Distribution of the Exotic Mustard *Brassica tournefortii* in the Mohawk Dunes and Mountains, Arizona

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Abstract
Ample winter-spring rains in southwestern Arizona in early 2001 allowed us to map the range of the exotic *Brassica tournefortii* in the Mohawk Sand Dunes. The mustard has colonized habitat ranging from creosote flats to dune crests, but it is most successful along ephemeral watercourses, the base of north-facing dunes, and along roads. An estimated 80-90% of the Mohawk Dunes, in both the Mohawk Valley and San Cristobal Valley, are host to *B. tournefortii,* with only the southernmost portion of the dunes uncolonized. Outside of the dunes, the mustard was found largely along roads frequented by the Border Patrol.

Resumen
Lluvias adecuadas desde invierno a primavera en el suroeste de Arizona en la primera parte de 2001 nos permite hacer mapas del exótico *Brassica tournerfortii* de las Mohawk Sand Dunes. La mostaza ha colonizado el terreno desde los llanos de creosote hasta la cumbre de las dunas. Sin embargo los que mejor crecen son los de arroyos efémiros, los de la base hacia las dunas, y los de las rutas y caminos. Se estima que un 80% - 90% de las Mohawk Dunes, en ambos el Mohawk Valley y el San Cristobal Valley contiene *B. tournerfortii* tan solo una porción de las dunas de la parte del sur sin colonizar. Fuera de las dunas la mostaza se encuentra majormente por las rutas y caminos frecuentados por la partrulla fronteriza.

There is not a single permanent human habitation in the 1.6 million acres of desert that make up the Barry M. Goldwater Air Force Range of southwestern Arizona. There are, however, plenty of visitors: the U.S. military and the Border Patrol, citizens seeking a bit of arid solitude, and job seekers from Latin America. The conflict between preserving a "natural" state for the Goldwater, while at the same time temporarily occupying it, is illustrated by the spread of the exotic mustard, *Brassica tournefortii* Guoan.

There are over three thousand species of mustards worldwide. Only a dozen or so inhabit this most arid corner of Arizona (Felger 1998, 2000), yet after a cool season rain the mustards appear to cover the Sonoran Desert. If you're walking out in the creosote flats or across the bajadas, you'll see native mustards like bladderpod and peppergrass. However, if you're driving along Interstate 8 in southern Arizona or California, you'll mostly see *B. tournefortii*.

Variously known as Sahara mustard, Asian mustard, Moroccan mustard, African mustard, wild turnip, or mostaza, *B. tournefortii* is an invasive weed, particularly of sandy and disturbed areas (Minnich and Sanders, 2000). It is a native of the Old World, where it ranges from northern India to the Iberian Penisula in a strip that encompasses the Caspian Sea, Mediterranean Europe, the Middle East and North Africa (Prakash 1974; Thanos et al. 1991). Within the United States, it was first collected at Coachella in southeastern California in 1927 (Minnich and Sanders, 2000), and has since spread to seven California counties: San Diego, Imperial, Riverside, San Bernardino, Kern, Santa Barbara, and, as of 1998, Shasta County (www.CalFlora.org). It is also in Texas, Nevada, and, since at least 1957, Arizona (USDA, NRCS, 2001; Mason 1960). It reaches into Mexico, ranging from Baja California to the Rio Grande/Rio Bravo Valley along the international border, and as far south as the Rio Mayo of Sonora (Felger 2000; Johnston 1990). Within Arizona its distribution is not formally mapped, but various floras, herbarium records and personal observations show *B. tournefortii* in Pima, Pinal, Yuma, La Paz, Maricopa, and Mohave counties.

The spread of *B. tournefortii* has provoked California to brand it "A-2," a category reserved for the "Most Invasive Wildland Pest Plants" (CalEPPC 1999). *B. tournefortii* has caused equal alarm among land managers in Arizona who hope to maintain the native biota. This study provides the baseline data needed to assess the velocity of *B. tournefortii* colonization in and around the Mohawk Dunes on the Goldwater Air Force Range, and to determine areas that are still free of *B. tournefortii* and thereby suitable for pre-invasion data collection of community composition.

Methods

The Mohawk Mountains and Mohawk Sand Dunes are about forty-five miles east of Yuma, Arizona, and just south of Interstate 8. The U.S. Bureau of Land Management established an Area of Critical Environmental Concern (ACEC) of 113,000 acres to provide for the long-term maintenance of the flora and fauna of the dunes and mountains, including the endangered Sonoran Pronghorn (*Antilocarpa americana sonoriensis).* This land is now under the management of the Department of Defense, and this study was entirely within the bounds of the Barry M. Goldwater Air Force Range.

