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DISCLAIMER

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TECHNICAL PROGRESS REPORT
DEPARTMENT OF RADIOLOGY AND RADIATION BIOLOGY
COLORADO STATE UNIVERSITY
FORT COLLINS, COLORADO

TO: U. S. Atomic Energy Commission
Chicago Operations Office
Argonne, Illinois

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RADIOECOLOGY OF SOME NATURAL ORGANISMS AND SYSTEMS IN COLORADO

FOR THE PERIOD: January 1, 1970 - December 31, 1970

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I. SUMMARY

I. Summary

The broad objective of this research is to provide information on the behavior of radionuclides in, and radiation sensitivity of, selected organisms and natural systems in Colorado. Components of several kinds of natural systems, including alpine tundra, montane forests, shortgrass plains, and freshwater lakes and streams are currently under investigation by this laboratory. This research is being conducted primarily by graduate students and faculty members in the Department of Radiology and Radiation Biology at Colorado State University, with the collaboration of W. C. Nelson, Colorado Division of Game, Fish & Parks on portions of the aquatic studies.

This report summarizes project activities and major findings during the calendar year 1970. Studies on the metabolism of strontium and calcium in captive mule deer have been in progress nearly two years and a general picture of the effects of sex, age, season, antler growth and lactation upon uptake and retention of the elements is beginning to emerge. Tissue samples were obtained from 12 wild deer from the Cache la Poudre Drainage and assayed for ^{137}Cs to measure long-term trends, and for ^{131}I to study the thyroid response to the Chinese test conducted October 14, 1970. East Twin Lake was dosed with 1 kg stable cesium on September 15, 1970 to measure the kinetics of the element within the ecosystem. Periodic measurements of cesium in samples of water, detritus, seston, vegetation, invertebrates, and trout is being performed by neutron activation in a Triga reactor. This method appears to have several logistic advantages over the use of radiocesium for systems that are on public lands. A six-year survey of ^{137}Cs and ^{90}Sr concentrations in trout from 51 mountain lakes in Colorado culminated in a report which has been prepared for journal publication. Another experiment on the comparative response of pikas to irradiation under varied degrees of social competition was completed which augmented and further strengthened conclusions from earlier studies. The early effects and recovery stages of the irradiated shortgrass plant community have been completed and results are being prepared for publication. Chronically irradiated sectors are continuing to receive treatment and recovery studies of semi-acutely treated sectors will continue to be pursued. Inventories of certain arthropods within the irradiated grassland community are continuing and significant new progress was made this year on the studies of arthropod food webs using tracer ^{32}P.

The principal investigator devoted considerable time in 1970 to preparation of a portion of a book on radiation ecology while in sabbatical residence at the University of North Carolina. Another book which

is a compilation of selected readings in radiation ecology was prepared in collaboration with Dr. Vincent Schultz, Washington State University. The first draft has been submitted to the publisher, Dowden, Hutchinson and Ross, Inc., which has expressed interest in publishing the readings; as well as to colleagues for review.

II. RADIONUCLIDE STUDIES WITH MULE DEER

II. A. Strontium and Calcium Metabolism in Mule Deer
R. G. Schreckhise and F. W. Whicker

Schultz[1] demonstrated a correlation of ^{90}Sr concentrations between the mandible and antlers in the white-tailed deer. This suggested the feasibility of using antlers as an indicator of the body burdens of the deer and environmental ^{90}Sr concentrations over the feeding area of the deer. Because of the unknown extent of the utilization of skeletal and/or dietary strontium in antler formation, more studies are required before antlers can be used as fallout indicators in deer.

The purpose of this study is to investigate the effects of seasonal and age variations on strontium and calcium kinetics in mule deer (Odocoileus hemionus). The relation of Ca-Sr kinetics to antler development, doe to fetus transfer during gestation, and doe to fawn transfer during lactation are of specific interest.

To study the effect of season on Sr and Ca kinetics in male deer, the year was divided into three seasons in reference to antler development as follows: 1) Early antler growth - first of March to the last of June - the new antler growth normally begins in March and is relatively slow through June; 2) Late antler growth - first of July to the last of September - this is probably the period of greatest visual antler growth, especially during the month of July. The bucks usually "polish" or strip the velvet off their antlers during the last two weeks in September; and, 3) Dormancy - first of October to the last of February - this includes the breeding season in which the bucks start establishing social hierarchy around the first of October with breeding probably occurring in December. The old antlers are shed around the middle of March and new antler growth begins immediately. Even though there is no visual antler growth during this period, preparation for the start of new antler growth may have already started due to the changes of blood hormone levels associated with the breeding season. Dates in these three different time periods were selected for spiking bucks of various ages. Spiking has been completed for the early and late antler development time periods and bucks are now being spiked for the period of dormancy.

For studies of Sr and Ca kinetics in the doe, fawn and fetus, the following dates were selected for spiking: 1) Pre-gestation - first

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[1] Schultz, V. 1965. Comparison of strontium-90 levels between antler and mandible in white-tailed deer. J. Wildlife Mgmt. 29(1): 33-38.

of November - at this time, prior to breeding, the doe is probably building a Ca and Sr reserve for fetal development and the tracer Sr and Ca that is laid down by the fetus would be skeletal Sr and Ca from the doe; 2) Mid-gestation - first of March - at this time, the Ca and Sr demands by the fetus are probably large, Sr and Ca in the fetus would come primarily from the doe's diet; 3) Pre-parturition - last of May - just before fawning, bone formation in the fetus is nearing completion; 4) Lactation - last of June - to determine the extent of transfer of Ca and Sr from the doe's diet to the nursing fawn. This work is difficult as the fawns that are left on the doe are very hard to work with. We hope to spike two fawns in June and study the Sr kinetics of bottle fed fawns. Does were spiked during pre-gestation and pre-parturition and the other spiking periods should be completed this year.

The methods, facilities and deer herd used for studying the uptake, retention and translocation parameters have previously been described[2, 3, 4]. Some modifications were made on the metabolic cage as described by Schreckhise et al.[4]. The lower sides around the metabolic cage were enclosed with 1/2" plywood and a thermostatically controlled electric heater was installed under the collection pan to enable collection of urine and feces during the winter months.

Completion of the counting room and chute[4] greatly improved the whole body counting results. The deer are counted at a distance of 6' 6" from the mid-line of the counting chute to the center of the 3" x 3" NaI crystal for a minimum of 5 minutes, then again at a distance of 3' 6" for at least 3 minutes. Movement by the deer when counted at the 6' 6" distance has a minimal effect on the whole body counting but movement by the deer at the 3' 6" distance, especially the first 2-3

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[2] Gist, C. S. 1969. Iodine-131 retention in mule deer. M. S. Thesis. Colorado State University, Ft. Collins. 75 p.

[3] Hakonson, T. E. 1967. Tissue distribution and excretion of ^{134}Cs in the mule deer. M. S. Thesis. Colorado State University, Ft. Collins. 121 p.

[4] Schreckhise, R. G., A. W. Alldredge, and F. W. Whicker. 1970. Strontium and calcium metabolism in mule deer. p. 5-8. In Eighth Annual Progress Report on Atomic Energy Commission Contract AT(11-1)-1156, Department of Radiology and Radiation Biology, Colorado State University, Ft. Collins.

days following ingestion when the ^{85}Sr is located primarily in the G.I. tract, can adversely affect the results, but as the ^{85}Sr diffuses throughout the body, the 3' 6" distance results closely follow the 6' 6" results. Thus, as the count rate of the deer decreases, the deer can be counted at the 3' 6" distance where the counting efficiency is approximately 2.5 times greater than at the 6' 6" distance. This enables whole body counting of the deer to be made for a longer duration.

The antlers were collected in November after they had hardened and all the velvet had been stripped. This is done primarily in an attempt to eliminate injury to the other deer and the investigators. The antlers were collected by confining the bucks in a squeeze chute and sawing off the antlers, leaving a nub approximately 2-3 cm long. The nubs were collected in February and March when the bucks normally shed their antlers. The antlers were then sectioned into 5-6 cm lengths, dried and then ashed at approximately 700°C for 24-30 hours. They were then ground to a fine powder with a mortar and pestle and a two gram aliquot was dissolved in 100 ml of 0.2 N HCl and counted on a 4" x 8" NaI crystal attached to a RIDL Model 34/12 analyzer. The results are listed in Table II. A. 1.

