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Fallout Cesium - 137 Accumulation in Two
Subpopulations of Black-tailed Deer
(*Odocoileus hemionus columbianus*)

By

STEVEN ARNOLD BOOK

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Fallout Cesium-137 Accumulation in Two Subpopulations of
Black-tailed Deer (Odocoileus hemionus columbianus)

By

STEVEN ARNOLD BOOK
A.B. (University of California, Berkeley) 1967

THESIS

Submitted in partial satisfaction of the requirements for the degree of

MASTER OF ARTS

in

Zoology

in the

GRADUATE DIVISION

of the

UNIVERSITY OF CALIFORNIA

Approved:

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ACKNOWLEDGMENTS

The author gratefully thanks Mmes. Ellen Haro and Roberta Rivers for assistance in preparation of the manuscript; Mr. H. G. Wolf and Dr. L. S. Rosenblatt, for comments; Mr. G. E. Connolly and Dr. W. M. Longhurst for Figs. 1-3 and 5-6, respectively; Mr. Connolly for collection of deer; the California Fish and Game Commission for deer collection permits, and the California Department of Fish and Game Food Habits Laboratory for rumen content analyses.

Appreciation is extended to Dr. L. K. Bustad, Director of the Radiobiology Laboratory, for support and use of the facilities, and to committee members, Drs. W. M. Longhurst, R. J. Della Rosa, and R. L. Rudd for assistance and encouragement.

I. INTRODUCTION

Uncontrolled nuclear reactions have released a number of radioactive fission products into the atmosphere. Of these radionuclides, $^{137}\text{cesium}$, $^{90}\text{strontium}$, and $^{131}\text{iodine}$ are easily incorporated into terrestrial and aquatic ecosystems because of their metabolic similarity to the required elements potassium, calcium, and stable iodine. These biologically important fallout components remain for times sufficient to subject contaminated animals and plants to doses of ionizing radiation.

Fallout levels have declined over the past several years (US AEC, 1969) due to the infrequency of nuclear testing. However, information on the behavior of radioactive fission products--i.e., the entrance of radionuclides into biological systems, their subsequent passage through various food webs and deposition in living tissues--is important, considering the threat of nuclear warfare and the increasing use of nuclear reactors.

This study was undertaken to investigate various parameters influencing the uptake of ^{137}Cs in a wild population of Columbian black-tailed deer (*Odocoileus hemionus columbianus*) at the Hopland Field Station of the University of California.* The variation in ^{137}Cs body burdens of deer living in relatively close proximity yet occupying different elevational habitats was studied in relation to rainfall, type and availability of forage species, foliar contamination by the radionuclide, and dietary preferences.

* This study was partially supported by US AEC Contract AT(11-1)-34.

II. LITERATURE REVIEW

Description of $^{137}\text{Cesium}$

Cesium-137 is one of 21 known isotopes of cesium, an alkali metal with properties similar to those of potassium and rubidium. It is produced with a yield of approximately 6% by the fission of a heavy nucleus such as ^{235}U or ^{239}Pu (Katcoff, 1960), one megaton of fission energy producing about 160,000 curies of ^{137}Cs (Langham, 1965). Cesium-137 is relatively long-lived, with a physical half-life of 30 years. The decay scheme of ^{137}Cs , its gaseous precursors, and its daughters following thermal neutron fission of ^{235}U is represented below (Katcoff, 1960; Strominger et al., 1958), with respective half-lives given in parentheses.

Ninety-two percent of ^{137}Cs nuclei decay to metastable $^{137\text{m}}\text{barium}$ by emission of a 0.514 MeV (maximum energy) beta particle; $^{137\text{m}}\text{Ba}$ in turn decays to stable ^{137}Ba with the emission of a 0.662 gamma ray. The remaining 8% of ^{137}Cs nuclei decay directly to ^{137}Ba emitting beta particles of 1.18 MeV maximum energy (Strominger et al., 1958).

$^{137}\text{Cesium}$ and Fallout

Cesium-137 is an important component of world-wide, that is, tropospheric and stratospheric, radioactive fallout. Because of its gaseous precursors and its relatively late formation after the fission reaction, the detonation of atomic weapons results in dispersion of the radionuclide high into the atmosphere. After a few months of residence in the troposphere, the small particles with which ^{137}Cs is associated settle out by sedimentation and precipitation. Particulate matter in the stratosphere may remain suspended for several years (Morgan, 1964), returning to earth when the two atmospheric layers mix. The stratosphere descends into the troposphere in a region corresponding to 40-50° north latitude. This latitudinal band in the Northern Hemisphere is the area of greatest radioactive fallout deposition; the similarly corresponding region in the Southern Hemisphere shows increased fallout deposition of lesser magnitude (Langham and Anderson, 1959).

Since radioactive fallout is generally deposited with precipitation, there are seasonal and geographical variations that relate directly to differences in rainfall and snowfall. Dry deposition of fallout also occurs, accounting for the appearance of fission products during dry periods or in completely arid locations (Holland, 1963).

Capture of particles suspended in the troposphere by rain or snow during descent represents the method of greatest fallout accumulation (Itagaki and Koenuma, 1962). Consequently, precipitation reaching areas of low elevation has more time and greater opportunity for particle capture. Itagaki and Koenuma (1962) sampled precipitation at elevations from 60 to 1020 meters and found that the concentration of fallout per unit volume generally increased as elevation decreased.

Behavior of $^{137}\text{Cesium}$ in Plants and Soil

Direct deposition of fallout particles onto the surface of leaves and other aerial parts of plants is the principle mechanism of entry for fission products into the various food webs. Fredriksson and Eriksson (1966a) found that, depending on soil type, 75-97% of ^{137}Cs found in Swedish hay in 1963 was deposited directly on the vegetation during the growing season; the remainder was attributable to root uptake.

Factors influencing the amount of radionuclide deposition and retention on plants include leaf size and shape, surface area and surface characteristics, time of contact between leaf surface and solution, and moisture content of leaf epidermis (Csupka et al., 1967; Gorham, 1959; Kirchmann et al., 1967; Miller, 1967), as well as climatic factors such as intensity and amount of precipitation, wind force and direction, and temperature.

Lower plants such as mosses, and especially lichens, are very effective accumulators of ^{137}Cs and other fission products. This is probably a reflection of their greater surface area per unit dry weight of tissue, which aids the trapping of particulate fallout and the absorption of dissolved nutrients in surface runoff (Gorham, 1959). The longevity of lichens--decades to centuries--and the persistence of aerial parts aid in the efficacy of concentration (Hanson, 1968).

The ^{137}Cs deposited on the foliar surface primarily by rain is subject to removal by leaching, again by rain. If the radionuclide is washed onto a root mat as found in good pasture, it will remain in a pool available to the plants (Fredriksson and Eriksson, 1966b). If, however, the ^{137}Cs is washed onto the mineral soil, much of it will be adsorbed onto the soil particles and bound tightly, thereby reducing its availability for plant uptake.

Some ^{137}Cs may be incorporated into the plant and translocated throughout its structure. The translocated burden may be sizeable relative to the initially retained amount (up to 50% in potato tubers, for example), contaminating parts of the plant not directly exposed to deposition (Middleton, 1958, 1959).

The uptake of ^{137}Cs from soils by plants is regulated by several factors. Increasing amounts of clay and soluble potassium content result in decreased cesium uptake; uptake is improved with higher organic matter content (Fredriksson and Eriksson, 1966a; Barber, 1964) and with lower soil moisture (Stewart and Hungate, 1967). Regardless of these conditions, however, ^{137}Cs generally remains unavailable to plants because it is bound tenaciously to the soil and its distribution is usually restricted to the top few inches (Walton, 1963).

Behavior of $^{137}\text{Cesium}$ in Animals

The entrance of ^{137}Cs into animal tissues is primarily through the ingestion of contaminated food. The contribution to the ^{137}Cs body burden from inhalation of the radionuclide or from drinking water is minimal (Langham and Anderson, 1959).

Absorption of cesium from the gut is close to 100% in monogastric animals (Richmond, 1958) but is generally only 50% to 80% in ruminants (McClellan et al., 1961; Wasserman et al., 1961). The reduced absorption, along with the high fecal-to-urinary ratio of excreted ^{137}Cs characteristically seen in ruminants (Hood and Comar, 1953), is probably a function of the kind and greater bulk of food material (Davis, 1963). Stewart et al. (1965) found that fecal excretion of ^{137}Cs increased with the crude fiber content of the diet. Addition of potassium to the diet has little effect on ^{137}Cs uptake, as observed by Wasserman and Comar (1961): a nine-fold increase in dietary potassium caused only a two-fold reduction in ^{137}Cs retention.

