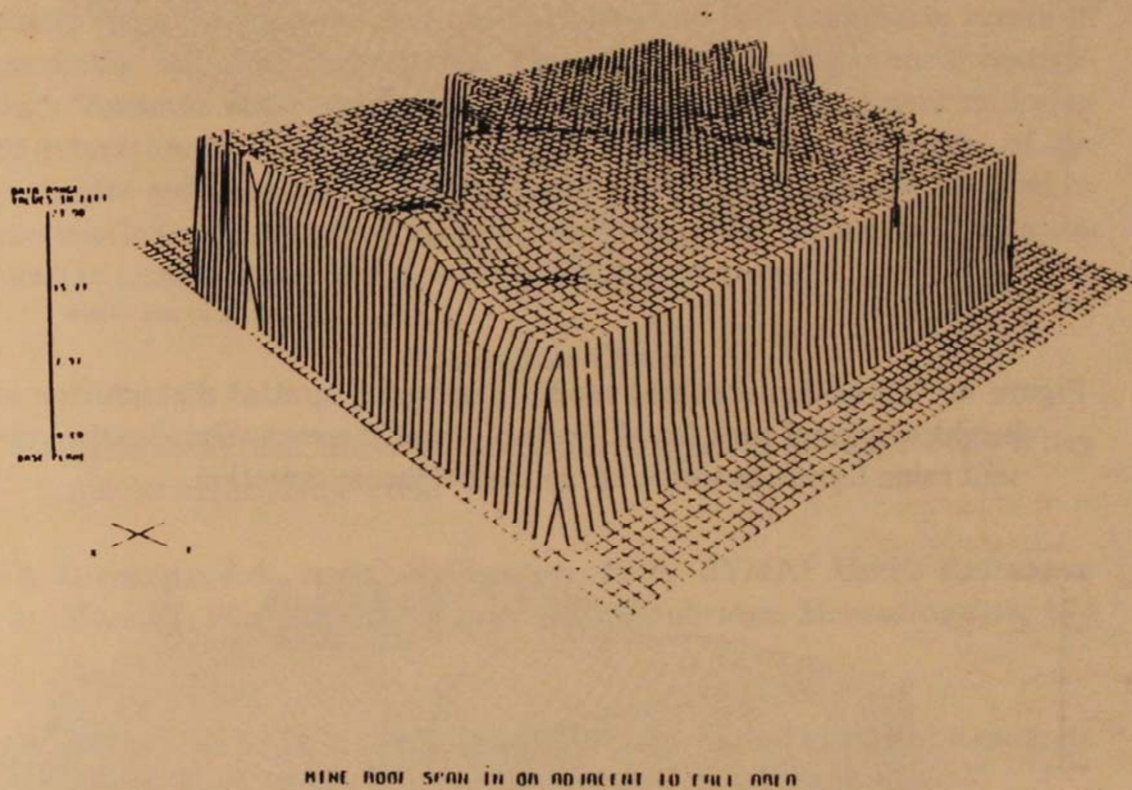

Figure 3. Three-dimensional model displaying spatial distribution of mine roof span in or adjacent to fall area for the present mine layout, as viewed from the northeast direction.

Discussion

As evident from Figures 2 through 5, and the statistical information displayed in Tables 2 through 4, significant and predictive trends exist for vertical height of mine opening, mine roof span in or adjacent to fall area, and height to second break horizon of roof strata. However, no trends

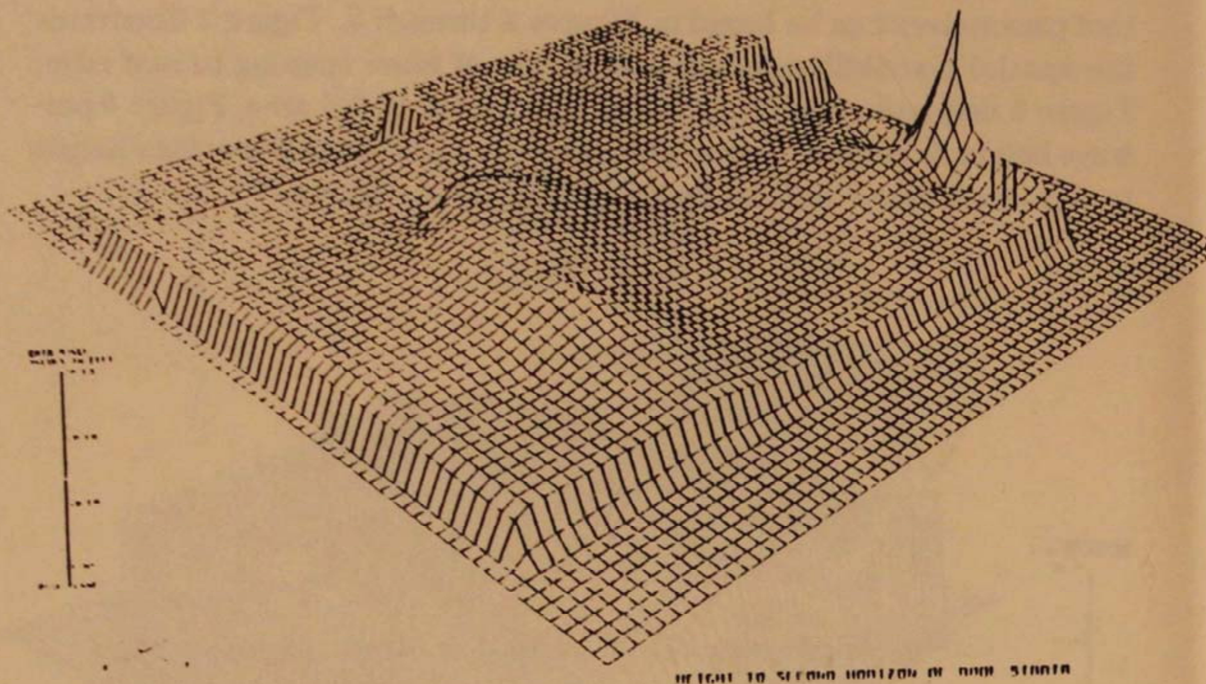

Figure 4. Three-dimensional model displaying spatial distribution of height to second rock break horizon, from the roof edge, for the present mine layout, as viewed from the northeast direction.

