DAILY FEEDING RATES OF BLUEGILL DETERMINED BY A RADIOISOTOPIC METHOD [1]

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The radioisotope method for determining the feeding rate of fish was suggested by Davis and Foster (1958). They calculated the feeding rate of fish with the intake of ^{32}P assuming the body burden of fish to be in equilibrium with the concentration of ^{32}P in the environment. The body burden of a radioisotope in fish, however, is not in equilibrium even though the concentration of a radioisotope stayed constant in fish. Fish grow during every summer and therefore the body burden increases yearly. Kevern (1966) also considered the growth of fish while calculating the mean annual daily food consumption in the White Ooak Lake carp *(Cyprinus carpio)* using the intake of ^{137}Cs. Kevern *(op. c.)* treated the growth of carp as a constant continuous process which is not true for any fish. Therefore Kevern's *(op. c.)* method is not quite accurate for field conditions. In a fallout situation Kolehmainen *et al.* (1967) calculated the daily meal of roach *(Leuciscus rutilus)* with the intake of ^{137}Cs in a non-equilibrium state. They used the formula:

$$A_t = A_o e^{-kt} + \frac{I}{k}(1 - e^{-kt}), \tag{1}$$

where A_t is the body burden of ^{137}Cs at time t, A_o the body burden at the previous time when analyzed, I the daily intake of ^{137}Cs, and k the excretion rate coefficient. In this equation I and k are considered constants during the time from t to o.

The purpose of this study was to estimate the feeding rate of bluegill using the radioisotopic method. Further refinements and application of the technique to natural situations are developed. This study was conducted in White Oak Lake, a small impoundment in Roane County, Tennessee receiving low-level radioactive effluents from Oak Ridge National Laboratory. Bluegill samples (5 to 10 fish) were collected one to three times a month during the period from June 1967 to January 1969. Radiocesium was counted by gamma-spectrometry in bluegill, the stomach contents and in different food items of bluegill.

In the calculations of ^{137}Cs intake all possible factors affecting the body burden and the intake of ^{137}Cs were taken into consideration, such as: (1) the growth of fish, (2) the fluctuation of ^{137} Cs concentration in fish, (3) the relationship between the excretion rates of cesium and the temperature, (4) the composition of blugill's diet, (5) the concentration of ^{137}Cs in different food items of bluegill, and (6) the percentage of ^{137}Cs absorption for different food items of bluegill (Kolehmainen, 1969a; Kolehmainen and Nelson, 1969).

INTAKE OF ^{137}Cs

Calculations of the intake of ^{137}Cs were based on average sized fish that belonged to the age-group III in January and weighed 91.6 g (mean of both sexes). By the next December, fish had gained weight 18.9 g. The growing season, or the time when 90% of the annual growth was achieved, was from the middle of April to the middle of November. Growth of bluegill was assumed to follow a sigmoid curve with a maximum instantaneous growth rate in May and June (Gerking, 1966). The weight of fish during a whole year is shown in Fig. 1. Concentrations of ^{137}Cs

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in bluegill had a seasonal cycle with a minimum of 29.0 pCi/g fresh wt. in August and a maximum of 47.4 pCi/g fresh wt. in February (Fig. 1).

Cesium-137 was excreted by two exponential rates in bluegill. From each absorbed intake 36.9% was excreted by a fast rate, k_1 (0.0912/day at 15.8 C) and 63.1% by a slow rate, k_2 (0.0037/day at 15.8 C) (Kolehmainen, 1969a, 1969b). Absorption is considered here as the absorption of ^{137}Cs from the stomach and gut into blood. Equation (1) was modified for a situation where the excretion consists of two rates:

$$A_t = a_1 A_o \cdot e^{-k_1 t} + a_2 A_o \cdot e^{-k_2 t} + \frac{Ip_1}{k_1} \cdot (1 - e^{-k_1 t}) + \frac{Ip_2}{k_2} \cdot (1 - e^{-k_2 t}) \quad (2)$$

where a_1 is the proportion of the *body burden* excreted by the rate of k_1, a_2 the proportion of the body burden excreted by the rate of k_2, p_1 the proportion of the *intake, I,* that goes to the compartment $a_1 A_o$ in the body burden, and p_2 the proportion of the daily intake that goes to the compartment $a_2 A_o$. Details of the calculations of ^{137}Cs intake are given in another paper (Kolehmainen, 1969b). The daily intake of ^{137}Cs was at a minimum (0.065 pCi/g of fish) in late March and at a maximum (0.334 pCi/g of fish) in the middle of August with an annual mean of 0.257 pCi/g of fish (Fig. 1).