Cesium-137 is rapidly distributed throughout the soft tissues of animals, and is most highly concentrated in muscle. Radiocesium is taken up more readily by physiologically active muscles than by less active muscles. However, less active muscles have a higher overall concentration (Ekman, 1961; Dean et al., 1965), due to the slower turnover rate. The thorough distribution of ^{137}Cs may lead to both somatic and genetic effects (Langham and Anderson, 1959). The hazard, however, may be considered transient because ^{137}Cs is moved out of tissues fairly rapidly, having a biological half-life of only 17 days in deer and sheep (Goldman et al., 1965). Thus, effects of exposure may not be as great as those of ^{90}Sr , which is essentially fixed in bone.

In pregnant animals some radiocesium is transferred to the fetus, but there appears to be no appreciable accumulation of the radionuclide in the fetal tissues. Hood and Comar (1953) found a maximum uptake of 3.2% of injected ^{137}Cs by fetal rats. Two to 3% of ^{137}Cs given orally to adult mule deer accumulated in fetuses (Dahl et al., 1967).

Cesium-137 is also passed on to nursing young through milk. Approximately 12% of orally administered ^{137}Cs was collected in goats' milk during the first 7 days after dosing (Ekman, 1961).

Food Chain Relationships

Herbivorous animals ingest forage bearing deposited or retained radionuclides. Predators then accumulate radionuclides that are distributed in the soft tissues of their prey; those radionuclides incorporated into bone remain largely unavailable. A discussion of tropic level effects of ^{137}Cs for a number of predator-prey relationships is given by Pendleton et al. (1965).

The lichen--caribou--man food chain in Alaska and the lichen--reindeer--man food chain in Scandinavia have been examined in depth with respect to radionuclide concentration. Each successive step in the sequence appears to be accompanied by a two-fold increase in ^{137}Cs concentration (Hanson, 1968). Many papers on these relationships are presented by Aberg and Hungate (1967).

III. DESCRIPTION OF THE STUDY AREA

The Hopland Field Station of the University of California is a multipurpose research facility located approximately 90 miles north of San Francisco in southeastern Mendocino County, at 38° north latitude by 123° 3' west longitude. It occupies 5,000 acres on the western slopes of the Mayacmas Mountains at elevations varying from approximately 600 ft to over 2900 ft. Approximately 55,000 acres of Public Domain land adjacent to the field station is available for University use; Pyramid Ridge (elevation ~3500 ft) was used as a supplementary chaparral area.

Climate

The local climate is typically Mediterranean with hot, dry summers and cool, moist winters. Average seasonal precipitation for 1953-1968 at the field station headquarters (800 ft elevation) was 35 in. and is correspondingly greater at higher elevations. Rainfall at 2900 ft, for example, was about 10 in. more per year. Snowfall regularly occurs during the winter above 2800 ft, but generally melts rapidly. Fog is common during the fall, winter, and spring.

Soils

Geologically, according to Gowans (1958), the area "is part of the Franciscan formation (Jurassic), and consists of plastic and chemical sediments with intrusive and extrusive igneous rocks. Hard, fractured sandstones and shales are the dominant rocks." Oak woodland and grassland are typically associated with Sutherlin, Laughlin, and Yorkville soils, while the chaparral cover type is associated with Los Gatos and Maymen soils (Gowans, 1958).

Vegetation

The vegetation at the field station is primarily oak woodland with a grass understory interspersed with patches of chaparral. Chaparral areas are more extensive at higher elevations, becoming predominant on the Public Domain land. Figures 1 and 2 are views of oak woodland and chaparral, respectively. Figure 3 is an aerial view of the chaparral area, showing areas of controlled burning that were included in the study; vegetative patterns differ between burned and unburned areas (Longhurst, 1969).

The plant species found in the various cover types (Table 1) are generally exclusive to particular areas. However, interior live oak (*Quercus wislizenii*) is found in both areas, as a large tree in oak woodland and as a shrub in chaparral, probably reflecting differences in soil type, fertility, and fire histories of the cover types.

Deer Forage

As browsing animals, deer feed mainly on new growth leaves and twigs. Deer residing primarily in the oak woodland cover type have a varied diet consisting of browse, acorns as they are available in the fall, and grasses and forbs during the late winter and early spring. The chaparral areas provide a more uniform diet throughout the year. In this situation grasses and forbs are not abundant, and the deer are forced to feed primarily on the leaves and twigs of the low growing shrubs and bushes. Oaks are present in the chaparral, but because of relatively frequent fires are unable to mature; hence the acorn crop is considerably smaller than that found in the oak woodland. Therefore, acorns are less significant as a dietary item in the chaparral areas than in oak woodland.

Fig. 1. View of area of oak woodland cover type.

Fig. 2. View of area of chaparral cover type.

Fig. 3. View of area of chaparral on Public Domain land above field station. Dark areas are the result of controlled burning.

Table 1. Characteristic Plant Species of Oak Woodland and Chaparral Cover Types at the Hopland Field Station

Common Name	Species
Oak Woodland	
Bedstraws	<i>Galium</i> spp.
Black oak	<i>Quercus kelloggii</i>
Blue oak	<i>Quercus douglasii</i>
Buckeye	<i>Aesculus californica</i>
California laurel	<i>Umbellularia californica</i>
Clovers	<i>Trifolium</i> spp.
Fescues	<i>Festuca</i> spp.
Interior live oak	<i>Quercus wislizenii</i>
Lichens	<i>Ramalina</i> spp., <i>Uenea</i> spp.
Madrone	<i>Arbutus menziesii</i>
Nit grass	<i>Gastridium ventricosum</i>
Quaking grass	<i>Briza minor</i>
Red-stem filaree	<i>Erodium botrys</i>
Soft chess	<i>Bromus mollis</i>
Squirrel-tail barley	<i>Hordeum jubatum</i>
Valley white oak	<i>Quercus lobata</i>
Wild geranium	<i>Geranium molle</i>
Wild oats	<i>Avena barbata</i>
Chaparral	
Buckbrush	<i>Ceanothus cuneatus</i>
Chamise	<i>Adenostoma fasciculatum</i>
Chaparral pea	<i>Pickeringia montana</i>
Deer brush	<i>Ceanothus integerrimus</i>
Interior live oak (shrub)	<i>Quercus wislizenii</i>
Leather oak	<i>Quercus durata</i>
Manzanita	<i>Arctostaphylos canescens</i>
	<i>Arctostaphylos glandulosa</i>
	<i>Arctostaphylos stanfordiana</i>
Scrub oak	<i>Quercus dumosa</i>
Wavyleaf ceanothus	<i>Ceanothus foliosus</i>
Yerba santa	<i>Eriodictyon californicum</i>

Because of the differences in variety and amount of vegetation oak woodland deer exist on a higher nutritional plane. This observation is borne out by higher body weights and proportionally smaller rumen contents, increased number of fetuses, and higher blood urea nitrogen levels of oak woodland deer relative to chaparral deer (Longhurst, 1969).

Deer

The nonmigratory habits of the estimated 700-900 Columbian black-tailed deer (*Odocoileus hemionus columbianus*) on the Hopland Field Station, serve to maintain an average density of one deer for each 5-7 acres as observed by Connolly (1969). Individuals reside at all elevations and in all cover types. Individual home ranges have been determined by personnel at the Hopland Field Station by means of live trapping and marking individuals and observing their movements. These home ranges average from one-half to three-fourths mile in diameter. Seasonal movements are rare, although some deer at higher elevations may descend in times of heavy storms. Because of their resident nature, the deer herd may be divided into three subpopulations according to vegetation type: those that inhabit oak woodland, chaparral, and areas of mixed cover.

IV. MATERIALS AND METHODS

In order to investigate the accumulation of ^{137}Cs in deer inhabiting areas of oak woodland and chaparral cover types, quarterly collections of deer and periodic collections of forage species were made. Soil and precipitation from the two vegetative areas were also sampled. Cesium-137 content was determined by gamma ray spectroscopy.

Precipitation

Data on rainfall at 800 and 2900 ft were obtained from established weather stations. The 800-ft. elevation is well within the oak woodland area of the field station; the 2900-ft station corresponds to the lower limits of the major chaparral areas.