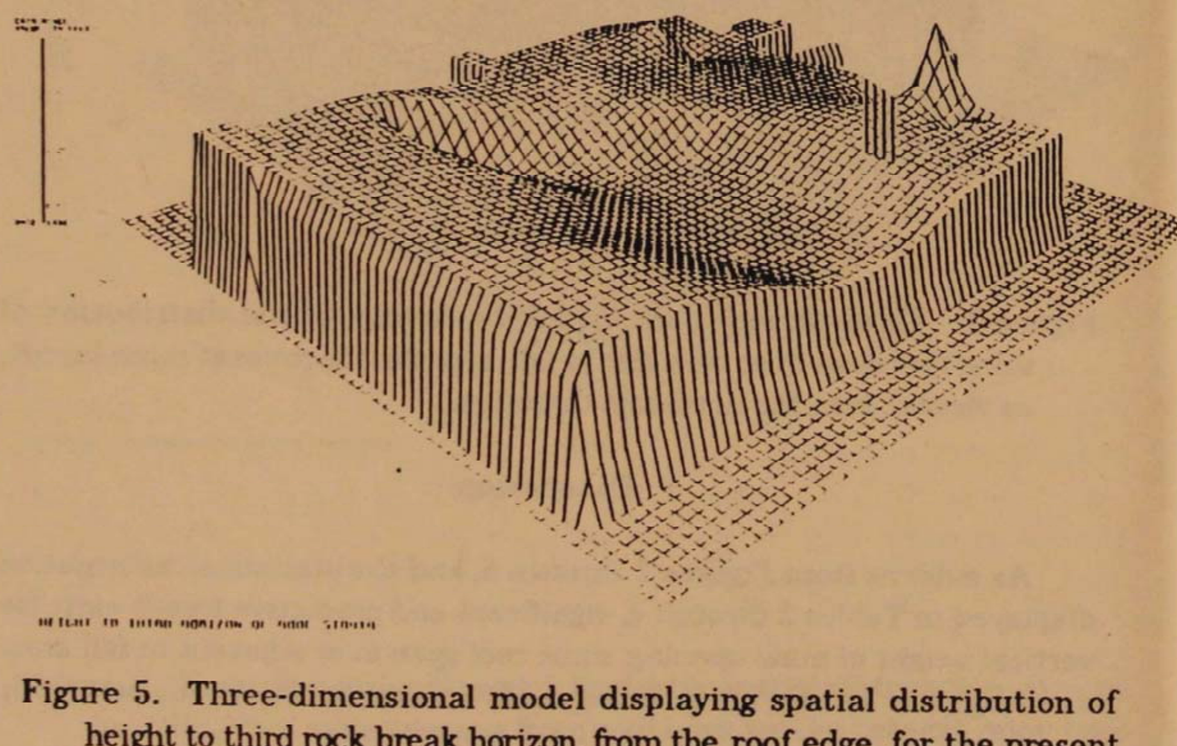

Figure 5. Three-dimensional model displaying spatial distribution of height to third rock break horizon, from the roof edge, for the present mine layout, as viewed from the northeast direction.

were found to be statistically significant for maximum mine roof height, above the roof edge, and third horizon of roof strata.

The major benefit of modeling research is to be able to visualize the actual distributions of important parameters associated with roof falls. Examples illustrated in this research allow the user to portray selected distributions of parameters in order to take preventative measures in the future to avoid potentially problematic areas. The use of plotting statistical as well as actual contour surfaces, allows the investigator a chance to actually visualize what the surface looks like and the residuals or errors in prediction and their magnitudes. This process can bring in the investigator's "common sense" and geological and engineering judgment into play to determine the best fit. With the increasing use and availability of appropriate software and hardware, computer modeling should be used in conjunction with statistical models in estimating the usefulness and limitations of trend-surface analyses for predictive purposes.

Literature Cited

1. Davis, J.C., 1973, Statistics and Data Analysis in Geology. John Wiley and Sons, Inc., New York.

2. Dougenik, J.A., and D.E. Sheehan, 1979. SYMAP User's Reference Manual. Harvard University Press, Cambridge, Massachusetts, 170 p.

3. Edwards, A.L., 1972. Experimental Design in Psychological Research, 4th ed. Holt, Rinehart, and Winston, Inc., New York, 488 p.

4. Ellison, R.D., and V.A. Scovazzo, 1981. Profit Planning Begins with Mapping. Coal Age, 81:68-81.

5. Hutchinson, T.L., 1981. Design and Operation of Powered and Entry Supports. In Proceedings of the First Annual Conference on Ground Control in Mining, West Virginia University, Morgantown, West Virginia, p. 201-208.

6. McNeil, K.A., F. J. Kelly, and J.T. McNeil, 1976. Testing Research Hypotheses using Multiple Linear Regression. South Illinois University Press, Carbondale, Illinois, 581 p.

7. Minium, E.W., 1978. Statistical Reasoning in Psychology and Education, 2nd ed. John Wiley and Sons, Inc. New York, 564 p.

8. Newman, I., and C. Newman, 1977. Conceptual Statistics for Beginners. Univ. Press of America, Washington, D. C., 245 p.

9. Nunnally, J., 1967. Psychometic Theory. McGraw-Hill Book Co., New York.

10. Rohatigi, V.K., 1976. An Introduction to Probability Theory and Mathematical Statistics. John Wiley and Sons, Inc. New York.

11. Sampson, R.J., 1978. SURFACE II Graphics System. Kansas Geology Survey, Lawrence, Kansas, 150 p.

12. Sawan, S.P., and T.L. Nash, 1974. Three-dimensional Plotting Program User Manual. Laboratory for Cartographic and Spatial Analysis. The University of Akron, Akron, Ohio, 50 p.

13. Smith, A.D., 1982. Hypothesis Testing and Model Comparisons of Trend Surfaces. Transactions of the Kentucky Academy of Science, 44 (1-2):17-21.

Education Section

Postdictions of College GPAs from ACT Composite Scores and High School GPAs: Comparison by Race and Gender

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Abstract

Postdictions of College GPAs (CGPA) from High School GPAs (HSGPA) and/or ACT Composite Scores (ACTComp) were compared by gender and by race for freshmen and sophomore students at a West Virginia College. Significant differences in postdictions were found for race and gender with substantially greater frequencies of over/under postdictions when the ACTComp score was the only predictor variable. Significant differences between validity coefficients (R_S^2) were found with HSGPA substantially contributing to the prediction efficiency. No significant gender or race difference was found between regression coefficients or intercepts in either predictive model. There were significant gender and race differences between HSGPAs, CGPAs, and ACTComp scores. CGPAs were under postdicted for female white students and over postdicted for male students.

Introduction

The prediction of college grade point average (CGPA) has been a research topic of interest for several years, especially as it applies to possible race and gender bias (Aleamoni & Oboler, 1978; Cole, 1973; Cordes. 1976; Gamache & Novick, 1983; Hunter & Schmidt, 1978). Various aptitude tests have been incorporated into selection procedures ranging from military and industrial applications to college admission programs and the predictive efficacy of these tests has been evaluated in many settings (Hunter, Hunter, & Schmidt, 1979). Linear equations based on the majority group and on combined groups often are used to ascertain systematic errors in prediction (Boehm, 1977; Calkins & Whitworth, 1974;Humphreys, 1973: Hunter, Schmidt, & Rauschenberger, 1977; Temp, 1971) and some research has found gender and race differences between regression slopes, intercepts, and validity coefficients. Linn (1973, 1978), however, believes that the essential issue relating to test bias is whether regression equations over- or under-predict a specific group.

Many studies of academic achievement prediction have utilized American College Test (ACT) scores or Scholastic Aptitude Test (SAT) scores, combined with high school grade point averages (HSGPAs) as predictor variables, and have compared resulting parameter estimates by race and by gender (Clark & Grandy, 1984; Thomas, 1975).

The purpose of this study is to compare each student's actual college grade point average with his/her postdicted CGPA from two predictive models based on different subsamples at a four-year state college. Actual and postdicted CGPAs will be compared by gender and by race when postdicted from ACTComp combined with HSGPA (Model A) and when only the ACTComp is the predictor variable (Model B). In addition to comparisons of over-under postdictions, regression coefficients, intercepts, and validity coefficients will be compared by race and gender.

Table 1. College grade point average (CGPA) and ACT Composite Score (ACTComp) for Freshmen and Sophomore students: By gender and race.