The preliminary results of ^{85}Sr retention in deer following acute oral ingestion of approximately 450 μCi ^{85}Sr during 1970 along with those reported by Schreckhise et al.[4] are also listed in Table II. A. 1. The following model, describing the ^{85}Sr retention curve, was used for these preliminary results,

$$A_t = A_1 e^{-\lambda_1 t} + A_2 e^{-\lambda_2 t}$$

where, A_t = fraction of the ingested dose retained at time t, A_1 and A_2 = fraction of the initial dose represented by the short and long components, respectively, λ_1 and λ_2 = $0.693/T_{biol}$ for the short and long components, and T_{biol} = biological half life in days.

Also listed are results from 3 fawns which were periodically whole body counted for approximately 3 weeks following their births from does that were spiked just prior to parturition. The listed values of A_2 for the fawns are taken by extrapolating the ^{85}Sr retention curve back to the time of ingestion by the doe and are approximations of the fraction of the dose ingested by the doe that was transferred to the fetuses. Doe S-9 was spiked 9 days prior to giving birth to twin fawns S-11 and S-12, while doe S-10 was spiked 8 days before giving birth to the fawn S-13.

No attempt will be made here to draw conclusions or make any comparisons as more data must be gathered before conclusive statements can be made regarding the effects of season, age and other factors on Sr and Ca metabolism in mule deer.

Table II. A. 1 Preliminary results of ^{85}Sr retention and translocation in mule deer following acute oral ingestions of approximately 450 μCi ^{85}Sr.

Deer	Sex	Age at Time of Spiking (months)	Weight (kg)	Period and Date of Spiking*	Antler Length at Time of Spiking as a Fraction of Final Antler Length	Intercept of the Long Component (A_2)	Biological Half-life of the Long Component T_{biol} (days)	Fraction of the Ingested Dose in the Antlers Corrected for Physical Decay Back to the Time of Spiking
S-8	M	11	42.2	EAG, 5/17/70	0.37	0.103	185.0	
S-1	M	12	45.4	EAG, 6/19/69	0.40	0.090	176.0	0.00201
S-14	M	14	62.7	LAG, 7/31/70	0.92	0.0988	168.0	
S-15	M	14	59.0	LAG, 8/14/70	1.00	0.114	352.0	
S-6	M	23	60.8	EAG, 5/4/70	0.00	0.150	282.0	
S-2	M	25	56.8	LAG, 7/6/69	0.48	0.041	181.0	0.00329
S-3	M	25	45.4	LAG, 7/30/69	0.83	0.088	140.0	0.0146
S-4	M	26	56.8	LAG, 8/14/69	0.95	0.054	288.0	0.00947
S-7	M	35	89.0	EAG, 5/9/70	0.11	0.0578	392.0	
S-17	M	37	76.3	LAG, 7/24/70	**	0.0639	112.0	
S-5	M	51	90.8	LAG, 9/2/69	1.00	0.152	144.0	0.0174
S-16	M	61	106.2	LAG, 7/15/70	0.88	0.0894	410.0	
S-18	F	16	44.9	PRG, 10/30/70	--	0.039	189.0	
S-19	F	16	65.4	PRG, 11/7/70	--	0.048	106.0	
S-10	F	24	52.2	PRP, 6/13/70	--	0.111	160.0	
S-9	F	60	61.7	PRP, 6/6/70	--	0.0221	181.0	
S-11	F	***	2.7		--	0.00349	30.6	
S-12	F	***	3.2		--	0.00390	17.2	
S-13	F	****	2.7		--	0.0124	50.2	

* EAG = Early Antler Growth, LAG = Late Antler Growth, PRG = Pre-gestation, PRP = Pre-parturition
** Died before antler growth was completed
*** Born 9 days after spiking doe S-9
**** Born 10 days after spiking doe S-10

II. B. Cesium-137 and Iodine-131 in Mule Deer, 1970

F. W. Whicker

Tissue samples from 12 wild mule deer killed within the Cache la Poudre Drainage of north-central Colorado were obtained in 1970. Five of the animals were killed by automobiles and provided by S. Palm of the Colorado Division of Game, Fish, and Parks while seven were killed by rifle hunters. All animals were on winter range at elevations below 8,000 feet when killed. Muscle tissues were assayed for ^{137}Cs, thyroids were analyzed for ^{131}I, and three metacarpals were saved for future ^{90}Sr assay.

Results of the ^{137}Cs and ^{131}I determinations are given in Table II. B. 1. Radiocesium values ranged from non-detectable levels to 324 pCi/Kg wet muscle. The mean of 11 determinations was 134 pCi/Kg. The mean of 2 values for 1969 winter range deer from the same area was 152 pCi/Kg.[1]

Iodine-131 was measured in 10 of 11 thyroids examined, with values ranging up to 365 pCi/g wet tissue. It is likely that the ^{131}I contamination was the result of the Chinese atmospheric nuclear test announced October 14, 1970.[2]

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[1] F. W. Whicker and O. D. Markham. 1970. Cesium-137 and Iodine-131 in mule deer, 1969. p. 9. In Eighth Annual Progress Report on Atomic Energy Commission Contract AT(11-1)-1156. Colorado State University, Fort Collins.

[2] U. S. Public Health Service. 1970. Reported nuclear detonations, October 1970. Rad. Health Data and Reports 11(11): 658.

Table II. B. 1 Concentrations of ^{137}Cs and ^{131}I in mule deer collected from the Cache la Poudre Drainage, Colorado, 1970.

No.	Date	Sex	Age Class	Location S	Location T	Location R	Elevation (feet)	pCi ^{137}Cs/Kg Fresh Muscle	pCi ^{131}I/g Fresh Thyroid
70-1	10/26	F	Mature	22	11 N	72 W	7,100	136	349
70-2	10/28	M	Yearling	6	7 N	69 W	5,500	110	365
70-3	10/27	M	Mature	18	9 N	70 W	6,400	85	201
70-4	10/22	M	Mature	22	11 N	72 W	7,100	324	--
70-5	11/4	F	Mature	12	8 N	70 W	5,300	289	217
70-6	11/11	F	Mature	1	8 N	72 W	7,100	109	330
70-7	11/18	F	Mature	32	9 N	72 W	7,950	75	251
70-8	11/18	F	Mature	36	9 N	70 W	5,400	96	151
70-9	11/19	M	Yearling	32	7 N	69 W	5,400	--	196
70-10	11/27	M	Yearling	1	8 N	72 W	7,000	169	119
70-11	12/5	M	Mature	20	10 N	70 W	6,000	81	56
70-12	12/24	M	Fawn	35	10 N	70 W	6,000	N.D.*	N.D.

* N. D. - Not Detectable

III. RADIONUCLIDE STUDIES OF AQUATIC SYSTEMS

III. A. Kinetics of Cesium in a Montane Lake Ecosystem
T. E. Hakonson and F. W. Whicker

The cesium kinetics study that was proposed to the Atomic Energy Commission in January 1970[1] called for the introduction of 0.5 curies of ^{134}Cs into the water of East Twin Lake (ETL). However, anticipated public opposition to the use of the radioactive tracer led us to consider an alternative method for determining cesium kinetics in ETL. This method utilizes stable cesium as a tracer which is easily detected by neutron activation of sample materials (^{133}Cs, n, γ, ^{134}Cs).

Laboratory studies demonstrated that 7 x 10^{-8} gram quantities of ^{133}Cs could be detected under our experimental conditions. Calculations based on previous cesium studies at ETL[2] revealed that a one kilogram "spike" was required to achieve detectable quantities of ^{133}Cs in all major ETL components.

Experiments (Table III. A. 1) with ^{133}Cs and selected ETL invertebrates (Gammarus lacustris and copepods of the genus Cyclops and Diaptomus) demonstrated that acute toxicity from ^{133}Cs Cl (LD_{50-5}) occurred at a ^{133}Cs concentration of 7 x 10^{-5} g ^{133}Cs/cc water, a concentration 10^4 times greater than the concentration initially expected at ETL after the 1 kg spike.

On September 15, 1970 one kilogram of ^{133}Cs as ^{133}Cs Cl was mixed with two five-gallon batches of filtered (28 μ mesh) ETL water. Motor boats and electric water pumps were used to distribute the ^{133}Cs solution uniformly in the lake. The ^{133}Cs solution was distributed in proportion to the water volumes located in the littoral and limnetic zones, about 15 per cent and 75 per cent, respectively. The spiking procedure for both zones was completed in less than one hour and the average time from beginning to end of spiding was taken as time zero (T_o).

