ECOLOGICAL FACTORS AFFECTING THE ACCUMULATION OF ^{137}Cs

FALLOUT BY A NATURAL POPULATION OF LARGEMOUTH BASS (*Micropterus salmoides*)¹

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ABSTRACT

In order to better define the variable accumulations of ^{137}Cs fallout by the individuals of a fish population, the effects of selected ecological parameters were tested. Individual fish characteristics (sex and weight), monthly precipitation, and time of year were statistically analyzed for their influence on ^{137}Cs activities of largemouth bass collected from Wintergreen Lake, Kalamazoo Co., Michigan.

Monthly collections of bass were analyzed for ^{137}Cs activity. No significant difference in ^{137}Cs activity was detected between male and female bass of equal size. However, body weight was a significant factor; larger bass accumulated more ^{137}Cs and total Cs per unit weight than small bass. The plots of ^{137}Cs vs. weight and total Cs vs. weight were very similar and supported the specific activity concept. The relationship between weight and ^{137}Cs in bass was estimated to be curvilinear with positive slope up to approximately 1000 gms and negative slope above 1100 gms.

Mean ^{137}Cs activities of bass collected monthly from May to October,

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1969 were significantly different. The maximum activities occurred during May, the minimum in August. No correlation was demonstrated between monthly precipitation levels and ^{137}Cs activities of bass.

INTRODUCTION

The implications of chronic low level contamination of the ecosystem by ^{137}Cs fallout have been investigated only recently. Cesium-137 has a long physical half-life (30 years), emits both beta and gamma radiations and is known to be biologically active. Potential deleterious ecological effects of ^{137}Cs contamination include: (1) specific physiological damage to the biota; (2) trophic level increases in activity; and (3) possible hazards to man as a consumer.

Bioaccumulations of ^{137}Cs in the aquatic environment have been correlated with various factors. Nelson and Whicker (1967) concluded that differences in the ^{137}Cs activities of populations of the same species were due primarily to climatic and limnological conditions prevailing within the system. Many authors have suggested feeding habits to be the cause of variable ^{137}Cs activities between species. Precipitation (fallout rate) has been shown to be correlated with ^{137}Cs accumulation by fish, especially during periods of relatively high fallout. Kolehmainen, et al. (1966) and Preston, et al. (1967) report a negative correlation between specific conductance of lake water and ^{137}Cs accumulation by fish. Preston, et al. (1967) report a positive correlation between ^{137}Cs of lake water and accumulation by fish.

Thus, most studies have dealt with the uptake and accumulation of ^{137}Cs in populations of fish, usually by comparing habitats or species.

This study is an attempt to (1) establish the existence of individual variability within a fish population; (2) elucidate some of the parameters which operate in controlling this variability; and (3) characterize the temporal changes in ^{137}Cs activities within the population.

METHODS AND MATERIALS

Largemouth bass (Micropterus salmoides) samples were collected at monthly intervals from Wintergreen Lake (Kalamazoo Co., Michigan). Wintergreen Lake, a small (40 acres), shallow, eutrophic lake, is managed as a waterfowl refuge by the Michigan State University Kellogg Biological Station. Although the alkalinity and specific conductance of this lake are typical of southern Michigan, considerable amounts of inorganic ions (K^+ , Na^+) are present, no doubt as a result of the large numbers of waterfowl that occupy the lake.

Fish were collected by hook and line and were kept frozen until analyzed. An attempt was made to collect a complete size range of bass from the lake. All fish were individually characterized as to sex, weight, length, and age. Stomach contents of each bass were identified and the relative volumes of each food item were measured.

Individual fish were completely digested in concentrated nitric acid (<150 C) and the subsequent solution was treated with ammonium molybdo-phosphate (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).

Chemical analyses of lake water were performed simultaneously with fish collections or on refrigerated samples (Table 1). Cs isotopes were preconcentrated from surface lake water by means of rapid flow (15 L/hr) ion exchange, using cobalt ferrocyanide resins (KCFC), as described by Prout *et al.* (1965), Boni (1966), Petrow and Levine (1967), and Folsom and Sreekumaran (1970). 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). Counting time intervals were calculated to ensure minimal counting error ($P < 0.05$). Cesium-137 activities of water are expressed as pCi/L; fish as pCi/gm wet weight.