The Mohawk Dunes are stabilized by a 7-15% perennial cover (depending on aspect) of *Pleuraphis (Hilaria) rigida* (big galleta grass), *Ephedra trifurca* (mormon tea) and *Ambrosia dumosa* (dune bursage), with *Larrea divaricata* (creosote bush) in the swales (Felger et al., 2002). From their northern terminus near Interstate 8, the dunes extend southeast for about 30 km, typically 2 to 3 km wide. They rise gradually up to 55 m above the Mohawk Valley to the southwest, the apparent direction of prevailing winds. In the lee of the wind the dunes fall sharply into the eastside valley between the dunes and the Mohawk Mountains. At their southernmost extent the dunes hook ninety degrees to run northeast through a pass in the Mohawks. The dunes fade in the broad and shallow saddle that the Border Patrol calls "Rat Gap", but then reappear for a four-mile run into the San Cristobal Valley (Figure 1).

Elevations within the ACEC range from 110 m to almost 860 m at the summit of the Mohawk Mountains. It is torrid Sonoran desert, with mean daily highs in the summer of 40 to 42 C. The mean annual rainfall at the nearest long-term station, Tacna, AZ, some ten miles to the northwest, is only 11 cm; the mean October to March rainfall is about 6 cm (Sellers, Hilld, and Sanderson-Rae 1985). From October of 2000 to the time of the survey in March of 2001, there were 7 cm of rain at Tacna.

Surveys for *B. tournefortii* were conducted from car and on foot. The species was known from the dunes (Felger et al., 2002), so the initial focus was to simply map the extent of infested dunes. The abundance of *B. tournefortii* was quantified by either "spot checks" at single localities, or by estimating density. A spot check was simply discovering a solitary cluster of one or more *B. tournefortii;* if there were no other *B. tournefortii* within view (typically a 20 meter circle), the number of individuals was recorded, along with a GPS reading.

In areas where there were more *B. tournefortii* within view of the first plants encountered, densities were estimated by recording the location of the first plants, then counting all others within a four-meter wide transect for a distance of at least 50 m or, in areas of high density, until at least 50 *B. tournefortii* were counted. In both cases the transect ended with the last sighting of *B. tournefortii*. This method of beginning and ending a transect with the presence of *B. tournefortii* exaggerates absolute densities, and makes this data suitable only for rough comparisons of densities between other dune sites in this survey, and not in comparison with the densities on the road surveys, whose transects begin and end with randomly determined points (see below). It is not a standard sampling technique, nor should it be; we seek only to explain how the distribution map was created.