About 1.5 hours after T_o, sampling was initiated and included items such as water, sediment, sedge (Carex aquatilis), Duckweed (Lemna trisulcata), water lilly (Nymphaea sp.), zooplankton (Daphnia spp., Cyclops spp. and Diaptomus spp.), amphipods (Gammarus

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[1] Whicker F. W. 1970. Radioecology of Some Natural Organisms and Systems in Colorado. Atomic Energy Commission Renewal Proposal, Contract AT(11-1)-1156. 22 pp mimeo.

[2] Gallegos, A. F. 1969. Radiocesium Kinetics in the Components of a Montane Lake Ecosystem. Ph.D. Dissertation, Colorado State University, Fort Collins, 342 p. (COO-1156-34)

lacustris), fish (Salmo gairdneri), and assorted aquatic mollusks, insects and annelids. Seston was filtered from the water samples for separate assay. Sampling intervals were gradually lengthened from every few hours at the beginning of the experiment, to every two weeks at the present time.

Currently samples are being prepared for activation analysis. This procedure involves oven drying and weighing of the sample, reducing sample volume if considerable bulk is involved (e. g. water and vegetation) and encapsulation of the sample in polyethylene vials which are compatible with the irradiation facility.

Samples submitted for irradiation are exposed to a neutron flux of 2×10^{12} n/cm^2-sec in the U. S. Geological Survey's TRIGA research reactor located in Denver, Colorado. Samples are normally irradiated for four hour periods although considerable flexibility is permitted.

Short-lived activation products such as Cl^{38} and Na^{24} are allowed to decay for two weeks prior to counting the samples on a 4 x 8 inch NaI (Tl) detector coupled with a 400 channel pulse height analyzer.

Since sample counting has just begun, results can only be qualitative. However, ^{133}Cs can be detected 1.5 and 4.5 hours after T_o in 10 g samples of zooplankton and amphipods, respectively.

Currently, gamma ray spectra stripping techniques are being developed to account for unwanted contributions to the ^{134}Cs photopeak areas (e. g. longer lived activation products such as Fe^{59} and Zn^{65}).

Total lake biomass estimates of the major components sampled were made prior to and following the cesium spiking. This will, in conjunction with the temporal pattern of ^{133}Cs concentrations, permit an analysis of the cesium exchange kinetics between major lake compartments. Analogue and digital computer techniques will be used to solve for the various rate constants.

Table III. A. 1 Percent survival of selected East Twin Lake (ETL) invertebrates exposed for five days to various ^{133}Cs concentrations. *

Grams ^{133}Cs/ cc water	Percent Survival	
	Gammarus lacustris**	Cyclops bicuspidata**
0	90	90
7×10^{-9}	100	100
7×10^{-8}	100	100
7×10^{-7}	100	100
7×10^{-6}	100	100
7×10^{-5}	50	30
7×10^{-4}	0	0
7×10^{-3}	0	0

* Initial ^{133}Cs concentration in ETL water after a one kilogram spike was calculated to be about 7×10^{-9} g ^{133}Cs/ cc water (ETL volume = 1.45×10^{8} liters).

** Ten individuals were placed in 1.5 liters of ETL water having the desired ^{133}Cs concentration.

III. B. Fallout ^{137}Cs and ^{90}Sr in Trout from Colorado's Mountain Lakes

F. W. Whicker, W. C. Nelson, and A. F. Gallegos

This work is summarized in the following abstract of a paper by the above title (COO-1156-39) which is in manuscript form and ready for submission to a journal for publication.

Abstract

Concentrations of ^{137}Cs and ^{90}Sr were measured in tissues of five trout species taken from 51 mountain lakes in Colorado during the period 1965-70. Fisheries biology information and limnological data were gathered from each lake in an effort to relate radionuclide levels to ecological factors. ^{137}Cs levels ranged from 116 to 5802 pCi/kg wet muscle while ^{90}Sr values ranged from 6 to 238 pCi/g bone ash. A yearly decrease in ^{137}Cs levels was observed with the rate of decrease becoming smaller through the sampling period. The temporal trend was fit by a model employing a fallout "rate" factor and a "cumulative deposition" factor. Radionuclide concentrations generally were higher at the more northerly latitudes. Trout from lakes in certain watersheds were much higher in ^{137}Cs than trout from other regions. Trout from montane and alpine lakes contained much more ^{137}Cs and ^{90}Sr than fish from waters at lower elevations. Dissolved calcium was significantly related to ^{90}Sr values in trout, but potassium had little relationship to ^{137}Cs values. A trophic relationship for ^{137}Cs of 3.26 was found between large predatory trout and small trout which were presumably prey. General lake characteristics associated with relatively high ^{137}Cs and ^{90}Sr burdens in trout are described.

IV. STUDIES ON THE PIKA

IV. A. Effects of Radiation and Social Stress on the Pika

O. D. Markham and F. W. Whicker

An experiment similar to the one reported for 1969[1] was completed in 1970. The pikas were released in the two one-acre enclosures in early July and irradiated two months later in late September. Many of the released animals did not survive the pre-irradiation period, probably due to battles over territory. Two attempts were made during the experiment to restock the two enclosures back to their original density. These attempts were not successful because of the aggressiveness of the originally stocked animals. The sex and the age of the irradiated and control pikas in the 1969 and 1970 experiments are shown in Table IV. A. 1.

The mortality data for the irradiation experiments are listed in Table IV. A. 2. Significantly more irradiated animals died in the 15 cage area than in the individual pens during both experiments. The response in the 31 cage area is not significantly greater than the response in the individual pens for each experiment but when the statistical analysis is applied to both experiments together the values are significantly different (α = .05). During the 30 day post-irradiation periods, no mortalities were recorded among the control animals. Although there were more irradiation mortalities in both experiments in the 15 cage area than in the 31 cage area these data were not significantly different.

Survival times for irradiation caused mortalities are shown in Table IV. A. 3. Pikas in the 15 cage area that died from the irradiation within the 30 day period lived for an average of 9.85 days in the two experiments while pikas in the individual pens and in the 31 cage area that died, lived on an average of 13.8 days and 12.0 days, respectively. A statistical analysis demonstrated that the survival times in the three areas were significantly (α = .01) different.

The average number of chases in each enclosure for the two experiments are given in Table IV. A. 4. The chases per pika hour in each enclosure for each year is not significantly different from the other enclosure. However, there was a significant difference (α = .05) between the daily average number of chases per pika-hour between the 1969 and 1970 experiments in the 15 cage enclosure.

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[1] O. D. Markham and F. W. Whicker. 1970. Effects of radiation and social stress on the pika. p. 16-21. In Eighth Annual Progress Report on Atomic Energy Commission Contract AT(11-1)-1156. Colorado State University, Ft. Collins.

During the 1970 experiment, adults sampled in the 31 cage area gained significantly (α = .025) more weight during the two months after being released and prior to irradiation than did the individually confined animals (average of 24.9 grams per pika versus -4.32 grams). Data gathered on the 15 cage area were insufficient to make a comparison for the above time period. The average adult weight prior to irradiation in early September was 174.6 grams in the 31 cage area, 164.6 grams in the 15 cage area and 149.1 grams in the individual cages.

Both experiments indicated that pikas which are free to interact in enclosures appear to be more sensitive than animals which are individually confined. The data are very similar to that from a previous study in the natural environment[2].

The increased radiation induced mortalities in the enclosures as compared to the individual cages may result from aggressive interaction necessary for competition in gaining and retaining territories. The increased mortality in the enclosures was not likely due to diet as these animals appeared to be in better health than the animals in the individual cages.

In both experiments the irradiated pikas in the 15 cage area suffered a slightly higher mortality than irradiated animals in the 31 cage area. However, these differences were not statistically significant. Since there was no corresponding pattern or significant difference in the chases per unit time per pika between the two areas in either of the experiments, it does not appear that the irradiation mortality figures can be explained by any differential aggressiveness as displayed by the number of chases in each area. After pikas died or disappeared in the enclosures, no attempt was made to close a corresponding number of cages. Therefore, in the 31 cage area there were more cage-den assemblies per pika than in the 15 cage area at the time of irradiation. These additional cage-den assemblies and rock piles may have offered additional places for the animals to hide or escape from their neighbors and also there may have also been more territories available per pika. These extra cages may have also provided for a more secure territory as many of the pikas controlled several cage-den assemblies in their territory and at least one pika in the 31 cage area stored vegetation in four cages. Therefore, the extra cage-den assemblies and rock piles may have accounted for fewer irradiation deaths in the 31 cage area.

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[2] O. D. Markham, and F. W. Whicker. 1970. Radiation $LD50_{(30)}$ of pikas (Ochotona princeps) in the natural environment and in captivity. Am. Midland Naturalist 84(1): 248-252.

