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EFFECTS OF LAND CLEARING ON BORDERING WINTER ANNUAL POPULATIONS IN THE MOHAVE DESERT

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ABSTRACT.—Construction of a 10-MWe solar thermal power plant in Daggett, California, involved clearing and leveling 53 ha of desert land. Transient offsite effects of this construction were apparent as a reduced density of annual plants within 100 m downwind of the edge of the cleared area. *Schismus arabicus* populations recovered within four years, but *Erodium cicutarium* populations did not. The effects appeared to be related more to an interaction of seed-dispersal mechanisms with the large, open space than to the obvious sand movement and deposition associated with the clearing operations.

The solar thermal power plant (Solar I) completed in 1983 at Daggett, California, is the first of a type which could eventually cover large areas of the southwestern United States. It consists of a field of mirrors (heliostats) that focus sunlight on a collector atop a tower, the heat being used to generate electricity. Such power plants, requiring neither transported fuels nor emission of fuel residues, obviate many of the environmental effects expected of nuclear and fossil-fueled plants. We studied the desert biota in the vicinity of Solar I in a search for potentially detrimental environmental effects. Winter annuals, which are ubiquitous around the site and whose growth is closely related to environmental conditions, were moderately affected during the construction phase.

Native Mohave Desert winter annuals produce impressive displays of wildflowers at five- to ten-year intervals (Went 1949). There are now a number of introduced Eurasian species present nearly every year in relatively high densities. These introduced species are the main subject of this paper.

STUDY SITE

Solar I was constructed on land adjacent to the Southern California Edison Coolwater power plant at Daggett, California. It lies at an elevation of 590 m, lat. 34°53′N and long. 116°47′W. Annual rainfall averaged 92 mm between 1951 and 1974 at the Daggett airport 2 km S of the site. Rainfall was divided evenly between winter storms and summer thundershowers (NOAA 1977). Daily average temperatures during the spring growing season were roughly 8 (minimum) and 24 C (maximum). Winter annuals germinated between December and March and died in late April or early May between 1978 and 1983.

The bed of the Mohave River forms the northern boundary of the Coolwater site. The river rarely flows, and wind has deposited sand from its bed on the site. Soils are therefore sands at the surface, but lenses of silt and hillocks of clay have been bared by human disturbance.

Perennial vegetation at the site was removed in 1953 in anticipation of farming operations. The land was never farmed, however, due to a shortage of water (Robert Speth, personal communication). A population of the shrub *Atriplex polycarpa* dominated the site prior to the start of construction.

TABLE 1. Changes in heights of sand mounds on the lee sides of shrubs.

Distance from perimeter fence	10/78–1/80	1/80–5/81	5/81–10/81
meters	cm	cm	cm
26–37	18 ± 7*	10 ± 2	7 ± 2
40–49	14 ± 2	1 ± 1	0 ± 2
51–58	7 ± 2	2 ± 2	2 ± 2
60–79	—	—	3 ± 1
87–98	0.4 ± 0.2	1.1 ± 0.4	0.2 ± 0.2

*Error estimates are ± sem.

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TABLE 2. Wind ablation or dune growth as measured by changes in surface level downwind of the heliostat field during spring 1982.

	Distance from perimeter fence (m)			
Date	40 m mm	80 m mm	130 m mm	200 m mm
22 Feb–23 Apr	−3.3	−3.4	0	0.3
23 Apr–16 Jun	−1.8	+1.4	−1.1	0.7
16 Jun–10 Jul	+2.2	+1.1	+3.9	+1.4
22 Feb–10 Jul	−2.9 ± 1.4*	−0.9 ± 1.3	+2.8 ± 1.1	+0.4 ± 0.7

*Error estimates are ± sem

TABLE 3. Densities and sizes of *Schismus arabicus* and *Erodium cicutarium* plants with respect to distance from the heliostat field. Negative distances are on the field.

	Schismus		*Erodium*	
	1981			
Distance	n/m²	mg/plant	n/m²	mg/plant
0–100 m	280 ± 73*	2 ± 1	8 ± 4	9 ± 4
100–200 m	218 ± 70	9 ± 4	116 ± 4	77 ± 20
	1982			
40 m	400 ± 50	30 ± 4	0	—
80 m	1600 ± 250	14 ± 2	10 ± 4	112 ± 41
200 m	2100 ± 250	25 ± 3	24 ± 6	97 ± 24
	1983			
−100 m	17 ± 9	28 ± 10	0	—
−20 m	18 ± 10	150 ± 139	0	—
40 m	4800 ± 1800	28 ± 5	0	—
200 m	3100 ± 640	38 ± 11	80 ± 33	464 ± 202

*Error estimates are ± sem.

