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EFFECTS OF SELECTED LIMNOLOGICAL FACTORS ON THE
ACCUMULATION OF ^{137}CS FALLOUT BY
LARGEMOUTH BASS (*MICROPTERUS SALMOIDES*)¹

MASTER

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ABSTRACT

Variation between ^{137}Cs concentrations in natural populations of largemouth bass in six southern Michigan lakes was studied. The lakes were selected to provide a wide range of limnological types ranging from very low to high specific conductance.

Mean ^{137}Cs concentrations of age-three bass collected from each of the six study lakes during June, 1969, were compared and a multiple regression analysis was performed to determine the correlation between water chemistry parameters (Na, K, ^{137}Cs , total Cs and specific conductance) and the accumulations of ^{137}Cs by bass. Simple correlation coefficients indicated inverse relationships between total Cs, Na and specific conductance of lake water and ^{137}Cs activity of bass, with specific conductance providing the best linear fit ($R^2 = -0.8716$).

Multiple regression analysis altered the relative importance of each water parameter and resulted in the deletion of Na and specific conductance from the model due to lack of significant addition to the multiple correlation coefficient. The estimated linear prediction equation is:

$$^{137}\text{Cs}_{\text{Bass}} \text{ pCi/gm wet wt} = 1.5912 + 6.8118 (^{137}\text{Cs}_{\text{pCi/liter}}) - 0.0557 (\text{Cs}_{\text{ng/liter}}) - 0.3838 (\text{K}_{\text{mg/liter}}).$$

INTRODUCTION

Cesium-137 is generally considered to be potentially hazardous to man for several reasons. It is a significant component of fallout from nuclear testing, it is present in leakage from power reactors, it has a long physical half-life (30.5 years), it emits both beta particles and gamma radiation and it is known to be biologically active, often being compared to potassium. Because of the potential hazard of ^{137}Cs , the environmental factors influencing the ecological distribution of the element have come recently under investigation.

The dynamics of Cs in the terrestrial environment have been studied by numerous workers. Bioaccumulations of ^{137}Cs have been correlated to altitude (Nelson and Whicker, 1967); precipitation levels (Rickard, 1966; Eberhardt, et al., 1969); climate and latitude (Pendleton, et al., 1964) and specific feeding habits (Pendleton, et al., 1964; Gustafson, 1969).

Radiocesium tends to be a potentially greater hazard to the high trophic level predators in the freshwater ecosystem than in the terrestrial system due to the increased availability of Cs to the biota and the more numerous predator trophic stages, allowing for more accumulation of Cs. The rate and equilibrium levels of uptake by the various compartments of a pond spiked with radiocesium were reported by Pendleton (1962). Cline (1967) and Rickard (1967) studied the uptake of ^{137}Cs by aquatic macrophytes. Uptake by freshwater algae was determined by Williams (1960). Accumulations of ^{137}Cs by fish from various locations have been correlated with: precipitation levels and feeding activities (Davis, 1963); specific conductance of the medium (Preston, et al., 1967; Kolehmainen, et al., 1966); ^{137}Cs activity of the medium (Preston, et al., 1967); and ^{137}Cs activities of bottom sediments (Gustafson, 1969).

Although organisms from many aquatic systems have been analyzed for ^{137}Cs activity, only a few investigators have attempted to characterize the effects of limnological and biological factors on the uptake and accumulation of ^{137}Cs by fish.

Kolehmainen, et al. (1966) were among the first to report that factors relating to lake type were involved in regulating the uptake of ^{137}Cs by fishes. Along these lines, this study was an attempt to further identify and isolate the effects of factors causing variability in ^{137}Cs accumulation in a single species of fish from contrasting lakes.

SAMPLING DESIGN AND METHODS

The objectives of measuring the ^{137}Cs concentration in a species of fish and subsequently determining the limnological factors causing differences in the concentrations directed the selection of the fish species and the lakes. The largemouth bass (Micropterus salmoides) was selected as the test species due to its relative abundance in all of the lakes, its large size allowing measurements of ^{137}Cs on individuals and thus the individual error terms, and its position as a top carnivore thus taking advantage of any trophic level concentrations for analysis of ^{137}Cs .