DAILY FEEDING RATES

Feeding rates of blugill, r^1, were caculated with the formula:

FIGURE 1. Calculated values of the weight, the concentration of ^{137}Cs, the body burden of ^{137}Cs, the excretion rate (k_2), of ^{137}Cs during a year for bluegill belonging to age-group III in January.

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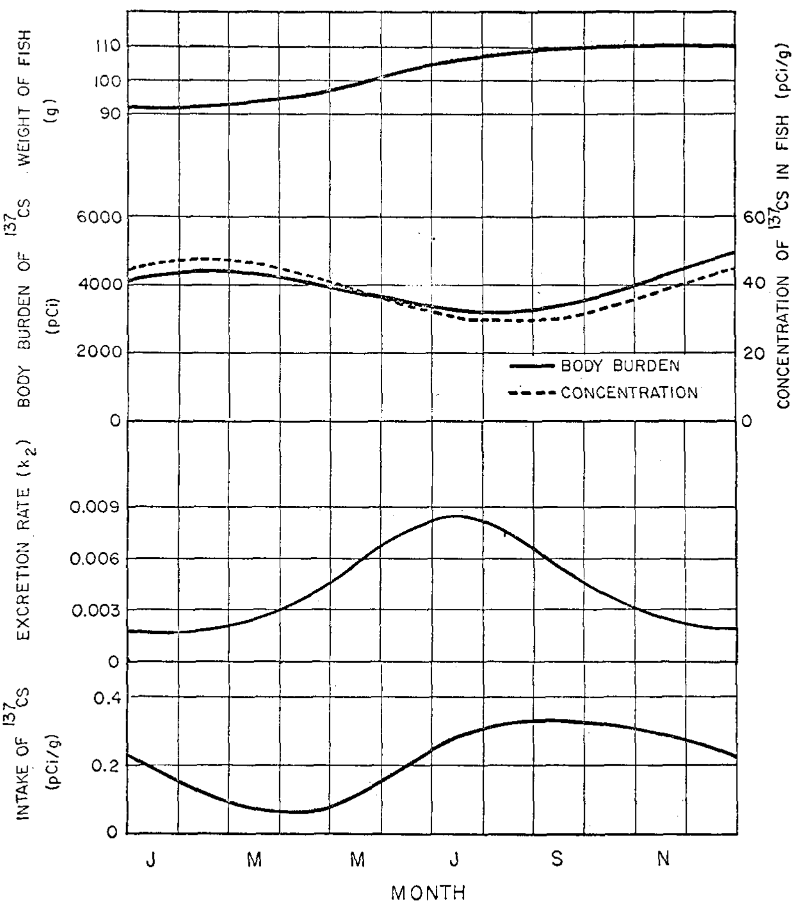


$$r' = \frac{I}{b_i \cdot d_i \cdot f_i} \tag{3}$$

where I was the daily intake of ^{137}Cs, b_i the absorption percentage of ^{137}Cs for the ith food item, d_i the concentration of ^{137}Cs in the ith food item, and f_i the proportion of ith food item in the diet of bluegill.

The feeding habits of bluegill were determined on the basis of stomach samples. Proportions of different food items in the stomach contents were estimated visually under a microscope. Some stomach samples were weighed after different food items had been separated into groups to check the validity of the visual estimation. The agreement between visual and the gravimetric estimation was good and the visual estimation was applied throughout the remaining samples to determine the composition of the diet of bluegill on an annual basis (Table 1).

