Effects of Nuclear Testing on Desert Vegetation

Three years later, plants of pioneer character are invading the denuded areas of the Nevada test site.

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Abstract. Detonation of fission-type nuclear devices results in an inner circle of complete denudation of desert shrub vegetation, often about 0.5 mi in radius, surrounded by a zone of partial and selective destruction which is variable in width. The gross injury to vegetation appears to be attributable to mechanical and thermal effects. Successional change in the composition of the vegetation, due to invasion by plants of pioneer character, is taking place in all disturbed areas.

Except for the initial (Trinity) test in 1945, continental testing of nuclear weapons by the U.S. Atomic Energy Commission has been confined to the Nevada test site—Yucca and Frenchman flats in the northern Mohave Desert. Yucca Flat, an arid internal drainage basin about 20 mi long, has been subjected, during 1951 to 1958, to more atmospheric detonations of nuclear weapons than any other place on earth except possibly certain sites in the U.S.S.R. It might be expected that after 8 years of nuclear testing very little vegetation would remain. On the contrary, except for the usual barren playa, no part of this basin lacks flowering plants. At a distance of 2 mi from most "ground zeros" the vegetation shows no visible effects of weapon testing. Grotesque Joshua trees (*Yucca brevifolia* Engelm.) relieve the gray monotony of the dominant shrubs, hopsage (*Grayia spinosa* Moq.) and blackbrush (*Coleogyne ramosissima* Torr.).

It has been calculated that a typical detonation of a fission-type nuclear device releases 50 percent of its energy as shock, 35 percent as heat, and 15 percent as other forms of radiation (*1*). Detonation of a nuclear weapon with an energy yield of about 40 kilotons at a point 300 ft above the surface eliminates all of the above-ground parts of a desert shrub vegetation to a distance of about 0.5 mi from ground zero. This denudation may be attributed to the overwhelmingly predominant thermal and shock effects. The level of ionizing radiation in the zone of complete denudation is very high, but the question of amount of radiation injury to the vegetation is, of course, academic where the plants are largely vaporized, burned, or destroyed mechanically.

A suggestive feature of the devastated areas around some of the ground zeros is that the zones of shrub destruction are by no means circular. One of the most asymmetrical disturbed areas (designated area 1) is located near the boundary between two large tracts of surficially dissimilar substratum. At this site, four shots (the largest, 43 kilotons) were detonated in alternate years at a single ground zero situated at the southern margin of an area of compact, unsorted alluvial valley fill with a well-developed desert pavement of inlaid lag gravel on the surface. Immediately to the south lies a broad tract of loose, sandy alluvium without desert pavement, the strath of one of the major drainageways discharging into Yucca Basin. Lateral migration of the main entrenched channel or dry wash is the apparent cause of this extensive sandy upland, in places a mile wide. On the compact desert pavement surface the vegetation dominated by *Grayia* survives, with considerable unilateral damage from blast, within 0.7 mi of ground zero. But on the loose, sandy surface most of the *Grayia* shrubs were severely damaged or killed for a distance of 1.0 mi to the south and southwest and 1.6 mi to the southeast of this ground zero. The more extensive killing on sand reaches well beyond the zone of unilateral blast injury to the stems of the shrubs and could result from disruption of the root systems correlated with the greater instability of loose sand under the influence of the intense terrestrial shock wave from the bombs.

The destruction of shrubs was selective, with some species surviving where others were severely injured or killed. *Grayia*, the dominant shrub in the vicinity of area 1, is highly susceptible to mechanical injury because of the brittleness of its wood. Large numbers of disrupted, dead skeletons of this species still persist in 1961 and constitute the principal evidence of the former composition of the shrub cover.

