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Standing Crops of Elements and Atomic Ratios in a Small Mammal Community*

[With 4 Tables]

Specimens of *Blarina brevicauda*, *Peromyscus gossypinus* and *Ochrotomys nuttalli* were analyzed for their content of calcium, potassium, sodium, magnesium, iron and zinc. Elemental concentrations and atomic ratios for every element except iron were found to be essentially the same for each species. Standing crops of these six elements were calculated for the small mammal populations of two sites located in the lowland mesic-hardwood forests on the Savannah River Plant in South Carolina, USA. Total standing crops of elements were similar for all sites regardless of the presence or absence of certain species of the small mammal community.

I. INTRODUCTION

Under the impetus of the International Biological Program, much emphasis has recently been placed on the flow of matter and energy through ecological systems (Goldman, 1966; Petrusewicz, 1967). The measurement of the standing crop of various elements within the biomass is a first step toward understanding mineral cycling. Elements follow stoichiometric relationships in biogeochemical cycling. It is thus important to look at the atomic ratios when studying the relationships between elements (Harvey, 1957) and ultimately, the transfer coefficients between compartments of the system. It is with these considerations in mind that the present preliminary study on a small mammal community was undertaken.

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II. METHODS

In the late summer of 1968, specimens of *Blarina brevicauda* (Say, 1823), *Peromyscus gossypinus* (Le Conte, 1853) and *Ochrotomys nuttalli* (Harlan, 1823) were snap-trapped on two Polish Standard Minimum grids (Grodziński, Pucek & Ryszkowski, 1966) located in a lowland mesic-hardwood forest. The habitat at these two sites (Holly Road and Mill Creek), on the Savannah River Plant near Aiken, South Carolina USA has been described by Gentry, Golley & Smith (1968). They are relatively stable forest environments with no history of logging or other disturbance by man for at least 20 years. Since the habitats were similar, data from animals from both sites were combined for statistical analysis. Each animal was dried at 60°C, weighed, redried and digested by the ternary acid digestion procedure (Jackson, 1958). Some of the dried specimens were ground in a Wiley mill with a no. 20 mesh screen before digestion and others were digested intact. They were individually analyzed for calcium, potassium, sodium, magnesium, iron and zinc on a Perkin-Elmer Model 290 atomic absorption spectrophotometer. Atomic ratios were calculated by dividing the concentration (ppm) by the atomic weight of each element.

III. RESULTS

The elemental composition of the three species are shown in Table 1. Data from ground and unground specimens are also shown for comparison. Atomic ratios for each element expressed as a percentage of calcium are given in Table 2. Calcium was used as the basis for comparison because it was the most abundant of the six elements.

The means and variances of all the elemental compositions were rank ordered for the three species. The results were tested by a Chi-Square test in which expected values were calculated assuming a random distribution. If the distribution were log normal, the rank order of the variance and the mean should be correlated. However, this is not the case ($P<.09$; $\chi^2=3.074$; $df=1$), and the trend was in the opposite direction from that expected from a log normal distribution. This strongly indicates that the data were normally distributed.

Population density estimates on two other sites containing similar habitats (Water Gap Road, Kaufman, *et al.*, 1971 and Cato Road, Smith, *et al.*, 1971) were used in conjunction with our elemental composition figures to calculate an area-based standing crop of elements contained in the small mammal biomass. One of these habitats was more diverse than the Holly Road and Mill Creek sites where the animals used for elemental analysis were collected. Cato Road was an area of uniform habitat very similar to the first two sites. Water Gap Road was much larger and could be roughly divided into three separate areas: Area 1 had a large number of fallen logs on the ground, no vines and some dwarf palmetto trees (*Sabal minor* (Jacq.) Pers.); Area 2 had many vines

Table 1

The elemental composition (ppm dry weight) of three species, *Blarina brevicauda*, *Peromyscus gossypinus*, and *Ochrotomys nuttalli*. Speciemens were digested whole or after being ground in a Wiley Mill. Standard error ($S_{\bar{x}}$), number in sample and coefficient of variation (*CV*) are also given.