The assimilation of ^{137}Cs was determined for White Oak Lake chironomid larvae (16%), algae (69%), and detritus (3%) (Kolehmainen, 1969a, c; Kolehmainen and Nelson, 1969). Assimilation of ^{137}Cs for other insect larvae was assumed to be the same as for chironomid larvae. Concentrations of ^{137}Cs in different food items are shown in Table 2. These values were used to interpolate and extrapolate ^{137}Cs concentrations in different food items, d_i, at different times of the year. The proportions of each food item in the diet, f_i, were determined on the basis of the stomach contents. Observed (γ-counted) and calculated culated ($d_i f_i$) concentrations of ^{137}Cs in the stomach contents agreed well (Table 3).

The feeding rates of bluegill were calculated with the equation (3) as in the following example:

TABLE 1. Volume of the Main Food Items in the Stomach Contents of 153 Bluegill

Food Item	Percentage
Chironomid Larvae	56.1
Chironomid Pupae and Adults	6.4
Other Insects: Larvae, Pupae and Adults	14.4
Roe	3.5
Fish	0.9
Plant Material	4.9
Detritus and Sediments	9.6
Others	4.2
	100.00

TABLE 2. Concentration of ^{137}Cs in Different Food Items of White Oak Lake Bluegill

Date	Chironomid Larvae	Other Aquatic Insect Larvae	Algae	Terrestrial Insects	Roe	Detritus	Other Bottom Animals
Dec. 15, 1967	105.7					381.7	
Dec. 22, 1967	123.2	20.2	49.8				
March 28, 1968	55.2	18.4	23.4			190.4	
June 3, 1968			13.7		20.5	221.3	
July 16, 1968	72.4						39.7
Aug. 14, 1968				17.9			
Sept. 9, 1968		58.1	39.8				
Sept. 27, 1968	125.3		48.1			245.8	
Avg.	96.4	32.2	35.0	17.9	20.5	259.8	39.7
SD	28.0	18.3	14.2			73.0	

All values are given in pCi per gram fresh weight.

TABLE 3. ^{137}Cs Concentration in Stomach Contents, γ-Counted and Calculated ($\sum d_i f_i$), Daily Assimilated Intake of ^{137}Cs (I), and the Quantity of ^{137}Cs Assimilated From one Gram of Stomach Contents ($\sum a_i d_i f_i$).

Date	γ-Counted pCi/g	^{137}Cs in Stomach Contents $\sum d_i f_i$ pCi/g	I pCi/g fish	$\sum a_i d_i f_i$ pCi/g	No. of Stomach Samples
Sept. 29, 1967	81.3	74.0	0.333	18.0	11
Nov. 2, 1967	100.4	102.5	0.332	19.0	3
Dec. 1, 1967	105.1	101.0	0.283	21.9	4
Jan. 4, 1968	148.6	160.5	0.216	20.7	4
Feb. 20, 1968	109.4	115.5	0.111	13.3	3
Mar. 11, 1968	74.1	70.1	0.076	7.5	2
April 5, 1968	79.6	84.0	0.065	6.2	14
April 18, 1968	65.7	65.7	0.071	5.0	5
June 4, 1968	68.0	69.0	0.168	6.4	7
June 20, 1968	60.9	58.5	0.220	6.8	4
July 26, 1968	55.6	59.1	0.305	11.5	2
Aug. 6, 1968	58.4	60.7	0.315	14.0	12
Aug. 14, 1968	17.9	17.9	0.323	12.2	4
Sept. 7, 1968	85.1	81.1	0.333	19.7	5
Sept. 27, 1968	87.3	79.5	0.333	27.4	5
x	79.9	80.7	0.233	13.5	$\sum 84$
SD	28.7	30.0	0.106	6.7	

All values are given for fresh weight.