Stem injury from blast and root injury from the shock wave traveling through the ground possibly account for all of the gross damage to vegetation beyond the perimeter of complete denudation. Radiation can scarcely be ascribed a major role because of the marked difference in destructive effects to the vegetation on two different types of substratum. On the other hand, it is reasonable to suppose that some radiation effects may exist. The shrubs surviving nearest to the ground zeros undoubtedly sustained doses of intense radiation. The estimated cumulative dosage at 0.6 mi from ground zero at area 1 is on the order of 10^4 r (*2*). Most of the shrubs that survived more or less severe mechanical injury at this distance flowered and fruited in 1961 (*3*). Moreover, some of the species produced an abundance of seed with well-developed embryos. An investigation of seed viability in the survivors is in progress. The possibility might be considered, however, that sustained residual radiation from fallout particles (as much as 1 r/hr, 5 days after detonation) could have caused an asymmetric killing of vegetation at certain ground-zero areas.

During the 3 years that have elapsed since the end of the 8-year period of nuclear testing there has been little disturbance at most of the target areas. During this 11-year period some invasion by perennial plants has taken place, and the physiognomy and floristic composition of the perennial vegetation has often changed. For example, a zone of bunchgrass (*Stipa speciosa* Trin. and Rupr.) is conspicuous as a ring around ground zero in area 4, immediately beyond the perimeter of denudation—