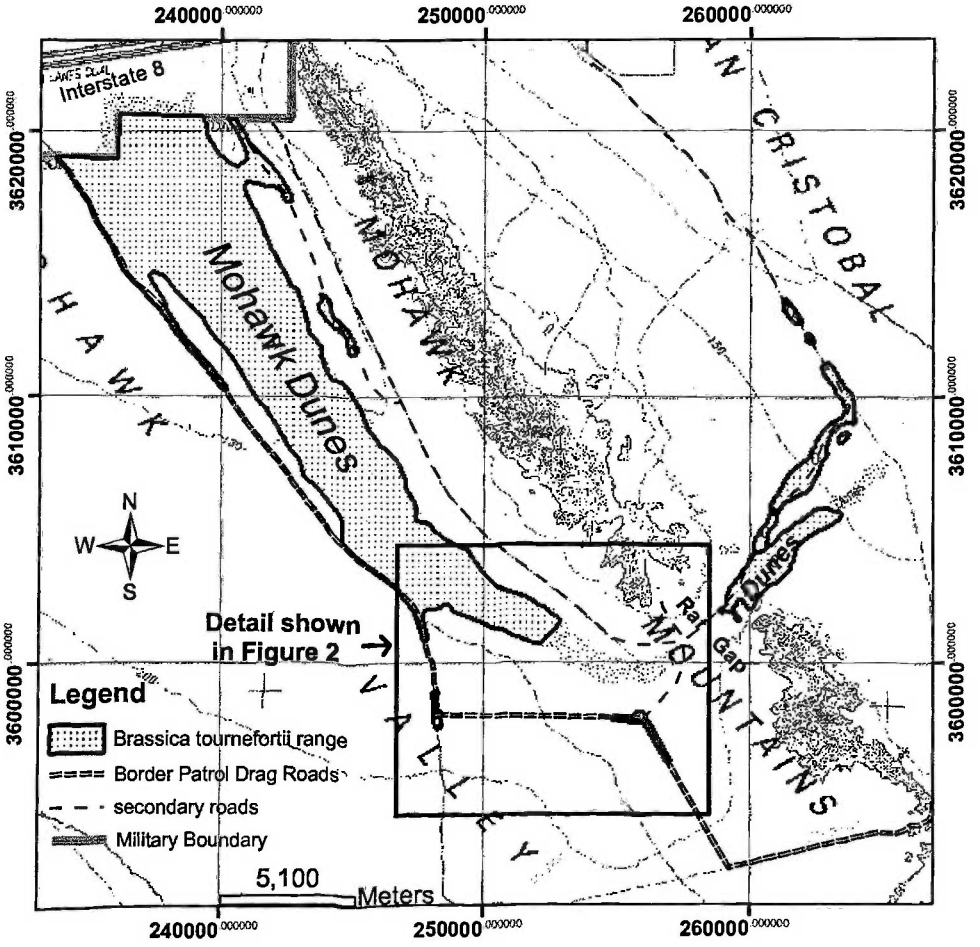

Figure 1.

Within the dune proper, this method amounted to hiking to the foot of the dune, taking note of the first plants, then continuing to hike into the dune field while counting plants within the four-meter wide corridor. To sample all aspects and slopes, there were typically three to five transects on each loop through the dunes.

The U.S. Border Patrol uses the roads to the west and south of the dune field as "drag roads" which are regularly swept by a truck towing a gang of seven to nine tires chained together to form a triangle. The resulting "tire-drag" produces a swath about ten feet across, and smooth enough to reveal footprints. *Brassica tournefortii* densities along these roads were estimated by counting plants for one hundred meters of road, both sides, extending 2 m back from the road's edge. The sampling points were determined by beginning a count with a UTM reading that ended with three zeros, e.g., 36 03 000 N, 36 04 000 N, and so forth. For roads that run due north-south or east-west, this would be precisely every kilometer.

Surveys beyond the roadside and dunes included five hikes of 3 to 6 km onto the alluvial fans of the Mohawk Mts. In addition, at the two places where the Border Patrol parked their tire-drags along the drag roads, high densities of roadside *B. tournefortii* prompted further survey several hundred meters into the surrounding desert of primarily creosote bush; when no *B. tournefortii* were seen for the last 100 m, the survey returned to the road.

All paths taken in the study were either walked or driven very slowly, with the exception of the drag road surveys, where data were taken at approximately 1 km intervals. Absence of data along secondary roads or paths indicates a lack of *B. tournefortii*, but without recording coordinates from the GPS.

All perennial species associated with *B. tournefortii* were also recorded at 48 locations, as part of an ongoing effort to map the vegetative associations and sub-associations within the range of the Sonoran Pronghorn. This information, in concert with USGS 7 ½ minute orthophoto quadrangles of the study area, allowed us to estimate the range of *B. tournefortii* in regions not directly surveyed. For example, if there were continuous sand dunes between two dune surveys that showed *B. tournefortii* present, then the dunes between were mapped as also holding *B. tournefortii*.

Results

A total of 323 spot checks and density (belt) transects were collected between 13 February and 13 March 2001. These data are available on the internet at the Southwest Exotic Plant Mapping Program of the US Geological Survey, at http://www.usgs.nau.edu/SWEPIC/swemp/maps.html. Maps were created with Arc Map 8.1. The overall distribution map, with every datum mapped, can be viewed at http://usgsbrd.srnr.arizona.edu/nbii/.

The summary map is shown in Figure 1. *Brassica tournefortii* was found between 110 m (the lower limit of the survey) and 230 m above sea level, i.e., it was absent from the stoney alluvial fans and steep mountain slopes. The southernmost Mohawk Dunes are still free of *B. tournefortii*, but the remaining dunes are infested, with the exception of the far eastern tail of the dunefield, in the San Cristobal Valley. However, judging from the spring annual bloom, there was considerably less winter rain at this one location.