	Calcium	Potassium	Sodium	Magnesium	Iron	Zinc
Blarina-Ground ($N=12$)						
Mean	34900	14700	4010	1206	710	110
$S_{\bar{x}}$	1566	778	360	36	70	7
CV	15	17	31	10	34	22
Blarina-Whole ($N=4$)						
Mean	34400	17200	4220	1438	500	120
$S_{\bar{x}}$	1532	509	147	74	38	8
CV	8	5	6	10	15	13
Blarina-Combined ($N=16$)						
Mean	34700	15300	4060	1264	660	116
$S_{\bar{x}}$	1210	671	270	50	57	6
CV	14	16	26	16	34	20
Peromyscus-Ground ($N=10$)						
Mean	35300	17700	3470	1343	430	120
$S_{\bar{x}}$	1986	741	186	63	9	14
CV	17	13	16	14	50	36
Peromyscus-Whole ($N=3$)						
Mean	40500	16700	2380	1234	220	98
$S_{\bar{x}}$	5134	1318	588	141	13	8
CV	21	13	42	19	10	13
Peromyscus-Combined ($N=13$)						
Mean	36500	17500	3220	1318	380	118
$S_{\bar{x}}$	1913	629	226	57	58	11
CV	19	13	25	16	55	35
Ochrotomys-Ground ($N=11$)						
Mean	41200	16500	3780	1396	440	130
$S_{\bar{x}}$	1357	767	163	49	96	5
CV	10	15	14	11	72	13
Ochrotomys-Whole ($N=5$)						
Mean	37400	19200	3570	1377	240	110
$S_{\bar{x}}$	4331	772	251	117	15	10
CV	25	8	15	18	14	18
Ochrotomys-Combined ($N=16$)						
Mean	40000	17300	3700	1390	374	123
$S_{\bar{x}}$	1615	651	134	47	69	4
CV	16	15	14	14	74	15
All Animals-Ground ($N=33$)						
Mean	37100	16300	3770	1311	530	120
$S_{\bar{x}}$	1047	477	153	31	65	5
CV	16	17	23	14	70	25
All Animals-Whole ($N=12$)						
Mean	37100	18000	3490	1361	320	120
$S_{\bar{x}}$	2173	585	268	63	41	6
CV	20	11	26	16	45	17
All Animals-Combined ($N=45$)						
Mean	37100	16700	3690	1324	480	120
$S_{\bar{x}}$	949	399	133	28	51	4
CV	17	16	24	14	71	23

Table 2

Atomic ratios or relative concentration of various elements in the bodies of three species of small mammals. All elements are expressed as a percentage of the value for calcium plus or minus one standard error.

Species	Sample Size	Calcium	Potassium	Sodium	Magnesium	Iron	Zinc
Blarina brevicauda							
Whole	4	100	50.83 ± 1.52	21.43 ± .66	6.87 ± .18	1.06 ± .11	.22 ± .01
Ground	12	100	45.74 ± 3.46	20.27 ± 1.75	5.78 ± .21	1.49 ± .17	.20 ± .02
Combined	16	100	46.83 ± 2.77	20.56 ± 1.31	6.04 ± .20	1.38 ± .14	.20 ± .01
Peromyscus gossypinus							
Whole	3	100	43.23 ± 4.34	10.70 ± 2.70	5.20 ± .29	.39 ± .03	.15 ± .02
Ground	10	100	52.53 ± 3.24	17.38 ± .90	6.32 ± .17	.85 ± .12	.21 ± .02
Combined	13	100	50.38 ± 2.84	15.83 ± 1.19	6.06 ± .20	.74 ± .11	.20 ± .02
Ochrotomys nuttalli							
Whole	5	100	54.74 ± 5.01	17.28 ± 2.06	6.28 ± .68	.46 ± .04	.19 ± .01
Ground	11	100	41.58 ± 2.95	16.22 ± 1.05	5.62 ± .22	.78 ± .20	.18 ± .01
Combined	16	100	45.69 ± 2.93	16.55 ± .94	5.83 ± .26	.68 ± .14	.19 ± .01
All Animals Whole and Ground	45	100	47.48 ± 1.64	17.77 ± .72	5.97 ± .13	.64 ± .09*	.20 ± .01

* Values for Iron calculated from whole animals only.

Table 3

Standing crops of six elements (g/ha) in the small mammals at two sites in a lowland mesic-hardwood forest. Areas 1, 2, and 3 are subdivisions of the Water Gap Road site.

	Elements					
Species	Calcium	Potassium	Sodium	Magnesium	Iron	Zinc
Cato Road						
Blarina	.508	.224	.060	.019	.007	.002
Peromyscus	.917	.397	.005	.032	.006	.003
Ochrotomys	1.041	.456	.083	.034	.006	.003
Subtotal	2.466	1.077	.228	.085	.019	.008
Water Gap Road Area 1-Logs						
Peromyscus	1.663	.719	.154	.058	.010	.005
Ochrotomys	.328	.142	.030	.011	.002	.001
Subtotal	1.991	.861	.184	.069	.012	.006
Water Gap Road Area 1-Vines						
Blarina	.287	.127	.034	.010	.004	.001
Ochrotomys	1.012	.443	.081	.033	.006	.003
Subtotal	1.299	.570	.115	.043	.010	.004
Water Gap Road Area 3-Palmetto						
Blarina	.016	.007	.002	.001	.000	.000
Peromyscus	.403	.174	.037	.014	.002	.001
Ochrotomys	.865	.378	.069	.029	.005	.003
Subtotal	1.284	.559	.108	.044	.007	.004
Water Gap Road Entire Plot						
Blarina	.103	.046	.012	.004	.002	.000
Peromyscus	.706	.305	.065	.025	.004	.002
Ochrotomys	.864	.378	.069	.029	.005	.003
Subtotal	1.673	.729	.146	0.58	.011	.005