Plastic dishpans, screened with cheesecloth to keep out debris, were maintained at both stations for collection of precipitation. Water was transferred to 5-gallon plastic jugs for transport to the laboratory.

Samples were concentrated to 0.1 volume by evaporation over low heat. Evaporating beakers were washed several times with 6N HCl to free any ions clinging to the glass. The concentrated sample and washings were combined in a 1000-ml polyethylene bottle for determination of radioactivity.

Soils

Soil samples were taken to a depth of eight in., to test the hypothesis that ^{137}Cs is relatively immotile and remains in the thin upper layer of soil. Using a core sampler (2-in. diameter x 1-in. deep), three samples were taken at each of six sites, three each from oak woodland and chaparral areas.

Soil from oak woodland and chaparral was collected in November, 1968. A repeat sampling of the same oak woodland sites was made in February to investigate the effects of the winter's heavy rains on cesium deposition in the soil.

Samples were oven-dried but otherwise untreated. After drying they were weighed and counted in 1000-ml polyethylene containers.

Vegetation

Determination of forage species to be collected was made on the basis of rumen content analyses, observations on feeding deer, and plant availability. Collections of known food items were carried out from August through November, 1968, and during February and March, 1969. Interior live oak (*Quercus wislizenii*), chamise (*Adenostoma fasciculatum*), and the lichen *Ramalina reticulata* are present throughout the year and were collected for the duration of the study. Acorns were collected from August through November. Grasses were sampled in October and November and February and March. Forbs were collected once, in February; *Ceanothus cuneatus* in March.

New growth from each plant species was collected from at least four different sites and the samples were pooled. Grasses and forbs were clipped near the ground; the leaves were stripped from browse types. Acorns were picked directly from oaks in the August collection; by September ripening acorns had fallen and thereafter were collected from the ground. *Ramalina reticulata* and other oak-associated lichens were removed from trees or collected from the ground after heavy storms and wind. All vegetation samples were dried at 100C for at least 24 hr, ground in a hammer mill or Wiley mill through a 1/16-in. screen, and weighed into polyethylene bottles for counting.

Several species of lichens, *Usnea arizonica*, *Usnea* spp., *Evermia prunastri*, and *R. reticulata* were collected from a number of sites in February. The samples were not pooled but were dried, ground, weighed, and counted individually, in order to demonstrate variability in ^{137}Cs content among species and between locations and elevations. Lichen samples were counted in small plastic bags rather than in bottles.

Deer

A total of 17 Columbian black-tailed deer were collected from oak woodland by shooting six in the summer (August-September, 1968), six in the fall (November-December, 1968), and five in the winter (February-March, 1969). Sixteen animals were taken from the chaparral cover type, six in the summer, five in the fall, and five in the winter. Five of these animals, two in the fall and three in the winter, were collected from the chaparral edge, and are treated as a third subpopulation.

Because parameters such as age and sex have little effect on ^{137}Cs accumulation relative to environmental factors (Whicker et al., 1965), deer were randomly sampled.

One pint of thoroughly mixed fresh rumen contents from each deer was preserved in 10% formalin for analysis of plant species by the Food Habits Laboratory of the California Department of Fish and Game. Results of analyses were expressed in terms of percentage by volume of forage species in the aliquot of rumen contents.

The remaining rumen contents and ~2-kg thigh muscle were obtained from each deer, and were oven-dried at 100C for at least 24 hr. For smaller deer, a sufficient amount of muscle tissue from the entire body was collected to make up the 2-kg sample. After the percentage of dry matter was determined, samples were ground in a hammer mill through 1/16-in. screen and weighed into 1000-ml polyethylene containers for determination of ^{137}Cs content.

Additional rumen contents obtained from 20 adult male deer killed on the field station during the 1968 hunting season were similarly analyzed for plant species and ^{137}Cs content.

Determination of $^{137}\text{Cesium}$ Content

The ^{137}Cs concentration of samples was determined by gamma ray spectrometry. The whole-body counter at the Radiobiology Laboratory, School of Veterinary Medicine, University of California, Davis, was used. This apparatus consists of a shielded 20- x 10-cm thallium-activated sodium iodide crystal and multichannel pulse-height analyzer, calibrated at 10 KeV per channel; complete description of the facility is given by Goldman et al. (1963).

Cesium-137 has a characteristic peak at 0.662 MeV which was separated from peaks of other radionuclides by computer analysis. Quantitation of ^{137}Cs activity resulted from comparison of the 0.662 peak of samples to the peaks of ^{137}Cs standards of known activity. Standards of known ^{137}Cs concentration in 0.1N HCl were sealed in 1000-ml polyethylene bottles (diameter, 9 cm) or in 100-ml volumes in plastic bags, thus approximating the dimensions of the samples. Standards of samples were counted in the same geometrical configurations: materials in polyethylene bottles were placed immediately in front of the crystal, centered 4.5 cm from the crystal face. Standards and samples in small plastic bags were positioned directly at the face of the crystal.

Because of the random nature of radioactive emissions from samples of low activity, long count times give more valid counting statistics. A counting time of 100 minutes for the 1000-ml samples was found to be of sufficient duration to keep the coefficient of variation below 0.05,

or the percentage of variability below 5%. The coefficient of variation, a function of the ratio of counting rates of source (or sample) and background, was determined by methods of England and Miller (1969). The 25 individual lichen samples were counted for only 30 minutes each. The coefficient of variation for these samples was generally less than 0.1.

V. RESULTS

Precipitation

Rainfall records for the nine-month period from August, 1968 to April, 1969 show that 59 in. of rain fell at 2900 ft elevation and 50 in. at 800 ft. The 16-yr average for the same nine-month period at 800 ft elevation is 34.6 in. As shown by the monthly precipitation data in Fig. 4, the heaviest precipitation occurred in January, accounting for 14.6 in. and 17.6 in. of rain at 800 and 2900 ft, respectively. Snow was present at higher elevations at times during the winter.

Radioactivity in rainfall collections was very slight. Gross gamma activity in the concentrated samples was of such low magnitude that, on a per liter basis, counts were less than one per minute. Cesium-137 concentration could not be detected by the methods used.

Soils

Soil samples were collected from the oak woodland area in November, 1968, and in February, 1969; soil from chaparral was obtained only in November. Concentration of ^{137}Cs in the pooled samples is shown in Table 2.

Soil collected in November from oak woodland showed the highest concentration of ^{137}Cs (3.97 pCi/g oven-dried soil) within the top inch of soil. From 2 to 8 in., consecutive one-inch samples contained less than 1 pCi/g.

The soil cores taken from chaparral in November also contained the highest concentration of ^{137}Cs (2.98 pCi/g) within the top one-inch layer. The remaining one-inch samples contained, on the average, ^{137}Cs concentrations of greater than 1 pCi/g.

Fig. 4. Monthly precipitation at the Hopland Field Station.

Table 2. Concentration of ^{137}Cs in Pooled Soil Samples
from Oak Woodland and Chaparral Cover Types
(picocuries/gram oven-dried soil)

Soil Depth, inches	Chaparral	Oak Woodland	
	Nov., 1968	Nov., 1968	Feb., 1969
0-1	2.98	3.97	5.38
1-2	0.96	0.94	0.70
2-3	1.24	0.63	0.54
3-4	0.85	0.50	0.50
4-5	1.50	0.61	0.56
5-6	1.11	0.54	0.47
6-7	1.37	0.79	0.65
7-8	<u>1.07</u>	<u>0.61</u>	<u>0.49</u>
Total	11.08	8.59	9.29

The total ^{137}Cs concentration for the 8-in. sample from chaparral was higher than for that from oak woodland, even though it contained less ^{137}Cs per gram in the 0- to 1-in. layer, probably because of increased precipitation at higher elevations and because of the porous nature of the chaparral soils and subsequent leaching by precipitation.

Cesium-137 concentration in soil collected from the same oak woodland sites in February followed the pattern described above: the highest concentration (5.38 pCi $^{137}\text{Cs}/\text{g}$) was found in the top inch, with concentrations of less than 1 pCi/g at depths greater than one inch (Table 2). The difference in total ^{137}Cs between oak woodland soils obtained in November and February is not large. There is, however, a sizeable difference between soil samples from the 0- to 1-in. layer, presumably as the result of rains during the interim.

The concentrations of ^{137}Cs in the soil are not truly indicative of the availability of the radionuclide to plant root systems, since much of the ^{137}Cs is tightly adsorbed to soil particles and remains inaccessible (Fredriksson and Eriksson, 1966b).