White Male N	White Male CGPA	White Male ACT Comp	Black Male N	Black Male CGPA	Black Male ACT Comp
459	2.32	16.64	94	1.88	11.59
White Fem N	**White Fem CGPA**	**White Fem ACTComp**	**Black Fem N**	**Black Fem CGPA**	**Black Fem ACTComp**
486	2.61	15.97	82	2.05	11.62

Table 2. Regression analyses: gender and race comparisons by model.

	n	R^2	E	$B_{ACTComp}$	$SE_{ACTComp}$	B_{HSGPA}	SE_{HSGPA}	INTERCEPT	SE_I
				Model A: CGPA = ACTComp + HSGPA					
Gender:									
Male	553	.2083	72.35	.04156	.0066	.42426	.0585	.5164	.1512
Female	568	.2757	107.51	.04777	.0077	.44081	.0598	.2352	.1625
t	-	-	-	(0.5039)	-	(1.5103)	-	(.12669)	-
Race:									
White	945	.2230	135.14	.03792	.0057	.42710	.0442	.4074	.1287
Black	176	.2515	29.07	.04874	.0120	.47317	.0991	.2653	.2382
t	-	-	-	(0.8147)	-	(0.4970)	-	(0.4242)	-
Total N	1121	.2539	190.25	.04223	.0050	.4278	.0404	.3154	.1098
				Model B: CGPA = ACTComp					
	n	R^2	E	$B_{ACTComp}$	$SE_{ACTComp}$	B_{HSGPA}	SE_{HSGPA}	INTERCEPT	SE_I
Gender:									
Male	553	.1326	84.26	.05898	.0064	-	-	1.3218	.1072
Female	568	.1668	113.35	.07805	.0074	-	-	1.3219	.1197
t	-	-	-	(0.0098)	-	-	-	(.0006)	-
Race:									
White	945	.1059	111.68	.06112	.0058	-	-	1.4797	.0986
Black	176	.1529	31.40	.06741	.0120	-	-	1.1828	.1493
t	-	-	-	(0.4720)	-	-	-	(1.6594)	-
Total N	1121	.1398	181.84	.0699	.0050	-	-	1.3531	.0815

Methods

Subjects

ACT Comp scores, HSGPAs and CGPAs were available for freshmen and sophomore students (N = 1121) enrolled at a four-year institution of higher learning in West Virginia in 1985 (see Table 1). The problem of this investigation concerns race and gender differences in over-under-postdictions of CGPA; consequently, in-depth analyses were performed on these data.

Procedures

Two linear regression models, derived from same gender and same race sub-samples, as well as combined data were used to postdict student CGPAs. The ACTComp score and HSGPA were independent variables in Model A, with the ACTComp score as the sole independent variable in Model B. Regression equations, validity coefficients, and intercepts were

Table 3. Comparisons of frequencies of over/under-postdictions of CGPAs by gender and race.

Model A: CGPA = ACTComp + HSGPA: R^2 = .2529, N = 1121		
	Over-Postdiction	Under-Postdiction
Gender		
Male ($\underline{n}$ = 553)	88	50
Female ($\underline{n}$ = 568)	65	84
($\underline{df}$ = 1) = 10.9, $\underline{p}$ < .001		
Race		
White($\underline{n}$ = 945)	128	123
Black ($\underline{n}$ = 176)	25	10
χ^2 ($\underline{df}$ = 1) = 4.4, $\underline{p}$ < .05		
Model B: CGPA = ACTComp: r^2 = .1398, N = 1121		
	Over-Postdiction	Under-Postdiction
Gender		
Male ($\underline{n}$ = 553)	92	39
Female ($\underline{n}$ = 568)	63	113
χ^2 ($\underline{df}$ = 1) = 34.3, $\underline{p}$ < .001		
Race		
White($\underline{n}$ = 945)	130	38
Black ($\underline{n}$ = 176)	25	11
χ^2 ($\underline{df}$ = 1) = 5.3, $\underline{p}$ < .02		

Table 4. Comparisons of frequencies of over/under-postdictions by race based on same gender sample.

Model A: CGPA = ACTComp + HSGPA		
	Over-Postdiction	Under-Postdiction
All Male Students (N = 553. R^2 = .2083		
White (n = 459)	62	64
Black (n = 94)	15	4
χ^2 (df = 1) = 4.7, p < .05		
All Female Students (N = 568. R^2 = .2757		
White(n = 486)	59	58
Black (n = 82)	8	6
χ^2 (df = 1) = .04, p > .05		
Model B: CGPA = ACTComp		
	Over-Postdiction	Under-Postdiction
All Male Students (N = 553. r^2 = .1326		
White (n = 459)	65	69
Black (n = 94)	14	6
χ^2 (df = 1) = 2.4, p > .05		
All Female Students (N = 568. r^2 = .1668		
White(n = 486)	65	66
Black (n = 82)	10	5
χ^2 (df = 1) = 1.0, p > .05		

derived from both predictive models based on the following samples of subjects: (a) total sample (N = 1121), (b) white students (n = 945), (c) black students (n = 176), (d) male students (n = 553), and (e) female students (n = 568) (see Table 2).

The CGPA for each student was individually postdicted by each regression model, within each sample, and compared with his/her actual CGPA. Actual CGPAs falling one standard error of estimate ($-SE_{est}$) below the regression line were defined as overpostdicted; CGPAs above $+SE_{est}$ were defined as underpostdicted.

Frequencies of over-the-postdictions of CGPAs based on both models and derived from the total sample were compared by gender and by race (see Table 3, 4, & 5).

Mean differences of ACTComp, HSGPAs, and CGPAs were analyzed by independent t tests as follows: male vs. female, black male vs. white male, black male vs. black female, black female vs. white female, and white male vs. white female (see Table 6).

Table 5. Comparisons of over/under-postdictions by gender based on same race sample.

	Over-Postdiction	Under-Postdiction
Model A: CGPA = ACTComp + HSGPA		
All White Students (N = 945. R^2 = .2230		
Males (n = 459)	78	55
Females (n = 486)	48	56
χ^2 (df = 1) = 3.2, p > .05		
All Black Students (N = 176. R^2 = .2516		
Males (n = 94)	17	7
Females (n = 82)	8	13
χ^2 (df = 1) =3.6, p > .05		
Model B: CGPA = ACTComp		
All White Students (N = 945. r^2 = .1059		
Males	73	30
Females	56	94
χ^2 (df = 1) = 26.2, p < .01		
All Black Students (N = 176. r^2 = .1529		
Males	16	8
Females	10	17
χ^2 (df = 1) = 3.4, p >.05		

Results

Postdictions of CGPAs based on the total college sample (N = 1121) revealed a significantly greater frequency of over-postdicted male CGPAs and under-postdicted female CGPAs with both predictive models (See Table 3). When comparing postdictions by race (N = 1121), there was a greater frequency of over-postdicted black student CGPAs derived from both models. All chi square (χ^2) analyses of frequencies of postdictions by race and gender were significant when based on total sample Models A and B (Table 3).

Table 6. Comparisons of gender and race differences between means of ACTComp. HSGPA and CGPA (Independent ts).

GROUPS	ACTComp	HSGPA	CGPA
Female vs Male	1.6	*8.01	*5.95
Black F vs Black M	0.06	*2.68	1.46
White F vs White M	2.08	*7.53	*4.78
Black vs White	*3.49	1.54	*9.01
Black F vs White F	*8.63	*5.71	*5.83
Black M vs White M	*9.38	0.24	*5.07

*Sig. $p < .01$

When postdictions of CGPAs were based on the all-male sample (Table 4), black males were significantly overpostdicted in Model A, but not in Model B. When the all-female sample was used, no race difference in postdiction was found in either model.

Postdictions by gender were analyzed (see Table 5) using both regression Models A and B and based on same-race samples. There were significantly over-postdicted CGPAs for male students and under-postdicted CGPAs for female students in Model B in the all white sample.

Analyses of differences between regression coefficients and intercepts (Table 2) by race and by gender revealed no significant difference in either model. The intercept difference between white and black student postdictions, Model B, approached significance ($t = 1.65$, $p > .05$). Validity coefficients (R^2) were significantly different between Model A and Model B, with HSGPA substantially contributing to the prediction efficiency of Model A. Validity coefficients in both models were consistently higher for female than for male student samples.