(*Vitis* and *Smilax* sp.) on the ground, some dwarf palmetto but no logs; and Area 3 had no logs or vines but many small dwarf palmetto trees. All sites and subsites can still be considered to be lowland mesic-hardwood forest. Standing crop values for each element and species were calculated for Cato and Water Gap Roads and the three subsections of Water Gap Road (Table 3).

There was no statistically significant difference induced by grinding animals in a Wiley mill except in the case of iron (Table 1). Grinding appears to add iron to the dry material and increases the coefficient of variation for the analytical determinations of this element. Therefore, in subsequent calculations only the iron values from unground animals were used. Values for the concentrations of calcium, sodium, magnesium, potasium and zinc from ground and whole animals were pooled for each species because the means plus or minus two standard errors overlapped for the two treatments. The same considerations are true for atomic ratios (Table 2). There was also an overlap between species in all elemental concentrations except in iron (Table 1 and 2). Lack of difference in concentrations of elements along with low coefficients of variation indicate that there are probably no statistically significant concentrational differences between the animals at the two sites.

IV. DISCUSSION

B. brevicauda had an iron concentration of 500 ppm while *O. nuttalli* and *P. gossypinus* had concentrations of 240 and 220 ppm respectively. The difference between the smaller *Blarina* and the other two species can probably be attributed to the ratio of body size to blood volume in mammals. Although blood volumes depend on many functional constants such as cardiac output, renal clearances, or total body water (Gregersen & Rawson, 1959), relative blood volume decreases with increasing body size in mammals (Prosser & Brown, 1961). Since more than half of the iron present in the body occurs as hemoglobin in the blood (McDonald, Edwards & Greenhalgh, 1966), it is reasonable to assume increased relative blood volume in *B. brevicauda* ($\bar{X}=2.3$ g dry weigth per animal) would be correlated with an iron content higher than that of *O. nuttalli* or *P. gossypinus* ($\bar{X}=4.6$ and 6.3 g dry weight per animal, respectively).

The statistical overlap of the mean concentrations of the other elements is somewhat surprising. This overlap occurs both in absolute concentration and in the atomic ratios (Tables 1 and 2). One is tempted to postulate that there is no difference between the relative amounts of various elements stored in small mammals except that due to body size.

If this is true, then as a first approximation in ecosystem analysis, population density estimates on a gram dry weight per hectare basis times the concentrations of the elements presented in this paper equals the standing crop of these elements on a per hectare basis. The use of a simple calculation instead of the laborious collecting, processing, and analyzing of representative native mammals would greatly aid the study of the flow of matter through large ecosystems such as the lowland mesic-hardwood type.

Lack of suitable data hinders confirmation of the hypothesis that the concentration of the suite of elements within a small mammal and the atomic ratios of these elements to each other with the exception of iron remains constant across species. There are many analyses of various organs (*e.g.*, Tipton & Cook, 1963; Wiener, Field & Wood, 1969; Yunice, Perry & Perry, 1968) and some whole body data for one or two elements (Kinnamon, 1966; Schlicker & Cox, 1968) but very few values for whole body data on a multiple suite of elements. Davis & Golley (1963) and Bowen (1966) attempted to construct a table of elemental composition in dry mammal tissue from organ data such as that of Tipton & Cook (1963) or Spector (1956). The relationship of ppm dry mammal=0.33 ppm dry bone+0.67 ppm dry muscle was used, thus ignoring the elemental composition of the blood and internal organs. Deuver & Golley (unpubl.) collected data on the elemental composition of mammals in the Panamanian rain forest, however these data were not limited to small mammals. The results of Bowen (1966), Davis & Golley (1963), and Deuver & Golley (unpubl.) along with our own are shown in Table 4. The

Table 4

Absolute concentration of various elements and atomic ratios in mammals as calculated by Bowen (1966; B), Deuver & Golley (unpublished; DG), Davis & Golley (1963; GD) & the present work (BY). Data are presented as a percentage of calcium.