There were significantly more chases per pika-hour in the 15 cage area in 1969 than in the 1970 experiment (.174 per pika-hr in 1969 compared to .005 per pika-hr in 1970). The irradiation mortality response was eight out of nine animals in 1969 compared to five out of eight in 1970, however, these data are probably not sufficient to indicate a causal relationship.

The survival times indicate that the more radiosensitive a group of pikas were, the shorter the survival time for radiation induced mortalities. This same relationship also occurred in a previous study, where pikas in the natural environment were more sensitive and had shorter survival times than animals held captive in individual pens[2]. Survival times in the natural environment may have been shortened by predation.

Table IV. A. 1 Numbers and description of pikas present in each area at time of irradiation

	15 Cages/Acre		31 Cages/Acre		Individual Cages	
	Control	Irradiated	Control	Irradiated	Control	Irradiated
Aug.-Sept. 1969:						
Male Adults	1	4	5	5	3	5
Male Subadults		2	2	1	5	1
Female Adults	1	3	3	3	2	3
Female Subadults	1	1	1	1	5	1
* Unsexed Adult			1			
* Unsexed Subadult			1			
Totals	3	10	13	10	15	10
Sept.-Oct. 1970:						
Male		5	5	6	3	3
Female	2	5	4	4	5	7
* Unsexed Adult	1		1		2	
Totals	3	10	10	10	10	10

* Lost identification tags

Table IV. A. 2 Comparison of the number of deaths of pikas 30 days after an acute exposure to 500 r ^{60}Co irradiation in three areas by the chi-square test

	Individually Caged (Expected)		15 Cages/Acre*		31 Cages/Acre	
	Aug. -Sept. 1969	Sept. -Oct. 1970	1969	1970	1969	1970
Number alive	7	7	1	3	5	5
Number dead	3	3	8	5	5	5
Chi-square value			14.86***	4.02**	1.90	1.90
Chi-square value on both years				18.13***		3.81**

* One animal in 1969 and two in 1970 not included died from non-irradiation causes

** $\alpha = .05$

*** $\alpha = .005$

Table IV. A. 3 Survival times (days) of pikas which died within 30 days after receiving 500 r ^{60}Co irradiation.

Individually Caged	15 Cages/Acre	31 Cages/Acre
	1969	
10	10	12
11	9	11
20	11	14
	9	12
	9	15
	11	
	13	
	9	
	1970	
14	9	16
14	6	12
14	12	10
	12	10
	8	8

Table IV. A. 4 Daily average number of chases per pika-hour in two one-acre enclosures for a three week period ending one week after acute exposure to 500 r from ^{60}Co.

	15 Cages/Acre	31 Cages/Acre
August-September 1969	.174 ± .037*	.152 ± .052
September-October 1970	.005 ± .027	.137 ± .053

* Standard Error

IV. B. Reproduction in the Pika

O. D. Markham and F. W. Whicker

Reproductive data obtained from animals collected in 1970 on Mount Evans, Colorado are listed in Table IV. B. 1. Techniques were the same as those reported for 1968[1]. The births in captivity during 1970 are listed in Table IV. B. 2. The average size of 47 litters was 3. 19 young. Five animals were trapped in 1970 that were used in the 1968 experiment on Mount Evans. Two of these served as controls in 1968, two received 300 r ^{60}Co irradiation and one had lost all ear tags and was unidentifiable. One of the females which received 300 r produced a litter of three and the other which received 300 r did not have young after her July 3 capture. A captive animal from the 1969 experiment which received 500 r ^{60}Co irradiation produced a litter of one.

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[1] O. D. Markham and F. W. Whicker. 1969. Pika density and reproduction at Mount Evans. p. 64-68. In Seventh Annual Progress Report on Atomic Energy Commission Contract AT(11-1)-1156. Colorado State University, Fort Collins.

Table IV. B. 1 Reproduction and weight data from pikas collected on Mount Evans during 1970.

Collection No.	Date of Collection	Sex	Weight (grams)	Remarks Fetal Weight in grams; Testis Length in mm
70-1	5/26/70	M	139.6	13.2, 13.9 mm
70-2	5/26/70	F	159.2	Two fetuses: 3.9, 4.1 grams
70-3	5/26/70	M	157.3	15.7, 14.6 mm
70-4	5/26/70	M	185.5	16.0, 15.4 mm
70-5	5/26/70	M	186.6	17.4, 16.0 mm
70-6	5/26/70	M	182.3	14.5, 13.8 mm
70-7	5/26/70	F	172.1	Three fetuses: 11.4, 10.4, 10.0 grams
70-8	5/26/70	F	177.3	Two fetuses: 10.3, 12.4 grams, lactating in two teats May not have suckled young yet.
70-9	5/26/70	F	153.6	Lactating, two recent scars
70-10	5/27/70	M	173.3	16.0 mm, other testical destroyed
70-11	5/27/70	F	165.0	Three fetuses: 10.9 damaged, 12.7, 10.0 grams
70-12	5/27/70	F	184.8	Three small embryos, one damaged badly
70-13	5/27/70	M	178.7	15.7, 16.0 mm
70-14	5/27/70	M	177.8	13.5, 13.5 mm
70-15	5/27/70	M	58.6	Young
70-16	6/22/70	M	158.5	Testis damaged
70-17	6/22/70	M	122.3	12.8, 12.3 mm
70-18	6/22/70	F	188.0	Four fetuses: 8.0, 8.5, 8.5, 8.5 grams; lactating
70-19	6/22/70	M	168.7	13.2, 12.4 mm
70-20	6/22/70	F	151.8	Destroyed uterus, lactating, recent parturition
70-21	6/23/70	M	171.8	14.0, 14.2 mm
70-22	6/23/70	M	173.3	12.5 mm other testical destroyed
70-23	6/23/70	M	178.5	15.9 mm other testical destroyed
70-24	6/23/70	F	176.9	Three fetuses: 6.9, 7.7, 6.6 grams; not lactating but had recently suckled young
70-24 A	6/24/70	F	--	Two small embryos, lactating

Table IV. B. 1, continued

Collection No.	Date of Collection	Sex	Weight (grams)	Remarks Fetal Weight in grams; Testis Length in mm
70-25	6/24/70	F	58.9	Young
70-26	6/24/70	F	154.6	Three recent scars, lactating
70-27	6/24/70	F	157.3	Four small fetuses, all four in one side of uterus, lactating
70-28	6/24/70	M	166.0	15.2, 14.0 mm
70-29	6/24/70	M	147.0	Testis destroyed
70-30	6/26/70	F	151.2	Four small fetuses, damaged; lactating
70-30 A	6/26/70	F	--	Three embryos. Died in trap. This animal was a control in the 1968 experiment on Mount Evans.
70-30 B	7/1/70	F	--	Four large unweighed fetuses, died in trap
70-30 D	7/5/70	F	--	Two large unweighed fetuses, died in captivity
70-31	7/9/70	F	177.4	Lactating, three scars
70-32	7/9/70	F	205.7	Four fetuses: 7.2, 7.1, 7.4, 8.2 grams; had recently suckled young
70-33	7/9/70	F	68.5	Young
70-34	7/9/70	M	198.2	8.5, 9.4 mm
70-35	7/9/70	M	177.3	9.0, 9.0 mm
70-36	7/9/70	F	199.2	Four fetuses: 2.0, 1.7, 1.9, 1.7 grams; lactating
70-37	7/9/70	M	183.0	13.0, 11.0 mm
70-38	7/9/70	M	163.2	10.0, 12.5 mm
70-39	7/10/70	F	170.7	Lactating, three recent scars, older scars also present
70-40	7/10/70	F	145.0	Lactating, four scars, five small embryos
70-41	7/10/70	M	161.2	14.8, 13.0 mm
70-42	7/10/70	M	189.5	14.9, 15.0 mm
70-42 D	7/10/70	F	--	Died in trap at Mount Evans, three large fetuses
70-42 E	7/20/70	F	117.9	Young

