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FALLOUT RADIOCESIUM IN SEDGES AND TROUT OF A CASCADE MOUNTAIN BOG

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DISCLAIMER

ABSTRACT

Radiocesium from worldwide fallout was measured in the sedges and in the eviscerated bodies of cutthroat trout collected from a Cascade Mountain bog during the years 1967, 1968, 1969 and 1970.

The bog is poor in essential mineral nutrients and located in a high rainfall area. These environmental features enhance the incorporation of radiocesium into the mineral cycling of bog biota.

The early spring harvests of sedges generally had the highest concentration of radiocesium and the autumn harvested the smallest amounts. Radiocesium values in sedge ranged between 5 and 30 picocuries per gram dry weight. The peak harvest yield of sedge mat vegetation amounted to 210 g/m^2 in 1968 and 1969.

The radiocesium concentration of eviscerated trout ranged from less than 1 picocurie per gram dry weight to 5 picocuries. In general the larger sized fish had higher burdens of ^{137}Cs than smaller sized fish.

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INTRODUCTION

Cesium-137 is a persistent radionuclide that enters the biological environment as a component of the debris formed during nuclear explosions. When injected high into the atmosphere this debris becomes widely distributed over the earth. In general, geographic regions in the Northern Hemisphere with high rainfall have received more fallout than areas of low rainfall. The conifer forests of the more moist western slopes of the Cascade Mountains have accumulated more radiocesium in the forest floor than forests located on the climatically drier eastern slope (Rickard, 1971).

This study presents the results of radiochemical analyses of sedges and trout inhabiting a bog in the Cascade Mountains over the period of years ranging between 1967 and 1970. Bog sedges appeared to be assimilating radiocesium from the surrounding substrate and the fish have probably obtained most of their burdens of radiocesium through the aquatic food web.

DESCRIPTION AND LOCATION OF THE BOG

The bog investigated is located in the Cascade Mountains of Washington immediately eastward of the summit of Snoqualmie Pass

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at an elevation of 2500 feet. The bog basin occupies several acres. About half of the area supports a dense mat of sedges and the central portion of the basin consists of a shallow pond.

The coniferous forest surrounding the bog has been partially logged but the climax forest is a mixture of Western Hemlock (Tsuga heterophylla) and Pacific Silver Fir (Abies amabilis). Much of the vegetation of the sedge mat consists of Carex rostrata, but Equisetum sp. is abundant, especially in the deeper water adjacent to the sedge mat. A few water lilies, Nuphar sp., grow scattered in the open water. Other characteristic bog plants grow in scattered locations along the bog margins. Bog laurel, Kalmia polifolia, bog cinquefoil, Potentilla palustris and sphagnum moss are most conspicuous.

There is no apparent inlet stream to the bog but a small permanent stream drains the basin. A population of native trout, Salmo clarkii, lives in the bog pond.

METHODS EMPLOYED

Five locations were scattered 30 meters or more apart in the sedge mat along the southern edge of the bog and marked with wooden stakes. Plots 1 x 1 meter in size were used as plant harvest areas. One plot was harvested at each of the five sites during spring, summer, and fall during the years 1967, 1968 and 1969. New growth of sedges identified by green color was harvested separately from dead plant material (litter). In 1967 the green shoots were clipped near ground level but in 1968, 1969 and 1970 the shoots were pulled individually by hand. The collections were brought to the laboratory for drying. Dried plants were milled to a homogenous powder. A subsample of the powder was used to fill a 500 ml plastic bottle. The bottle was counted inside a large 9 x 11 inch well-type NaI (Tl) crystal for 30 minutes. Radiocesium was determined using a computer program for analyzing pulse height spectra.

Fish were collected by angling and the number taken ranged between 2 and 11 at each collection time. The fish were individually weighed, eviscerated and reweighed. After oven drying, each eviscerated fish was counted for radiocesium in the same manner as the vegetation samples.

Chemical analyses of stable minerals in the sedges, fish and unfiltered water were conducted using Atomic absorption techniques.

RESULTS

A comparison of the stable mineral concentration of fish, green sedge shoots, litter and bog water is shown in table 1. Clearly higher concentrations of minerals were in the fish. Especially abundant were calcium, phosphorus and potassium. Potassium and phosphorus concentrations were especially low in the bog water.

The low mineral content of the bog water indicates the bog as a mineral deficient (oligotrophic) habitat. The pH of bog water averaged 6.5.

Potassium was the most abundant nutrient in the green sedge, however, the sedge litter showed a much lower potassium concentration indicating a rapid loss of potassium from sedge tissues as they aged and died.