Discussion

Most high school students are required to take the SAT or ACT as part of the college admission procedures. The ACT is the predominant college admission tests used in West Virginia; however, some students are admitted to colleges based on other criteria. Only students for whom ACT scores were available were included in this study. Further, no effort was made to control for possible confounding effects of different curricula chosen by students, which may contribute to some gender and/or racial differences in CGPAs (Gamache & Novick, 1983).

Most studies have shown that predictions (medium $\underline{R} = .58$) of college freshmen GPA are more accurate when HSGPA is combined with the ACTComp. Postdiction accuracy in this study was substantially increased by including HSGPA with the ACTComp in the predictor model. Usually, reported validity coefficients in the literature have been somewhat higher for white students than for black students contrary to the results of this study (see Table 2) (Cleary & Grandy, 1984; Darlington, 1971).

Comparisons of CGPA and ACTComp (Table 1) revealed that the average CGPA of white students was higher than black students in this study. Also, the ACTComp scores were significantly higher for white than black students. Male students earned higher mean ACTComp scores than female students: however, their mean GPAs were lower. Gender differences also have been found on the SAT scores for the past several years (Cordes, 1986).

Results of this study support the hypothesis that female academic performance tends to be higher than expected while white male academic performance tends to be lower. Frequencies of over-under- postdictions are decreased when HSGPA is included in the predictive model. When the total sample ($\underline{N} = 1121$) was used in Model A, black student CGPAs were over-postdicted.

White students in this study earned higher ACTComp scores than black students; consequently, white students would be favored over black students in a college admission program when only an ACTComp cutting score is used. Frequently, minimum test scores are used in college admission procedures; as a result, black students would more likely be rejected than white students when only aptitude test scores are used in making college admission decisions.

Gender and racial differences were found in ACTComp scores, CGPAs and in postdictions of CGPAs (Tables 2 and 6). Historically, such differences have been explained by genetic, social, environmental, and demographic theories, others have argued that psychological tests are racially biased. Zajonc (1986) has posited the "confluence family expectation" model to explain racial differences in academic performances. Explanatory theories of gender and racial differences in academic achievement are elusive at best; no definitive theory has been developed.

From a pragmatic view, however, results of this study suggest that college admission policies should be cognizant of documented gender and racial differences in test scores and academic grades, as well as CGPA predictive differences, in an effort to minimize unintentional gender and/or racial discrimination in their college admissions procedures.

Literature Cited

1. Aleamoni, L. M., and L. Oboler. 1978. ACT versus SAT in predicting first semester GPA. Educational and Psychological Measurement. 38(2):393 - 399.

2. Boehm, V. r. 1977. Differential prediction: A methodological artifact? Journal of Applied Psychology. 62:146 - 154.

3. Calkins, D. S., and R. H. Whitworth. 1974. Differential prediction of freshman grade point average for sex and two ethnic classifications at a southwestern university. El Paso, Texas: University of Texas. (ERIC Document Reproduction Service No. ED 102 199).

4. Clark, M. J., and J. Grandy. 1984. Sex differences in the academic performance of Scholastic Aptitude Test takers (Report No. CB-R-84-8). New York, N.Y.: College Entrance Examination Board. (ERIC Document Reproduction Service No. ED 253 584).

5. Cleary, T. A., and T. I. Hilton. 1968. Test bias: Prediction of grades of Negro and White students in integrated colleges. Journal of Educational Measurement. 5:115-124.

6. Cole, N. S. 1973. Bias in education. Journal of Educational Measurement. 10:115-124.

7. Cordes, C. 1986. Test tilt: Boys outscore girls in both parts of SAT. The APA Monitor (June) p. 30.

8. Darlington, R. B. 1971. Another look at "cultural fairness". Journal of Educational Measurement. 8:71-82.

9. Gamache, L. M., and M. R. Novkick. 1983. Choice of variables and gender differentiated prediction within selected academic programs (RR105). Iowa City, Iowa: The American Testing Program.

10. Humphreys, L. G. 1973. Statistical definitions of test validity for minority groups. Journal of Applied Psychology. 58:1-4.

11. Hunter, J. E.. and F. L. Schmidt. 1978. Differential and single-group validity of employment tests by race: A critical analysis of three recent studies. Journal of Applied Psychology. 63:1-11.

12. Hunter, J. E., F. L. Schmidt, and R. Hunter. 1979. Differential validity of employment tests by race: A comprehensive review and analysis. Psychological Bulletin. 86(4):721-735.

13. Hunter, J. E., F. L. Schmidt, and J. M. Rauschenberger. 1977. Fairness of psychological tests: Implications of four definitions for selection utility and minority hiring. Journal of Applied Psychology. 62(3):245-260.

14. Linn, R. L. 1973. Fair test use in selection. Review of Educational Research. 43:139-161.

15. Linn, R. L. 1978. Single group validity, differential validity and differential prediction. Journal of Applied Psychology. 63:507-512.

16. Temp, G. 1971. Test bias: Validity of the SAT for blacks and whites in thirteen integrated institutions. Journal of Educational Measurements. 8:245-253.

17. Thomas, C. L. 1973. The overprediction phenomenon among black collegians: Some preliminary considerations. Paper presented at the annual meeting of the American Educational Research Association, New Orleans. February.

18. Thomas, P. J. 1975. Racial differences in the prediction of class "A" school grades. (TR 75-39). San Diego: Navy Personnel Research and Development Center.

19. Zajonc, R. B. 1986. The decline and rise of scholastic aptitude scores, a prediction derived from the confluence model. American Psychologist. 41:862-867.

Mathematics/ Statistics Section

Probability Distributions and the Definite Integral

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Abstract

Beginning with the most basic and elementery notations in probability, a mathematical model is developed for predicting the outcome of experiments based on assumptions about certain associated events. This model is stated in the form of a continuous function and its accompanying graph. Then using this function and its graph, it is shown how the areas under the graph can be used to calculate probabilities for various events.

Discussion

Probability theory attempts to develop models for predicting the outcomes of experiments based on assumptions about the likelihood of certain associated events occurring. Those assumptions are stated in the form of a function called a probability distribution. First, we shall develop the basic principles of probability theory that let us determine a function to use for this purpose. Secondly, we shall show how the definite integral is used to calculate probabilities for various events.

We shall develop these principles of probability theory that will lead us to a probability distribution function through a series of carefully chosen questions. We begin with the question:

QUESTION 1

HOW MANY DIFFERENT ORDERINGS, P, ARE POSSIBLE WITH N OBJECTS?

Table 1. Solution 1.

Objects	Number of objects	Permutations	Number of P.
A	1	(A)	1
A,K	2	((A,K),(K,A))	2
A,K,Q	3	((A,K,Q),(K,A,Q),(Q,A,K), (A,Q,K),(K,Q,A),(Q,K,A))	6
A,K,Q,J	4	$4! = 4 \cdot 3 \cdot 2 \cdot 1$	24
	-	-	-
	-	-	-
A,K,Q,,J,...	N	$N! = N(N-1)(N-2)\ldots(3)(2)(1)$	N!

Thus, there are N! different orderings possible with N objects.

QUESTION 2

IF ONE HAS FOUR FACE CARDS PLACED FACE-DOWN, WHAT IS THE PROBABILITY OF TURNING THE CARDS FACE-UP IN THE FOLLOWING ORDER: A, K, Q, J?

SOLUTION

Since there are 24 = 4! possible outcomes, the probability of selecting this single event (randomly of course) is:

$$P(A, K, Q, J) = 1/24$$

In Question 2, we have associated a probability value with a *single event*.

Now consider the set (A, B, C, D). Rank the objects by two's:

Table 2. Ranking four objects by two's.