On the 4th of July 1968, the calculated intake, I, of ^{137}Cs was 0.168 pCi/g of fish. Stomach contents of bluegill consisted of 50% chironomid larvae, 20% other insect larvae, 11% plants, and 19% detritus. The absorbed quantity of ^{137}Cs for 1 g of food was:

Food item	b_i %	d_i pCi/g of food	f_i %	$b_i d_i f_i$ pCi/g of food
Chironomid larvae	16	40	50	3.2
Other insect larvae	16	28	20	0.9
Plants	69	14	11	1.0
Detritus	3	221	19	1.3
				6.4

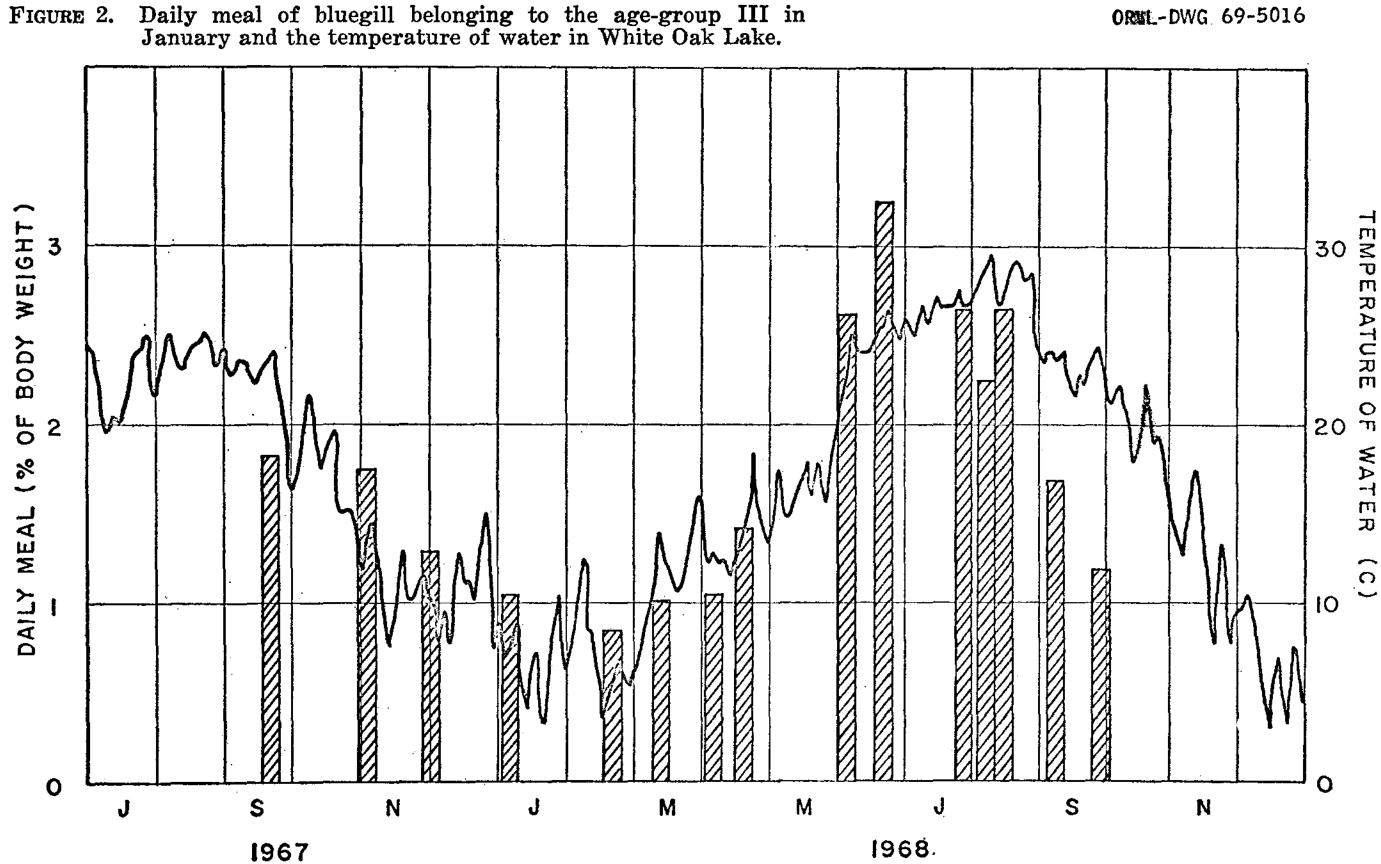
A bluegill's daily food consumption was:

$$\underline{r}^i = \frac{0.168 \text{ pCi/g of fish}}{6.4 \text{ pCi/g of food}} = 0.0263 \text{ g food/g of fish}$$

which gives a daily meal of 2.63% of the body weight.

