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DIFFERENTIAL EFFECT OF A CHRONIC DOSE OF GAMMA
IRRADIATION ON SHRUBS IN THE NORTHERN MOJAVE DESERT

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Abstract--A 33,600 curie Cs¹³⁷ source which was differentially shielded to increase the uniformity of the distribution of irradiation was set up on a 15-meter tower in the center of a 9-hectare plot in January 1964 in the Rock Valley Area of the Northern Mojave Desert. In the spring of 1969 the large majority of 5000 Ephedra nevadensis within the plot failed to produce flowers and very little vegetative growth occurred in contrast to a control plot and to other nonirradiated areas. The cumulative irradiation dose throughout the plot ranged from 3000 to 29,000 r. Irradiation effects on Lycium andersonii were uncertain and effects were doubtful on other species. E. nevadensis and L. andersonii have higher nuclear volume than do the other shrub species. Considerable resistance to gamma irradiation is experienced for several of the other species.

Introduction

Several groups of workers have shown that irradiation of an ecosystem can result in differential injury to plant species and hence can result in changes in botanical composition of the system (2, 6, 8,

9, 14). Since Sparrow et al. (3, 10-14) have shown that susceptibility to irradiation injury is systematically related to nuclear volume for different species, and since there is a wide difference in nuclear volume among the species involved in the desert ecosystem, it can be expected that wide differences in susceptibility to ionizing irradiation would occur.

The study was initiated as a comprehensive ecological investigation in a desert environment of the effects of a chronic low level dose of gamma irradiation. Following earlier background studies, a 33,600 curie Cs¹³⁷ source was placed in the study area in the winter of 1964.

The location of the study area is 12 miles west of Mercury in Nye County, Nevada. It lies in the southwest corner of the U. S. Atomic Energy Commission's Nevada Test Site in the Rock Valley Section. The elevation is about 1050 meters and the slope is downward to the northwest with a gradient of 3 to 4%. The study area approaches the limits of the Northern Mojave Desert with some overlap with Great Basin species. Indigenous shrub composition is characterized by the following species with their approximate frequencies: Larrea divaricata - 21%, Lycium andersonii - 22%, Lycium pallidum - 5%, Franseria dumosa - 17%, Ephedra nevadensis - 12%, Krameria parvifolia - 13%, and 10% other species (Unpublished data of W. Martin). Plant taxonomy has been worked out by Beatley⁽¹⁾. The soils are a highly calcareous alluvium with heavy impenetrable "caliche" deposits lying from 35 to 50 cm below the surface. The radiation source (4, 7) is a 33,600 curie Cs¹³⁷ source mounted atop a 15-meter tower. In order to achieve some uniformity of dose over

the irradiated plot, the source is subtended with a lead shield of differential thickness. The resulting dose at ground level is approximately 750 mr/hr. Twenty meters from the tower and at the periphery of the plot 170 meters distant, the dose is 75 mr/hr and 350 meters from the tower the dose is less than 10 mr/hr. The cumulative dose at inception of this experiment was 29,000 r 20 meters from the tower, 3000 r at 170 meters and approximately 200 r at 350 meters. The cumulative exposure time was 1636 days. The source is lowered into a heavy lead cask below ground about 5 days each month to permit entry for study purposes.

Field data obtained in these plots in the years 1964-1968 were subjected to multivariate analysis by species using Biomedical Computer Programs BMDX63, Multivariate General Linear Hypothesis of the Health Sciences Computing Facility (5). The variables simultaneously considered in each analysis were:

1. Increase in shoot length (millimeters)
2. Number of leaves per centimeter of shoot length
3. Increase in lateral shoot length per centimeter of shoot length
4. Number of flowers per centimeter of shoot length
5. Number of fruits per centimeter of shoot length

The results from this analysis indicated differences among years for each species and between plots for the species Larrea divaricata, Lycium andersonii, and Ephedra nevadensis but not for Grayia spinosa, Franseria dumosa, or Lycium pallidum. Estimated nuclear volume for these six shrub species respectively, are 212, 466, 600 - 800, 128,

152, and 156. If one were predicting that three of the six species would respond to the irradiation, the three predicted ones appeared to respond. The reasons for differences among years is easily explained by the pattern of rainfall (Table 1).

The variability of the data from which the multivariable analyses were made led us to suspect that some of the differences among plots were not real so additional comparisons were made in 1969.