Factors suspected of influencing the accumulation of ^{137}Cs in the bass were specific conductance and the water concentrations of ^{137}Cs , Cs, K and Na. Lakes were selected on the basis of specific conductance and alkalinity with the selection aimed at representing a broad range and assuming that the other element concentrations would vary accordingly. Six eutrophic lakes in southern Michigan (Figure 1) were chosen that were similar in locality, fallout deposition (precipitation) and fish species composition. Geographic and rainfall data for each lake are presented in Table 1. Physical and chemical data from 1967, 1968 and 1969

Table 1. Geographic and precipitation data for six study lakes

Lake	County	Location	Sections	Latitude	Longitude	Elevation	Annual Precipitation (")	
							1968	1969
Cable	Cass	T5S, R16W	5	41°	86°	735'	39	41
Dewey	Cass	T5S, R16W	4,5,8,9	41°	86°	735'	39	41
Fair	Barry	T1N, R9W	1,2,11,12	42°	85°	890'	41	33
Fine	Barry	T1N, R8W	19,29,30	42°	85°	890'	41	33
Schnable	Allegan	T2N, R12W	26,35	42°	85°	629'	32	35
Wintergreen	Kalamazoo	T1S, R9W	8	42°	85°	890'	41	33

are recorded in Tables 2 and 3.

Differences in ^{137}Cs activity of bass from the six study lakes were determined by analyzing fish collected from each lake during June, 1969. Multiple regression analyses were applied between the five water parameters and the ^{137}Cs activity of bass. Data were adjusted for within-lake parameters that proved significant, thereby statistically eliminating these sources of variation.

Depth profiles in each lake for dissolved oxygen, temperature, and specific conductance were determined using calibrated electronic sensors. Alkalinity and pH were measured using standard procedures. Concentrations of Na and K in lake waters were analyzed by flame spectrophotometry.

Fish were collected by hook and line and electric shocking (115 volt, D.C.) and were kept frozen until analyzed. Individual fish, less gut contents, were digested in concentrated nitric acid and the subsequent solution was treated with ammonium molybdophosphate (AMP) resin to collect the cesium isotopes (Smit, 1958; Feldman and Rains, 1964). The AMP residue was dissolved in sodium hydroxide and extracted with sodium tetraphenylboron (TPB). Total Cs analysis on TPB extracts of fish were accomplished by means of flame emission spectrophotometry (8521 Å). The detection limit was about 0.1 ug Cs/ml.

Stable Cs and ^{137}Cs were preconcentrated from lake water by means of rapid flow (15 liter/hr) ion exchange, using cobalt ferrocyanide resins (KCFC), as described by Prout et al. (1965), Folsom and Sreekumaran (1970); Petrow and Levine (1967), and Boni (1966). Approximately 500 liters of lake water were preconcentrated per sample. Cesium-137 activities of water (KCFC resins) and fish (AMP resins) were determined by single channel gamma scintillation (0.662 Mev). Calculations of counting time intervals were made to ensure a minimal counting error ($P < 0.05$). Cesium-137 activities

Tabl. Limnological characteristics of study lakes during 1967-1968.