There was a positive relationship between the daily meal of bluegill and the daily temperature of water in White Oak Lake. The linear regression between the feeding rates and the daily temperature was $Y = 0.32 + 0.081X$ ($r^2 = 0.665$) where Y was the daily meal in percent of the body weight and X the temperature in C. The daily meal was at a minimum (0.84% of the body weight) in February and increased slowly

FIGURE 2. Daily meal of bluegill belonging to the age-group III in January and the temperature of water in White Oak Lake.



during March and April (Fig. 2). During May the daily meal increased rapidly towards a maximum (3.24%) in June after which there was a gradual decrease until February. The main daily meal for the whole year was 1.75% of the body weight. The feeding rates of bluegill did not decrease in the fall 1967 as rapidly as in the fall 1968. This difference might have been caused by the low temperatures in the summer 1967 (Fig. 2.) Food consumption of bluegill was calculated also with the balances of stable cesium and potassium. These results agreed well with the calculations based on ^{137}Cs balance (Kolehmainen, 1969a; Kolehmainen and Nelson, 1969).

There were three possible sources of errors in the calculations of the feeding rates: (1) The excretion rates of cesium were assumed to follow the so called Q_{10} law, or double for an increase of 10 C in the temperature. This, however, has not been proved for the biokinetic range of any species of fish. (2) The number of ^{137}Cs analyses of different food items and stomach contents was small. (3) The assimilation of ^{137}Cs for minor food items was not determined.

DISCUSSION

Studies on the quantitative feeding habits of fishes have been conducted either in the laboratory conditions or, if made under field conditions, have been performed almost entirely in the summer time. Therefore knowledge of the feeding rates of fishes on an annual basis is lacking. In laboratory experiments it has been shown that the feeding rates of fishes increase with temperature until a certain optimum temperature is reached, after which the feeding rates again decrease (Pentelow, 1939; Ricker, 1946; Baldwin, 1957; Kinne, 1960; Warren and Davis, 1967). In nature, temperature is not the only factor affecting the feeding rates on a seasonal basis, but fish are undergoing continuous adaptation processes seasonally. Therefore it is apparent that the feeding rates of bluegill are only partly correlated with temperature on a seasonal basis. However, annual differences in the daily water temperatures caused by weather or thermal pollution may cause differences in the daily feeding rates that are completely correlated with the daily temperatures if they are below the optimum temperature of the species.

The maximum daily meal of bluegill in the age-group IV in White Oak Lake was 3.2% of the body weight. This was somewhat lower than the maximum daily meal of bluegill (3.6%) in laboratory conditions (Gerking, 1962). Daily meals of White Oak Lake bluegill in June were close to those determined by Keast and Welsh (1968), 2.5%, in the Lake Opinicon bluegill in Ontario. White Oak Lake bluegill had a mean daily consumption rate of 2.0% of the body weight for the period from June to September. In Minnesota the daily meal of bluegill varied from 1 to 2% for the same period (Seaburg and Moyle, 1964), thus the feeding rates in White Oak Lake were somewhat more than in Minnesota.

The ecological growth efficiency (growth (g)/food consumption (g) during the same period) in the age-group IV in White Oak Lake bluegill was 4.2% for the period from April to October which is somewhat lower than determined by Gerking (1962) for the same age-group in Wyland Lake in Minnesota for the period from May to October. The low ecological growth efficiency in White Oak Lake bluegill was probably caused by the declining growth rate at that age (Kolehmainen, 1969a; Kolehmainen and Nelson, 1969).

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