Vegetation

Plant species in the diets of individual animals from oak woodland and chaparral are presented in Appendix Tables A-1 and A-2, respectively. The average values for the deer show seasonal and subpopulation variations in diet composition (Table 3).

For deer from the oak woodland area, acorns appear to be the primary food item during the summer, fall, and winter constituting an average of 47% of rumen content samples by volume. Grasses show more seasonal variation, accounting for 32% of the diet in summer, 11% in fall, and 26% in winter. Grasses are not a usual forage item during the summer, and their importance as part of the summer diet in this study is attributable to early sprouting caused by uncommon summer rains. Forbs appear to be the final major forage item, accounting for 13% overall, with little variation. Lichens represent only 6% of the total diet.

Table 3. Average Values of Forage Species in Rumen Contents
from Deer of Oak Woodland and Chaparral Cover Types
(Percent by Volume)

Species	Collection Period			Average
	Aug - Sept	Nov - Dec	Feb - Mar	
Oak Woodland				
<i>Quercus</i> spp. acorns	45	57	38	47
Grasses	32	11	26	23
Forbs	13	11	16	13
<i>Quercus</i> spp. leaves	3	10	9	7
Lichen	6	10	3	6
<i>Photinia arbutifolia</i>			5	2
<i>Umbellularia californica</i>			2	1
Other	1	1	1	1
Chaparral				
<i>Adenostoma fasciculatum</i>	4	12	72	29
<i>Quercus</i> spp. leaves	63			21
<i>Quercus</i> spp. acorns	21	50	1	24
Grasses	8	27		11
<i>Ceanothus cuneatus</i>	2		9	4
Lichen		9	3	4
<i>Arctostaphylos</i> sp.		1		
<i>Arbutus menziesii</i>			7	2
<i>Eriodictyon californicum</i>			4	1
<i>Umbellularia californica</i>			4	1
Other	2	1		1

In the chaparral, more noticeable changes with season are evident. Chamise (*Adenostoma fasciculatum*) is the major food item on a yearly basis, but represents only 4% of the diet in summer, 12% in fall, and 72% in winter. Leaves of *Quercus* spp. comprise 63% of the diet in summer, but disappear entirely by winter. Acorns are of moderate importance, 21% in summer, rising to 50% in fall, and decreasing markedly by winter. Grasses are important forage items in the fall; forbs are relatively absent.

The presence of lichens in the diet of chaparral deer is an anomaly. The rumens of five deer (two in the fall, three in winter) contained *Usnea* spp. and other lichens. These deer were sampled from the edge of the chaparral cover type, an area of mixed vegetation. Because the dietary composition was otherwise essentially chaparral-like, the deer were included in the chaparral population. In other instances, when their inclusion may have hindered the interpretation of data, the five animals were treated as a third subpopulation.

The results of rumen content analyses for bucks killed in the oak woodland cover type during August and September, 1968, (Appendix, Table A-3) indicate that *Quercus* leaves are a more important dietary constituent (47% of the diet) than is suggested by analyses of the rumen contents of other deer sampled from the same period. Under certain conditions, adult bucks apparently because of their differing nutritional requirements are known to have different food habits from does or immature deer (Longhurst, 1969). These findings appear to be a manifestation of this phenomenon. The results of analyses for bucks killed in the chaparral area during the hunting season (Appendix, Table A-4) are in agreement with data obtained from chaparral deer collected for the study. Oak leaves and acorns were the primary forage items present in chaparral and oak woodland during late summer.

¹³⁷Cesium in Vegetation

Cesium-137 concentrations varied considerably among plant species and sampling dates (Table 4). Forage items from oak woodland can be arranged by increasing ¹³⁷Cs concentration in the following order: acorns, leaves, forbs/grasses, lichen (*R. reticulata*). It is interesting that acorns and oak leaves, lowest in ¹³⁷Cs concentration (~0.1 pCi/g and 0.5 pCi/g), respectively, make up the majority of the oak woodland forage. Conversely, lichens, which constitute about 6% of the diet, contain the highest concentration of ¹³⁷Cs, ~6 pCi/g for pooled samples of *R. reticulata*.

Vegetation samples from chaparral can be arranged according to increasing average ¹³⁷Cs in the following order: acorns, leaves, buckbrush (*C. cuneatus*), chamise (*A. fasciculatum*); none of these samples demonstrated the activity found in *R. reticulata*.

The lichen *R. reticulata* (Fig. 5), then, is an effective accumulator of fallout ¹³⁷Cs. However, other lichens (Fig. 6), *Usnea* spp., *Evernia prunastri* and *Usnea arizonica* collected in February, demonstrated mean concentrations two to three times greater than that of *R. reticulata* (Table 5). The lower ¹³⁷Cs concentration in *R. reticulata* may be associated with morphological and physiological differences, or perhaps different rates of growth. The individual samples show a variation in ¹³⁷Cs accumulation between location sites which appears to be unrelated to changes in elevation.

¹³⁷Cesium in Rumen Contents

Appendix Tables A-5 and A-6 for deer from oak woodland and chaparral, respectively, present data on characteristics such as sex, age, body weight, and weight of rumen contents of individual deer. The average percentage of dry matter for rumen contents was 22% (range 16-33%).

Table 4. Concentration of ^{137}Cs in Pooled Forage Samples
(Picocuries ^{137}Cs /gram Oven-Dried Material)

Species	Collection Period						Average
	Aug	Sept	Oct	Nov	Feb	Mar	
Oak Woodland							
<i>Quercus wislizenii</i> leaves	0.22	0.28	0.38	0.36	0.72	0.74	0.45
<i>Quercus wislizenii</i> acorns	0.10						0.10
<i>Quercus douglasii</i> acorns	0.13	0.14	0.11	0.10			0.12
Grasses			0.66	0.96	3.31	1.42	1.59
Forbs					1.60		1.60
<i>Ramalina reticulata</i>		6.22	6.93	6.27	5.83	4.57	5.96
Chaparral							
<i>Quercus wislizenii</i> leaves	0.57	0.51	0.6	0.49	0.94	0.99	0.82
<i>Adenostoma fasciculatum</i>	0.39	0.85		1.24	2.22	2.23	1.39
<i>Quercus dumosa</i> leaves	0.53	0.69					0.61
<i>Quercus dumosa</i> acorns	0.3	0.14					0.22
<i>Ceanothus cuneatus</i>						1.20	1.20

Fig. 5. Heavy growth of *Ramalina reticulata* on blue oak.

Fig. 6. Lichens on oak branch. Species present are *Usnea* spp. and *Evernia prunastri*.

Table 5. Cesium-137 Content of Lichen Collected February 1969
(picocuries/gram oven-dried material)

Elevation (ft)	<i>Ramalina reticulata</i>	<i>Usnea</i> spp.	<i>Evernia prunastri</i>	<i>Usnea arizonica</i>
600	3.3			
700	3.0			
800	3.5	11.7	11.3	13.6
1000	2.8			
1000	6.8			
1100	5.9			
1100	4.7	10.8	10.8	15.8
1200	3.2			
1500	3.1	11.2	9.7	11.2
1600	4.9			
2000	4.5	8.7		
2400		13.0	16.4	
2800		11.6	21.1	
Average	4.1	11.2	13.9	13.5

Spectra from rumen contents of two animals are given in Figs. 7 and 8. Figure 7 represents an animal collected in mid-December, 1968, and displays the characteristic ^{40}K potassium peak along with the fallout ^{137}Cs peak. Figure 8 illustrates the spectrum from a deer collected in February, 1969, which also contains peaks of short-lived fission products (^{141}Ce , ^{103}Ru , and $^{95}\text{Zr-Nb}$) produced by the Chinese nuclear detonation in late December, 1968.

The concentration of ^{137}Cs in rumen contents of sampled deer is presented in Table 6. The average value for deer of the oak woodland in summer is 1.28 pCi ^{137}Cs /g. The considerable range (0.2-3.3 pCi/g) suggests that the deer were feeding on a variety of forage items with different radiocesium concentrations. For example ^{137}Cs concentrations were low in the rumen contents of deer Nos. 874 and 877, whose major forage item was acorns (Appendix Table A-1); acorns have exceedingly low concentrations of the radionuclide. Similarly, the high concentration of ^{137}Cs in the rumen content of deer No. 859 may be related to the predominance of forbs in the diet. These herbaceous plants, though sampled only once, did show a ^{137}Cs concentration value 10 times higher than that of acorns.