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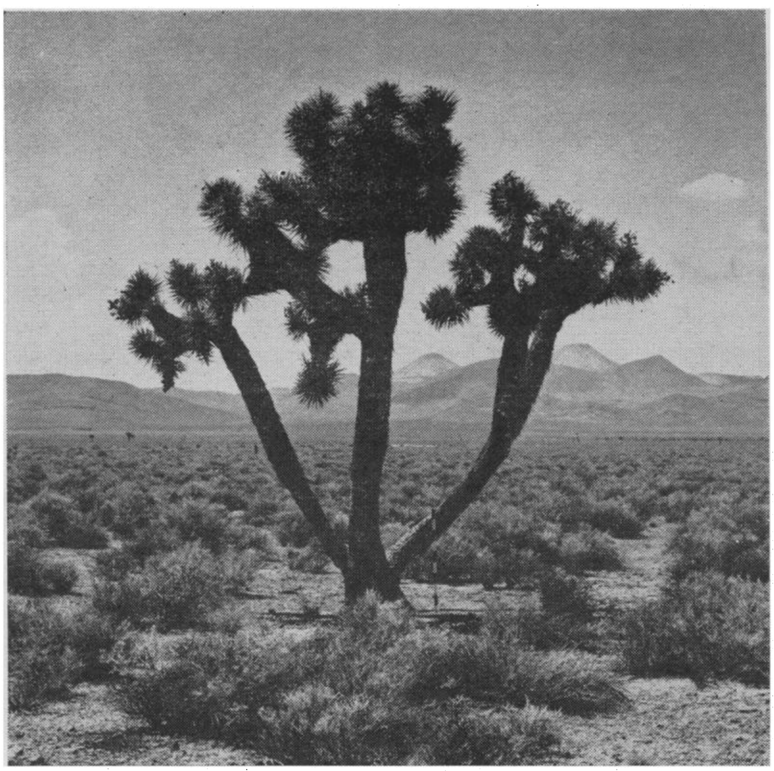
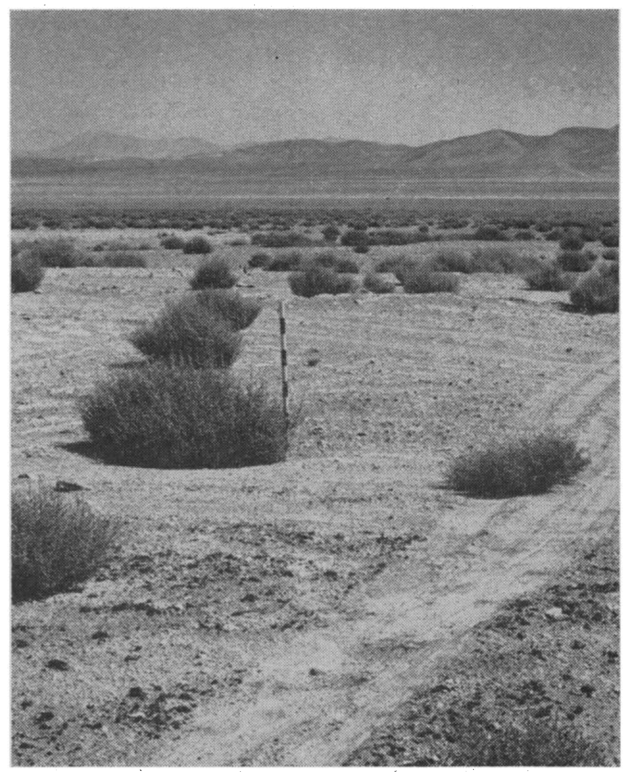
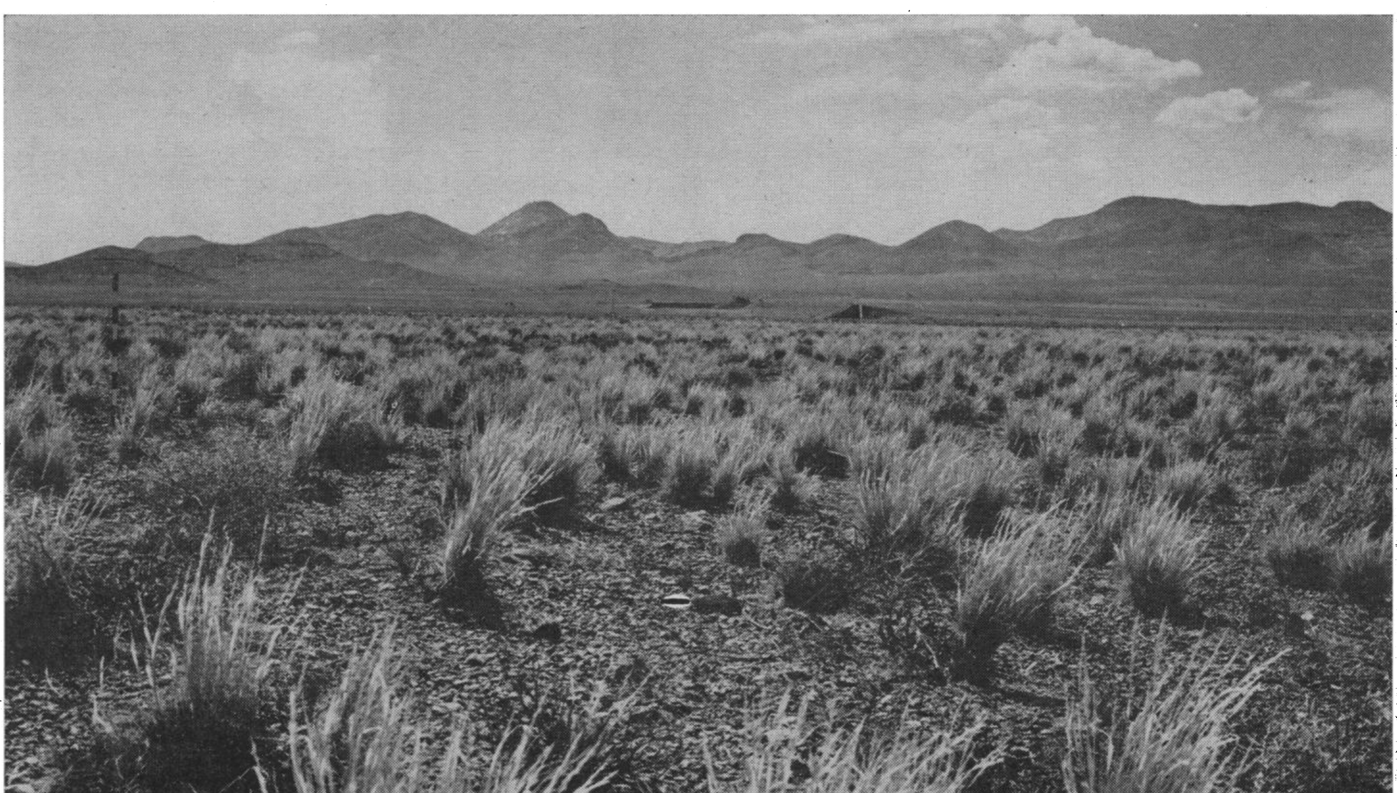
 