Lake	D.O. (mg/l)	Temp. (°C)	Alkalinity (mg/l CaCO ₃)		Specific Conductance (µmhos/cm 25C)	pH	Secchi disc meters
			(Phth)	(M.O.)			
Schnable (Nov.)							
Surface	10.0	5.5	0.0	203.0	365	8.0	2.44
3.0M	9.6	5.0	0.0	205.0	365		
bottom (6.5M)	8.8	5.0	0.0	205.0	365		
Wintergreen (July)							
Surface	12.1	22.0	15.0	109.0	269	8.6	2.14
1.0M	11.5	22.0	11.0	105.0	---	8.3	
bottom (2.5M)	8.3	21.0	7.0	110.0	321	8.3	
(Nov.)							
Surface	14.2	4.5	0.0	150.0	286	8.1	2.5
1.5M	14.8	4.0	0.0	144.0	280	---	
Fine (July)							
Surface	9.3	27.0	6.0	81.0	217	8.7	2.4
3M	9.4	25.0	10.0	74.0	211	8.7	
bottom (6M)	2.5	21.0	0.0	102.0	233	7.5	
(Nov.)							
Surface	12.5	5.0	0.0	88.0	200		2.5
1.0M	13.0	4.0	0.0	90.0	192	---	
2.5M	13.0	4.0	0.0	89.0	192		
Fair (Nov.)							
Surface	9.6	4.0	0.0	44.0	106		
2.5M	9.6	4.0	0.0	41.0	106	7.5	4.0
bottom (4.5M)	8.7	4.0	0.0	41.0	106		
Dewey (May)							
Surface	11.4	16.0	0.0	18.0	49	7.5	1.68
3M	11.3	15.5	0.0	17.0	---	---	
bottom (7.5M)	0.8	14.0	0.0	18.0	48	7.6	
Cable (May)							
Surface	9.8	15.5	0.0	6.0	39	---	3.48
6M	9.8	14.8	0.0	7.0	---		
bottom (10.5M)	1.1	10.3	0.0	6.0	36		

Table 3. Limnological characteristics of study lakes during 1969.

Lake	D.O. (mg/l)	Temp. (°C)	Alkalinity (mg/l CaCO ₃)		Specific Conductance (µmhos/cm-25C)	pH	K (mg/l)	Na (mg/l)	¹³⁷ Cs (pCi/l)	Cs* (ng/l)
			(phth)	(M.O.)						
Schnable (June)										
Surface	13.2	17.2	14	161	370	8.3	4.0	3.0	0.08	9.0
4M	4.5	8.9	0	175	370	7.5	---	---		
6.5M	1.0	8.3	0	194	400	7.3	---	---		
(Nov.)										
Surface	10.3	8.9	0	203	450	7.6	3.0	2.5		
4M	9.0	7.8	0	203	450	7.7	---	---		
6M	8.5	7.8	0	202	460	7.7	---	---		
Wintergreen (June)										
Surface	11.0	15.5	9	112	300	8.3	6.5	4.5	0.27	8.7
1.0	11.0	15.5	12	110	300	8.3	---	---		
1.5	11.0	15.0	13	111	290	8.3	---	---		
(Oct.)										
Surface	---	9.4	0	133	340	7.5	13.0	8.0		
1M	---	9.4	0	133	350	7.5	---	---		
2M	---	9.4	0	130	350	7.4	---	---		
Fine (June)										
Surface	9.0	17.8	7.0	90	220	8.4	4.5	3.5	0.14	3.9
2.5M	8.5	17.2	7.0	88	220	8.4	---	---		
4.5M	2.0	14.4	7.0	88	225	8.4	---	---		
(Nov.)										
Surface	10.5	7.7	0	82	210	7.8	2.0	3.0		
1M	10.5	7.7	0	82	210	7.7	---	---		
3M	10.5	7.8	0	82	210	7.7	---	---		
Fair (June)										
Surface	10.5	16.7	0	36	100	7.4	5.0	2.0	0.24	3.6
2.5M	9.5	15.0	0	35	98	7.1	---	---		
4.5M	8.2	13.9	0	34	100	6.9	---	---		
(Nov.)										
Surface	10.2	7.7	0	41	118	7.4	14.0	3.0		
3M	10.0	7.7	0	41	118	7.5	---	---		
7M	9.5	7.7	0	41	118	7.5	---	---		

