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USE OF AGRICULTURAL LANDS BY SAN JOAQUIN KIT FOXES

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ABSTRACT.—Although the current range of the endangered San Joaquin kit fox (*Vulpes macrotis mutica*) borders large areas of farmland, the ecology of this species rarely has been studied within an agricultural setting. In central California, we examined habitat use, prey availability, and diet of radio-collared kit foxes inhabiting an aqueduct right-of-way (ROW) bordered by farmland. During both years of study (1998–1999), nocturnal locations of foxes occurred more often than expected (based on habitat availability) in the ROW and less often than expected within annual crops. Orchards were used disproportionately more than their availability during 1998 and were used in proportion to availability during 1999. Kit foxes traveled up to 1.1 km into annual crops and up to 1.5 km into orchards. Among diurnal locations (den sites) of foxes, 98% were within the ROW. Live-trapping revealed higher densities and greater diversity of rodents along the ROW than within farmland. Remains of murid rodents were found in 79% of kit fox scats. Our findings indicated that kit foxes ranged into orchards and annual croplands at night, but almost never occupied these areas during the day. The lack of den sites and low prey availability within farmland probably limited the ability of kit foxes to exploit and occupy these areas. Providing artificial den sites within croplands (especially within orchards) and along canals may increase use of farmland by kit foxes and facilitate their movement between isolated patches of natural lands.

Key words: agricultural lands, California, endangered species, farmland, food habits, habitat use, San Joaquin kit fox, Vulpes macrotis mutica.

Historically, San Joaquin kit foxes (*Vulpes macrotis mutica*) occupied much of the San Joaquin Valley of California (Grinnell et al. 1937). However, in the last 50 years, much of the natural land within the San Joaquin Valley has been converted to farmland, and this conversion is thought to have been a major factor in the endangerment of this subspecies (U.S. Fish and Wildlife Service 1998). Because less than 5% of the San Joaquin Valley remains uncultivated (U.S. Fish and Wildlife Service 1998) and many of the remaining parcels of natural land are bordered by farmland, understanding the use or avoidance of different types of crops is important in the conservation of this subspecies. Gene flow between isolated areas will depend largely on the ability of kit foxes to either occupy or successfully move through agricultural lands.

Kit foxes have been observed denning adjacent to alfalfa fields (Morrell 1972), and the closely related swift fox (*Vulpes velox*) inhabits some types of farmland (Kilgore 1969, Sovada et al. 1998, Matlack et al. 2000). However, the use of cropland by kit foxes is not well documented and little is known about the potential for kit foxes to travel through or occupy farmlands. In the late 1990s, kit foxes were found along an aqueduct in central California that was bordered almost entirely by nut orchards and annual crops. This finding provided an opportunity to study the ecology of kit foxes in a landscape composed mostly of farmland and extremely limited in natural vegetation. The objectives of this study were to (1) compare kit fox use of habitats (crop types and natural lands) with availability, (2) relate habitat use with prey abundance within different habitats, and (3) describe kit fox diet in this largely unnatural landscape.

STUDY AREA

The study area was located along an approximately 32-km stretch of the California Aqueduct near the town of Lost Hills, Kern County, California (Fig. 1). Both sides of the aqueduct right-of-way (ROW) included a relatively undisturbed strip of land (approximately 60 m wide) typical of the valley grassland vegetation