Total Cs analyses on TPB extracts of fish were accomplished by means of flame emission spectrophotometry (8521 Å). The detection limit was about 0.1 µg Cs/ml. Flame emission analyses of lake water samples were hampered by extremely low concentrations (ppt) of natural Cs and inadequate existing procedures for the preconcentration of water samples. These constraints resulted in the estimation of cesium concentrations of water by considering the specific activities of fish and water to be equal (Nelson, 1967); i.e.,

$$\frac{{}^{137}\text{Cs in fish}}{\text{Cs in fish}} \approx \frac{{}^{137}\text{Cs in H}_2\text{O}}{\text{Cs in H}_2\text{O}}$$

TABLE 1. Limnological characteristics of Wintergreen Lake
during June and October, 1969

Depth (meters)	Month	Alkalinity (mg/l CaCO ₃)		Specific Conductance (μmhos/cm-25C)	pH	K ⁺ (mg/l)	137Cs (pCi/l)	Cs ppt (Est.)
		(phth)	(M.O.)					
Surface	June	9	112	300	8.3	6.5	0.27	8.7
1.0		12	110	300	8.3			
1.5		13	111	290	8.3			
Surface	October	0	133	340	7.5	13.0		
1.0		0	133	350	7.5			
2.0		0	130	350	7.4			

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RESULTS AND DISCUSSION

The effects of individual fish characteristics (sex and weight) on the accumulation of ^{137}Cs were tested utilizing bass collected during May, 1969. An analysis of variance of the data revealed no significant difference in the ^{137}Cs activities of male and female bass of the same weight groups ($P > 0.1$ for sex and sex by weight interaction). The activities of the arbitrary weight groups were significantly different ($P < 0.005$), as were total Cs concentrations ($P < 0.01$).

In general the mean ^{137}Cs activities of the bass weight groups increased as weight increased (Table 2). The relationship between actual weight and ^{137}Cs activity was curvilinear, with positive slope up to approximately 1000 grams and negative slope above 1100 grams. This relationship was further characterized by polynomial least squares deletion analysis. The estimated regressions for May are presented in Figure 1. The similarity of responses of ^{137}Cs and total Cs in these two estimated functions supports the assumption of biological equality of Cs isotopes. No such response function was evident for the calculated specific activities ($^{137}\text{Cs}/\text{Cs}$) of different sized bass. Since ^{137}Cs and ^{133}Cs (stable) are assumed to be biogeochemically equal, it follows that the specific activities should be about equal for all bass collected at the same time. The variability in mean specific activities for weight groups (Table 2) is perhaps a result of the large standard errors associated with the mean Cs concentrations.

The obvious change in accumulation of Cs with increasing weight indicates the influence of behavioral or physiological changes with increasing

TABLE 2. Mean ^{137}Cs activities of weight groups of bass (Wintergreen Lake, May, 1969)

Weight Group (gms)	Number Analyzed	^{137}Cs (pCi/gm) (± 1 S.E.)	Cesium (ng/gm) (± 1 S.E.)	Specific Activity (pCi/ng) (10^{-2})
<300	5	0.36 ± 0.07	4.23 ± 0.77	8.51
300-399	5	0.46 ± 0.03	5.17 ± 0.76	8.90
400-499	4	0.53 ± 0.07	4.82 ± 0.41	11.00
500-599	4	0.58 ± 0.03	7.44 ± 1.14	7.80
600-699	4	0.60 ± 0.07	8.80 ± 2.10	6.82
700+	5	0.76 ± 0.06	6.88 ± 0.83	11.05

Figure 1. Estimated ^{137}Cs activities and total Cs concentrations of bass of various weights (Wintergreen Lake, May, 1969)

size. Numerous authors have suggested that diet is a major factor affecting the accumulation of Cs by fish (Pendleton, 1962; Hasanen and Miettinen, 1963; Gustafson, 1967). Such a relationship probably accounts for a majority of the variation of ^{137}Cs activities between species of fish. However, the relationship demonstrated between weight and Cs accumulation by bass cannot be adequately correlated with feeding behavior. Stomach content identifications of bass collected in May exhibited few differences in food items between size groups. It has been shown that largemouth bass over 80 mm (3") progressively shift from a predominately invertebrate diet to one of small fish, frogs and crayfish (Ewers and Boesel, 1935). Such feeding behavior would, in part, account for the increased ^{137}Cs activity found in larger bass, assuming trophic level increases in ^{137}Cs .