Calcium	Potassium	Sodium	Magnesium	Iron	Zinc	Ref:
			PPM — Dry Weight			
85,000	7,500	7,300	1,000	160	160	B
11,645	3,847	3,990	2,298	3,737	251	DG
15,000	3,500	2,500	500	40	8	GD
37,100	16,700	3,690	1,324	480	120	BY
			Atomic Ratios			
100	9.05	14.15	1.94	.14	.14	B
100	33.87	45.79	32.52	23.03	1.32	DG
100	23.92	29.06	5.44	.19	.04	GD
100	47.48	17.77	5.97	.64	.20	BY

discrepancies in these data both in absolute concentration and in atomic ratios make it clear that either the hypothesis regarding the uniformity of elemental concentrations and atomic ratios in small mammals is invalid or that sufficient data is not yet available. Similar techniques and methods should be used over a wide range of habitats and species to demonstrate the validity of the hypothesis for small mammals.

1. Standing Crops of Elements

In the lowland mesic-hardwood forests of the Savannah River Plant, the three species, *B. brevicauda*, *P. gossypinus* and *O. nuttalli*, make up between 79 and 98% of the small mammal fauna (Gentry *et al.*, 1968; Smith *et al.*, 1971). Thus the standing crop of elements contained within the bodies of these three species account for most of the material contained within the entire small mammal community. The Cato Road sample contained a larger standing crop of biomass (63.62 g dry weight per ha) than the sample from Water Gap Road (37.19 g dry weight per ha). The small mammal fauna at Water Gap Road had only 58.5% as much biomass as the standing crop at Cato Road. The standing crop of elements followed the same general pattern of standing crop of dry biomass. The population of mammals at Water Gap Road had 67.8% as much calcium, 67.7% as much potassium, 64.0% as much sodium, 68.2% as much magnesium, 57.9% as much iron and 62.5% as much zinc per ha as did the mammals at Cato Road.

Species differences among the subsections at the Water Gap Road were found. *B. brevicauda* was completely missing from Area 1 while *P. gossypinus* was not present in Area 2. All three species occurred in Area 3. In all three areas the total standing crops of elements were quite similar (Table 3), suggesting that when one species is not present the other two avail themselves of the mineral resources normally used by the absent member of the community. This hypothesis however, needs additional support.

2. Normal Distribution of Elemental Composition

The lack of a skewed distribution (*e. g.*, log normal) for elemental concentrations argues for the fact that there is as strong a selection pressure against a small mammal having too much of any one given element as against having too little. This has long been known to animal nutritionalists (Maynard & Loosli, 1962) and is in contrast to the luxury consumption of trace elements in plants (Allen & Pearsall, 1963; Gerloff & Skoog, 1957). Perhaps there is a theoretical physiological explanation; an animal as opposed to a plant can not very too far from the optimum concentrations of his natural suite of elements without approaching toxic conditions.

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BIOMASA I CIĘŻARY ATOMOWE PIERWIASTKÓW W ZESPOLE DROBNYCH SSAKÓW

Streszczenie

Na dwóch powierzchniach polskiej metody Standard Minimum założonych w nizinnym, mezotroficznym lesie liściastym (Południowa Karolina, USA) łowiono osobników *Blarina brevicauda, Peromyscus gossypinus* i *Ochrotomys nuttalli.* Analizowano zawartość wapnia, potasu, sodu, magnezu, żelaza i cynku w ciele zwierząt. Stwierdzono, że zawartość tych pierwiastków (Tabela 1) oraz ich ciężary atomowe (Tabela 2) z wyjątkiem żelaza, były zasadniczo jednakowe dla każdego gatunku (zawartość w ppm suchej masy: Ca — 37 100; K — 16 700; Na — 3690; Mg — 1324; Fe — 220—500; Zn — 120) (Tabela 1). Biomasę tych sześciu pierwiastków w drobnych ssakach wyliczono też dla dwóch innych stanowisk w takim samym na ogół środowisku. Jedno stanowisko zawierało tylko 58,5% suchej masy drugiego stanowiska. Biomasa pierwiastków wykazywała identyczny ogólny układ przy wahaniach od 57,9 do 68,2% w zależności od pierwiastka. (Całkowita biomasa pierwiastków w g/ha: Ca — 1,67—2,47; K — 0,73—1,08; Na — 0,15—0,23; Mg — 0,06—0,09; Fe — 0,01—0,02; Zn — 0,005—0,008) (Tabela 3). Całkowita biomasa pierwiastków była podobna we wszystkich stanowiskach bez względu na obecność lub brak pewnych gatunków w zespole drobnych ssaków. To sugeruje, że gdy jakiś gatunek nie występuje, pozostałe dwa zużywają zasoby mineralne normalnie zużywane przez brakującego członka zespołu. Porównawcze dane z literatury wykazały poważne rozbieżności co do całkowitych zawartości pierwiastków w ciałach ssaków (Tabela 4).