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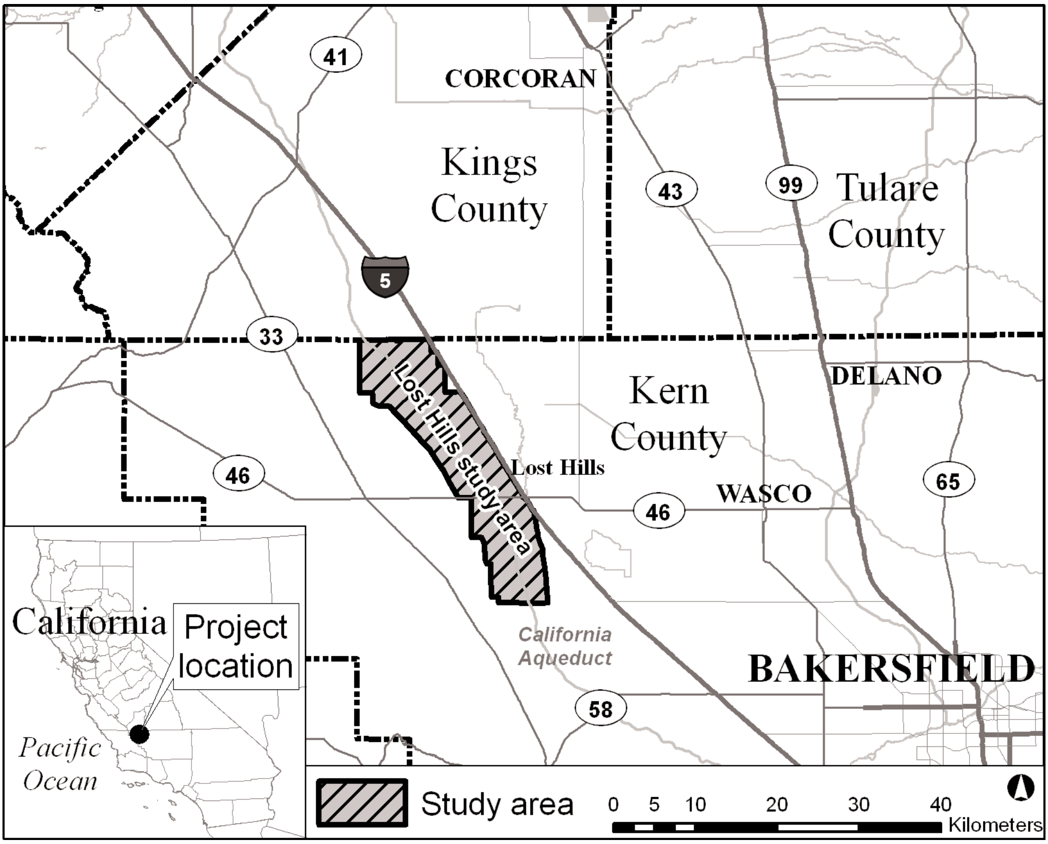

Fig. 1. Study area location near Lost Hills, Kern County, California.

type (Heady 1977). Herbaceous vegetation was dominated by red brome (*Bromus madritensis*) and filaree (*Erodium* spp.), and the most common shrub species was desert saltbush (*Atriplex polycarpa*). Mesquite trees (*Prosopis glandulosa*) were found within the southern portion of the study area, and occasional almond and pistachio trees were found within the ROW in areas bordering orchards.

Farmland bordered both sides of the aqueduct throughout most of the study area. Major crops included cotton, barley, almonds, and pistachios. Less abundant crops included alfalfa, onions, lettuce, watermelons, olives, tomatoes, and grapes. Annual crops were typically planted in spring and harvested in fall. After harvesting, the ground was disked and left bare until the following spring. Nut orchards were drip-irrigated and harvested in September or October of each year. Along much of the west side of the aqueduct, the adjacent farmland was <1.6 km wide and bordered the Lost Hills Oil Field.

The study area was predominately flat, with elevations ranging from approximately 80 m in the east to approximately 150 m along the Lost Hills anticline. The Lost Hills are gentle, rolling hills in the western portion of the study area that run parallel to the California Aqueduct.

Climate for Lost Hills, California, is characterized by hot, dry summers and cool, wet winters, with thick fog during winter months (National Climatic Data Center 2000). Weather data recorded 40 km east of Lost Hills in Wasco, California, indicate that average daily maximum temperatures range from 13.4°C in December to 37.5°C in July and that average daily minimum temperatures range from 2.1°C in December to 18.7°C in July. Precipitation during the growing season (October–March) averages 13 cm annually. Growing season precipitation was 33.0 cm in 1998 and 16.5 cm in 1999.

METHODS

Kit Fox Capture and Telemetry

Kit foxes were captured by using wire-mesh traps (38 × 38 × 107 cm) baited with mackerel, wieners, bacon, or chicken, or by plunging them from culverts (O'Farrell 1987). Captured foxes were eartagged, measured, and fitted with radio-collars (Advanced Telemetry Systems, Isanti, MN) containing mortality sensors. Each collar weighed approximately 60 g. Endangered kit foxes were captured and handled per protocols established in permit TE023496-1 from the U.S. Fish and Wildlife Service and in a memorandum of understanding with the California Department of Fish and Game.

