1973 JOURNAL OF HERPETOLOGY 7(2): 79-85

Effects of Radiation on a Fenced Population of Horned Lizards (*Phrynosoma platyrhinos*) in Southern Nevada

Philip A. Medica, Frederick B. Turner and Donald D. Smith

Laboratory of Nuclear Medicine and Radiation Biology,
University of California, Los Angeles, 90024

ABSTRACT—Between 1964 and 1966 minimum spring densities of horned lizards ranged from 1.0-2.5/hectare (ha) in 3 8 ha enclosures in Rock Valley, Nevada. Minimal survival of hatchling horned lizards to the age of 8 months was about 26-38 per cent. Annual minimal survival of older lizards was 50-60 per cent. Female horned lizards usually laid one clutch of eggs per year, but multiple clutches were observed in 1969. Conversely, no reproduction was observed in 1970. The maximum life span of horned lizards is at least 94 months.

One of the enclosures was subjected to continuous gamma irradiation from a centrally located source of ^{137}Cs. Between 1964 and 1966 numbers of horned lizards declined in all 3 plots. Between 1967 and 1970 numbers of horned lizards increased in the two control areas, but continued to decline in the irradiated plot. Female sterility owing to regression of ovaries is judged to be the cause of the population decline. Similar radiation effects have previously been observed among leopard lizards (*Crotaphytus wislizenii*), whiptail lizards (*Cnemidophorus tigris*), and side-blotched lizards (*Uta stansburiana*).

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INTRODUCTION

Populations of vertebrates have been studied in Rock Valley at the U. S. Atomic Energy Commission's Nevada Test Site since 1964. From an applied point of view, the primary questions raised have concerned the function of natural populations exposed to continuous gamma irradiation. The demographic behavior of irradiated populations of both rodents (French, Maza and Aschwanden, 1967; French and Kaaz, 1968; French, Maza and Kaaz, 1969; French, 1970) and lizards (Turner et al., 1969b; Turner et al., 1972) have been examined.

In earlier papers, we have discussed the effects of continuous radiation exposure on leopard lizards (*Crotaphytus wislizenii*) and whiptail lizards (*Cnemidophorus tigris*) occupying the irradiated area, and called attention to the apparent lack of response in a third species (*Uta stansburiana*) inhabiting the experimental plot (Turner et al., 1969b; Turner et al., 1972). We now know that the sterility observed among female leopard and whiptail lizards has also developed among older irradiated female *Uta stansburiana*, and female horned lizards (*Phrynosoma platyrhinos*). The occurrence of this radiation effect among natural populations of lizards emphasizes the importance of basic demographic data in the elucidation of an applied problem. The population consequences of this effect vary according to the life-histories of the species involved. Longer lived species with deferred sexual maturity, long life spans and low fecundity (e.g., *Crotaphytus*) are evidently more vulnerable than shorter-lived forms with higher reproductive capacity (e.g., *Uta*).

In this paper we first wish to discuss both direct and indirect evidence of radiation-induced sterility among female horned lizards occupying the irradiated area in Rock Valley. Secondly, we will present data relating to maturation and survival of this species and show that in these attributes horned lizards are similar to *Crotaphytus wislizenii*.

METHODS

Rock Valley is located 12 mi west of Mercury, Nye County, Nevada. The study area includes 4 8 ha (20 ac) plots, of which three are fenced. One of the fenced areas has been continuously irradiated by a centrally located source of ^{137}Cs since January 1964 (French, 1964; Lucas, Burson and Lagerquist, 1966). Tissue doses to animals have been estimated by French et al. (1966), Turner and Lannom (1968), and Turner et al. (1972). In addition to the 8 ha plots in Rock Valley, 6 0.4 ha (1 ac) enclosures have been constructed one mile west of Mercury (Medica, Hoddenbach and Lannom, 1971).