Table 3 - continued

Lake		D.O. (mg/l)	Temp. (°C)	Alkalinity (mg/l CaCO ₃)		Specific Conductance (umhos/cm-25C)	pH	K (mg/l)	Na (mg/l)	¹³⁷ Cs (pCi/l)	Cs* (ng/l)
				(phth)	(M.O.)						
Dewey	(June)										
	Surface	8.5	21.6	0	14	56	7.0	3.0	3.0	0.05	1.3
	2M	8.5	21.1	0	14	56	7.1	---	---		
	5M	5.0	17.2	0	15	56	6.6	---	---		
	(Oct.)										
	Surface	8.7	8.3	0	15	62	6.6	2.0	3.0		
	2M	8.5	7.8	0	15	62	6.7	---	---		
	6M	8.2	7.8	0	16	60	6.8	---	---		
Cable	(June)										
	Surface	9.5	22.2	0	6	40	6.5	4.0	2.0	0.15	2.9
	2M	9.0	18.3	0	6	40	6.8	---	---		
	4M	6.5	12.8	0	6	41	6.3	---	---		
	(Oct.)										
	Surface	---	11.1	0	6	45	6.6	3.0	3.5		
	3M	---	10.6	0	6	45	6.5	---	---		
	7M	---	10.6	0	6	46	6.5	---	---		

*Calculated from specific activity of fish and ¹³⁷Cs concentration in water: $\frac{^{137}\text{Cs}}{\text{Cs}}$ (fish): $\frac{^{137}\text{Cs}}{\text{X}}$ (water)

of water are expressed as pCi/liter; fish as pCi/gm wet weight.

Considerable effort was devoted to attempts to measure stable Cs in lake water. Despite using several methods of preconcentration and chemical extraction we were unable to measure the very low (ppt) concentrations of natural Cs in solution using flame emission analysis. In lieu of direct analyses, efforts then were directed at obtaining data to support the assumption that the specific activity of all components of a given lake would be the same when corrected for lag time of transfers. The specific activities of two fish species tested were not significantly different, therefore, the stable cesium concentration was calculated from the concentration of ^{137}Cs in the water and the specific activity of the fish. This concept also has been used by Nelson (1967).

RESULTS AND DISCUSSION

Data pertaining to levels of Cs isotopes in age three bass that were used to compare the lakes appear in Table 4. Lake parameters for regression analysis are located in Table 3. The mean ^{137}Cs activities of bass were significantly different for the study lakes ($P < 0.001$) (Table 5). In general, bass from soft water lakes (Fair, Cable, Dewey) had higher ^{137}Cs activities than those from medium to hard water lakes (Fine, Wintergreen, Schnable). Fair Lake was the single exception to an exact linear relationship between ^{137}Cs in bass and alkalinity or specific conductance. The only unusual characteristic of Fair Lake in collected data was the clarity of water indicated by the maximum Secchi disc reading of 4.0 meters (Table 2). Despite the intermediate alkalinity of Fair Lake, water clarity may indicate low particulate removal of ^{137}Cs by sedimentation.

The relationship with alkalinity was anticipated being reported previously by Kolehmainen et al. (1966), and logically since the paucity of

Table 4. Comparisons of ^{137}Cs and total Cs levels in bass and water of six study lakes (June, 1969). (± 1 S.E.)

Lake	Number of Bass	^{137}Cs in Bass (pCi/gm wet)	^{137}Cs in H_2O (pCi/ml) ($\times 10^{-3}$)	Conc. Factor (Bass/ H_2O)	Cs in Bass (ng/gm wet)	Specific Activity (Bass) (pCi/ng) ($\times 10^{-2}$)
Fair	7	1.11 ± 0.10	0.24 ± 0.01	4,600	16.80 ± 0.10	6.6
Cable	6	0.91 ± 0.19	0.15 ± 0.01	6,100	15.57 ± 0.22	5.8
Dewey	7	0.71 ± 0.09	0.05 ± 0.01	14,200	16.28 ± 0.10	4.4
Fine	5	0.60 ± 0.15	0.14 ± 0.01	4,300	16.86 ± 0.15	3.6
Wintergreen	6	0.45 ± 0.14	0.27 ± 0.01	1,700	13.40 ± 0.07	3.4
Schnable	6	0.10 ± 0.19	0.08 ± 0.01	1,300	11.88 ± 0.19	0.8

Table 5. Analysis of variance for lake effect on ^{137}Cs accumulation by bass (June, 1969).