MATERIALS AND METHODS

The field work conducted in the plots in the spring of 1969 was designed to obtain additional information on those species having the largest nuclear volume which are the species with significant differences between plots in the previous study (5). For two species, Lycium andersonii and Larrea divaricata, two sample transact lines were laid out. One extended eastward and one westward from the source tower with three discrete locations being sampled for each transact line. At distances of 20, 170, and 350 meters along each line, five plants of each of the two species were chosen. Five shoot areas were marked for each plant and volume determinations were measured for each plant. At appropriate times total flower counts were made for each shoot and at a later date, fruit counts were made for these shoots. Fruits were then removed and counted, samples of seeds from each of the transact locations were reserved for viability testing. All plants taken were as closely clustered to the transaction locations as possible. A total of 30 plants of each species were sampled. Care was taken in establishing the transact lines to maintain the same elevation and plants

were picked from the same general soil type.

We then determined the percentage of flowers producing fruit and additionally tested the seed for viability.

Ephedra nevadensis, the species having the largest nuclear volume, was studied somewhat more intensively. With this species we compared plants in the irradiated plot with those growing in a control plot about 215 meters away from the edge of our irradiated plot. We divided each 340-meter circular plot into parallel strips with alternating widths of 15 and 30 meters. Every plant with 50% or more of its ground cover lying inside the 15-meter strip was sampled. Thus we effectively censused approximately one-third of all E. nevadensis plants in each plot. E. nevadensis is a dioecious species and counts were made to determine the number of staminate cones on each male plant. Ovulate cones were not sampled but fruit counts were made for all ovulate plants. Each plant was classified vegetatively as follows:

Poor - little or no new shoot growth

Fair - shoot growth sparse and less than 7 cm

Good - shoot growth heavy and many shoots 15 to 30 cm long

Very good - shoot growth luxuriant with many shoots in excess of
30 cm

RESULTS AND DISCUSSION

The choice of 1969 for detailed studies of irradiation effects was a good choice for at least one reason. The rainfall in February and March, 1969 was abundant (Table 1) and conditions following were very favorable for growth of shrubs. Over 20 cm of precipitation occurred

from October, 1968 through March, 1969 and April and May had the highest mean temperature for 7 years of record. A more favorable season has not been available for many years. These favorable conditions could be expected to allow any stress from irradiation to become the limiting factor and consequently to be expressed. This proved to be the case for E. nevadensis. In some years growth can hardly be detected on this species but in 1969 it grew extremely well except in the irradiated plot.

The results in 1969 for E. nevadensis show that the irradiation had caused great differences in flowering, fruiting, and vegetative growth (Table 2). The results observed in the irradiated plot were not observed anywhere else on the test site and it must be concluded that the results were due to irradiation. A greatly important aspect of the 1969 results is that it was a year conducive to large amounts of shrub growth and reproduction because of winter rains and favorable temperature conditions throughout the spring of 1969. The rainfall assured that soil moisture was above field capacity and not acting as a limiting factor in plant growth and reproduction.

Laboratory studies with E. nevadensis indicate that 1000-2000 r of γ irradiation as an acute dose greatly decreased vegetative growth (Unpublished data).

The results obtained in 1969 for L. andersonii were inconclusively related to irradiation (Table 3). Laboratory studies with acute doses of γ irradiation indicate that 5000-8000 r are necessary to cause severe injury in the species (Unpublished data).

No effects of L. divaricata were evident for irradiation in 1969

(Table 4). Acute doses of irradiation for the species of around 12,000 r have been shown to be necessary for injury of the species (Unpublished data).

These results as well as those of Rhoads et al. (9) concerning irradiation from nuclear detonations indicate that shrub species can be differentially injured or killed in a desert ecosystem by excessive amounts of ionizing irradiation. The species E. nevadensis is common to the ecosystem studied by Rhoads et al. and the ecosystem in the present study. The results for both systems are similar. As in ecosystems studied elsewhere (2, 6, 8, 9, 14) these results show that ionizing irradiation can profoundly change an ecosystem by differentially removing some of the plant species.