In the fall, oak woodland deer averaged 1.03 pCi ^{137}Cs /g dried rumen contents (range 0.4-1.6 pCi/g). In the winter, the value increased to 1.82 pCi/g (range 1.6-2.6 pCi/g). The narrower autumn range might be attributable to deer's feeding on a diet with relatively constant ^{137}Cs concentration.

In the summer collection, three deer from the chaparral cover type averaged 0.7 pCi ^{137}Cs /g dried rumen contents. Three other samples were ignited in the drying oven and could not be replaced due to collection restrictions. In the fall and winter the concentration of

Fig. 7. Spectrum of rumen content sample of deer No. 900 collected in December, 1968.

Fig. 8. Spectrum from rumen content sample of deer No. 914 collected in February, 1969.

Table 6. Cesium-137 Concentration in Rumen Contents of Deer from Oak Woodland and Chaparral Cover Types (oven-dried material)

Summer		Fall		Winter	
Deer Collection Number	pCi $^{137}\text{Cs/g}$	Deer Collection Number	pCi $^{137}\text{Cs/g}$	Deer Collection Number	pCi $^{137}\text{Cs/g}$
Oak Woodland					
859	3.3	891	0.4	909	1.7
862	1.1	892	0.7	910	1.6
866	1.2	893	1.1	911	1.6
874	0.3	894	1.4	912	1.6
875	1.6	895	1.6	913	2.6
877	0.2	896	1.0		
Average	1.28		1.03		1.82
Chaparral					
867	0.7	890	0.7	905	0.8
868	0.9	897	0.5	906	1.5
876	0.5	898	0.7	907*	2.8
		900*	2.3	914*	3.2
		901*	3.6	915*	3.8
Average	0.7		1.56		2.42

* Deer collected from chaparral edge

radiocesium in rumen contents rose to 1.56 and 2.42 pCi/g, respectively. The average fall and winter values are misleading, however, for they include five animals sampled from the chaparral edge, actually members of another subpopulation. The forage habits of these five deer were different, as indicated by the presence of certain lichens in the diet. Thus, excluding these animals, the radiocesium levels in the rumens of chaparral deer averaged ~0.6 and 1.2 pCi ^{137}Cs /g for fall and winter, respectively. For the same periods, the values for rumen contents of deer from the chaparral edge averaged 2.5 and 3.3 pCi/g.

Bucks. Rumen contents were sampled from 20 male deer taken during the regular hunting season (August-September, 1968). These samples were categorized as from oak woodland or chaparral primarily on the basis of kill site. Bucks killed in mixed vegetation were placed into either category on the basis of rumen content analyses. Data on individual bucks are presented in Appendix Table A-7.

As shown in Table 7, bucks taken from oak woodland averaged 2.7 pCi ^{137}Cs /g dried rumen contents (range 0.9-4.7 pCi/g). Those from chaparral averaged 0.8 pCi/g (range 0.6-1.2 pCi/g). As mentioned above, the considerable range seen in deer from the oak woodland may be indicative of a diverse diet; also, oak woodland bucks were taken from a larger geographical area than the chaparral deer. The narrow range of values for deer of the chaparral may reflect the absence of essentially all important forage other than oak leaves and acorns (Appendix Table A-4). The values of ^{137}Cs concentration in the two groups differ significantly ($P < .01$).

Cesium-137 concentration in rumen contents of bucks from the oak woodland averages about twice the value seen in the deer sampled from the same area during the same season. This can be attributed to

Table 7. Cesium-137 in Dried Rumen Contents of Male Deer
Taken in 1968 Hunting Season (August-September)

Oak Woodland		Chapparal	
Deer Collection Number	pCi $^{137}\text{Cs/g}$	Deer Collection Number	pCi $^{137}\text{Cs/g}$
1	2.5	3*	0.8
2	4.7	7*	0.8
5	2.1	11	0.6
8	2.2	13*	0.7
10	3.9	15	0.5
12*	3.6	22	0.9
16	2.4	27	0.6
17	1.2	31	1.2
18	1.1	36*	0.7
19	4.6		
23	0.9		
Average	2.7		0.8

* Deer collected in areas of mixed cover type and placed in chaparral or oak woodland according to rumen content analyses

dietary differences previously discussed. In bucks from the chaparral cover type, where the diet was approximately the same as that of the sampled deer, the ^{137}Cs concentration was not noticeably different.

$^{137}\text{Cesium}$ in Muscle

A characteristic spectrum of muscle sample is given in Fig. 9, demonstrating ^{137}Cs and ^{40}K peaks. On the average, muscle samples contained 25% (range 22-29%) dry matter.

The concentration of ^{137}Cs in muscle of deer from the oak woodland averaged 1.02 pCi/g oven-dried material in the summer samples (Table 8). The range was considerable, 0.6-1.8 pCi/g. In the fall, oak woodland deer contained an average of 0.88 pCi ^{137}Cs /g (range 0.6-1.2 pCi/g); the winter collection contained 1.32 pCi/g (range 1.0-1.5 pCi/g).

Muscle from chaparral deer averaged 0.38 pCi ^{137}Cs /g for summer, with a range of 0.2-0.5 pCi/g. Animals collected in fall showed a mean ^{137}Cs concentration of 0.48 pCi/g (range 0.3-0.7 pCi/g), those sampled in winter contained 1.08 pCi/g (range 0.6-1.2 pCi/g). The inclusion of animals from chaparral edge did not affect the mean values as it did for the rumen contents; however, these deer were excluded in statistical analyses.

Whicker (1965) found no significant variations in ^{137}Cs accumulation in Colorado mule deer with age or sex, and concluded that any variability resulting from age or sex would be insignificant in comparison to other sources of variation within the population. However, Rabon (1968) found that small white-tailed deer had higher ^{137}Cs burdens than larger deer, attributable to dietary differences.

Fig. 9. Spectrum from muscle sample of deer No. 859.

Table 8. Cesium-137 Concentration in Muscle Tissue of Deer from Oak Woodland and Chaparral Cover Types (oven-dried tissue).

Summer		Fall		Winter	
Deer Collection Number	pCi $^{137}\text{Cs/g}$	Deer Collection Number	pCi $^{137}\text{Cs/g}$	Deer Collection Number	pCi $^{137}\text{Cs/g}$
Oak Woodland					
859	1.8	891	0.7	909	1.0
862	0.6	892	0.6	910	1.3
866	1.1	893	0.6	911	1.5
874	0.7	894	1.2	912	1.3
875	1.2	895	1.1	913	1.5
877	0.7	896	1.1		
Average	1.02		0.88		1.32
Chaparral					
861	0.4	890	0.3	905	0.6
863	0.4	897	0.5	906	1.4
864	0.5	898	0.3	907*	1.1
867	0.3	900*	0.6	914*	1.1
868	0.3	901*	0.7	915*	1.2
876	0.4				
Average	0.38		0.48		1.08

* Deer collected from chaparral edge

Variation in ^{137}Cs Concentration with Season and Habitat

Tables 9 and 10 show the average ^{137}Cs concentration by season in rumen contents and muscle of deer from oak woodland and chaparral. Cesium-137 concentrations remained constant through summer and fall, but rose considerably in winter. However, analyses of variance showed that the seasonal differences of ^{137}Cs in rumen contents and muscle were not significant. Similarly, no significant seasonal differences were detectable in samples from deer of the chaparral.

Since seasonal values did not differ statistically, samples were pooled into a larger sample representative of the cover type (Table 11). Analyses of variance showed that ^{137}Cs concentration in rumen contents of deer from oak woodland was significantly higher ($P < .01$) than ^{137}Cs concentration in rumen contents of deer from chaparral. Cesium-137 concentrations in muscle of deer from the two cover types also differed significantly ($P < .01$).

The data in Table 11 suggest that the relationship between average ^{137}Cs concentrations in rumen contents and muscle ^{137}Cs is similar regardless of cover type. Rumen contents, on the average, contained 0.3 pCi $^{137}\text{Cs}/\text{g}$ more than muscle. The ratio of ^{137}Cs in rumen contents to ^{137}Cs in muscle was 0.8 for oak woodland deer and 0.6 for deer from chaparral. The difference between rumen contents of deer from oak woodland and from chaparral is consistent with the difference seen in ^{137}Cs concentration in muscle from both areas. Rumen contents from deer in the oak woodland contained an average of 0.56 pCi $^{137}\text{Cs}/\text{g}$ more than rumen contents of deer from the chaparral. The average concentrations of ^{137}Cs in muscle also differed by very nearly the same amount, 0.57 pCi/g.