Source	S.S.	d.f.	M.S.	F	F 0.95
Between Lakes	4.0643	5	0.8128	36.95**	2.50
Within Lakes	0.6827	31	0.0220		

elemental nutrients in soft water should result in increased accumulation by fish of any biologically active fallout isotopes. The mean concentrations of total Cs in bass did not differ greatly between Fair, Cable, Dewey, and Fine Lakes; but the concentrations were lower in Wintergreen and Schnable Lakes, indicating that the abundance of elements in the hard water lakes did have an effect on the uptake and accumulation of Cs. The specific activities of ^{137}Cs ($^{137}\text{Cs}/\text{Cs}$) in bass followed the same pattern as ^{137}Cs suggesting that either measurement is a valid indicator of ^{137}Cs accumulation by fish.

The concentration of ^{137}Cs in lake waters demonstrated little linear relationship with alkalinity. The maximum concentration factor for ^{137}Cs (bass/water) occurred in Dewey Lake (soft water), the minimum in Schnable Lake (hard water), but no direct relationship between alkalinity and concentration factor was evident. The range of concentration factors (1,300-14,200 x) agrees favorably with those published by Pendleton (1962) for carnivorous fish. Such high accumulations by bass are probably the result of the long biological half-time of Cs and the high rate of uptake by bass due to their carnivorous diet.

In order to better define the combined effects of water parameters on the accumulation of ^{137}Cs by bass, a least squares deletion analysis was performed using specific conductance and concentrations of ^{137}Cs , Cs, K, and Na of water as fixed independent variables. Simple and multiple correlation coefficients (R^2) are recorded in Table 6. Simple correlations indicated relatively strong linear relationships between ^{137}Cs activity of bass and Cs concentration, specific conductance, and Na concentration of lake water, with specific conductance having the best linear fit ($R^2 = -0.8716$). Such a correlation has been proposed by other authors (Kolehmainen et al., 1966 and Preston, et al., 1967). Preston, et al.

Table 6. Linear correlation coefficients between ^{137}Cs activities of bass and lake parameters.

Dependent Variable (Y)	Independent Variables (X)				
¹³⁷ Cs (Bass)	¹³⁷ Cs	K	Cs	Sp. Cond.	Na
Simple R ²	0.3298	-0.0549	-0.7605	-0.8716	-0.6218
Multiple R ² (X ₁ -X ₅)					1.0000
(X ₁ -X ₄)				0.9999	
(X ₁ -X ₃)			0.9999		
(X ₁ -X ₂)		0.9352			
Estimated Regression Equation:					
¹³⁷ Cs = 1.5912 + 6.8118 (¹³⁷ Cs) - 0.0557 (Cs) - 0.3838 (K)					

(1967) and Hannerz (1968) suggested that the K concentration also was inversely related to the ^{137}Cs activity of fish. However, the simple correlation coefficient for K was the lowest of the five variables tested ($R^2 = -0.0549$), implying that the K concentration of water is not correlated in a linear manner to Cs uptake by bass.

The ^{137}Cs activity of water would seem to reflect the total amount of ^{137}Cs in the aquatic ecosystem which, in turn, should influence the accumulation by fish; but the simple correlation coefficient between ^{137}Cs in bass and ^{137}Cs in water was relatively low ($R^2 = +0.3298$). Thus, based on the simple correlations, it would seem that specific conductance and the concentrations of Cs and Na in water are inversely correlated with ^{137}Cs uptake by bass; ^{137}Cs activity of water is positively correlated; and specific conductance is the best linear predictor of the five variables tested.