However, the decreasing accumulation in bass weighing over 1100 gms definitely suggests that physiological changes are influencing the equilibrium Cs body burden. The sigmoid shape of the curves in Figure 1 implies that the accumulation of Cs reflects the growth rate of bass, having positive slope or acceleration during early stages of life and negative slope or deceleration after the growth rate has decreased in later stages. The division of the curve into "age areas" adds further credence to this explanation. Preston, et al. (1967) state that the $\text{TB}_{1/2}$ of fish tends to increase with body weight, implying that the equilibrium body burden of ^{137}Cs would also increase.

Thus, it seems that young actively growing fish tend to deposit less

^{137}Cs in body tissues than do older fish which show decreased growth rates and longer retention times for Cs. Under such conditions maximum body burdens of Cs would occur in large fish that experience reduced metabolic rates but continue to feed actively, especially on other fish.

The implications of this relationship between weight and Cs uptake should not be overlooked. The tendency for higher ^{137}Cs accumulation by larger fish could have serious consequences on sport and commercial fishing and fish culture, especially in areas of high environmental contamination.

Differences between the ^{137}Cs activities of bass collected in Wintergreen Lake during the months of May to October, 1969 (Table 3) were tested by analysis of covariance, using weight and inches of precipitation (prior month) as covariates. It was assumed that the correlation between weight and ^{137}Cs activity was constant with time; consequently, weight was included as a covariate. Since the level of precipitation has been positively correlated with ^{137}Cs uptake by organisms (Davis, 1963; Eberhardt, et al., 1969) and an equilibrium time of 10-12 days for adult fish has been suggested by Pendleton and Hanson (1958), the precipitation level of the prior month was used as a covariate to allow for the time required for fallout ^{137}Cs to reach the upper trophic levels. The ^{137}Cs activities of age three bass were significantly different during the months of study ($P < 0.005$).

In order to compare monthly samples, ^{137}Cs activities of bass were adjusted for weight differences between the samples by means of the

TABLE 3. Mean ^{137}Cs activities and Cs concentrations of age three bass during May-October, 1969 (Wintergreen Lake)

Collection Period	Number Analyzed	^{137}Cs (pCi/gm) (± 1 S.E.)	Cesium (ng/gm) (± 1 S.E.)	Specific Activity (pCi/ng) (10^{-2})
May	20	0.547 ± 0.028	6.79 ± 0.26	8.06
June	6	0.413 ± 0.090	13.40 ± 0.07	3.08
July	6	0.348 ± 0.010	14.87 ± 0.07	2.34
August	5	0.278 ± 0.027	13.12 ± 0.10	2.12
September	5	0.366 ± 0.060	12.61 ± 0.10	2.90
October	4	0.375 ± 0.026	11.43 ± 0.24	3.28

slope of the estimated regression between weight and ^{137}Cs of bass collected during that month:

$$Y_{\text{adj}} = Y_{\text{abs.}} - b_1(X_1 - \bar{X})$$

where: $Y = ^{137}\text{Cs}$ activity,

$b_1 =$ slope,

$X_1 =$ bass weight, and

$\bar{X} =$ mean weight of sample.

The relationships between month, ^{137}Cs activities and Cs concentrations of bass are depicted in Figure 2. The estimated regressions were determined by means of least squares deletion analysis.

The maximum ^{137}Cs activities and specific activities during the months of study occurred in May, the minimum in August. Such a time response indicates that the isotopes of Cs are differentially available to the biota and, consequently, the relative quantities accumulated by bass differ in time. Since ^{137}Cs input depends upon fallout, the contribution of precipitation as a factor affecting the monthly variation in ^{137}Cs accumulation was anticipated, but the slopes of the regressions between precipitation (same and prior months) and ^{137}Cs activities of bass were not significantly different from zero. Also, there was no evidence of correlation between specific activities of bass and precipitation.