METHODS

Annual populations were measured in quadrats placed randomly along lines at specific distances from the perimeter fence surrounding the heliostat field. Initial studies were done with nested quadrats varying from 0.01 to 100 m² in area. Based on those studies, we chose quadrat sizes of 0.01 and 0.025 m² for these studies on the more abundant annuals.

All annual plants within a quadrat were counted, harvested, dried, and weighed. Because plants were harvested without loosening the soil, only small portions of the root systems were included.

Sand mounds deposited beneath and in the lee of shrubs were delimited by the presence of small pebbles on the original surface. Heights were measured from the highest point on the mound to the level of the nearest bare spot. In the spring of 1982, deposition-ablation of sand was determined by driving marked aluminum stakes into the ground and measuring changes in the apparent surface level with time.

Seeds dispersed near the boundary of the heliostat field were trapped on plastic 10-cm square plates coated on the top side with a tacky material (Tangletrap; The Tanglefoot Company, Grand Rapids, Michigan) and left at the ground surface from 26 April to 5 May 1983. Trapped seeds were counted using a dissecting microscope.

RESULTS

Native annual species, which were abundant in 1978 and present in 1979, did not germinate in significant numbers after clearing began in September 1979. Species that germinated and grew from 1980 to 1983 were the introduced annuals *Schismus arabicus* Nees, *Erodium cicutarium* (L.) L'Her., and *Salsola paulsenii* Litv. The latter was sparse.

Sand was deposited downwind of the heliostat field during and following clearing. Sand mound heights behind shrubs increased dramatically through 1981 in the area immediately adjacent to the cleared site (Table 1). In 1982, however, following installation of he-

TABLE 4. Effects of mounds and distance from the perimeter fence on density, size, and productivity of *Schismus arabicus* in 1982.

	Distance from fence (m)					
	40		80		200	
	Bare	Mound	Bare	Mound	Bare	Mound
Density (#/m^2)	4 ± 1*	3 ± 2	16 ± 5	9 ± 5	21 ± 5	11 ± 5
Size (mg/plant)	30 ± 8	61 ± 14	14 ± 4	43 ± 24	25 ± 6	75 ± 60
Biomass (kg/ha)	85 ± 32	141 ± 71	172 ± 46	124 ± 56	336 ± 82	313 ± 140

*Error estimates are 95% confidence limits.

TABLE 5. Densities of *Schismus arabicus* trapped seeds and floret parts in relation to the heliostat field edge. Negative distances are on the field.

Distance from fence (m)	Total seed #/cm^2	Chaff #/cm^2	Naked seed %
−100	0.4 ± 0.0*	5.3 ± 0.1	16 ± 4
20	0.8 ± 0.0	4.8 ± 0.2	24 ± 3
40	3.6 ± 0.1	4.3 ± 0.1	3 ± 2
200	4.4 ± 0.2	1.3 ± 0.1	1 ± 0

*Error estimates are ± sem.

liostats, sand mounds were ablated in the first 50 m and deposition occurred further downwind. During the spring of 1982, marked aluminum stakes showed a similar pattern, with slight ablation occurring at sites 40 m from the heliostat field, slight deposition at 130 m, and no significant changes at 80 and 200 m (Table 2).

In 1981, a very poor year for growth and reproduction of annuals, the average size and density of *Erodium cicutarium* were reduced within 100 m of the eastern border of the heliostat field. Neither density nor size of *Schismus arabicus* differed with respect to distance from the border (Table 3). In 1982 *Schismus* densities were considerably reduced and *Erodium* was absent. Sizes of *Schismus* plants were reduced at 80 m, but *Erodium* size was the same at 80 and 200 m. In 1983 densities of *Schismus* had fully recovered 40 m from the heliostat field, sizes were constant at all distances, and *Erodium* was still absent (Table 3).

Comparison of populations on and off the sand mounds in 1982 showed the density depression at 40 m was not solely related to sand movement and drifting: densities were reduced both on the mounds and the bare areas. Sizes of *Schismus* plants were uniformly greater on the mounds than in the bare areas (Table 4).