Changes in the concentration of radiocesium in the green sedge from year to year and from spring to fall are illustrated in table 2.

In 1967 and 1969 a decrease in radiocesium concentration in standing live sedge was apparent as the season progressed and senescence approached, but there was little seasonal change detected in 1968. A general inventory of the radiocesium distribution within the sedge mat is shown in table 3. These data indicate that more radiocesium was associated with living material than with the dead material, but the amount of radiocesium associated with the peat and roots was not determined. The total radiocesium present in the inventoried components averaged about 5 nanocuries per square meter. This is far less than the 100 nanocuries per square meter present on the floor of some Cascade Mountain forest stands (Rickard, 1971).

The concentration of radiostrontium in eviscerated trout is shown in Figure 1. The concentration of ^{137}Cs ranged between 1 and 5 picocuries per gram dry weight. Examination of the stomachs of the freshly caught fish showed that damsel flies (Odonata) larvae and adults were important food items and suggests that the ^{137}Cs burdens in the trout are derived from their foods.

A major source of primary energy to bog animals is the sedge mat. Dead sedges are decomposed by bacteria and fungi and some is probably consumed by small invertebrates. Damsel flies are predaceous insects and these feed on smaller invertebrates. The damsel flies are eaten by fish which in turn may be eaten by man. Since the primary food supply (sedge) acts as a reservoir for radiocesium it is passed to higher trophic levels in the bog food chain. The primary production by the sedges is of major ecological importance. Seasonal changes in sedge biomass are shown in figure 2. Most of the growth was made by mid-July with little growth added in August and September. The final harvest of the year in October for 1968 and 1969 showed 210 grams of dry matter at maximal harvest yield.

Nelson and Whicker (1969) measured fallout radiocesium in different fish species from a variety of lakes and reservoirs from different climatic and topographic regions in the front range of Colorado. In general, trout collected from oligotrophic habitats at high elevations had higher concentrations of radiocesium than trout from low elevations. The flesh of cutthroat trout, <u>Salmo clarkii</u>, from Colorado Alpine lakes had concentrations of radiocesium ranging between 0.6 and 1.6 pCi/g fresh weight. The food of Colorado trout was varied, ranging from microcrustaceans to terrestrial insects as important dietary items. However, damsel flies were not included in the cutthroat diet.

Nelson and Whicker (1969) indicate that trout flesh had higher levels of radiocesium than the flesh of wild deer which in turn was higher than domestic animals. Gustafson (1969) indicated that freshwater systems would continue to provide an important source of dietary cesium for some time even in the absence of inputs of fresh fallout debris, especially for people who depend upon freshwater fish for a major share of their diets.

Comparison of fish body-burdens of ^{137}Cs (Figure 1) are complicated by the influence of body size on concentration per unit weight. Eberhardt (1967, 1969) had demonstrated a relationship between retention time and body weight, and a paper by Thomas and Eberhardt (this symposium) provides some further discussion of the apparent relationship. Figure 1 shows the relationship between concentration (pCi/g dry wt.) and square root of fresh body weight (less gut content) obtained in the present study.

The rationale behind the plot is briefly as follows. We assume that fish body burdens of ^{137}Cs are in equilibrium with concentration in the food supply, so that body burden may be represented by:

(1) $$y = \lambda/\mu$$

where λ = intake of ^{137}Cs per unit of time (per day, say) and μ = loss rate per unit time.

We further assume that intake and loss follow a well-known power law relationship for metabolic processes (Kleiber, 1961), giving

(3) $$\lambda = a_1 w^{.75}$$

(4) $$\mu = a_2 w^{-.75}$$

where a_1 and a_2 are constants, and w = body weight.

Equation (4) is effectively the basis of the relationship proposed by Eberhardt (1967, 1969), and shown to hold for fish by Morgan (1964). Combining equations 1-4 gives:

(5) $$y = \frac{a_1}{a_2} w^{1.5} \quad \text{(body-burden)}$$

and we convert to concentration per unit weight by a further division by w:

(6) $$y/w = \frac{a_1}{a_2} w^{1/2} = \text{concentration per unit weight}$$

Equation (6) is then the relationship postulated for the plot in Figure 1.