Rank	Different Orderings 1	2	3	4	5	6	7	8	9	10	11	12
1	A	A	A	B	B	B	C	C	C	D	D	D
2	B	C	D	A	C	D	A	B	D	A	B	C

QUESTION 3

IF A COMMITTEE MUST RANK TWO APPLICANTS OUT OF A TOTAL OF FOUR THEY CONSIDER TO BE THE BEST FOR THE JOB, WHAT IS THE PROBABILITY THAT APPLICANTS A AND C WILL BE SELECTED WITH A RANKED FIRST?

SOLUTION

If we are concerned with order, i.e., "What is the probability that applicants A and C being selected with applicant A ranked first, and applicant C ranked second," then we have one possible event out of 12, or P(event) = 1/12.

We denote 4 objects taken 2 at a time:

$${}_4P_2 = 4!/(4-2)! = 4!/2! = (4*3*2*1)/(2*1) = 12$$

FORMULA 1
In general

$${}_nP_x = n!/(n-x)!$$

In QUESTION 3, we have associated a probability value with a *subset of events.*

In both QUESTION 2 and QUESTION 3, we have been concerned with the number of ways objects of a set can be ordered, i.e., the numbrer of ***permutations.***

Now, we may not be concerned with the order the committee ranks the two applicants. That is, we may be concerned only with which two have been selected. In this case two sets of objects are considered to be identical if they contain exactly the same elements, no matter how these objects are arranged.

A set of objects where order is unimportant is called a ***combination.***

Notice in Table 2 that ordering # 2 and # 7 represent the same two applicants, just in different order. This is also true for #'s 1 and 4; #'s 3 and 10; #'s 5 and 8; #'s 6 and 11 and #'s 9 and 12.

Thus, we have these six combinations:

Table 3. Combinations.

Different Combinations					
1	2	3	4	5	6
A	A	A	B	B	C
B ,	C ,	D ,	C ,	D ,	D

There are always fewer combinations than permutations for a given n and x, since different orderings do not count as combinations, but do count as permutations.

We saw in Table 2 that 4 objects taken 2 at a time gives us 12 permutations:

$${}_nP_x = n!/(n-x)! = 4!/(4-2)! = (4*3*2*1)/(2*1) = 12$$

permutations

And we saw in Table 3 that 4 objects taken 2 at a time gives us 6 combinations:

	$_nC_x$	=	$_4C_2$ = 6 combinations
Now,	$6 \cdot 2!$	=	12
Or,	$_nC_x \cdot x!$	=	$_nP_x$
=>	$_nC_x$	=	$_nP_x/x!$
but,	$_nP_x$	=	$n!/(n - x)!$
so,	$_nC_x$	=	$n!/(n - x)! \cdot 1/x!$
		=	$n!/[x!(n - x)!]$

FORMULA 2
Thus

$$_n C_x = n!/[x!(n - x)!]$$

QUESTION 4

WHAT IS THE PROBABILITY (ALL THINGS BEING EQUAL) THAT APPLICANT A WILL GET THE JOB?

SOLUTION

$$_nC_x = n!/[x!(n - x)!]$$

$$_4C_2 = 4!/[2!(4 - 2)!] = ((4 \cdot 3 \cdot 2 \cdot 1)/[2 \cdot 1)]) = 12/2 = 6$$

All things being equal, the probability that applicant A gets the job is 1/6.

QUESTION 5

THREE PEOPLE ARE ASKED IF THEY VOTED FOR GOVERNOR MOORE. DETERMINE THE OUTCOME "TWO VOTED *FOR*, ONE AGAINST"

From the following diagram we know that there are eight different sample points:

P(one sample pt.) = 1/8

The following sample points have two YES and one NO:

Relevant pts = (YYN), (YNY), (NYY) = 3.

In these circumstances the probability of an event can be determined by:

P(Event) = (No. of relevent points) X P(1 sample pt.)

Thus, P(2Y,1N) = (3)(1/8) = 3/8 = 0.375

OR, P(Event) = (No. of relevant points) X P(1 sample pt.)

$= {}_{n}C_{x}$ X P(1 sample pt.)

SOLUTION

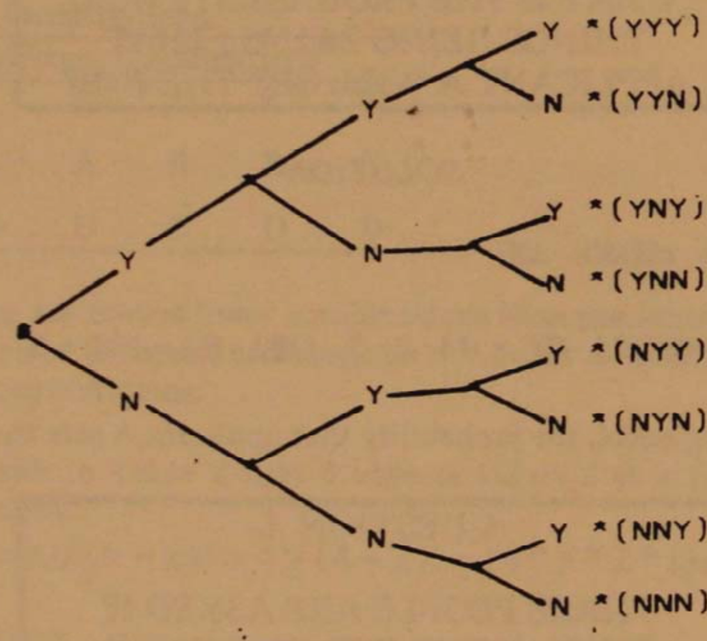


DIAGRAM 1

$$= (n!/[x!(n - x)!]) * (1/8)$$

$$= (3!/[2!(3 - 2)!]) * (1/8)$$

$$= (6/2) * (1/8)$$

$$= 3/8 = 0.375$$

Again, in QUESTION 5, we associated a probability value with a *subset of events.*

Finally, let us consider *all possible events* in an experiment.

QUESTION 6

SUPPOSE WE ROLL TWO DICE. WHAT IS THE PROBABILITY THAT WE WOULD ROLL A NINE?

SOLUTION

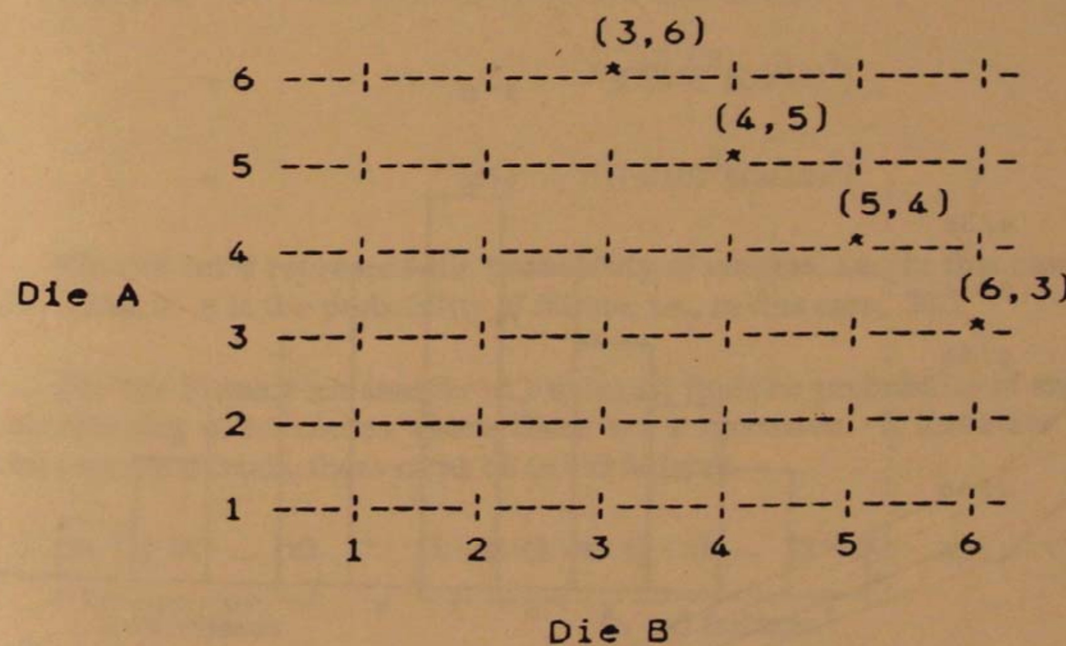


DIAGRAM 2

The probability of any value x is given by the number of sample points for which the number equals x, divided by the total number of sample points:

For (x = 9) ---> {(3,6), (4,5), (5,4),(6,3)] = 4 points
Thus, P(9) = 4/36 = 0.111

Let us determine the possibilities of all possible events and graph this distribution:

P(2) = 1/36 = 0.0278
P(3) = 2/36 = 0.0556
P(4) = 3/36 = 0.0833
P(5) = 4/36 = 0.1111
P(6) = 5/36 = 0.1389
P(7) = 6/36 = 0.1666
P(8) = 5/36 = 0.1389
P(9) = 4/36 = 0.1111
P(10) = 3/36 = 0.0833
P(11) = 2/36 = 0.0556
P(12) = 1/36 = 0.0278

Total = 1.0000

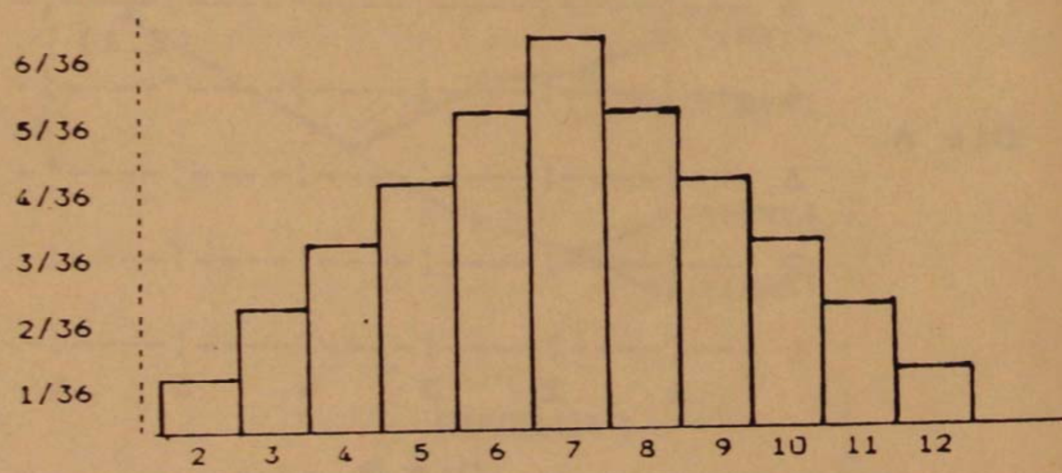


DIAGRAM 3

QUESTION 7

SUPPOSE FOUR COINS ARE RANDOMLY SELECTED FROM A BOX CONTAINING 70% DIMES AND 30% NICKELS. WHAT IS THE PROBABILITY THAT THREE OF THE FOUR COINS SELECTED WILL BE DIMES?

The probability that the first coin selected is a dime is .7. The probability that the first two coins are dimes is .7 • .7 and the probability that the first *three* coins are dimes is .7 • .7 • .7. And the probability of selecting a nickel is .3. Thus, the probability of selecting three dimes and one nickel is:

$$.7 \bullet .7 \bullet .7 \bullet .3 = 1029/10000 = 0.1029$$

There are four relevant points (combinations):

(d, d, d, n), (d, d, n, d), (d, n, d, d), (n, d, d, d)

P(Event) = (No. of relevant pts) • P(one such point)

$$= \quad {}_nC_x \quad \bullet [(7/10)^3][(3/10)^1]$$

$$= \quad {}_4C_3 \quad \bullet [(7/10)^3][(3/10)^1]$$

We will let π represent the probability of success, i.e., in this case, .70. Thus, 1 - π is the probability of failure, i.e., in this case, .30.

For the P(one such sample pt.) we must find the probability of any one ordering of outcomes where there are x successes. If there are x successes in n trials, there must be (n - x) failures.

$$\underbrace{(\pi)(\pi)(\pi)\ldots(\pi)}_{x \text{ successes}} \bullet \underbrace{(1-\pi)(1-\pi)(1-\pi)\ldots(1-\pi)}_{(n-x) \text{ failures}}$$

$$(\pi)^x \quad \bullet \quad (1-\pi)^{n-x}$$

Thus, $P(\text{Event}) = {}_nC_x \cdot [(\pi)^x(1 - \pi)^{n - x}]$

FORMULA 3
Therefore

$$P(\text{Event}) = \{n!/[x!(n - x)!]\} \cdot \{(\pi)^x (1 - \pi)^{n - x}\}$$

$$= \{4!/[3!(4 - 3)!]\} \cdot \{(.70)^3 (1 - .70)^{4 - 3}\} = 0.4116$$

Diagram 2 is the ***sample space*** and diagram 3 is the **probability distribution** for random variable x in Question 6.

For the experiment in Question 6 we can define many events and determine their probabilities. For example:

$P(x = 2, 3, \text{ or } 4)$	$= 1/36 + 2/36 + 3/36$	$= 1/6$
$P(x \leq 5)$	$= 1/36 + 2/36 + 3/36 + 4/36$	$= 10/36$
$P(3 < x \leq 5)$	$= P(x = 4) + P(x = 5) = 3/36 + 4/36$	$= 7/36$

DEFINITION 1

If X is a random variable on the sample space $(x_1, x_2, \ldots, x_n)$ and p_i is the probability $p_i = p(X = x_i)$ for $i = 1, 2, \ldots, n$, then the *expected value of X* $E(X)$, is:

$$E(X) = x_1p_1 + x_2p_2 + \ldots + x_np_n$$

For the experiment in Question 6 the expected value of X is:

$$E(X) = 2(1/36) + 3(2/36) + 4(3/36) + 5(4/36) + 6(5/36) + 7(6/36) + 8(5/36) + 9(4/36) + 10(3/36) + 11(2/36) + 12(1/36) = 7.$$

> **DEFINITION 2**
>
> **Variance**
>
> The variance of X, V[X], is the expected squared deviation of the values of X around their expected value E[X]:
>
> $$V[X] = E[(X - E[X])^2]$$
> $$= (X_1 - E[X])^2 P_1 + (X_2 - E[X])^2 P_2 + \ldots + (X_n - E[X])^2 P_n.$$

For the experiment in Question 6 the variance of X is:

$$V(X) = (2 - 7)^2(1/36) + (3 - 7)^2(2/36) + (4 - 7)^2(3/36) + (5 - 7)^2(5/36) + (6 - 7)^2(5/36) + (7 - 7)^2(6/36) + (8 - 7)^2(5/36) + (9 - 7)^2(4/36) + (10 - 7)^2(3/36) + (11 - 7)^2(2/36) + (12 - 7)^2(1/36) = 35/6.$$

> **DEFINITION 3**
>
> **Standard Deviation**
>
> The standard deviation, sigma, of a random variable X is:
>
> sigma = $\sigma = SQR(V[X])$

For the experiment in Question 6 the standard deviation is:

$$\sigma = SQR(V[X]) = SQR(35/6) = 2.415$$

In many situations the outcome of an experiment can be one of infinitely many real numbers.

A random variable that can equal any number in an interval (its sample space) is a ***continuous random variable*** .