Brassica tournefortii was also found in low gradient watercourses adjacent to valley floors that support creosote, dune and triangle-leaf bursage (*Ambrosia deltoidea)*, and, if sandy, big galleta grass. It was not, however, found among the saltbush *(Atriplex* spp.*)* of the San Cristobal Valley, despite having been collected with saltbush at Organ Pipe Cactus N.M. in 1978 (Felger, 1990).

Along roads, *B. tournefortii* was most common in three places: First, along the northern boundary of the Goldwater Range, near the heavily infested Interstate 8. Second, near the intersections where the Border Patrol parks the tire-drags they use to sweep the roads in their search for footprints. Third, where the road's edge led to a partial damming of rainwater that would otherwise be flowing perpendicular to the road; such damming was apparent from the unusually large creosote or triangle-leaf bursage at the road's edge.

Finally, there were three outposts of *B. tournefortiii* 10 to 25 km to the southeast. Two of these were along the main Border Patrol drag road; the furthest west population held around 100 plants under several large creosote growing next to the road berm. The second population was in a pass in the Mohawk Mountains, with another 100 plants growing along the roadside where it crossed a large arroyo, and in the arroyo itself. The third population was seven plants in the middle of a secondary road on the east side of the Mohawk Mts, only 100 m outside the north boundary of the Cabeza Prieta National Wildlife Refuge. The refuge (whose airspace is part of the Goldwater Range) has been infested with *B. tournefortii*, but to date it is mostly limited to the Pinta Sands, some twenty miles further south, near the Mexican border. As part of the Sonoran Pronghorn vegetation mapping project, Malusa hiked 180 miles during the wet spring of 2001 through a variety of habitats between the southern Mohawk and Bryan Mountains and the Growler Mountains. This area is roadless wilderness, and is upslope of the Pinta Sands and the Mohawk Dunes. No *B. tournefortii* were noted.

Discussion

The distribution of *B. tournefortii* fits well with what is known of its reproductive ecology and physiology. Felger (2000) and Minnich and Sanders (2000) note that the mustard appears to be self-compatible and hence able to spread from a single isolated seed. Thanos et al. (1991), in

their study of Mediterranean plants, showed that *B. tournefortii* has the highest germination rates at temperatures of 15 to 25 C, and at seed depths of 5 mm. The rate was fairly low – only 8.4% – but a single *B. tournefortii* holds 750 to 9000 seeds (Minnich and Sanders, 2000). There was 0% germination of seeds lying on the surface, apparently due to photoinhibition. Seeds at depths greater than 5mm did germinate, but at lower frequencies.

This survey was not designed to test hypothesis of dispersal, nor correlations between a particular habitat and *B. tournefortii*. However, it should be noted that the prerequisite of its seeds being thinly buried helps explain the observed distribution of *B. tournefortii* in the Mohawk dunes, roads and arroyos, and agrees with the habitat observations of Minnich and Sanders (2000) as "most common in wind-blown sand deposits and in disturbed sites such as roadsides and abandoned fields."

Minnich and Sanders (2000) also note that "hot, dry spells frequently cause plants to reach premature flowering," and that *B. tournefortii* was "virtually absent in the (Sonoran Desert of California) after the dry (less than 25% of normal) winters of 1995-96 and 1996-97." Throughout the Mohawk Dunes study area it appeared that *B. tournefortii* prefers places with the most moisture, such as arroyos. Roadsides are not only disturbed but also benefit from enhanced runnoff. Within the dunefields, *B. tournefortii* was most often observed at the foot of slopes facing northeast, north, and northwest, where up to 500 plants could be found within 50 m. South-facing slopes and the swales between dune crests were the least favorable. Dune crests were intermediate.

The southernmost stretch of the Mohawk Dunes (Figure 2) are still free of *B. tournefortii* probably because they are isolated from the main dunes by a swale of creosote bush that is apparently less desirable habitat. This barrier will likely be breached, as the swale is less than 100 m wide, and *B. tournefortii* was, elsewhere, occasionally found growing in full sun on creosote flats. With a mean seed weight of a mere 1.3 mg (Thanos et al. 1991), even sheet flooding across creosote flats is apparently sufficient to transport *B. tournefortii*. Circumstantial evidence can be found in the distribution of *B. tournefortii* on the downslope side of colonized roads. For example, along the main tire-drag road south of the dunefield (Figure 2), *B. tournefortii* could be found up to 60 meters downslope (north) of the road, among creosote. Upslope, to the south, none were found.