However, the limited procedure of simple linear regression does not adequately explain the variation existing between the body burdens of bass from the study lakes. The multiple regression analysis (least squares deletion) resulted in a considerably altered order of importance for the independent variables (water parameters) as indicated by the multiple correlation coefficients for each set of variables in Table 6. Deletion of Na and specific conductance from the model did not reduce the multiple R^2 , while deletion of ^{137}Cs , K or Cs reduced the coefficient appreciably.

Therefore, the apparent effects of Na and specific conductance indicated by simple regressions were proved non-significant by the multiple technique. This altered ranking of effects is probably due to the relatively high correlations between some of the independent variables. Indeed, specific conductance is simply a measure of the concentrations of natural ions such as Na, K, and Cs. In addition, the geochemical characteristics of drainage

basins tend to provide proportional concentrations of similar ions such as the alkali metals (Na, K, Cs, etc.). As a result, the "independent" variables are actually correlated to varying extents and their combined effects on the ^{137}Cs accumulation by fish are considerably different than their apparent individual effects.

The estimated multiple regression equation for ^{137}Cs activity of bass is:

$$^{137}\text{Cs} = 1.5912 + 6.8118(^{137}\text{Cs}) - 0.0557(\text{Cs}) - 0.3838(\text{K}).$$

Thus, as an example, if the ^{137}Cs activity of bass were to be estimated in an "average" southern Michigan lake (mean values of independent variables):

$$\begin{aligned} ^{137}\text{Cs} &= 1.5912 + 6.8118(0.15 \text{ pCi/liter}) - 0.0557(4.9 \text{ ng/liter}) \\ &\quad - 0.3838(4.5 \text{ mg/liter}) \\ &= 0.61 \pm 0.023 \text{ pCi/gm wet weight} \end{aligned}$$

The combined effects of ^{137}Cs , K, and Cs concentrations of lake water on the ^{137}Cs activity of bass appear reasonable. It is evident from the equation and from the contributions to the multiple correlation coefficient that K concentration has a major inverse influence. Potassium and Cs are similar in chemical and metabolic properties. Potassium is a smaller ion and may well be the preferred element physiologically. Thus, Cs uptake may be accelerated under conditions of low K levels in a substitution fashion. The strong direct contribution of ^{137}Cs in the water to uptake by bass also is evident in the equation. The ^{137}Cs activity of the water should indicate the availability of ^{137}Cs to the biota and the concentrations in the components of the ecosystem.

The influence of the Cs concentrations in the water is slight and inverse according to the equation. It is understandable that the influence is slight since water concentrations were so low. The inverse correlation

is explainable if one allows the same fallout into all lakes. The specific activities of the water then decrease with increasing Cs in the series of lakes. If specific activities remain the same in bass as water then a decline in ^{137}Cs uptake results if stable Cs uptake is less than a direct proportion with the increase in the lake series. The result is an inverse correlation for ^{137}Cs uptake with stable Cs in water.

It seems unlikely that the variation in ^{137}Cs activity of bass between lakes could be totally "explained" ($R^2 = 0.9999$) by three linear variables. The very structure of the experimental design (six mean observations and five independent variables) lends itself to criticism due to a lack of sufficient error degrees of freedom. As variables were deleted from the model, error degrees of freedom remained small (< 3). Hoerl and Kennard (1970) warn that very high multiple correlation coefficients are frequently obtained under conditions of correlated independent variables (non-orthogonal) and low error degrees of freedom. Thus, it must be emphasized that the reported multiple correlation coefficients may be overestimates of the combined linear effects of ^{137}Cs , K, and Cs concentrations of water on the ^{137}Cs activities of bass.

The study contributes by supporting previous indications of the importance of K (Preston, et al., 1967 and Hannerz, 1968) and by directing future research efforts. More information could be obtained by increasing the number of lakes (and thus the degrees of freedom) and by selecting lakes to represent a wider range of K concentrations.

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