Observations of horned lizards have been made in the fenced areas in Rock Valley since 1964, and in two of the 0.4 ha plots since 1969. Our most intensive sampling efforts have been devoted to 3 other species (*Uta stansburiana, Cnemidophorus tigris, Crotaphytus wislizenii*). For these species we have developed rosters of absolute numbers over the years, and (for *Uta*) have estimated age-specific survival and fecundity (Turner et al., 1969a,c; 1970). Our counts and observations of horned lizards have been made incidentally in the course of research on these 3 species. Hence, annual rosters of horned lizards in the large areas cannot be taken as absolute densities, but are fair measures of relative abundance. In the 0.4 ha enclosures the counts represent actual densities. In compiling the annual registries we used all information directly or indirectly available as to the presence of horned lizards in an area. Frequently, marked individuals were not captured in one or more years, but were seen later. We could then infer their presence during intervening seasons. Hatchling horned lizards are recognizable in the summer, and as juveniles (ca. 8 months of age) the ensuing spring. Although we could not estimate ages of older animals when the experiment began, the continued sampling and marking of horned lizards and disappearance of the oldest individuals eventually led to populations in which the age of every individual was known.

Reproduction by horned lizards has been partially inferred from observed numbers of hatchlings and yearlings, and also evaluated in 1969 by recurrent inspections of 3 marked females in the smaller plots. These females were captured regularly between late March and late July. Body weight changes were recorded and reproductive state inferred by palpation. Procedures were generally as outlined by Medica et al. (1971).

TABLE 1. Minimal numbers of *Phrynosoma platyrhinos* observed in 3 fenced 8 ha areas in Rock Valley, Nevada, between 1964 and 1971. For each area the 3 columns represent, respectively, numbers of adults (≥20 months), yearlings (8 months), and summer hatchlings. For each area spring populations are the totals of the first two columns. Area 2 is irradiated.

Year	Areas								
	1			2			3		
1964	12	2	0	7	5	4	10	10	5
1965	8	0	6	8	3	0	13	4	12
1966	4	5	5	8	0	1	6	6	24
1967	7	5	11	5	1	0	10	18	5
1968	10	11	18	6	0	0	19	4	14
1969	13	16	46	2	0	2*	15	8	31
1970	21	32	0	1	2*	0	12	20	0
1971	25	0	0	2	0	0	12	0	0

*probable immigrants

RESULTS

Density.—Between 1964 and 1966, minimum spring densities of *Phrynosoma platyrhinos* ranged from 1.0 to 2.5/ha in the fenced enclosures in Rock Valley (Table 1). During this time the number of horned lizards generally declined in all plots. Between 1967 and 1970 numbers increased in the two nonirradiated plots, attaining minimal densities of as high as 6.6/ha. However, the irradiated population declined during this time. Considerably higher densities were observed in the 0.4 ha plots (Table 2); as high as 32/ha in plot 6 in 1970. We cannot interpret the higher densities in the small plots, but call attention to 3 factors which may be implicated. First, the density estimates for the large plots have already been qualified as minimal, whereas essentially all individuals could be captured in the smaller enclosures. Second, the vegetation in the small plots is different from that in Rock Valley. Third, the fences surrounding the smaller enclosures may have enforced short-term local increases which would

TABLE 2. Numbers of *Phrynosoma platyrhinos* in two 0.4 ha fenced plots near Mercury, Nevada, 1969-1972.

		Spring			Summer
Plot	Year	Adults (20+ months)	Yearlings (8 months)	Total	Hatchlings
6	1969	4	4	8	19
	1970	5	8	13	0
	1971	7	0	7	0
	1972	5	0	5	
7	1969	2	2	4	15
	1970	4	5	9	0
	1971	5	0	5	0
	1972	4	0	4	

not have occurred in the absence of fences. This effect has been described among experimental populations of *Microtus pinetorum* (Gentry, 1968).