Similarly, the northernmost *B. tournefortii* in the valley between the Mohawk Dunes and the Mohawk Mts. (Figure 1) were likely derived from the thriving Interstate 8 population, and transported down slope, south, towards the Mohawk Playa at the foot of the dunes. Further south from this playa it is uphill – and there are no more *B. tournefortii* in the valley.

The further spread of *B. tournefortii* is likely hastened by a combination of disturbance and moisture. Minnich and Sanders (2000) noted that "During rains, a sticky gel forms over the seed case that permits seeds to disperse long distance by adhering to animals. The rapid spread of *Brassica tournefortii* through the Sonoran Desert, with first occurances along roadsides, may be related to its ability to adhere to automobiles during rare periods of wet weather." Along the drag roads near the Mohawk Dunes it is not even necessary to adhere to an automobile, because the Border Patrol tire drags inadvertantly scoops up plants, scatters the seeds, and promptly buries them.

The arroyos are avenues of dispersal also, but perhaps slower than might be expected, because the watercourses in this arid stretch are discontinuous. Small arroyos are tributaries to larger arroyos, but these in turn do not reach to the center of the valley. Instead, they fan out in distributaries that ultimately fade among the creosote and bursage. Such a pattern is seen in the arroyos draining into the San Cristobal Valley from Rat Gap, fanning out from the presumed point of original colonization where the road crosses the upper watershed (Figure 1).

It is likely that the road through Rat Gap introduced *B. tournefortii* to this arroyo system (and subsequently the eastern dunes of the San Cristobal Valley) in recent years. On the 1997 aerial photos of the Goldwater Range this road is scarcely visible. In the intervening four years it has been graded so even a car can pass. Judging from the vehicle tracks that were observed leading to abandoned water jugs, or paralleling the footprints of walkers, the Border Patrol often leaves the road in their trucks and in the process drive through patches of *B. tournefortii*, further spreading the seed.

The ecological effects of *B. tournefortii* colonization remain to be documented. In a land with so much open space, it's not hard to imagine that it's simply moving into unoccupied terrain. But some species, like the desert iguana, favor open habitat, possibly because predators can't hide in thin air. For example, the numbers of desert iguanas seen along road transects in Avra Valley near Tucson, AZ., declined substantially between June 1977 and June 1978, following a very wet winter that produced a bumper crop of the invasive grass, red brome (*Bromus rubens)*. (C. Schwalbe, pers. comm.).

The pervasive concern among botanists is simply the shading of native species, particularly on the dune fields. The sand hills are unique in that 74% of their plant species are cool season annuals (Felger et al. 2002). *B. tournefortii*, with its preferred germination temperature of 15 to 25 C, can get the jump on most of the native species if there is a late season hurricane in October or November. There is, naturally,