Kit foxes were located at night using 2 truck-mounted null-tracking systems with paired 2-element antennae. Telemetry vehicles were driven along access roads of the aqueduct and positioned such that at least 1 radio-collared fox was between vehicles. After setup and calibration of the systems, biologists communicated with handheld radios and simultaneously took bearings on radio-collared foxes. Telemetry sessions were initiated at approximately the time of sunset and continued for 2–4 hours to cover the period when activity by kit and swift foxes is usually highest (Zoellick 1990, Hines and Case 1991, Kitchen et al. 1999). Locations were collected on all collared foxes in the vicinity, and successive locations of individual foxes were separated by ≥10 minutes. Attempts were made to locate each radio-collared fox ≥2 times per week.

Diurnal locations of radio-collared kit foxes also were recorded. Kit foxes often used metal culverts found under the access roads of the ROW as daytime dens. Because these culverts attenuated radio signals, it was difficult to track foxes to these structures. Therefore, in an effort to locate foxes, we periodically conducted systematic searches of these culverts using flashlights or reflected sunlight. We also used telemetry to track kit foxes to earthen dens on those occasions when signals were audible during the day.

Telemetry error of the truck-mounted systems was determined by triangulating reference transmitters at 30 locations that were representative of fox locations and unknown to the 2 people conducting telemetry. The average telemetry error was 37.9 ± 6.8 m (range 4–186 m). Eighty percent of the triangulated locations had an error of <45 m. The mean distance between the reference transmitters and telemetry vehicles was 552.2 ± 34.7 m (range 74–1318 m).

Habitat Use Analyses

We used information gathered from global positioning system (GPS) units, U.S. Geological Survey (USGS) maps, and ground mapping to develop a geographic information system (GIS) for the study site (PC ARC/INFO, Environmental Systems Research Institute, Redlands, CA). A survey-grade GPS unit was used to determine locations of telemetry stations and to delineate boundaries of the ROW. We drove farm roads in the spring of each year to map crops within 2.5 km of the aqueduct. Roads, section lines, and other pertinent data were taken from USGS 7.5-minute quadrangle maps. These data and telemetry locations of foxes were entered into the GIS for spatial analyses.

Because radio-collared kit foxes often used the ROW (which is generally linear), they were at times found directly between the telemetry stations. In these cases, bearings either followed an identical pathway or they missed intersecting by a few degrees. Because we felt that automatically discarding these bearings would bias the habitat selection analysis, we individually evaluated these locations. If a pair of bearings fell entirely within 1 habitat type, the location was assumed to be in that habitat. Cases in which a pair of bearings crossed >1 habitat type were excluded from analyses. Locations for which bearings intersected at <20° also were deleted from analyses. Less than 5% of locations were excluded.

We evaluated habitat selection by comparing the proportion of nocturnal fox locations in each habitat type to the proportion of each habitat type available within the study area. We only used 1 randomly selected location per night for each fox to reduce the effect of autocorrelation in the analysis. Locations of juvenile foxes recorded after June were included with adults in the analysis because juvenile kit foxes tend to forage independently when 4–5 months old (Morrell 1972). For each year of the study, we defined habitat availability as the 1.6-km-wide area on both sides of the aqueduct between the northernmost and southernmost locations of radio-collared kit foxes. This 1.6-km width was well within the average nightly foraging range of kit foxes (Zoellick et al. 2002) and generally corresponded with the maximum range of our telemetry systems. We delineated 4 habitat types: orchard, annual crops, ROW, and other. Orchards included almond, pistachio, and olive trees. Annual crops included cotton, barley, and other row or grain crops. The other category included residential, grassland, and fallow fields. The proportion of each habitat type within the available area was determined using ARC/INFO. We compared proportions of habitat use and habitat availability using chi-square goodness-of-fit tests and 95% Bonferonni confidence intervals (Neu et al. 1974, Byers et al. 1984). Nocturnal locations also were used to determine the maximum distance foxes traveled into different types of cropland.

Diet and Prey Availability

Rodent abundance was assessed by live-trapping. Traplines consisting of 10 traps spaced 10 m apart were established within the ROW and within some farm fields and orchards that we were permitted to enter. Eighteen traplines were placed within the ROW, 6 traplines were placed within almond orchards, and 6 traplines were placed within cotton fields. Traplines within croplands and orchards were placed 50–100 m from the outside edge of the ROW. Traps were baited with millet seed in the afternoon and were checked 2–4 hours after dark. Captured rodents were weighed, and fur on their rump was clipped to identify recaptured animals. Trapping sessions were conducted in December of 1998 and 1999, and traps were operated for 3 consecutive nights. The number of small mammals captured was compared among habitat types and between years using analysis of variance.