Referring to equation (6), we can estimate the quantity $^{a_1}/_{a_2}$ from a simple ratio estimator ($\Sigma y/\Sigma x$):

$$(7) \qquad \text{Estimate of } (^{a_1}/_{a_2}) = \frac{\Sigma \text{ concentrations}}{\Sigma \text{ weights}}$$

we thus find the following approximate values of $^{a_1}/_{a_2}$:

	Season	
Year	Summer	Fall
1967	(no data)	.16 (6)
1968	.20 (9)	.15 (4)
1969	.22 (8)	.26 (2)
1970	(no data)	.13 (8)

(The number of fish used in each estimate is shown in parentheses).

We thus observe a tendency for a higher value of $^{a_1}/_{a_2}$ in the summer than observed in the fall, with the exception of fall, 1969 values, which are based on two small fish.

At this writing, we have not had an opportunity to complete a statistical analysis of the available data, but it seems clear that an appropriate analysis (presumably an analysis of covariance) will permit us to test the summer-fall difference in slopes and perhaps make more efficient between-years comparisons, by adjusting for weight differences. For present purposes, the pattern of open (fall) and closed (summer) symbols illustrates the apparent differences in slope between the two seasons. An obvious and immediate interpretation, of course, is that summer concentrations are higher than fall values at the same body weight while mean concentrations in fall 1970 are obviously much lower than those in the first year of study (fall, 1967) it is also evident that mean body weights are also much smaller. If we can legitimately adjust to common body weights (using the $^{a_1}/_{a_2}$ ratios) there is evidently remarkably little change in adjusted ^{137}Cs burdens over the four years of study. There are, of course, many uncertainties in our analysis. We suspect that there is a seasonal cycle in concentration of ^{137}Cs in fish so that our assumption of equilibrium body burdens may be questioned. Quite possibly such a seasonal cycle may account for the apparent difference in summer-fall ratios, but it may also be supposed that seasonal shifts in water temperature and feeding intensity (by trout) may also be implicated.

While it seems unquestionable that there is a definite relationship between ^{137}Cs concentration and fresh weight of fish, it might be argued that a simple proportional relationship to body weight (rather than to square-root of body weight) may be adequate. While further study seems essential, we think it quite suggestive that the relative variation (measured by the coefficient of variation, $s/\bar{x}$) is uniformly smaller for the ratio: concentration / w than it is for the ratio: concentration/w (where w = weight in grams). Values of the coefficients of variation are as follows (excluding the 2 fish of fall, 1969):

	Summer		Fall	
	conc/w	conc/w	conc/w	conc/w
1967	(no data)		.391	.252
1968	.450	.323	.622	.342
1969	.287	.179	(two fish only)	
1970	(no data)		.815	.547

Using equation (6) and the fall, 1967 and fall, 1970 ratios (.16 and .13), it may be speculated that mean concentration of ^{137}Cs in fish of the same weight has decreased in the ratio .13/.16 = .812 in four years time, giving a loss rate calculation of

(8) $$.812 = e^{-4\mu} \text{ so that } \hat{\mu} = .052$$

for a half-time calculation of $\frac{.69315}{.052}$ = 13.3 years which is very much like the rates calculated for ^{137}Cs in arctic lichens (Cf. Eberhardt and Hanson 1969:796).

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Table 1. THE STABLE MINERAL CONTENT (mg/g DRY WEIGHT) ± standard error OF FISH, LIVE SEDGE, LITTER AND WATER (mg/liter) FROM A CASCADE MOUNTAIN BOG, 1968.

	Fish	Sedge	Litter	Water
Calcium	19.9 ± 1.40	1.9 ± .115	3.00 ± .394	2.6 ± .03
Magnesium	1.9 ± .20	1.4 ± .086	.74 ± .065	.46 ± 0
Sodium	2.4 ± .13	0.1 ± 0.24	.18 ± .018	1.2 ± 0
Potassium	12.3 ± .47	9.8 ± .640	1.20 ± .205	.24 ± 0
Phosphate	16.1 ± 1.41	.64 ± .056	.44 ± 0.39	> .001
Percent Ash		4.12 ± .295	7.63 ± .304	

± standard error, n=5

Table 2. RADIOCESIUM (picocuries/g dry wt.) IN LIVE SEDGE FROM A CASCADE MOUNTAIN BOG, 1967, 1968, 1969.

MONTH	1967	1968	1969	1970
May		11.1 ± 1.31		
June	29.4 ± 8.98		22.8 ± 6.60	
July	17.3 ± 4.22	11.0 ± 1.63	15.1 ± 1.14	
Sept.	10.4 ± 1.88			7.52 ± 1.88
Oct.		10.7 ± 1.08	5.1 ± .40	

± standard error, n=5

Table 3. INVENTORY OF THE DISTRIBUTION OF RADIOCESIUM (Picocuries/m^2) IN THE SEDGE MAT OF A CASCADE MOUNTAIN BOG IN JULY, 1968.