(Left) A Joshua tree (*Yucca brevifolia* Engelm.) growing in *Grayia-Lycium* vegetation, a type predominant on the basin floor of Yucca Flat. (Right) A stand of robust Russian thistle (*Salsola Kali*), extending 0.3 mi northeast of a ground zero, in the growing season after a nuclear detonation.



A zone of bunchgrass (*Stipa speciosa*) forming a ring around ground zero 4 at the Nevada test site. The view is toward ground zero from 0.8 mi to the east, about 4 years after the last detonation at this site.

that is, between 0.6 and 1.0 mi from ground zero. This grass is widely but more sparsely distributed throughout most of Yucca Flat. The zone of increase in *Stipa* coincides with the zone of injury to the shrubs. On the sandy substratum in area 1, the zone of shrub injury is marked by an unusual abundance of another bunchgrass [*Oryzopsis hymenoides* (R. and S.) Ricker] and a perennial four-o'clock (*Mirabilis pudica* Barneby), which is a common roadside weed in this area. *Atriplex canescens* (Pursh) Nutt., a characteristic saltbush of sandy washes and dunes, silty playa margins, roadsides, and other disturbed areas, is extraordinarily abundant on disturbed sandy soil near ground zero 1, where it has apparently increased in proportion to the amount of dead or damaged *Grayia*. Other pioneer shrubs or subshrubs of dry washes and roadsides, such as *Hymenoclea salsola* T. & G. (burrobrush) and *Sphaeralcea ambigua* Gray (globe mallow) occur in unusual numbers on upland sites in the zone of injury to the original shrub cover, chiefly on the more compact type of substratum with desert pavement. These species appear to be invading at the perimeters of the totally denuded portions of certain ground-zero areas. That these short-term changes in perennial vegetation are analogous to succession is confirmed by observations of older disturbances in the same general area (*4*).

Few native plants have thus far invaded the central portions (0.3-mi radius) of most ground-zero areas; they did not do so even during 1958, a year of exceptionally heavy rainfall which promoted dense stands of native annuals on immediately adjacent sites. Of the numerous species of native annuals, only one, *Mentzelia albicaulis* Dougl. (stickleaf), has grown in appreciable numbers within a distance of 0.1 to 0.3 mi of ground zero (*5*).

Nevertheless, the central portions of all the ground-zero areas have repeatedly produced abundant crops of the highly invasive Russian thistle, *Salsola Kali* L. This annual tumbleweed, introduced from Eurasia, invaded the ground zeros en masse in the first growing season after the detonation of nuclear weapons (*6*).

References and Notes

1. "The effects of nuclear weapons," *U.S. Atomic Energy Comm. Publ.* (Washington, D.C., 1957).
2. R. L. Corsbie (director, Civil Effects Test Organization, U.S. Atomic Energy Commission), unpublished data.
3. The flowering survivors included *Coleogyne, Grayia, Larrea divaricata* Cav., *Lycium Andersonii* Gray, and *Menodora spinescens* Gray.
4. P. V. Wells, *Science* **134**, 670 (1961).
5. L. M. Shields and W. H. Rickard, annual reports to the U.S. Atomic Energy Commission for 1958 and 1959 (New Mexico Highlands Univ. Press, Las Vegas).
6. This report is based on investigations performed at the Nevada test site during the period 1957 through 1961 under contract AT(29-2)517 between New Mexico Highlands University and the U.S. Atomic Energy Commission. On-site logistic support was provided by the Civil Effects Test Operation, Atomic Energy Commission.