Reproduction.—Female *Phrynosoma platyrhinos* in southern Nevada first lay eggs at an age of 19-22 months, and are similar in this respect to *Cnemidophorus tigris* and *Crotaphytus wislizenii* (Turner et al., 1969a,c). In the latter species we have occasionally witnessed reproduction by 9-month-old females, but we have not observed such precocity among female *Phrynosoma* (see also Tanner and Krogh, 1973).

The number of hatchlings registered during the summer, and juveniles encountered in the spring, are both measures of reproductivity (Tables 1 and 2). We observed distinct year to year differences in reproduction of the sort already described for *Uta stansburiana* (Hoddenbach and Turner, 1968; Turner et al., 1970) *Cnemidophorus tigris* (Turner et al., 1969c), *Crotaphytus wislizenii* (Turner et al., 1969a): *Uma* spp. (Mayhew, 1965, 1966), and *Xantusia vigilis* (Zweifel and Lowe, 1966). Reproduction during the summers of 1966, 1968 and 1969 was conspicuously better than that of other years, but in 1970 there was no evidence of reproduction—either in Rock Valley or in the small enclosures near Mercury. Palped females exhibited no follicular development during the spring. No hatchlings were observed during the summer, and no juveniles were registered during the spring of 1971.

What contributed to the relatively large numbers of young produced in 1966, 1968 and 1969? The mean clutch size observed by Tanner and Krogh (1973) among 20 females was 6.8. Adult females were able to produce two clutches of eggs in 1969. The most direct evidence for multiple clutches came from continued observations of 3 marked females, which by changes in body weight and reproductive state (as inferred by palpation) clearly produced two clutches of eggs (Table 3). Observed weight losses associated with egg-laying ranged from 6.5 to 12.8 g (up to 35 per cent of body weight). We also recorded hatchlings 35-40 mm in snout-vent length during late July and early August, 1969. Multiple clutches among species normally producing but one clutch of eggs in southern Nevada have been reported in *Cnemidophorus tigris* and *Crotaphytus wislizenii* (Turner et al., 1969a,c). As suggested previously with respect to *Cnemidophorus* and *Uta* (Hoddenbach and Turner, 1968; Turner et al., 1970), increases in population size result from increases in the number of clutches produced rather than from changes in clutch size.

TABLE 3. Records for 3 adult female *Phrynosoma platyrhinos* observed in fenced 0.4 ha plots in 1969. For each individual, body weights (g) are given on the upper line and reproductive condition (as inferred by palpation) on the second line. Animals without detectable follicles or eggs are designated N, estimated follicle sizes are given in mm, and animals with oviducal eggs are designated E. Underlined body weights indicate that eggs were laid since the previous capture.

Animal number	March	April	May		June				July		
	27	15	12	19	4	12	16	24	7	14	23
1121	23.7 N	— 4 mm	30.4 E	—	28.3 N	29.9 E	31.4 E	24.9 N	26.8 N	28.1 N	32.1 N
1122	—	27.8 N	36.5 E	23.7 2 mm	23.5 4 mm	27.5 6 mm	29.2 7 mm	31.9 E	20.8 N	21.2 N	27.7 N
3221	26.4 N	— 5 mm	33.2 E	23.8 4 mm	29.8 E	—	27.4 E	26.0 E	26.9 E	19.7 N	26.1 N

Reeve (1952) judged the incubation period for *Phrynosoma platyrhinos* to be over 50 days. During 1969, we were able to relate the appearance of the hatchlings to the time of clutch deposition by females in the 0.4 ha plots. The 3 females laid their first clutches between 16 and 24 May and the first young hatched between 17 and 23 July (after 60-68 days). The second clutches were laid between 21 June and 11 July and the young hatched 50 to 59 days later.

TABLE 4. Minimal survivorship of *Phrynosoma platyrhinos* (≥8 months old) observed in 3 fenced 8 ha areas in Rock Valley, Nevada.