Seeds collected in the spring of 1969 were tested for germination. Either two or four sets of 100 seeds each were planted in flats of vermiculite in a glasshouse and the number of germinating seeds were counted. The low percentage of germination was typical of other results obtained with these species in this laboratory. Six (3, 3) of 200 seeds of E. nevadensis from inside plot B (irradiated) germinated while 3 (0, 3) from inside plot D (nonirradiated) germinated. No seeds from a collection made randomly in Rock Valley from outside the study area germinated in the test. Eleven L. divaricata seeds (3, 0, 6, 2) of 400 within 15 meters of the source in plot B germinated. Three of these died. Seventeen (6, 5, 3, 3) of 400 seeds collected 160 meters from the source germinated while 13 (2, 2, 6, 3) collected 325 meters from the source germinated. It is not known whether or not the death of seedlings from seeds close to the source was

related to irradiation or not.

With L. andersonii 5 seeds (1, 1, 2, 1) from 15 meters, 6 seeds (0, 3, 1, 1) from 160 meters and 8 seeds (2, 2, 4, 0) from 325 meters germinated. The results with these three species do not suggest an effect of irradiation on the seed germination in the test.

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Table 1. Mean Monthly Precipitation in the study area for 5 years

	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	
1964-1965	0.0	0.16	0.13	0.0	0.42	0.0	0.49	2.37	0.09	0.02	0.36	0.19	4.23 ¹
1965-1966	0.0	0.03	1.94	2.46	0.35	0.64	0.05	0.03	0.34	0.07	0.27	0.15	5.83
1966-1967	0.04	0.01	0.10	0.42	1.29	0.0	0.0	1.05	0.21	0.45	0.28	1.98	5.83
1967-1968	0.40	0.0	1.11	0.40	0.06	1.21	0.29	0.22	0.0	0.12	2.01	0.17	5.99
1968-1969	0.0	0.46	0.10	0.17	2.68	4.06	0.77	0.12	0.07	0.48	-	-	8.91
Accumulated total by month	0.44	0.66	3.38	3.45	4.80	5.91	1.60	3.79	0.71	1.14	2.92	2.49	

¹ Accumulated total by year. (Data assembled by B. Maza, from U. S. Weather Bureau Records).

Table 2. Effect of 5 years of γ irradiation on some characteristics of E. nevadensis in the spring of 1969.

	Plot B	Plot D	Chi square
Condition of new growth	Irradiated	Nonirradiated	Probability of Nonsignificance
	New vegetative shoot growth* (No. of plants)		
Poor	472	58	< .01
Fair	650	296	< .01
Good	505	1066	< .01
Very good	0	495	< .01
Total**	1627	1915	
No. of staminate cones on each plant	Cone production (staminate plants only) (No. of plants)		
25 or fewer	63	238	< .01
26-100	11	242	< .01
101 and over	3	208	< .01
Total No. with cones	77	688	< .01
No. of fruits on each plant	Fruit production (No. of plants)		
25 or fewer	19	238	< .01
26-100	1	169	< .01
101 and over	0	109	< .01
Total No. with fruits	20	516	< .01
Summary of Cones and Fruits			
Percent with cones	4.8	35.9	< .01
Percent with fruit	1.2	27.0	< .01

*For meaning of poor, fair, good, and very good see text.

**Includes both staminate and pistillate plants.

Table 3. Effect of 5 years of γ irradiation on some characteristics of L. andersonii in the spring of 1969.

Location from γ source meters	Mean vol of shrub (mean of 5) m^3	No. of flowers per plant segment (mean of 25 segments)	No. of fruits (mean of 25 segments)
West 60	0.57	54.0	14.2
East 60	0.74	65.0	7.8
West 152	0.82	56.9	8.0
East 152	0.87	79.9	45.2
West 335	0.45	61.8	28.2
East 335	0.25	55.5	17.9
F value	2.36*	4.26*	9.3**
LSD .05	0.46	12.8	13.0
LSD .01	--	16.9	17.2

Table 4. Effect of 5 years of γ irradiation on some characteristics of
L. divaricata.

Location from γ -source	Mean vol of shrub mean of 5	No. of flowers mean of 25 shoots on 5 plants	No. of seeds mean of 25 segments on 5 plants
meters	m ³		
West 60	0.55	45.6	42.0
East 60	1.97	44.7	32.9
West 152	0.71	45.6	41.0
East 152	0.93	60.5	51.7
West 335	0.59	47.6	35.2
East 335	0.51	52.1	49.8
F value	0.5	2.7*	2.2
LSD .05	N.S.	10.3	N.S.
LSD .01	N.S.	N.S.	N.S.