Table IV. B. 1, continued

Collection No.	Date of Collection	Sex	Weight (grams)	Remarks Fetal Weights in grams; Testis Length in mm
70-42 D1	7/20/70	M	189.0	9.0, 8.2 mm
70-42 E1	7/23/70	M	119.5	Young
70-42 F	7/23/70	F	178.5	Three recent scars
70-42 G	7/21/70	F	126.2	Young
70-42 H	7/23/70	F	134.7	Four small fetuses, minimum of three old scars
70-42 I	7/23/70	F	144.6	Six old scars, possibly from two litters
70-42 J	7/21/70	F	152.4	Uterus not usable
70-42 K	7/21/70	M	114.2	Young
70-42 L	7/25/70	F	111.2	Reproductive tract not usable
70-42 M	7/25/70	M	131.6	Reproductive tract not usable
70-42 N	7/25/70	M	147.1	Reproductive tract not usable
70-42 O	7/25/70	F	178.9	Reproductive tract not usable
70-43	7/30/70	F	159.4	Three scars, not lactating
70-44	7/30/70	F	148.2	Five scars, lactating
70-45	7/30/70	M	191.4	6.1, 6.4 mm
70-46	7/30/70	F	149.2	Three scars?
70-47	7/30/70	-	105.4	Young
70-48	7/30/70	F	170.0	Four scars
70-48 A	7/30/70	F	203.8	
70-48 B	7/30/70	F	152.1	Four scars
70-48 C	7/30/70	F	189.6	Four recent scars
70-48 D	7/30/70	M	175.5	6.1, 5.9 mm
70-48 E	7/29/70	M	172.3	5.6, 5.8 mm
70-48 F	7/29/70	F	181.5	Three scars
70-48 G	7/30/70	M	181.2	6.5, 6.4 mm
70-48 H	7/30/70	M	132.0	Young
70-48 I	8/6/70	F	158.7	

Table IV. B. 1, concluded

Collection No.	Date of Collection	Sex	Weight (grams)	Remarks Fetal Weights in grams; Testis Length in mm
70-48 J	8/6/70	F	130.4	
70-48 K	8/5/70	F	117.2	
70-48 L	8/3/70	M	138.8	
70-48 M	8/5/70	F	149.1	Four small fetuses
70-48 N	8/6/70	F	189.8	
70-48 O	8/5/70	F	149.1	
70-48 P	8/3/70	F	186.7	
70-48 Q	8/5/70	M	183.8	
70-48 R	8/3/70	F	252.7	Three large fetuses
70-48 S	8/5/70	M	190.8	

Animals with Alpha suffixs collected by J. Brunson, Zoology Department, Colorado State University.

Table IV. B. 2 Pika reproduction data from animals born in captivity.

Pika Location	Estimated Date of Birth	Number of Young	Remarks
A 1	6/20/70	2	
A 9	6/24/70	3	
A 3	6/24/70	3	
A 4	6/26/70	4	
A 6	6/29/70	1	
B 3	7/1/70	4	Found 7/5/70
A 7	7/3/70	4	Found 7/5/70
A 15	7/9/70	4	Found 7/10/70. This animal was captured on 7/5/70 at Mount Evans and had received 300 r in 1968 during the experiment conducted at Mount Evans.
B 24	7/16/70	2	Found 7/17/70
B 21-22 rocks	7/22/70	3	
I 42	7/19/70	3	
B 19	7/? /70	1	This animal received 500 r in the 1969 experiment.
B 15-16 rocks	7/24/70	2	

V. RADIATION EFFECTS ON A NATIVE SHORTGRASS PLANT STAND

V. Radiation Effects on a Native Shortgrass Plant Stand

L. Fraley and F. W. Whicker

The following is a partial summary of progress to date on the shortgrass plant stand study (Fig. V. 1). The complete findings will be presented in a Ph. D. dissertation to be completed in June 1971.

Studies initiated in 1969[1] were continued through 1970. The focus of this summary will be the effect of chronic irradiation on the diversity index ($\bar{H}$):

$$\bar{H} = -1.433 \sum_{i=1}^{n} p_i \ln(p_i)$$

where p_i is the probability (frequency) of sampling the i^{th} specie. The frequency data were collected in early April, 1969; mid-June, 1969; late September, 1969; April, 1970; late June, 1970, and September, 1970. The September, 1970 data have not been sufficiently processed to date to include in this report. The remainder of the data were adjusted to the mean of the June, 1970 control sector data to remove the effects of annuals and some perennials which were present for some sampling periods but not for others. The data were then plotted and hand-fit with curves to estimate exposure rates which gave a 50 per cent reduction in the diversity index (D50). The results are given in Table V. 1. The D50 values dropped sharply during 1969 (38% from June to September), changed a lesser amount during the winter of 1969-70 (22% from September to April), and then dropped sharply again during the spring and early summer of 1970 (52% from April to June).

The diversity index, time, and exposure rate data were combined to give a three-dimensional plot, Figure V. 2. This gives a response surface which yields to easy visual interpretation. It can be seen that the diversity index of the shortgrass plant stand was more sensitive to the radiation each spring than during the other seasons of the year. Also, by following the diversity index for a given exposure rate through time, there is an indication that the stand was more sensitive the second spring than the first spring. Consider the exposure rate of 20 R/hr (log 20 = 1.3). The diversity index changes from 4.4 to 3.1 from spring, 1969 to summer, 1969 - a decrease of 30 per cent.

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1 Fraley, L. and F. W. Whicker. 1970. Radiation Effects on the Plant Community. p. 23-29. In Eighth Annual Progress Report on Atomic Energy Commission Contract AT(11-1)-1156, Department of Radiology and Radiation Biology, Colorado State University, Ft. Collins.

From summer, 1969 to spring, 1970 the diversity index changes from 3.1 to 2.6 - a decrease of 16 per cent. Then from spring, 1970 to summer, 1970, it changed from 2.6 to 1.2 - a decrease of 54 per cent. This differential in sensitivity from one spring to the next might be attributed to an accumulation of residual damage in the cells during the late summer, fall and winter which was not expressed until the following spring when the rate of cellular reproduction increased.

Some interesting results are evident in the late fall semi-acute exposure section (sector 6), exposed during December, 1969 (Fig. V. 1). While the data for this sector have not been completely processed, it was apparently somewhat more sensitive to radiation than either the summer or spring treatment sectors. This can be evidenced by comparing the sectors in the photograph, although comparisons must be made with caution since sectors 4 and 5 have had a longer period of time for recovery and some measurable succession has taken place.

Data processing is continuing and the completed report on this study will be prepared within six months.