Area	Males	Females	Totals
1	36/72 (0.50)	22/45 (0.49)	58/117 (0.50)
2	15/26 (0.58)	7/9 (0.78)	22/35 (0.63)
3	39/69 (0.57)	16/47 (0.34)	55/116 (0.47)
All areas	90/167 (0.54)	45/101 (0.45)	135/268 (0.50)

Survivorship.—Minimal annual survivorship by horned lizards in Rock Valley is summarized in Table 4. Here we have considered the combined survival from one spring to the next of all animals 8 months of age or older. We have not attempted to evaluate differences between years or between age-classes, though such differences might be demonstrated with larger samples. Survivorship among individuals 8 months or older in the 0.4 ha plots between 1969 and 1970 was 75 per cent and between 1970 and 1971 about 55 per cent (Table 2). Table 4 shows that annual survival of older lizards was 50 per cent. Hence, we infer that minimal survival among older horned lizards (> 8 months) is about 50-60 per cent, comparable to that observed in *Cnemidophorus sexlineatus* (Fitch, 1958), *C. tigris* (Turner et al., 1969c), and *Crotaphytus wislizenii* (Turner et al., 1969a). The apparently higher survivorship (especially among females) in the irradiated plot may be real, for we have observed the same pattern among *Crotaphytus wislizenii* (Turner et al., 1969a). Maximum life span is long among horned lizards. At least 10 individuals in Rock Valley are known to be 70 months of age, and life spans of up to 94 months are on record.

Minimal survival to 8 months of age among 34 marked hatchlings in the two 0.4 ha plots during 1969 was 38.2 per cent (13/34). Among 34 hatchlings marked in two of the 8 ha areas in Rock Valley, minimal survival was about 26 per cent (9/34). These data may be compared to values of around 52 per cent for *Cnemidophorus* and 20-42 per cent for *Crotaphytus* (Turner et al., 1969a,c).

Apparent effect of gamma radiation.—Our conclusion from the demographic data summarized in Table 1 is that continued gamma irradiation has essentially blocked reproduction by *Phrynosoma platyrhinos* in the experimental fenced area since about 1966 or 1967. Between the inception of the experiment in 1964 and 1966 the demographic evidence was equivocal, but from the summer of 1967 to 1970 (and particularly in 1968 and 1969) the contrast between the two control plots and the irradiated plot was striking. Reproductive failure in the irradiated area was clearly manifested by the virtual absence of summer hatchlings and spring yearlings, and by the decline in older individuals during a time when nonirradiated populations were increasing.

Our conclusions regarding *Phrynosoma* are influenced by previous observations of sterility among female *Cnemidophorus tigris* and *Crotaphytus wislizenii*, and the gradual extinction of the latter species (Turner et al., 1972). Furthermore, one of the resident female *Phrynosoma* in the irradiated plot was collected during the spring of 1971 and a laparotomy performed. This individual showed the same absence of ovarian tissue and hypertrophy of fat bodies already described among whiptail and leopard lizards. Although the first appearance of sterility among females of the horned lizard population cannot be firmly established, the demographic evidence suggests 1966-67. This is about the time that sterility was first manifested in the irradiated leopard lizard population (Turner et al., 1972).

The radiation dose experience of horned lizards has not been measured directly as it has in 3 other species occupying the irradiated area (Turner and Lannom, 1968). However, judging from daily and seasonal activity patterns of *Phrynosoma*, we judge that tissue doses to horned lizards are similar to those received by *Crotaphytus*, i.e. about 400-500 rads/year (Turner et al., 1972).

DISCUSSION

Normal life spans and reproductive patterns are important factors in mediating the influence of continued irradiation on natural populations (French et al., 1969; Turner et al., 1972). Long-lived species of lizards generally have low reproductive capacity (usually uniparous) and deferred sexual maturity (Tinkle, 1969). In such populations, individuals older than 20 months play an important functional role. We have hypothesized that the condition of radiation-induced sterility takes several years to develop. Hence, in an irradiated environment, a species like *Uta stansburiana*, which matures at 9 months of age and in which some 65-70 per cent of the annual egg production is borne by the 9-month-old age class, has a distinct advantage over lizards which do not normally become sexually mature until an age of 20 months, and in which the production of eggs is shared by older age-classes. *Phrynosoma platyrhinos* is definitely a species of the latter type. Females are normally not sexually mature until an age of 19-22 months, and there is ordinarily but one clutch of eggs produced during the breeding season. Life spans are long; the maximum known age is presently 8 years.