Table 9. Average Concentration of ^{137}Cs in
Rumen Contents (pCi/g $\pm$ S.D.)

Cover Type	Summer	Fall	Winter
Oak Woodland	1.28 ± 1.13	1.03 ± 0.44	1.82 ± 0.44
Chaparral	0.70 ± 0.2	0.63 ± 0.12	1.15 ± 0.49

Table 10. Average Concentrations of ^{137}Cs in Muscle (pCi/g $\pm$ S.D.)

Cover Type	Summer	Fall	Winter
Oak Woodland	1.02 ± 0.45	0.88 ± 0.28	1.32 ± 0.20
Chaparral	0.38 ± 0.07	0.37 ± 0.12	1.00 ± 0.57

Table 11. Average Concentration of ^{137}Cs in
Muscle and Rumen Contents for Period
of Study (pCi/g $\pm$ S.D.)

Cover Type	Rumen Contents	Muscle	Difference
Oak Woodland	1.35 ± 0.78	1.06 ± 0.36	0.29
Chaparral	0.79 ± 0.32	0.49 ± 0.32	0.30
Difference	0.56	0.57	

The relationship between rumen contents and muscle is also represented graphically in Fig. 10. Values for deer from the oak woodland are estimated well by the line of regression; the correlation coefficient was 0.85. This means that 72% of the variability of muscle ^{137}Cs concentrations was accounted for by the relationship between ^{137}Cs in rumen contents and muscle.

Similarly, among the chaparral deer, 71% of the variation can be accounted for ($r = 0.84$). This high correlation hinges on the presence of deer No. 906 at the coordinates 1.5 and 1.4. If this deer were removed, there could be no correlation, and the slope of the curve, in fact, becomes negative and not significantly different from zero. This animal was collected from well within the chaparral area and its rumen content was typical of the vegetative cover of the area. No explanation, other than an unlikely migration to higher elevation by this deer, is offered.

Values for deer from the chaparral edge show little correlation ($r = 0.46$). Only ~22% of the variability in muscle is associated with ^{137}Cs concentration of the rumen contents. This low correlation may be expected in deer inhabiting these mixed cover types.

Because some forage items concentrate more ^{137}Cs than others (e.g., acorns, 0.1 pCi/g; lichen > 5 pCi/g), the concentration of ^{137}Cs in the rumen contents may vary considerably with daily dietary changes. These short-term changes, however, will not be reflected in muscle ^{137}Cs concentrations since the muscle ^{137}Cs burden is the result of long-term dietary patterns.

When the ^{137}Cs concentrations in muscle and rumen contents are highly correlated, there is the suggestion that the individual deer consumed a relatively constant diet for considerable periods of time,

Fig. 10. Relationship between ^{137}Cs concentration in rumen contents and muscle in deer collected from oak woodland, chaparral, and chaparral edge.

in terms of forage intake and, therefore, ^{137}Cs . The high correlation seen in Fig. 10 indicates that individual deer of the oak woodland tend toward a constant diet.

Any apparent similarity among deer of the chaparral with regard to constancy of diet is due to deer No. 906. As mentioned previously, exclusion of this animal from the data removed the correlation. Two explanations are suggested: (1) the forage items available at higher elevations have a more variable ^{137}Cs concentration which is reflected in the rumen contents but not in muscle, and (2) the radioactivity counting sensitivity at these very low levels (~ 0.5 pCi/g) is relatively poor and may obscure the correlation should one, in fact, exist.

The relationship between rumen content and muscle ^{137}Cs found in deer from the chaparral edge probably results from unusual short-term dietary fluctuations, in this case, the eating of lichens. Rumen content analyses as well as the fairly low muscle ^{137}Cs burden suggest that these animals were from the chaparral but had moved into the edge area, probably in response to the unusual presence of snow at the higher elevations.

VI. DISCUSSION

Seasonal variability in ^{137}Cs body burdens has been described for a number of ungulates (Whicker et al., 1965; Svensson and Lidén, 1965; Hanson, 1967; Rabon, 1968), as a function of seasonal fluctuations in the diet. The data obtained in this study did not show seasonal differences, although there was a marked rise in ^{137}Cs concentrations in all winter samples. The minimal seasonal changes observed may be the result of the small amount of data collected, or may be due to the excellence of range conditions at the field station during the period of study. Summer rains had resulted in an abnormally early growth of annual grasses and forbs. This, along with an exceptionally large acorn crop in the fall of 1968, produced unusually high quality forage for deer.

Rumen contents on the average contained greater concentrations of ^{137}Cs than muscle (Table 11). The lower concentration in muscle may result from a number of factors: (1) not all of the ^{137}Cs is absorbed from the gut in ruminants (McClellan et al., 1961), (2) there is a time lag between injection and appearance of the radionuclide in tissue, (3) the amount of ^{137}Cs absorbed is distributed throughout the soft tissues of the body and therefore diluted, and (4) the ^{137}Cs in tissue is continually being eliminated, in deer, with a biological half-time of 17 days (Goldman et al., 1965). When the ^{137}Cs concentrations in rumen contents and muscle are highly correlated, as seen with oak woodland deer in Fig. 10, the interaction of all these factors, and the constancy of forage items lead to a kind of dynamic equilibrium. This equilibrium changes as soon as diet is changed with season or as a result of individual preference.

The differences in ^{137}Cs content of muscle and rumen contents from deer of oak woodland and chaparral (Table 11) reflect differences in availability of preferred forage species. The presence of grasses, forbs, and lichens in the rumen contents of oak woodland deer may contribute to higher ^{137}Cs burdens. Lichens are absent from the diet of deer from the chaparral; grasses and especially forbs are comparatively rare. Since ^{137}Cs fallout is related to rainfall, concentrations of ^{137}Cs were expected to be greater in samples from higher elevations. The opposite was found to be true, however; deer living at lower elevations accumulated the highest ^{137}Cs burdens. This reversal of the expected trend was found to result from differences in availability of forage species and variations in fallout ^{137}Cs accumulation among these species.

Lichens, as effective accumulators of ^{137}Cs , are considered to be responsible for the high ^{137}Cs concentration seen throughout Alaskan and Scandinavian food webs (Hanson et al., 1967; Miettinen, 1967). Longhurst et al. (1967), considering deer food habits at the Hopland Field Station as a whole based on earlier rumen sample collections, suggested that lichens probably did not exert a major influence on ^{137}Cs body burdens of deer. However, this study was directed at individual cover types. Since lichens might contain from several to ~150 times the ^{137}Cs activity of other forage items on a per gram basis (Tables 4 and 5), the continual ingestion of small amounts of lichen would result in an elevated ^{137}Cs body burden. As an example, 10 g dry weight of lichen (with ~10 pCi $^{137}\text{Cs}/\text{g}$) could conceivably contribute as much ^{137}Cs to the rumen contents as could 1000 g of acorns (~0.1 pCi/g).

When the food habits of deer from the oak woodland are considered, it is apparent that they do ingest sufficient lichen to influence their radiocesium body burdens. The lichen *R. reticulata* is very palatable (Longhurst et al., 1968) and deer, according to Connolly (1969), are known to relish this and certain other lichens. The primary constraint on deer consumption of lichen is its lack of availability of significant amounts.

Cesium-137 uptake from other sources such as inhalation or ingestion of the radionuclide in drinking water is minimal (Whicker, 1965) relative to that from contaminated forage.

VII. SUMMARY

The results of this study indicate the following:

(1) The data do not show any statistically significant seasonal variation in ^{137}Cs concentrations in rumen contents and muscle, although samples collected in winter (February-March) contained more ^{137}Cs .

(2) Rumen contents contained greater concentrations of ^{137}Cs than did muscle.

(3) Rumen contents and muscle of deer from oak woodland contained significantly higher concentrations of ^{137}Cs than samples from deer of the chaparral ($P < .01$).

(4) Differences in ^{137}Cs concentration reflect differences in diet.

(5) Ingested lichens appear to contribute appreciably to the ^{137}Cs body burden of oak woodland deer.