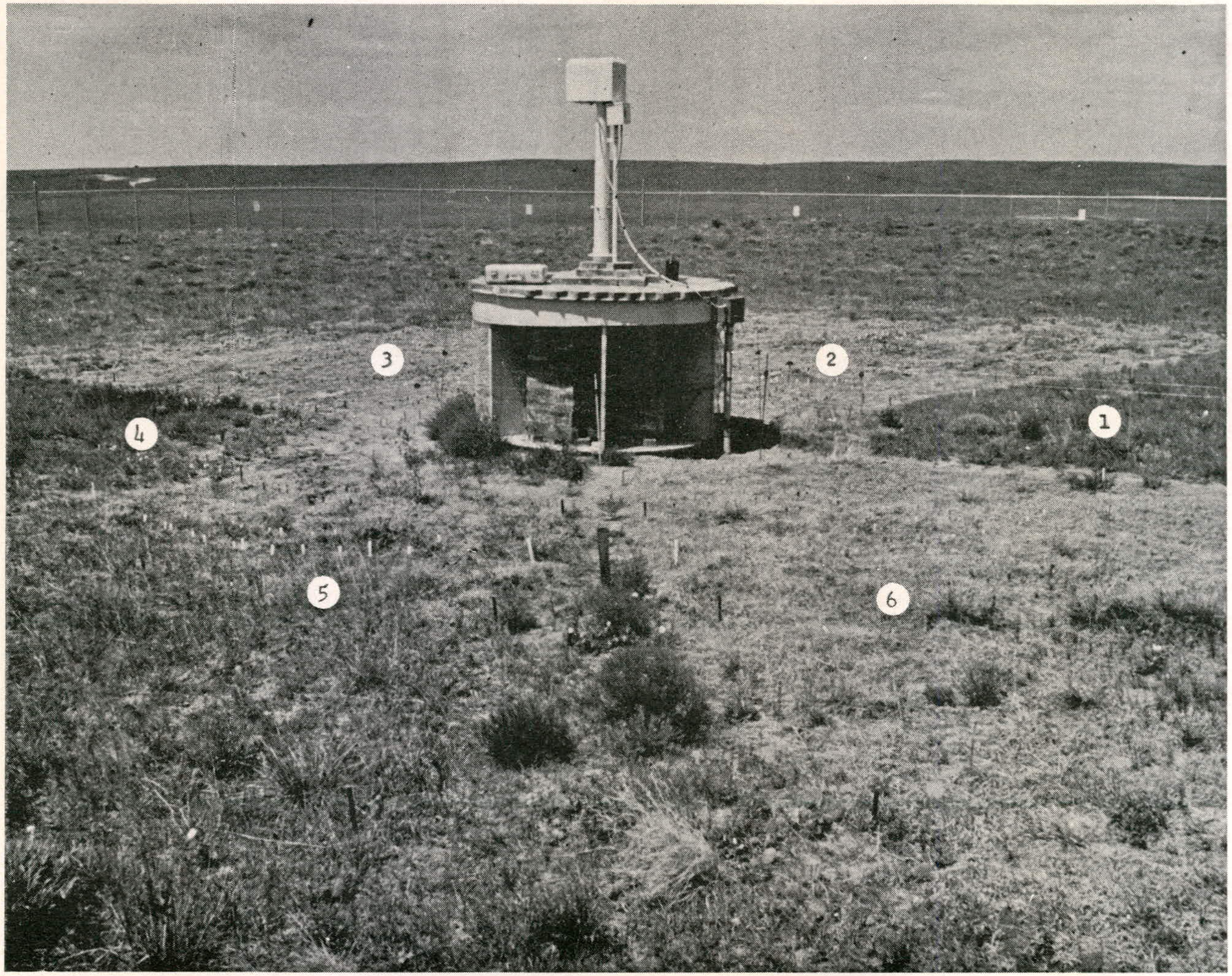

Fig. V.1. Shortgrass plant stand on 20 June 1970, nearly 15 months after the initiation of irradiation in the chronic sectors. Sector 1 is the control, 2 and 3 are chronically irradiated, 4 was irradiated during April 1969, 5 was irradiated during July 1969, and 6 was irradiated during December 1969.

Table V. 1 Exposure rates in the chronic irradiation sectors necessary to give a 50 per cent reduction (D50) in the diversity index for selected dates.

Date	Months of Chronic Irradiation	D50 (R/hr)
June 1969	2	52
September 1969	5	32
April 1970	12	25
June 1970	14	12

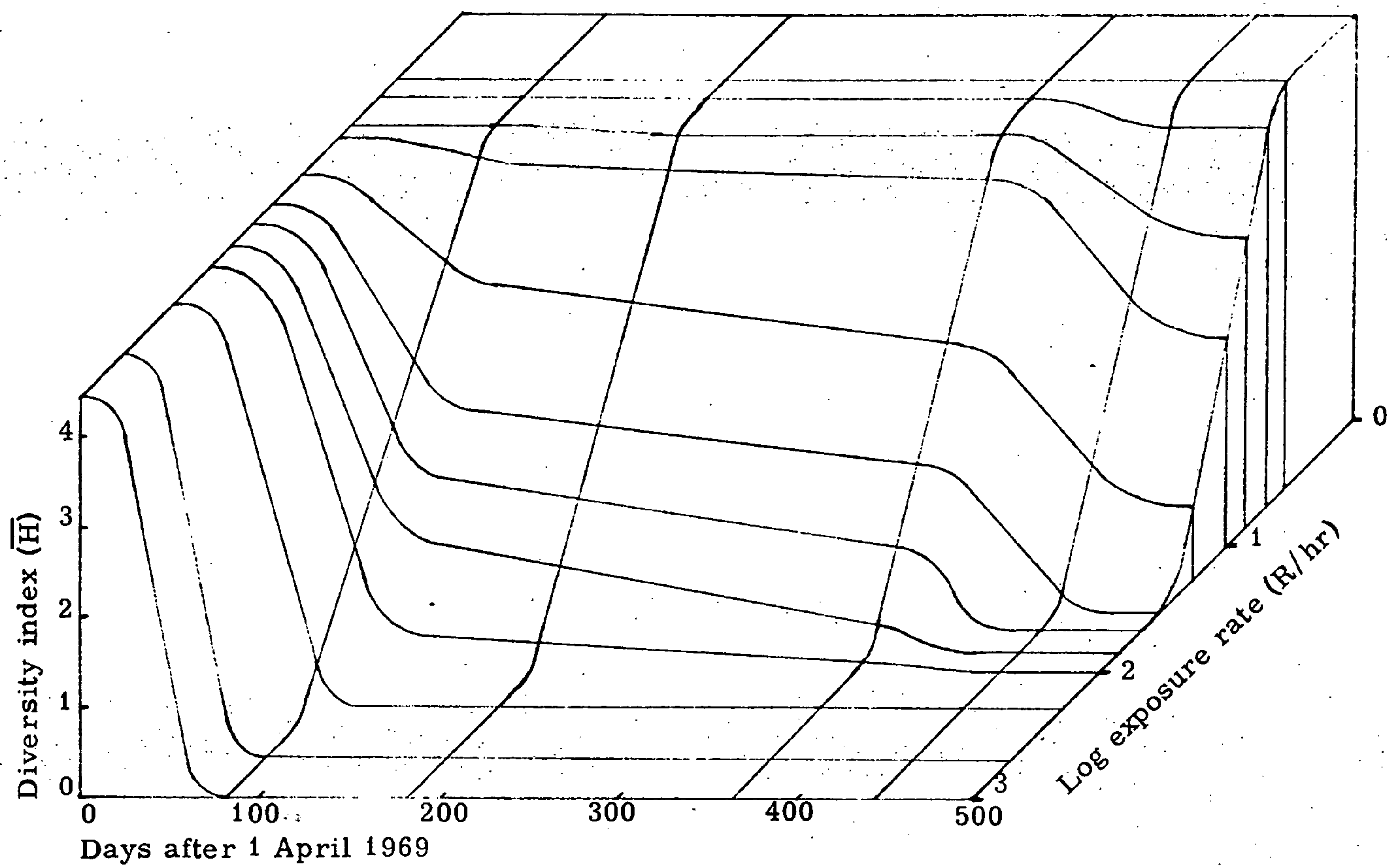

Fig. V.2. Diversity index - time-exposure rate response surface for the chronically irradiated sectors. The data were normalized to the June 1970 control sector mean. Irradiation was initiated 1 April 1969. Note that the exposure rate scale is logarithmic.

VI. RADIATION RESPONSE AND FOOD WEBS OF GRASSLAND ARTHROPODS

VI. Radiation Response and Food Webs of Grassland Arthropods

L. L. Cadwell and F. W. Whicker

The radioecological study of selected arthropods on the shortgrass prairie in Colorado is being carried out in two parts. First, within the gamma irradiation field, certain populations are being investigated to determine their response to ionizing radiation and modifications in the plant community. Secondly, tracer studies are being conducted to determine feeding relationships and forage consumption rates for a few insects.

Pitfall trapping of arthropods in the six treatment sectors of the irradiation facility was conducted from May through September. Trapping periods were approximately 24 hours in length and carried out every two weeks. Traps were set in the morning and emptied the following morning. All arthropods captured were returned to the environment except for occasional specimens collected for identification. Occasional trapping fatalities also occurred.

Professional assistance has been obtained in the specific identification of the families Tenebrionidae and Carabidae. A functional reference collection is currently being assembled. When complete, the analysis of these trapping data should indicate the relationships between relative population numbers and the primary and secondary effects of ionizing radiation on selected foraging (Formicidae and Tenebrionidae) and predaceous (Carabidae and some spiders) arthropods.

During the fall, observations were made on the numbers of galls formed on rabbitbrush (Chrysothamnus nauseosus) within the irradiation facility enclosure. This gall-forming fly (Aciurina bigeloviae) belongs to the family Tephritidae and is not a midge fly (family Cecidomyiidae) as previously suspected. The canopy diameter of each plant inspected was recorded as well as the number of galls that it contained. The plants were grouped into three size categories, but only plants of the smaller group (having a canopy diameter of 12 inches or less) were frequent enough to provide meaningful data.

Of the six irradiation treatment sectors, only the two irradiated chronically since April, 1969 were treated in 1970. Of the four remaining sectors, one is a control and has not been irradiated. The other three sectors were irradiated semi-chronically during the spring, summer, and fall of 1969[1].

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[1] Fraley, L., L. L. Cadwell, and F. W. Whicker. 1970. Radiation effects on a grassland community. p. 22-32. In Eighth Annual Progress Report on Atomic Energy Commission Contract AT(11-1)-1156. Colorado State University, Ft. Collins. 40 p.

Within each treatment sector plants were grouped into five areas ranging from high exposure rates during irradiation at points near the source to low exposure rates far from the source. The mean exposure rate for area one, near the source, was approximately 185 R/hr. The exposure rate for each adjacent more distant area was a factor of 10 lower than that for the preceding area. The five areas in the control sector correspond in location, relative to the source, to those in the treated sectors, but were not irradiated.