In emphasizing the typical demographic pattern of *Phrynosoma* we do not wish to minimize the fact that important deviations may occur. In seeking generalizations relating to the evolution of saurian life histories, Tinkle (1969) and Tinkle et al. (1970) categorized various species of lizards according to time of sexual maturity, number of clutches laid, and life span. In this pursuit Tinkle ignored variations and concentrated on modal patterns. Yet, to the functional ecologist, variations in reproductive activity are of considerable interest. These deviations may be intimately associated with various density-dependent regulating mechanisms or with differences in net primary production and availability of food.

We have already called attention to variations in reproductive patterns of *Cnemidophorus tigris* and *Crotaphytus wislizenii* in terms of earlier than usual sexual maturity and multiple clutches, and suggested how these departures may be related to annual differences in primary production (Turner et al., 1969a,c). Similarly, *Phrynosoma platyrhinos* may produce more than one egg clutch in a season. It is easy to misjudge the number of clutches laid unless one follows a group of marked females all the way through the reproductive season (Turner, 1968; Turner et al., 1970; Medica et al., 1971). For example, Parker (1971) has discussed reproduction by *Phrynosoma solare* in 1966 in central Arizona. He observed enlarged ovarian follicles (8 mm) in mid-June and oviducal eggs between mid-July and early August that year, and concluded that one clutch of eggs was laid. We consider these observations equivocal, and suggest that the data might also be interpreted as evidence of two clutches. In *P. platyrhinos* the time between development of follicles and egg deposition may be as short as 4-5 weeks (Table 3). Hence, the oviducal eggs observed in *P. solare* on July 28 and August 3 probably represent a second clutch. The procedure adopted by Parker was simply not adequate to decide the issue.

In 1970 our observations indicated lack of reproduction by *Phrynosoma platyrhinos* near Mercury and in Rock Valley. Since this conclusion was based on our failure to observe any hatchlings during the late summer of 1970 or yearlings the ensuing spring, we cannot argue that no young at all were born. Certainly, reproduction was enormously curtailed. This sort of thing apparently happens from time to time among longer-lived species. For example, we observed no reproduction by *Crotaphytus wislizenii* in Rock Valley during 1964 (Turner et al., 1969a), nor in 1970. Pianka (1970) reported lack of reproduction by *Cnemidophorus tigris* in 1964 near Mojave, California.

Although we have not followed the irradiated and control populations of horned lizards in Rock Valley as closely as we have *Uta, Cnemidophorus* and *Crotaphytus,* it appears that horned lizards are relatively sensitive to the type of radiation exposure inflicted in Rock Valley. We have observed some sterile females among the populations of *Uta* and *Cnemidophorus*, but there is as yet no evidence that these populations are being exterminated. The irradiated population of leopard lizards is becoming extinct, although the remaining adults persist with impressive tenacity. Horned lizards seem most similar to leopard lizards in their apparent response to the effects of radiation.

ACKNOWLEDGMENTS

We thank William Cobb, Carl Henderson, Danny Hensley, Gerard Hoddenbach, Michael Johnson, Gregory King, Joseph R. Lannom, Jr., Stephen Ruth, Sherburn Sanborn, Michael Skivington, Tim Stroud, and Claude Whitmyer who participated in the field work at various times. We also thank Wilmer W. Tanner and John E. Krogh for useful information. This work was supported by Contract AT(04-1) GEN-12 between the U. S. Atomic Energy Commission and the University of California.

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