BIBLIOGRAPHY

- ÅBERG, B., and HUNGATE, F. P., Eds. 1967. Radioecological Concentration Processes, Pergamon Press, Oxford.
- BARBER, D. A. 1964. Influence of soil organic matter on entry of caesium-137 into plants. *Nature*, 204: 1326-1327.
- CONNOLLY, G. E. 1969. Personal communication.
- CSUPKA, S., PETRESOVA, M., and CARACH, J. 1967. Seasonal variation in the concentration of Cs-137 in grass and alfalfa. *Nature*, 213 (5082): 1204-1206.
- DAHL, A. H., and WHICKER, F. W. 1967. A study of the food chain pattern of strontium-90, cesium-137, and iodine-131 in a wild deer population. Fifth Technical Progress Report, Colorado State University Research Foundation, Fort Collins, Colorado.
- DAVIS, J. J. 1963. Cesium and its relationship to potassium in ecology. In *Radioecology*, V. Schultz and A. W. Klement, Jr., Eds., Reinhold Publishing Corp., New York, pp. 539-556.
- DEAN, J. M., EAPEN, J., and NAKATANI, R. E. 1965. Metabolism of Cs-137 in trout, BNWL-122: 73-74.
- ENGLAND, J. M., and MILLER, R. G., JR. 1969. Counting times in the measurement of radioactivity. *Intl. J. Appl. Radiation Isotopes*, 20: 1-10.
- EKMAN, L. 1961. Distribution and excretion of radiocesium in goats, pigs, and hens. *Acta. Vet. Scand.* 2 suppl. 4: 9.
- FREDRIKSSON, L., and ERIKSSON, A. 1966a. Studies on plant accumulation of fission products under Swedish conditions. VII. Plant absorption of Sr-90 and Cs-137 from soil as influenced by organic matter. The Research Institute of National Defense, Stockholm, Sweden.
- FREDRIKSSON, L., and ERIKSSON, A. 1966b. Studies of fission products through food chain. I. Cs-137 in vegetation and milk at the experimental farms of the Swedish agricultural college in 1963. Research Institute of National Defense, Stockholm, Sweden.
- GOLDMAN, M., YOUNG, L., and EDMONDS, R. 1963. Whole body counting of beagles continually fed Sr-90, UCD-108, 6th Annual Progress Report, Radiobiology Laboratory, Univ. Calif., Davis.
- GOLDMAN, M., LONGHURST, W. M., DELLA ROSA, R. J., BAKER, N. F., and BARNES, R. D. 1965. The comparative metabolism of strontium, calcium and cesium in deer and sheep. *Health Physics* 11: 1415-1422.

- GORHAM, E. 1959. A comparison of lower and higher plants as accumulators of radioactive fallout. *Can. J. Bot.* 37: 327-329.
- GOWANS, K. M. 1958. Soil survey of the Hopland Field Station. California Agricultural Experiment Station. 31 p.
- HANSON, W. C. 1967. Radioecological concentration processes characterizing arctic ecosystems. *In* Åberg and Hungate, op. cit. pp. 183-191.
- HANSON, W. C., WATSON, D. G., and PERKINS, R. W. 1967. Concentration and retention of fallout radionuclides in Alaskan arctic ecosystems. *In* Åberg and Hungate, op. cit. pp. 233-245.
- HOLLAND, J. Z. 1963. Distribution and physical-chemical nature of fallout. *Fed. Proc.* 22: 1390-1397.
- HOOD, S. I., and COMAR, C. L. 1953. Metabolism of cesium-137 in rats and farm animals. *Arch. Biochem. Biophys.* 45: 423-433.
- ITAGAKI, K., and KOENUMA, S. 1962. Altitude distribution of fallout contained in rain and snow. *J. Geophys. Res.* 67: 3927-3933.
- LANGHAM, W. H. 1965. Considerations of biospheric contamination by radioactive fallout. *In* Radioactive Fallout, Soils, Plants, Food, Man. E. B. Fowler, Ed., Elsevier Publishing Co., Amsterdam.
- LANGHAM, W. H., and ANDERSON, E. C. 1959. Cs-137 biospheric contamination from nuclear weapons tests. *Health Physics* 2: 30-48.
- KATCOFF, S. 1960. Fission-product yields from neutron-induced fission. *Nucleonics* 18: 201-208.
- KIRCHMANN, R., FAGNIART, E., and VAN PUymbroECK, S. 1967. Studies on foliar contamination by radiocaesium and radiostrontium. *In* Åberg and Hungate, op. cit. pp. 475-478.
- LONGHURST, W. M. 1969. The effects of brush burning on deer. Progress Report, 1968, and Summary Report, 1963-1968. University of California, Hopland Field Station.
- LONGHURST, W. M. 1969. Personal communication.
- LONGHURST, W. M., GOLDMAN, M., and DELLA ROSA, R. J. 1967. Comparison of the environmental and biological factors affecting the accumulation of Sr-90 and Cs-137 in deer and sheep. *In* Åberg and Hungate, op. cit. pp. 635-648.
- LONGHURST, W. M., OH, H. K., JONES, M. B., and KEPNER, R. E. 1968. A basis for the palatability of deer forage plants. Transactions of the 33rd North American Wildlife and Resources Conference, Mar. 11-13, 1968.

- MC CLELLAN, R. O., MC KENNEY, J. R., and BUSTAD, L. K. 1961. Metabolism and dosimetry of Cs-137 in sheep. *Rad. Res.* 14: 483-484.
- MIDDLETON, L. J. 1958. Absorption and translocation of strontium and caesium by plants from foliar sprays. *Nature* 181: 1300-1303.
- MIDDLETON, L. J. 1959. Radioactive strontium and caesium in the edible parts of crop plants after foliar contamination. *Intl. J. Rad. Biol.* 4: 389-402.
- MIETTINEN, J. K. 1967. Concentration of ^{137}Cs and ^{55}Fe through food chains in the arctic and subarctic regions. In Aberg and Hungate, *op. cit.* pp. 267-274.
- MILLER, C. F. 1967. The retention by foliage of silicate particles ejected from the volcano Irazú in Costa Rica. In Aberg and Hungate, *op. cit.* pp. 501-525.
- MORGAN, K. Z. 1964. The body burden of long-lived isotopes. *Arch. Environ. Health* 8: 86-99.
- PENDLETON, R. C., MAYS, C. W., LLOYD, R. D., and CHURCH, B. W. 1965. A trophic level effect on Cs-137 concentration. *Health Physics* 11: 1503-1510.
- RABON, E. W. 1968. Some seasonal and physiological effects on ^{137}Cs and $^{89,90}\text{Sr}$ content of the white-tailed deer, *Odocoileus virginianus*. *Health Physics*, 15: 37-42.
- RICHMOND, C. R. 1958. Retention and excretion of radionuclides of the alkali metals by five mammalian species. Los Alamos Scientific Laboratory Report LA-2207. 139 p.
- STEWART, H. F., WARD, G. M., and JOHNSON, J. E. 1965. Availability of fallout Cs-137 to dairy cattle from different types of feed. *J. Dairy Sci.* 48: 709-713.
- STEWART, J. D., and HUNGATE, F. P. 1967. Effect of soil moisture on uptake and translocation of Cs-137, potassium, Ca-45, and Sr-90. In Aberg and Hungate, *op. cit.* pp. 399-407.
- STROMINGER, D., HOLLANDER, J. M., and SEABORG, G. T. 1958. Table of Isotopes. *Mod. Physics* 30(2): part 2.
- SVENNISON, G. K. and LIDÉN, K. 1965. The transport of ^{137}Cs from lichen to animal and man. *Health Physics* 11: 1393-1400.
- U.S. ATOMIC ENERGY COMMISSION. 1969. Annual Report to Congress. U.S. Government Printing Office, Washington, D.C.

WALTON, A. 1963. The distribution in soils of radioactivity from weapons test. J. Geophys. Res. 68: 1485-1496.

WASSERMANN, R. H., and COMAR, C. L. 1961. The influence of dietary potassium on the retention of chronically ingested cesium-137 in the rat. Rad. Res. 15: 70-77.

WASSERMANN, R. H., COMAR, C. L., and TWARDOCK, A. R. 1961. Metabolic behavior of Cs-137--Ba-137m in the lactating goat. Intl. J. Rad. Biol. 4: 299-310.

WHICKER, F. W. 1965. Factors influencing the accumulation of fallout ^{137}Cs in mule deer. Ph.D. dissertation. Colorado State University.