In the control sector the mean number of galls per plant (Table VI. 1) appears to be about six and remains relatively constant in the four areas where observations were made. The three sectors that were treated seasonally in 1969 appear to have somewhat lower numbers of galls. If this apparent response is real, one must conclude that some secondary factor is responsible for fewer galls in the previously irradiated sectors. Perhaps residual radiation damage effects the gall forming ability in rabbitbrush or lessens the attractiveness of the plants to ovipositing female flys. The fact that even fewer galls were formed in the chronically irradiated sectors may be due, in part, to direct irradiation of the eggs and larvae during early development, or may be wholly the result of more extensive plant damage in those sectors that have received greater exposures.

Outside the irradiation treatment area, but within the outer control fence, tracer studies were conducted to obtain information on arthropod food chains and consumption rates. One of the principle grassland primary producers, Boutelous gracilis, was tagged during the spring growing season. Labeling consisted of injecting a solution of ^{32}P into the soil in isolated clumps of B. g. within a 144 square meter treatment area. Occasional plant species other than B. g. were removed from the grass clumps.

Periodically obtained samples of the grass and arthropods within the 144 square meter area were oven dried and counted for the ^{32}P beta activity. Several herbivorous arthropods, the most noteworthy being the leafhoppers (family Cicadellidae), were found to be consumers of B. g. Few predaceous arthropods were collected, but one, the wolf spider, accumulated such high levels of activity that it was implicated as a predator of the leafhoppers. A more complete analysis awaits expert identification of many of the arthropods sampled during this phase of the experiment.

Preliminary experiments were conducted in an effort to obtain forage consumption information on several grassland arthropods. Four portable enclosures each covering 2 square meters were constructed for maintaining insects during the feeding studies. Again, Bouteloua gracilis was labeled with ^{32}P. Single clumps of grass were tagged as previously described and then covered with the portable enclosures. Other naturally occurring plant species remained in the enclosures, but only B. g. was labeled. Three grasshopper species, Arphia conspersa, Arphia pseudonietana, and a third as yet unidentified species were introduced into the enclosures. All three species consumed the labeled grass as indicated by the periodic counting of the grasshoppers.

These preliminary experiments indicate that it will be feasible to estimate feeding rates (I) of several larger grassland arthropods using the relationship:

$$Q = \frac{ICa}{\lambda}$$

where Q is the body burden of ^{32}P at steady state; C is the activity density of the food; a is the fraction of ingested ^{32}P assimilated; and λ is the effective loss constant. Values for λ and "a" will by necessity be determined from controlled studies.

Table VI. 1 Mean number of *Aciurina bigeloviae* galls per plant on *Chrysothamnus nauseosus* up to and including 12 inches in diameter.

Sector Treatment	Area-(Approximate Dose Rate in R/hr) 1-(185) X̄	S. E.	2-(18) X̄	S. E.	3-(2.2) X̄	S. E.	4-(0.22) X̄	S. E.	5-(0.02) X̄	S. E.
1 Control	*		7.00	**	5.58	1.67	6.25	1.89	6.93	1.49
2 Chronic	*		*		0	0	2.00	1.06	3.90	0.74
3 Chronic	*		*		0	**	2.40	0.87	2.81	0.53
4 Spring 1969	*		3.75	1.11	3.07	2.46	2.00	0.41	4.90	1.06
5 Summer 1969	*		0.75	0.48	3.80	1.36	3.38	0.83	9.25	1.76
6 Fall 1969	*		0	0	6.14	1.16	5.20	2.67	3.72	1.10

* No observations

** One observation

VII. LIST OF PUBLICATIONS

The following reports on work wholly or partially supported under AEC Contract AT(11-1)-1156 have been published or prepared for publication (the recent reprints and pre-prints accompany this report):

Hanson, W. C., F. W. Whicker, and A. H. Dahl. 1963. Iodine-131 in the thyroids of North American deer and caribou: comparison after nuclear tests. Science 140: 801-802. (COO-1156-2)

Hanson, W. C., A. H. Dahl, F. W. Whicker, W. M. Longhurst, V. Flyger, S. P. Davey, and K. R. Greer. 1963. Thyroidal radioiodine concentrations in North American deer following 1961-1963 nuclear weapons tests. Health Physics 9: 1235-1239. (COO-1156-4)

Whicker, F. W., E. E. Remmenga, and A. H. Dahl. 1965. Factors influencing the accumulation of I-131 in Colorado deer thyroids following 1961-1962 nuclear weapons tests. Health Physics 11: 293-296. (COO-1156-8)

Whicker, F. W., G. C. Farris, A. H. Dahl, and E. E. Remmenga. 1965. Factors influencing the accumulation of fallout Cs-137 in Colorado mule deer. Health Physics 11: 1407-1414. (COO-1156-10)

Whicker, F. W. 1965. Factors influencing the accumulation of fallout cesium-137 in mule deer. Ph.D. Dissertation. Colorado State University, Fort Collins. 230 p. (COO-1156-11)

Farris, G. C. 1965. Strontium-90 in antlers and selected bones of Colorado mule deer. M. S. Thesis. Colorado State University, Fort Collins. 83 p. (COO-1156-12)

Whicker, F. W., G. C. Farris, and A. H. Dahl. 1967. Concentration patterns of Sr-90, Cs-137, and I-131 in a wild deer population and environment, p. 621-633. _In_ B. Aberg and F. P. Hungate (Ed.) Radioecological Concentration Processes, Pergamon Press, New York. (COO-1156-13)

Whicker, F. W., R. A. Walters, and A. H. Dahl. 1967. Fallout radionuclides in Colorado deer liver. Nature 214: 511-513. (COO-1156-14)

Whicker, F. W., G. C. Farris, and A. H. Dahl. 1966. Radioiodine concentrations in Colorado deer and elk thyroids during 1964-65. J. Wildlife Mgmt. 30(4): 781-785. (COO-1156-16)

Farris, G. C., F. W. Whicker, and A. H. Dahl. 1967. Effect of age on radioactive and stable strontium accumulation in mule deer bone, p. 93-102. In J. M. A. Lenihan, J. F. Loutit, and J. H. Martin (Ed.). Strontium Metabolism, Academic Press, London. (COO-1156-17)

Whicker, F. W., G. C. Farris, and A. H. Dahl. 1968. Wild deer as a source of radionuclide intake by humans and as indicators of fallout hazards, p. 1105-1110. In W. S. Snyder (Ed.). Radiation Protection, Pergamon Press, New York. (COO-1156-18)

Remmenga, E. E. and F. W. Whicker. 1967. Sampling variability in radionuclide concentrations in plants native to the Colorado Front Range. Health Physics 13: 977-983. (COO-1156-19)

Whicker, F. W. and C. M. Loveless. 1968. Relationships of physiography and microclimate to fallout deposition. Ecology 49(2): 363-366. (COO-1156-20)

Nelson, W. C. and F. W. Whicker. 1969. Cesium-137 in some Colorado game fish, 1965-66, p. 258-265. In D. J. Nelson and F. C. Evans (Ed.). Symposium on Radioecology. CONF-670503. U. S. Atomic Energy Commission, Division of Technical Information Extension, Oak Ridge, Tennessee. (COO-1156-21)

Farris, G. C., F. W. Whicker, and A. H. Dahl. 1969. Strontium-90 levels in mule deer and forage plants, p. 602-608. In D. J. Nelson and F. C. Evans (Ed.). Symposium on Radioecology. CONF-670503. U. S. Atomic Energy Commission, Division of Technical Information Extension, Oak Ridge, Tennessee. (COO-1156-23)

Hakonson, T. E. and F. W. Whicker. 1969. Uptake and elimination of cesium-134 by mule deer, p. 616-622. In D. J. Nelson and F. C. Evans (Ed.). Symposium on Radioecology. CONF-670503. U. S. Atomic Energy Commission, Division of Technical Information Extension, Oak Ridge, Tennessee. (COO-1156-24)

Hakonson, T. E. 1967. Tissue distribution and excretion of ^{134}Cs in the mule deer. M. S. Thesis. Colorado State University, Fort Collins. 121 p. (COO-1156-25)

Farris, G. C. 1967. Factors influencing the accumulation of strontium-90, stable strontium, and calcium in mule deer. Ph. D. Dissertation. Colorado State University, Fort Collins, 189 p. (COO-1156-26)

Hakonson, T. E. and F. W. Whicker. Tissue distribution of radiocesium in the mule deer. Health Physics. In press; accepted December 2, 1970. (COO-1156-27)

Hakonson, T. E. and F. W. Whicker. The contribution of various tissues and organs to total body mass in the mule deer. J. Mammalogy. In press; accepted December 7, 1970. (COO-1156-29)

Gist, C. S. 1969. Iodine-131 retention in mule deer. M. S. Thesis. Colorado State University, Fort Collins. 75 p. (COO-1156-31)

Markham, O. D. and F. W. Whicker. 1970. Radiation $LD50_{(30)}$ of pikas (<u>Ochotona princeps</u>) in the natural environment and in captivity. Am. Midland Naturalist. 84(1): 248-252. (COO-1156-32)

Markham, O. D., F. W. Whicker, and R. M. Hansen. 1970. Radiation $LD50_{(30)}$ of Richardson ground squirrels. Health Physics 18(6): 731-732. (COO-1156-33)

Gallegos, A. F. 1969. Radiocesium kinetics in the components of a montane lake ecosystem. Ph.D. Dissertation. Colorado State University, Fort Collins, 342 p. (COO-1156-34)

Nagy, J. G., T. E. Hakonson, and K. L. Knox. 1969. Effects of food quality on food intake in deer. Trans. 34th North Am. Wild. and Natural Resources Conf. 34: 146-154.