It is apparent we cannot assign individual probabilities to each of the numbers in such a sample space as we did in Definitions 1, 2, and 3 above.

Thus, for continuous probabilities, $P(a \leq X \leq b)$, we define a ***probability density function*** as:

DEFINITION 4

Probability Density Function

$$P(a \leq x \leq b = \int_a^b f(x)dx$$

In diagram 3, there exist a graph, $y = f(x)$, [see diagram 3(a) below] so that the total area (1.000) of the sum of the rectangles is beneath the curve:

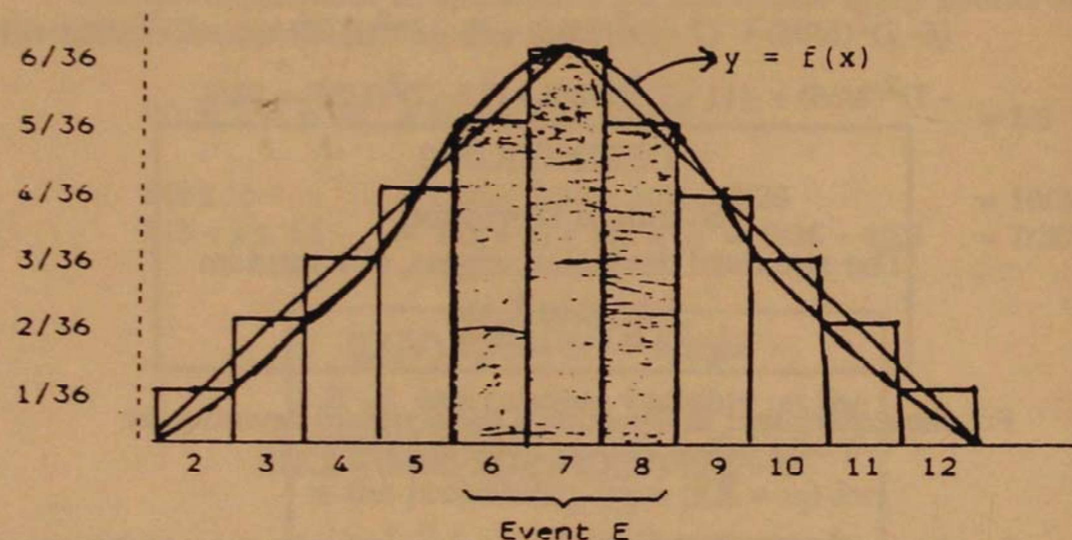


Diagram 3(a)

Notice that the area under the curve that forms a triangle with the x-axis is NOT equal to 1. Rather:

$$A = (1/2)bh = (11/2)(6/36) = 11/12.$$

However, the area under the curve, $y = f(x)$ does equal 1.

Now consider the Event E.

In the discrete case [sum of the areas of the three rectangles in diagram 3(a)] the probability of Event E = (6, 7, 8) is: $P(6 \leq x \leq 8) = P(6) + P(7) + P(8)$.

In the continuous case (shaded area) the probability of Event E = [a, b] is:

$$P(a \leq X \leq b) = \int_a^b f(x)dx$$

So we see that a probability density function determines the probability of an event associated with a random variable.

When we specify the cumulative probability associated with all values of the random variable less than or equal to a given number we define a similar, but different, function called a ***distribution function***, F(X):

$F(X) = P(X \leq x)$, for all x in the sample space for X.

Thus, we have the following relationship between the continuous probability density function, f, and the associated distribution function, F:

$$\begin{aligned}\int_a^b f(x)dx &= P(a \leq x \leq b)\\ &= P\{x \leq b\} - P\{x \leq a\}\\ &= F(b) - F(a).\end{aligned}$$

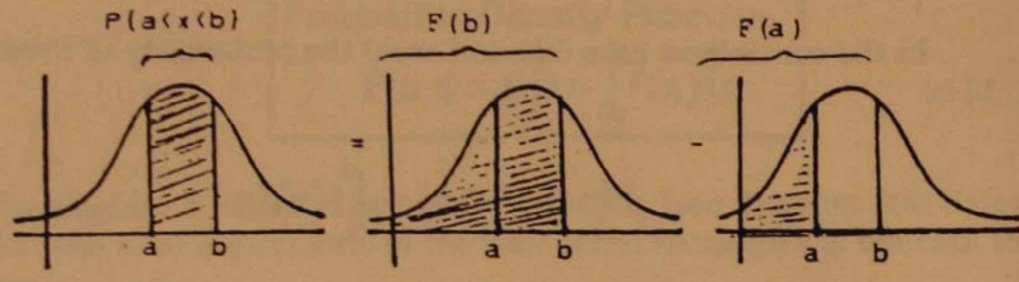
That is:

FORMULA 4
The Definite Integral

$$\int_a^b f(x)dx = F(b) - F(a)$$

The distribution function of F gives the area $\int_a^b f(x)dx$ of the region bounded by the probability density function on an interval [a, b].

Formula 4 is illustrated in Diagram 4 below:



$P[a \leq X \leq b] = \int_a^b f(x)\, dx \quad = \quad F(b) \quad - \quad F(a)$

Diagram 4

QUESTION 8

FIND THE NUMBER a SO THAT THE FUNCTION F(X) = aX(X - 4) IS A PROBABILITY DENSITY FUNCTION ON THE SAMPLE SPACE [0,4].

SOLUTION

Since the probability associated with an entire sample space is always one, the integral of f over the entire sample space must equal one. So we must find "a" such that:

$$\int_0^4 ax(x-4)dx = 1.$$

$$\int_0^4 ax(x-4)dx = a * \int_0^4 \left(x^2 - 4x\right)dx$$

$$= a * \left(x^3/3 - 2x^2\right)\Big|_0^4$$

$$= a * (64/3 - 32)$$

$$= a * (-10\ 2/3)$$

$= -10\ 2/3 * a = 1$

thus, $a = 1/(-32/3) = -3/32$

Therefore: $f(x) = (-3x/32)(x - 4) = \left(\frac{-3}{32}\right)(x^2 - 4x)$

The probability density function:

$$\left(\frac{-3}{32}\right)(x^2 - 4x)$$

is illustrated in diagram 5.

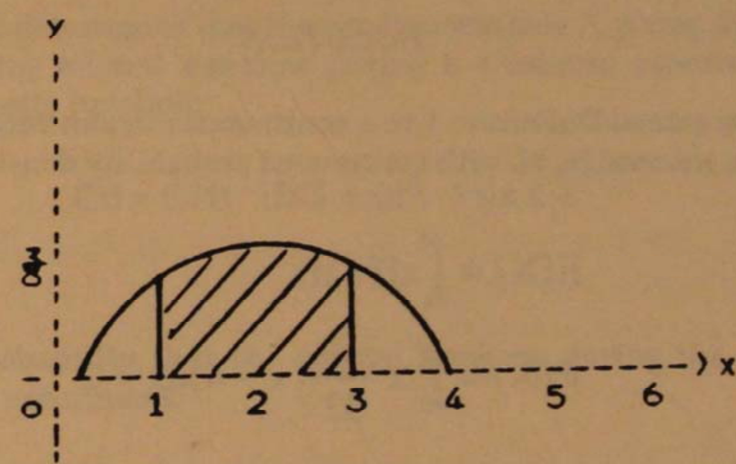


Diagram 5

QUESTION 9

FOR THE PROBABILITY DENSITY FUNCTION IN QUESTION 8 FIND P(1 ≤ X ≤ 3

SOLUTION

According to Formula 4 we have:

$$P(1 \le x \le 3) = \int_1^3 \left(\frac{-3x}{32}\right)(x-4)dx$$
$$= (-3/32)\int_1^3 (x^2 - 4x)dx$$
$$= (-3/32)(x^3/3 - 2x^2)\Big|_1^3$$
$$= 11/16$$

QUESTION 10
FIND THE EXPECTED VALUE OF THE RANDUM VARIABLE X WITH PROBABILITY DENSITY FUNCTION: F(X) = (-3X/32)(X - 4) ON [0,4].