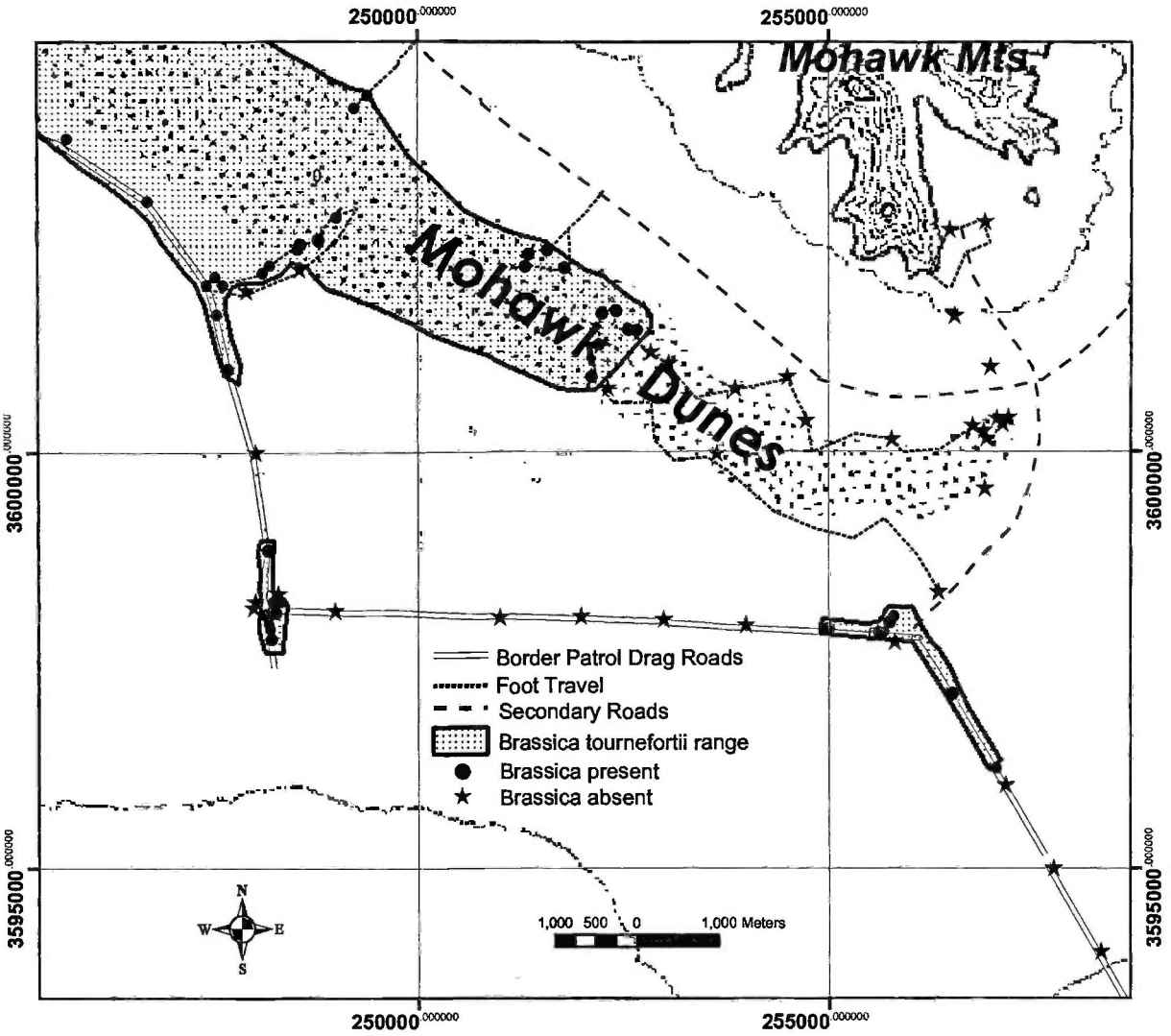

Figure 2.

nothing that can be done about this situation, except study the section of dunes that remain uncolonized. The uncolonized area is large enough to consider saving, via monitoring, and eradication when needed.

Roads facilitate further colonization of the Goldwater. Roads provide habitat by altering drainage patterns, provide a vector in the vehicles upon the roads, and in the case of the Border Patrol tire drags, provide the preferred germination conditions by burying the seeds of *B. tournefortii*. Studies of roadsides in the Nevada Test Site showed that exotic species of *Bromus, Erodium* (filaree), *Salsola* (tumbleweed), and *Sisymbrium* (a mustard) dominated all roads except one that had been closed to traffic for an undetermined number of years (Hunter 1990). Closed roads can recover.

Acknowledgements

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FIGURE CAPTION

FIGURE 1. The distribution of *Brassica tournefortii* in and around the Mohawk Dunes, Arizona, is shown by heavy outlines. Interstate 8 runs through upper left. Base map is Ajo 1:250,000. UTM coordinates are NAD 1927 Datum.

FIGURE 2. Detail of Figure 1, showing the uncolonized section of the Mohawk Dunes, and the Border Patrol Drag Roads. Data points are simplified to show only the presence/absence of *Brassica tournefortii.* Base map is Ajo 1:250,000. UTM coordinates are NAD 1927 Datum.