Allocation of biomass to reproductive structures did not vary with location of plants. On the mounds the larger plants (69 ± 14 vs. 31 ± 9 mg/plant) contained 26 ± 2% biomass in reproductive structures, compared to 25 ± 3% for bare area specimens. These data, combined with the density differences between mound and bare populations (Table 4), imply that seed production was not depleted in the area of sand deposition.

Schismus seeds deposited in 1983 on and downwind of the heliostat field were not proportional to densities of plants (Table 5). Seeds deposited on the largely unvegetated field were considerably more dense than would be expected from the associated plant densities. In addition, the nature of the dispersal units found on the heliostat field suggested that seeds had traveled a greater distance. Seeds frequently lacked the pilose floral parts, and these parts, less seeds, were also more common (Table 5). *Erodium* seed was deposited only on traps 200 m from the perimeter fence, where a population occurred near the traps.

Seeds of other species were sparse on our traps. Seeds with pappuses (of several species) averaged 26 per 100-cm^2 plate on the heliostat field and 2 per plate in the control area. Seeds without any obvious adaptations for wind dispersal averaged 2 per plate on the heliostat field and 35 per plate in the control area.

DISCUSSION

Plant size was only transiently affected during clearing and construction of the heliostat field. This argues against changes in general environmental variables (light, wind speed, precipitation). The primary effects seen were on density, and the observations to be explained are the reductions in density and rates of population recovery. Because the effects were unexpected and transient, these explanations necessarily derive from observations after the fact.

Fig 1. Plant populations on sand mounds downwind of the cleared heliostat field, April 1980. Shrubs are *Atriplex polycarpa* and the grass is *Schismus arabicus*.

Schismus density was reduced with respect to control areas only in 1982 (Table 4). During the 1981 harvest few *Schismus* in Daggett had flowers or fruit. We found 98% prereproductive mortality in another Mohave Desert *Schismus* population that year (unpublished data). Hence, we may presume 1982 populations were derived primarily from seeds produced in 1980 and earlier. Photographic evidence from 1980 (Fig. 1) suggests burial by sand affected density of *Schismus* on mounds, but increased plant size may have compensated and resulted in near normal seed production (Table 4, Fig. 1).

Seed burial by sand is not a satisfactory explanation for the reduced 1982 densities, since the density reduction occurred both on and off the sand mounds (Table 4). Invocation of Occam's razor suggests we look for an alternative hypothesis.

Another potential mechanism for low plant density was net immigration. Data in Tables 3 and 5 suggest that the large majority of seeds deposited on the heliostat field came from off the field. Seeds trapped per mg of plant were 3 to 8 on the heliostat field, 0.37 in the control area, and only 0.26 40 m east of the fence. Furthermore, the "chaff" (Table 5) can be considered an indicator of seeds moving onto the heliostat field. The proportions of chaff and naked seed found strongly suggest that *Schismus* dispersed greater distances near the heliostat field (40 m east) than in the control area (200 m east). There is, therefore, evidence that the large open field could act as a seed sink and that sand deposition was not a sufficient explanation for reduced densities. For *Schismus*, the rapidity of population recovery can be reasonably explained by the obviously effective dispersal demonstrated in 1983 (Table 5) coupled with good seed production in 1982.

Erodium cicutarium behaved somewhat differently. It became locally extinct near the heliostat field by 1982 and did not recover in 1983 (Table 3). We have fewer data on *Erodium* than on *Schismus*. In 1980, at 100–200 m from the heliostat field, essentially all *Erodium* fruited, while in 1981 roughly half had flowers or fruit at harvest (data not presented). In addition, in 1981 insects cut off many *Erodium* tap roots just below ground level, and ant mounds were seen with many *Erodium* seeds surrounding the holes. The local extinction, therefore, may be an interaction of several biotic and abiotic factors.

Failure of *Erodium* populations to recover could be related to both the causes of the original reduction and the failure of seed dispersal from the remaining inhabited sites. The failure to disperse might well be related to the *Schismus* population, since a dense *Schismus* stubble generally persists throughout the year.

Weiner and Conte (1981) modeled annual plant population dynamics and found dispersal "extremely important" in colonizing open areas. As disturbance becomes more frequent in the desert, we may well unwittingly favor weedy species with good dispersing abilities (like *Schismus* and *Salsola*) at the expense of the natives, which are unusually lacking in obvious dispersal mechanisms (Ellner and Shmida 1981).

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