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Method for Sensory Scaling with Animals

Abstract. Two pigeons were trained to peck at a transilluminated disk. The training procedure caused the rate of pecking to increase as a function of the luminance of the disk. The results suggest that the relation between apparent magnitude of light and physical intensity is a power function.

The customary subject in a psychophysical experiment is an adult human observer. This choice has been dictated by the obvious capacity of the human being to report on his sensory experiences. Severe practical problems would attend the use of a subhuman observer in a psychophysical experiment. Since the instructions to, and the responses from, the observer are usually verbal, the typical method of experimentation needs to be radically altered to accommodate animals.

Two principal difficulties have to be overcome when animals serve as observers. First, the experimenter must instruct an animal to attend to a stimulus. Second, the instructions must not limit too narrowly the answer the animal can give. The answer becomes trivial when no other answer is possible. Notwithstanding the difficulties, animals have been used successfully as observers for the determination of absolute and differential sensory thresholds. In most such studies, the animal is instructed to attend to a particular stimulus by the use of reinforcement. In the presence (or absence) of the stimulus, some behavior of the animal is reinforced, and in its absence (or presence), the behavior is not reinforced (*1*).

The study of sensation often involves more than the determination of thresholds. Human observers are instructed to respond, in some manner or other, to the apparent magnitudes of stimuli. From their responses, scales of subjective magnitude are constructed. Animals have not yet been used for sensory scaling, mainly because the "instruction" would presumably determine the outcome. If the animal's behavior is reinforced with respect to a stimulus continuum, then the experimenter seems to be building into the behavior the very scale that he would like the behavior to reveal. If the animal's behavior is not reinforced with respect to a stimulus continuum, then the animal is not being instructed to attend to the continuum.

The experiment reported here (*2*) used a method that partially resolves the dilemma just described. Two food-deprived pigeons (Nos. 109 and 110) were trained to peck a translucent Plexiglas disk and were reinforced by food for pecking at a prescribed rate. The disk was transilluminated with yellow light whose intensity changed at random intervals to one or another of five luminances spaced 0.6 log units (6 db) apart. The highest luminance was about 10 mlam. The variations in intensity of light were produced by changing the voltage across two 7-watt bulbs in parallel. A yellow celluloid filter minimized the apparent changes in hue. A MacBeth illuminometer was used for calibration. The various intensities succeeded each other in a random sequence. The pigeon was fed only if it pecked at a certain rate, and a different rate was correlated with each in-

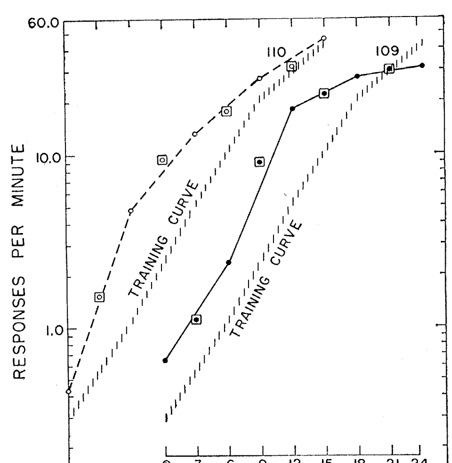

Fig. 1. Rate of pecking as a function of the luminance of the stimulus, for two pigeons (Nos. 109 and 110). The training curve shows the prescribed rate of responding at the training stimuli (0, 6, 12, 18, and 24 db). Points enclosed in squares give rates obtained with test stimuli (3, 9, 15, and 21 db), in whose presence responding was never reinforced.