Thus, it seems that a combination of variable fallout and the recycling of endogeneous Cs are causing relative temporal differences in the availability

Figure 2. Mean ^{137}Cs activities and Cs concentrations of monthly bass samples (Wintergreen Lake, 1969)

of ^{137}Cs and ^{133}Cs . The availability of ^{137}Cs could have increased during May as a result of heavy April rains (5") and the spring overturn which occurred in late April.

Gustafson (1969) states that as high as 80% of the ^{137}Cs accumulated by fish from Red Lakes, Minnesota during 1965 was a result of that already deposited within the aquatic system, and that the contribution to the total activity of fish due to recent fallout tends to decrease as fallout decreases. Since stratospheric fallout of ^{137}Cs has been decreasing since 1963 (Gustafson, 1969) it is reasonable to assume that the contribution of previously deposited ^{137}Cs to the total uptake by fish has increased while that of new fallout has decreased. Such a situation tends to explain the lack of influence of precipitation on the monthly variations in ^{137}Cs activities of bass. Consequently, it appears that internal limnological changes, such as seasonal overturns, precipitation with CaCO_3 , biological accumulation, sorption and sedimentation are affecting the availability of Cs isotopes within the system.

In addition, greater feeding activity of bass due to increasing water temperatures or metabolic demands would result in increased uptake of available Cs isotopes. The feeding habits of bass during these months shed some light on the variable monthly uptake (Table 4). During May, 1969, 73% of the volume of identified food items was composed of fish while only 27% was composed of aquatic insects. But during June, the majority of food items were aquatic insect larvae (Odonata) (59%), while fish were of

TABLE 4. Stomach contents of bass collected from Wintergreen Lake during 1969

Date Collected	Number Analyzed	Stomach Contents			
		Fish		Insects	
		(% Vol.)	(% Occ.)	(% Vol.)	(% Occ.)
May	13	73.0	62.0	27.0	62.0
June	8	41.0	38.0	59.0	75.0
July	6	100.0	100.0	0	0
August	4	100.0	100.0	0	0
September	4	100.0	100.0	0	0
October	1	100.0	100.0	0	0

secondary importance in the diet (41%). Assuming that successive trophic level accumulations of ^{137}Cs do occur in Wintergreen Lake, the decrease in ^{137}Cs activities of bass from May to June may have been, in part, due to dietary changes. During the remaining months of the sampling period, the only food item identified in bass was fish. It would seem that this change to a piscivorous diet should have increased the ^{137}Cs activities of bass, assuming that ^{137}Cs was available to the biota.

Speculation as to the reason for the decreased ^{137}Cs activities during July, August, and September could include many aspects of limnological and physiological change during these months. However, one curious coincidence that should be mentioned is the emergence of numerous aquatic insects during June and July. Obviously, the availability of aquatic insects decreased after June as evidenced by their complete absence from the bass diet. Hasler and Likens (1963) have shown that aquatic midges remove "significant amounts" of radioactivity from lakes when they emerge as adults; other authors have shown insignificant removal by insects. Depending upon the ^{137}Cs activity of aquatic insects and the magnitude of the hatches, such a mechanism of loss could account for a portion of the decrease in ^{137}Cs activity of bass during the late summer months. Such a loss would more likely represent a minute portion of the total ^{137}Cs within the lake. However, a reduction in immediate availability of ^{137}Cs to higher trophic levels (fish) could have resulted from the temporary loss of aquatic insects to the food chain.

Reasons for the increased ^{137}Cs activity of bass during October can only be surmised. Decreasing water temperatures and possible fall pulses of primary and secondary production could have stimulated bass feeding activity and resulted in a period of growth and ^{137}Cs accumulation.

The apparent minimum ^{137}Cs activity in bass during August was tested by orthogonal contrasts and it was determined that the mean value during August did not differ significantly from those during July and September. Thus, the estimated regression in Figure 2 appears to be a better approximation of the actual response with time.

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