Alldredge, A. W. Bottle fawns. Colorado Outdoors. In press; accepted May 25, 1970. (COO-1156-36)

Gallegos, A. F., F. W. Whicker, and T. E. Hakonson. Accumulation of radiocesium in rainbow trout via a non-food chain pathway. Presented November 5, 1970, Fifth Ann. Midyear Topical Symposium, Health Phys. Soc., Idaho Falls, Idaho. In press. (COO-1156-37)

Gist, C. S. and F. W. Whicker. Radioiodine uptake and retention by the mule deer thyroid. J. Wildlife Mgmt. In press; accepted November 5, 1970. (COO-1156-38)

Schultz, V. and F. W. Whicker. Readings in radiation ecology. (Submitted to Dowden, Hutchinson & Ross, Inc., Stroudsberg, Pa. January 1971).

Whicker, F. W., W. C. Nelson, and A. F. Gallegos. Fallout ^{137}Cs and ^{90}Sr in trout from Colorado's mountain lakes. Typewritten manuscript. 21 p. To be submitted for publication. (COO-1156-39)

VIII. LIST OF ORAL PRESENTATIONS

The following papers representing work conducted under AEC Contract AT(11-1)-1156 have been presented orally at scientific meetings:

Whicker, F. W. and A. H. Dahl. 1963. Accumulation of fallout radionuclides in Colorado mule deer. Presented June 13, 1963 at the annual meeting of the Health Physics Society, New York City. P/90. (COO-1156-3)

Dahl, A. H., F. W. Whicker, and G. C. Farris. 1964. A study of the food chain patterns of Sr-90, Cs-137, and I-131 in a mule deer population. Presented March 10, 1964 at the meeting on Radiation and Wildlife at the North American Wildlife Conference, Las Vegas, Nevada.

Farris, G. C. 1964. Strontium-90 concentrations in bones and forage plants. Presented April 24, 1964 at the AEC-ARMU Technical Conference at the University of New Mexico, Albuquerque. P/1, Session IV. (COO-1156-6)

Farris, G. C., A. H. Dahl, and F. W. Whicker. 1964. Accumulation of Sr-90 in selected bones and forage plants of Colorado mule deer. Presented June 18, 1964 at the annual meeting of the Health Physics Society, Cincinnati, Ohio. P/131. (COO-1156-7)

Whicker, F. W., G. C. Farris, A. H. Dahl, and E. E. Remmenga. 1965. Factors influencing the accumulation of fallout Cs-137 in Colorado mule deer. Presented May 4, 1965 at the Battelle-Northwest Symposium on Radiation and Terrestrial Ecosystems, Richland, Washington. (COO-1156-10)

Whicker, F. W. 1965. Fallout radionuclides in mule deer. Presented August 9, 1965 at the Central Mountains and Plains Section Conference of the Wildlife Society, Centennial, Wyoming.

Whicker, F. W., G. C. Farris, and A. H. Dahl. 1966. Concentration patterns of Sr-90, Cs-137, and I-131 in a wild deer population and environment. Presented at the Symposium on Radioecological Concentration Processes, April 25-29, 1966, Stockholm, Sweden. (COO-1156-13)

Farris, G. C., F. W. Whicker, and A. H. Dahl. Effect of age on radioactive and stable strontium accumulation in mule deer. Presented at the International Symposium on Some Aspects of Strontium Metabolism, May 5-6, 1966, Chapelcross, Scotland. (COO-1156-17)

Whicker, F. W., R. A. Walters, and A. H. Dahl. Fallout radionuclides in Colorado deer livers. Eleventh Annual Meeting, Health Physics Society, June 27-30, 1966, Houston, Texas. P/79.

Whicker, F. W., G. C. Farris, and A. H. Dahl. Wild deer as a source of radionuclide intake by humans and as indicators of fallout hazards. Presented at the First International Congress of IRPA, September 5-10, 1966, Rome, Italy. (COO-1156-18)

Nelson, W. C. and F. W. Whicker. Cesium-137 concentrations in some Colorado game fish, 1965-66. Presented at the Second National Symposium on Radioecology, May 15-17, 1967, Ann Arbor, Michigan. P/54. (COO-1156-21)

Farris, G. C., F. W. Whicker, and A. H. Dahl. Strontium-90 levels in mule deer and forage plants. Presented at the Second National Symposium on Radioecology, May 15-17, 1967, Ann Arbor, Michigan. P/42. (COO-1156-23)

Hakonson, T. E. and F. W. Whicker. Uptake and elimination of cesium-134 by mule deer. Presented at the Second National Symposium on Radioecology, May 15-17, 1967, Ann Arbor, Michigan. P/44. (COO-1156-24)

Hakonson, T. E. Uptake and elimination of cesium-134 by mule deer. Presented at the Institute of Arctic Biology, University of Alaska, College, Alaska, March 22, 1968.

Farris, G. C., F. W. Whicker, and A. H. Dahl. Factors influencing the accumulation of Sr-90, stable strontium and calcium in mule deer. Presented at the Thirteenth Annual Meeting, Health Physics Society, June 16-20, 1968, Denver, Colorado. P/114.

Whicker, F. W. and C. M. Loveless. Relationships of physiography and microclimate to fallout deposition. Presented at the AAAS-Ecological Society Meeting, June 24-29, 1968, Logan, Utah. P/36.

Gallegos, A. F. Curve fitting of biological models to ingrowth type equations. Presented April 26, 1969 at the Student Conference, American Nuclear Society, University of New Mexico, Albuquerque.

Gist, C. S. and F. W. Whicker. Radioiodine retention in mule deer. Presented May 9, 1969 at the AAAS-Colorado Wyoming Academy of Science Meetings, Colorado Springs, Colorado. P/204.

Gallegos, A. F. Radiocesium kinetics in a montane lake ecosystem. Presented May 10, 1969 at the AAAS-Colorado Wyoming Academy of Science Meetings, Colorado Springs, Colorado. P/240.

Whicker, F. W. Investigations in radioecology at Colorado State University. Presented June 6, 1969 at the Institute of Arctic Biology, University of Alaska, College.

Fraley, L. Response of a shortgrass plains community to ionizing radiation. Presented October 24, 1969 at the IBP Pawnee Site Research Seminar. Southern Colorado State College, Pueblo, Colorado.

Hakonson, T. E. Concepts concerning radioactive materials and their relationship to ecology. Presented December 22, 1969 to the Kiwanis Club, Cottage Grove, Oregon.

Fraley, L. and F. W. Whicker. The effect of ionizing radiation on a shortgrass plant stand. Presented April 22, 1970 at the Meeting of the Southwestern and Rocky Mountain Division of the AAAS, Las Vegas, New Mexico. P/23.

Markham, O. D. and F. W. Whicker. Effect of acute ionizing radiation on pikas (Ochotona princeps) in the natural environment and in captivity. Presented April 22, 1970 at the Meeting of the Southwestern and Rocky Mountain Division of the AAAS, Las Vegas, New Mexico. P/122.

Farris, G. C. and F. W. Whicker. Strontium-90, stable strontium and calcium in mule deer does and their fetuses. Presented April 22, 1970 at the Meeting of the Southwestern and Rocky Mountain Division of the AAAS, Las Vegas, New Mexico. P/123.

Gallegos, A. F., F. W. Whicker, and T. E. Hakonson. Accumulation of radiocesium in rainbow trout via a non-food chain pathway. Presented November 5, 1970 at the Fifth Annual Health Physics Society Midyear Topical Symposium on Health Physics Aspects of Nuclear Facility Siting. Idaho Falls, Idaho.