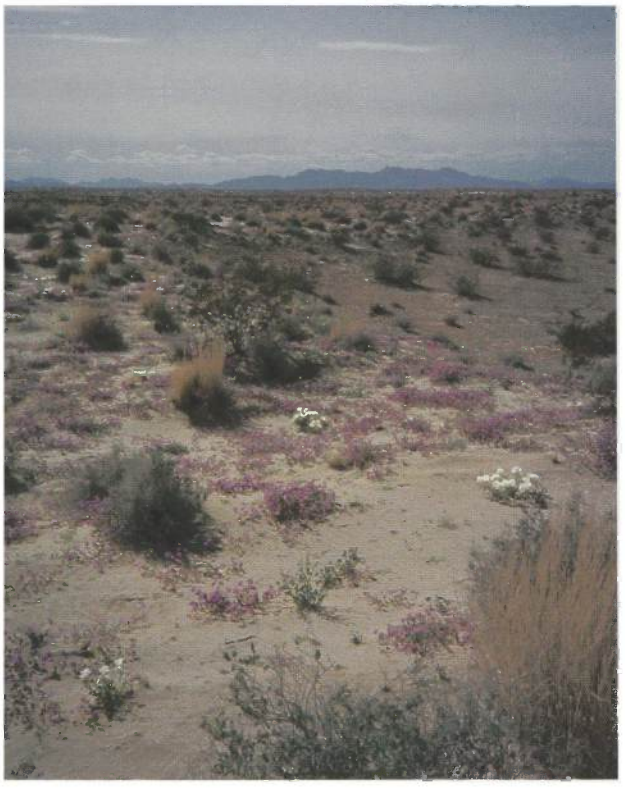

Figure 3. Mohawk Dunes where no *Brassica* is growing.

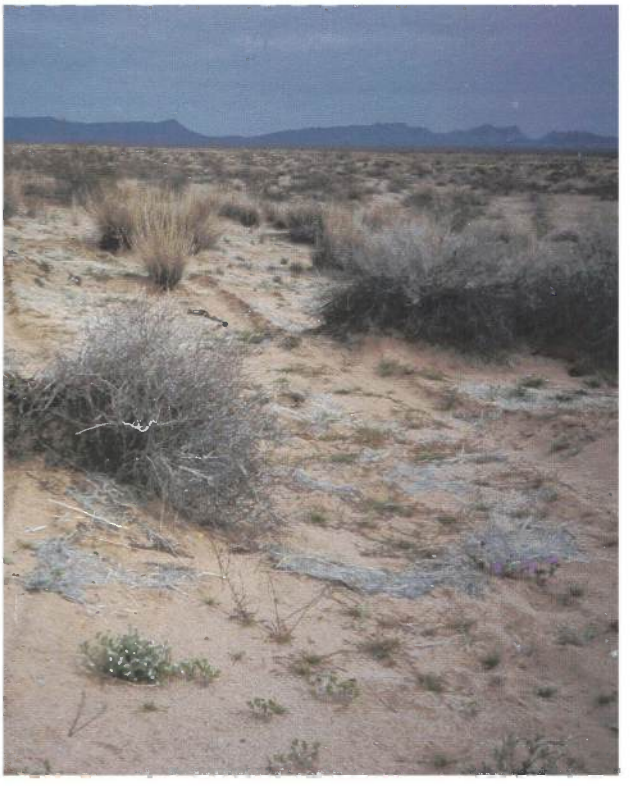

Figure 4. *Brassica* in the dune field.

Figure 5. *Brassica* growing outside the dunefield in area affected by roads.

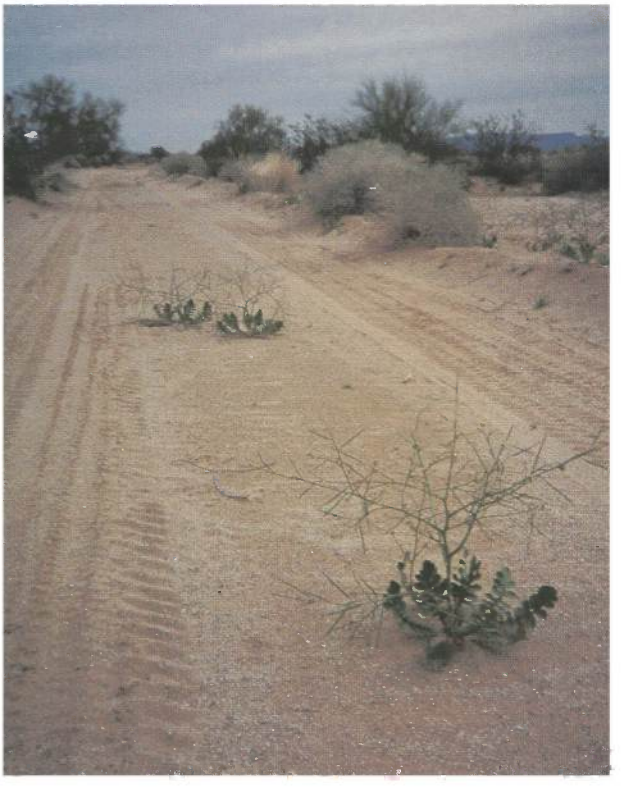

Figure 6. Fresh tire tracks through the Mohawk Dunes.