PLOT NO.	SEDGE	MOSS	HORSETAIL	TOTAL LIVE	TOTAL DEAD	TOTAL BIOMASS
1	2200	0	1600	3800	3200	7000
2	2500	2600	0	5100	800	5900
3	2300	0	0	2300	2200	4500
4	1300	2700	0	4000	70	4070
5	2000	0	0	2000	5000	7000
Avg.	-	-	-	3440	2254	5644

0 = not present in the quadrat sampled.

Figure 1. Concentration of ^{137}Cs in Cutthroat Trout in the Cascade Mountain Bog.

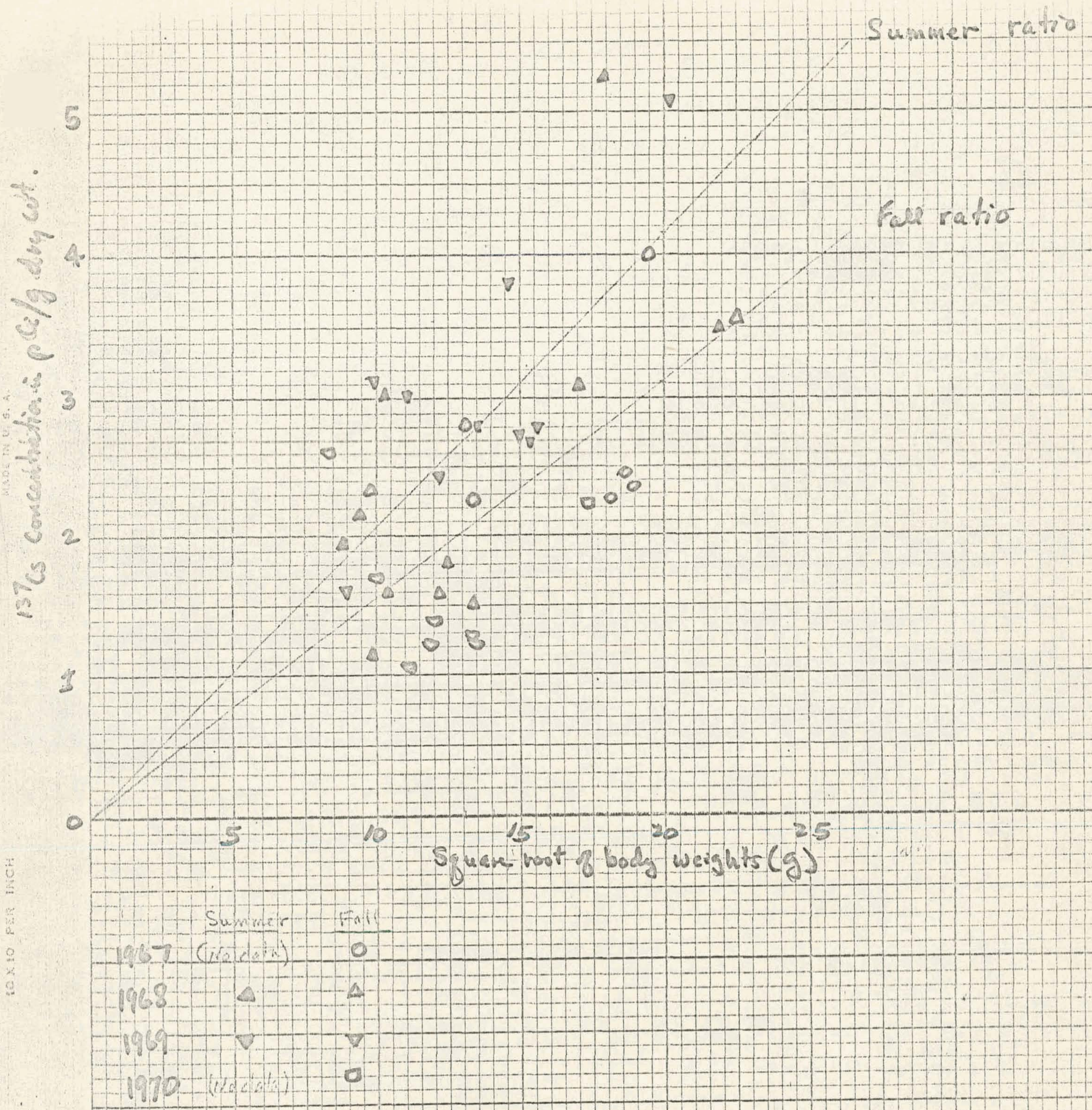
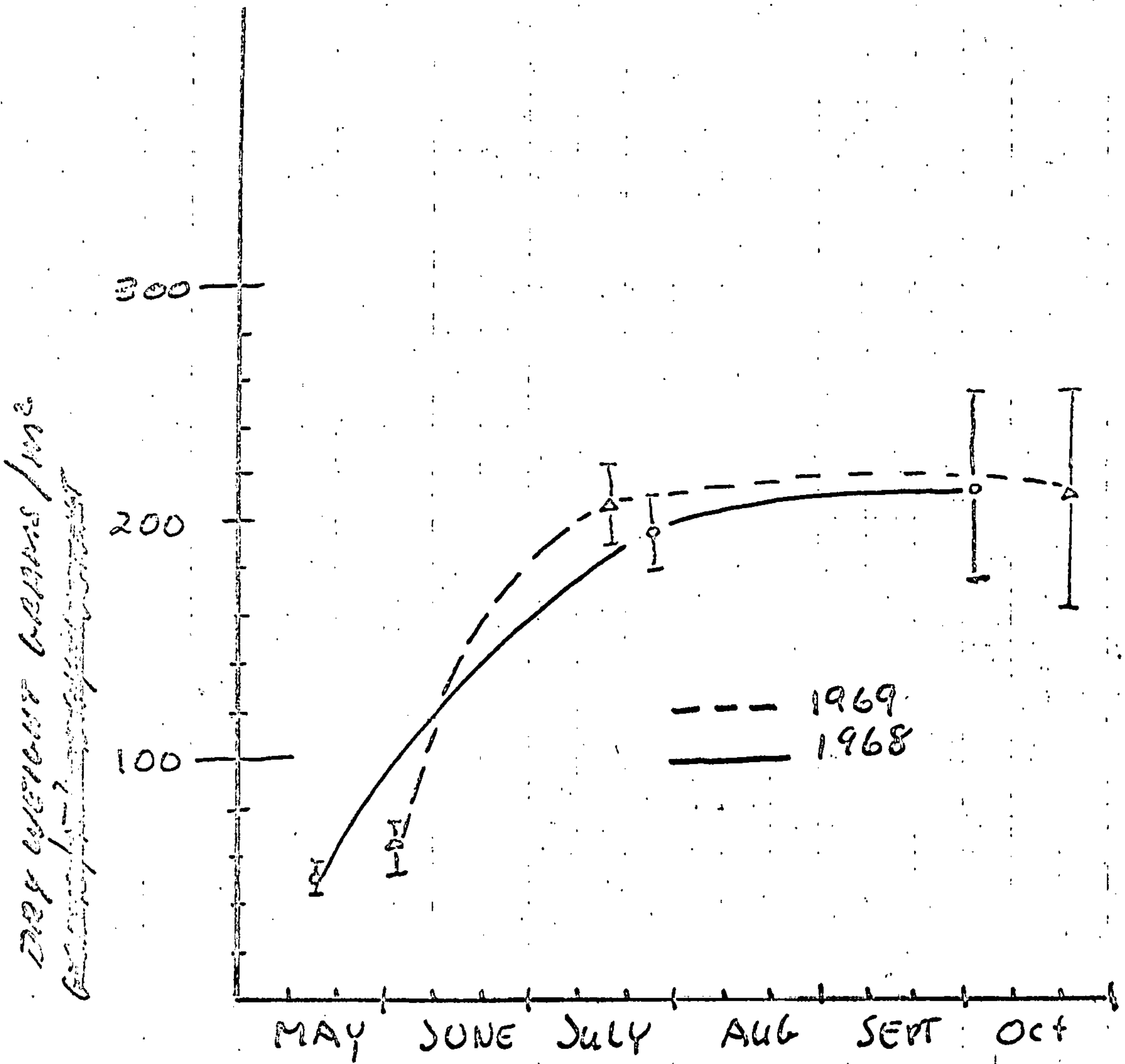


Figure 1. ^{137}Cs Concentration in Cutthroat Trout in a Cascade Mountain Bog.

Figure 2. Seasonal Change in Dry Weight of Sedge Mat Plants Growing in a Mountain Bog in 1968 and 1969.



DRY WEIGHT GRAMS / M²
300
200
100
MAY
JUNE
JULY
AUG
SEPT
OCT
1969
1968

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