WHICKER, F. W., FARRIS, C. G., REMMENG, E. E., and DAHL, A. H. 1965. Factors influencing the accumulation of fallout Cs-137 in Colorado mule deer. Health Physics 11: 1407-1414.

APPENDIX

Table A-1. Forage Species in Rumen Contents from Oak Woodland Cover Type (Percent by Volume)
(Numbers in parentheses represent contribution to total lichen in sample)

Forage Item	August - September						November - December						February - March				
	Deer Collection Number						Deer Collection Number						Deer Collection Number				
	859	862	866	874	875	877	891	892	893	894	895	896	909	910	911	912	913
<i>Quercus</i> spp. acorns	15	45	25	95	35	55	40	85	54	65	75	25	25	40	90	25	10
Grasses		45	70	2	35	40	40	1	5	1	tr*	20	70	2	4	45	10
Forbs	75	tr		tr	tr	5	10	1	1	tr		54	4	2		3	73
<i>Quercus</i> spp. leaves	5	5	3	tr	5		2	tr		33	25	tr	tr [†]	40	5 [†]	tr	
Lichen	1	5	1	3	25		7	13	40	1	tr	tr	1	5	1	2	7
<i>Evernia prunastri</i>									tr				tr	tr	tr	tr	tr
<i>Usnea arizonica</i>							(1)		tr								
<i>Usnea</i> spp.							(5)	(3)	(5)		tr			(3)	(1)	(2)	(5)
<i>Ramalina reticulata</i>								(10)	(35)				tr	(1)	tr	tr	(1)
<i>Ramalina farinacea</i>							(1)			(1)	tr	tr	tr	(1)	tr		(1)
<i>Photinia arbutifolia</i>														10		15	tr
<i>Umbellularia californica</i>																10	
Unidentified fruit	4																
<i>Arbutus menziesii</i>												1		1			
<i>Phoradendron villosum</i>			1														
<i>Vicia</i> sp.							1										

* tr - only trace amounts present

† unidentified lichens present in sample

Table A-2. Forage Species in Rumen Contents of Deer from Chaparral Cover Type (Percent by Volume)
(Numbers in parentheses represent contribution to total lichen in sample)

Forage Item	August - September							November - December					February - March				
	Deer Collection Number							Deer Collection Number					Deer Collection Number				
	861	863	864	865	867	868	876	890	897	898	900 [§]	901 [§]	905	906	907 [§]	914 [§]	915 [§]
<i>Adenostoma fasciculatum</i>	25	4	tr	tr	1			4	4	40	10	tr*	95	99	35	95	35
<i>Quercus</i> spp. leaves	65	85	85	10	98	98				tr					1		tr
<i>Quercus</i> spp. acorns	5	5	10	75		1	49	1	90	35	75	50	3		tr		
Grasses	tr			10			49	95	4	25	10	tr	1		tr	1	
Lichen				tr			tr					47			5 [†]	†	10 [†]
<i>Evernia prunastri</i>												tr			(1)	tr	
<i>Usnea arizonica</i>												(15)					
<i>Usnea</i> spp.											tr	(30)			(4)	tr	tr
<i>Ramalina farinacea</i>											tr	(2)				tr	
<i>Ceanothus cuneatus</i>	5	5	5		1	1	tr	tr	1	tr	tr		1	1		1	40
<i>Arbutus menziesii</i>															35		
<i>Eriodictyon californicum</i>												tr		tr	20		
<i>Umbellularia californica</i>											1				2	1	15
<i>Arctostaphylos</i> sp.											4	3				1	
<i>Rhus diversiloba</i>				4													
<i>Photinia arbutifolia</i>				1					tr	tr			tr		2		
<i>Phoradendron villosum</i>							1				tr					1	
<i>Ceanothus integerrimus</i>		1															
Forbs	tr	tr					1	tr	1			tr				tr	

* tr = only trace amounts present

† unidentified lichens present in sample

§ deer collected from chaparral edge

Table A-3. Forage Species in Rumen Contents of Bucks from Oak
Woodland Cover Type Taken in August-September, 1968
(Percent by Volume)

Forage Item	Deer Collection Number										Average
	1	2	5	8	10	12	16	18	19	23	
<i>Quercus</i> spp. leaves	85	71	10	90	70	90	35	4	10	5	47
<i>Quercus</i> spp. acorns	5	2		4	25	4	55	60	50	90	30
<i>Aesculus californicus</i>	5		75				8				9
<i>Lotus americana</i>								35	40		8
Lichen		26	3	5	15	2	2	tr	tr	1	5
Grasses	5	tr	1	tr				1		4	1
<i>Rhus diversiloba</i>				1		1					
Forbs	tr	tr	1	tr	tr		tr		tr		
<i>Photinia arbutifolia</i>	1										
<i>Phoradendron villosum</i>						1					
<i>Adenostoma fasciculatum</i>						1					
Fungi						1					

Table A-4. Forage Species in Rumen Contents of Bucks from Chaparral Cover Type Taken in August-September, 1968 (Percent by Volume)

Forage Item	Deer Collection Number						Average
	3	7	11	27	31	36	
<i>Quercus</i> spp. leaves	95	80	75	3	33	1	48
<i>Quercus</i> spp. acorns	2	5	27	70	5	95	34
Unidentified fibers					60		10
Grasses				25			5
<i>Arctostaphylos manzanita</i>	1	10					2
<i>Ceanothus cuneatus</i>		5					1
<i>Photinia arbutifolia</i>	1			2			
<i>Adenostoma fasciculatum</i>	1	tr	tr	tr		tr	
<i>Umbellularia californica</i>				tr	1		
Fungi					1		

Table A-5. Characteristics of Deer Collected at Various Elevations within Oak Woodland Cover Type

Deer Number	Approximate Elevation (ft)	Age* (yr)	Sex	Whole Body Weight (kg)	Rumen Contents Weight (kg)
859	800	1	F	29.5	--
862	1200	8+	F	39.1	5.39
866	1040	6	F	33.2	3.11
874	1280	1	M	22.9	2.10
875	1240	Fawn	M	17.3	1.67
877	1360	1	F	26.8	2.13
891	1000	1	F	22.3	1.57
892	840	Fawn	M	25.8	1.44
893	840	2	F	39.1	2.53
894	1240	Fawn	F	17.2	1.07
895	1240	Fawn	F	20.6	1.20
896	800	Fawn	F	22.3	1.67
909	640	1	M	33.2	1.96
910	1300	4	F	47.7	2.22
911	1300	2	M	41.8	2.69
912	1440	Fawn	F	25.2	2.03
913	1000	1	F	30.0	1.47

* Estimated from dentition

Table A-6. Characteristics of Deer Collected at Various Elevations within Chaparral Cover Type

Deer Number	Approximate Elevation (ft)	Age* (yr)	Sex	Whole Body Weight (kg)	Rumen Contents Weight (kg)
861	2960	8+	F	36.4	6.34
863	3100	1	F	25.9	4.05
864	3120	6	F	30.5	5.26
865	2200	2	M	32.3	4.85
867	2700	1	M	33.2	3.88
868	2700	Fawn	M	17.5	2.69
876	2560	4	F	31.4	3.67
890	3080	1	F	26.4	3.00
897	2840	Fawn	M	16.5	1.86
898	2640	7	F	42.7	3.31
900**	2750	8+	F	41.8	2.83
901**	2750	8+	F	46.8	3.23
905	2600	8+	F	43.6	3.61
906	3100	4	F	33.9	2.65
907**	2720	7	F	38.6	3.14
914**	2840	7	F	44.1	4.19
915**	2680	7	F	41.8	3.78

* Estimated from dentition

** Collected from chaparral edge

Table A-7. Characteristics of Bucks Taken from Various Elevations within Oak Woodland and Chaparral Cover Types

Deer Number	Elevation	Age (yr)	Body Weight (kg)
Oak Woodland			
1	1240	1	36.7
2	1400	2	46.8
5	900	2	50.4
8	1120	2	45.5
10	1320	4	48.1
12*	2300	4	37.7
16	1700	4	52.3
17	1300	4	53.2
18	990	3	57.3
19	1000	2	45.9
23	1100	2	36.7
Chaparral			
3*	2800	2	39.5
7*	2600	3	47.3
11	2600	5	33.5
13*	2500	6	67.3
15	2840	4	44.5
22	2900	4	50.0
27	2000	4	50.9
31	2900	7	47.7
36*	2600	5	61.8

* Deer collected in areas of mixed cover type and placed in chaparral or oak woodland according to rumen content analyses