SOLUTION

Let us extend Definition 1 to a continuous random variable X defined on a finite interval [a, b], with continuous probability density function f:

$$E(X) = \int_a^b xf(x)dx$$
$$E(X) = \int_0^4 x\frac{-3x}{32}(x-4)dx = 2$$

Since this function is a parabola with axis of symmetry x = 2, which is the midpoint of the sample space [0, 4], we are not surprised that the expected value is 2.

Extending Definition 2 we find the variance associated with the continuous random variable X on sample space [a, b] to be:

$$V[X] = E\left([X - E(X)]^2\right)$$
$$= \int_a^b [X - E(X)]^2 f(x)dx$$

Now, $\quad E(X) = 2$ and $f(x) = (-3x/32)(x - 4)$

so, $$\int_0^4 (x-2)^2 * (-3x/32)(x-4)dx = 8/10.$$

Thus, .8 is the expected value of the square of the deviations of X from its expected value.

The standard deviation for the above function would be:

$$\sigma = SQR(.8) = 0.894$$

The following example illustrates how the area under the graph of a continuous function can be used to calculate probabilities for various events.

EXAMPLE

A biologist determines that the random variable X giving the time at which a sleeping animal awakens during a 4 minute experiment has probability density function:

$$f(x) = (5/4) \cdot [1/(1+x)]^2, \; 0 \le x \le 4.$$

Find:

a. the probability that the animal awakens during the first two minutes of the experiment.

b. the probability that the animal awakens after one minute but before the experiment ends.

SOLUTION:

a.

$$\int_0^2 (5/4) * [1/(1+x)]^2 dx$$

$$= (-5/4)[1/(x+1)]\Big|_0^2 = 5/6 = 0.83$$

---

b. $$= (-5/4)[1/(x+1)]\Big|_1^4 = 3/4 = 0.75$$

Literature Cited

1. Eves, H. 1976. An Introduction to the History of Mathematics. 4th edition. Holt, Rinehart, and Winston. New York.

2. Hacking, I. 1975. The Wmergence of Probability. CambridgeUniv. Press. London.

3. Kline, M. 1972. Mathematical Thought from Ancient to Modern Times. Oxford Univ. Press. New York.

4. Maistrov, L. E. 1974. Probability Theory -- A Historical Sketch. Academic Press. New York.

5. Pearson, E. S., and M. S. Kendall. 1970. Studies in the History of Statistics and Probability. Hafner Pub. Co. Conn.

6. Todhunter, I. 1949. A History of the Mathematical Theory of Probability. Chelsea Pub. Co. New York.

Minutes of the Sixty-Seventh Annual Meeting
West Virginia Academy of Science
April 4, 1992
West Liberty State College
West Liberty, West Virginia

Executive Session 10:00 A. M.

1. Members present: Dr. Don Tarter, Dr. Tom Weaks, Ben Stout, Ralph Booth, Roger Sebert, Dr. Andy Cook, and Dr. Phil Cottrill.

2. Dr. Tom Weaks: "The abstracts of papers have not been published since 1984. Biology abstracts are going to be published. We must get back to publishing the abstracts that the informed membership needs."

3. The Science Fair (Junior Academy) will be held soon at West Liberty State College. The West Virginia Institute of Technology voted to take the Science Fair for next year. President Tarter thanked West Liberty for hosting the Science Fair.

4. President Tarter thanked the executive committee for their work.

5. Dr. Martin from West Virginia State talked about the problem of acid precipitation in West Virginia. He proposed a symposium of The Academy in conjunction with fisheries organizations to find a solution to the problem. President elect Weaks said this would be taken up at the October (1992) planning meeting.

6. Executive session ended at 10:20 A. M.

General Session 10:25 A. M.

1. Welcome by President Tarter.

2. Welcome by Dr. Lawrence H. Bailey, Vice President of West Liberty State College.

3. Guest speaker: Raymond C. George, U.S. Environmental Protection Agency. Mr. George presented a history of the EPA, its present organization, and its current goals.

4. End General Session at 11:41 A. M.

Luncheon General Session 12:10 P. M.

1. Outstanding Teacher Awards:

   Darlene Boyles, Fairmont Senior High School

   Ed Keller, III, Morgantown Elementary School

Business Meeting 12:21 P. M.

1. Welcome by President Tarter.

2. Plaque presented to Dr. Andy Cook for chairing the West Liberty meeting.

3. Dr. Andy Cook, Treasurer of the Academy, gave his report. The Academy had a bank certificate of deposit in the amount of $7,637.10. The figures in the Treasurer's report were from former Treasurer, Dr. Roy Clarkson.

4. Dr. Tom Pauley reported from the nominating committee that Ralph Booth from Davis and Elkins College was nominated for Presidcent Elect. It was moved and seconded that the Academy nominate Ralph Booth for President Elect. The members voted in the affirmative.

5. The future annual meetings will be held:

   1993 - Davis and Elkins College
   1994 - Fairmont State College
   1995 - Marshall University
   1996 - Concord State College

6. Dr. Ed Keller, Jr. said the 1991 Proceedings of the Academy are being readied. Dr. Keller said that Dr. John Chisler at Glenville State College does all the setups to save costs. The 1990 Proceedings are being processed.

7. Dr. Tom Weaks presented research about the number and topics of Academy papers. He made available a list called "Profile of Publications." He said we needed more papers from the chemistry content area.

8. President-Elect Weaks presented a plaque to Dr. Don Tarter to recognize his work as President of the Academy.

9. Dr. Roger Seebert, West Liberty State College, discussed the State Science Fair and the Junior Academy. President Elect Weaks said we should create a committee to study the Science Fair.

10. 12:53 P.M. Outgoing President Tarter presented the Academy gavel to new President Weaks.

11. 12:55 meeting adjourned.

Minutes presented by
Dr. Phil Cottrill
Glenville State College

WEST VIRGINIA ACADEMY OF SCIENCE

Annual Treasurer's Report
January 1, 1991 to December 31, 1991

April 4, 1992
West Liberty State College
West Liberty, WV 26074

BANK BALANCE JANUARY 1, 1991		**$4,048.29**
CASH RECEIPTS	1,700.00	
Institutional Membership	1,600.00	
Libraries	1,035.00	
Contributions (Talent Search)	125.00	
Annual Meeting	401.00	
Interest (Checking Account)	82.42	
Advertisements	75.00	
Abstract Charges	170.00	
Contributions (DuPont, Etc.)	0.00	
WVU Library (Exchange Copies)	0.00	
TOTAL CASH RECEIPTS FOR YEAR	**$5,188.42**	
TOTAL CASH RECEIPTS PLUS BALANCE		**$9,236.71**
CASH DISBURSEMENTS		
Printing	1,797.25	
NAAS Dues	27.00	
Plaques	74.00	
Talent Search	175.00	
Annual Meeting	129.90	
Postage & Shipping	225.89	
Best Student Paper	273.90	
Editorial Help	20.70	
Miscellaneous	652.87	
TOTAL CASH DISBURSEMENTS FOR YEAR	**$3,376.51**	
BANK BALANCE DECEMBER 31, 1991		**$5,860.20**

In addition to the above: CD No. 001-D158099 is held by the First National Bank of Morgantown. Value on anniversary date April 8, 1992 is $7,634.10.

Respectively submitted,

H. A. Cook, Treasurer WVAS