Kit fox diet was determined by analyzing scats collected from trapped foxes and scats collected at known kit fox dens. Scats were oven dried for ≥24 hours at 60°C, and prey remains were identified by macroscopic characteristics of hairs and through comparison of teeth, bones, scales, skin, and exoskeletons to reference specimens. For each food item found in scats, the frequency of occurrence was calculated as 100 · [number of occurrences / total number of scats]. More than 1 item commonly occurred in a given scat; therefore, the sum total of all item frequencies exceeded 100%.

RESULTS

Four adult kit foxes (2 males, 2 females) and 3 male kit fox pups were captured and radio-collared during this study. Three foxes were radio-tracked for <6 months, 2 foxes were tracked for 6 months, and 2 foxes were tracked for >14 months.

Radio-collared kit foxes were found during the day on 54 occasions. Kit foxes were found denning within the ROW habitat 53 times (46 culverts, 7 earthen dens) and 1 kit fox was found denning in a stack of irrigation pipes at the edge of a cotton field.

Habitat Use

Nocturnal telemetry data were collected from June through December in 1998 (287 locations) and all year in 1999 (393 locations). Foxes ranged up to 1.5 km into orchards and up to 1.1 km into annual croplands. The reduction of the telemetry data set to 1 random location per fox per night for the habitat use analyses yielded 64 locations in 1998 and 98 locations in 1999. During both years, kit foxes were located most frequently within the ROW (48.4%–58.2%), followed by orchards (22.5%–32.8%), annual croplands (17.2%–18.4%), and other habitats (1%–1.6%; Fig. 2). Available habitat during the 2 years consisted mostly of annual croplands (55.8%–68.6%), followed by orchards (11.9%–23.9%), other habitat (14.5%–15.6%), and the ROW (4.7%). Goodness-of-fit tests indicated differences in habitat use versus availability in 1998 (χ^2 = 287, df = 3, P < 0.001) and 1999 (χ^2 = 658, df = 3, P < 0.001). Kit foxes used the ROW more than expected based on availability, and annual croplands and other habitats were used less than expected (Fig. 2) during both years. Kit fox use of orchards was higher than expected based on availability in 1999, but this habitat was used in proportion to its availability in 1998.

Diet

In 1999, 207 fox scats were gathered from active kit fox dens, from captured animals, and during necropsies. Most scats were collected

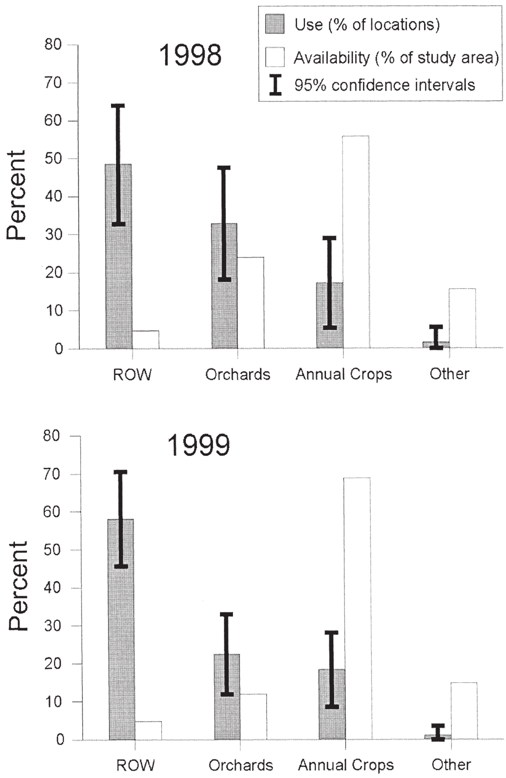

Fig. 2. Proportional use of habitats by kit foxes and habitat availability in northwestern Kern County, California, during 1998–1999.

from pupping dens in April (32.4%), June (64.3%), and July (1.9%). The remaining 3 scats (1.4%) were collected from captured or dead individuals in July, August, and October.

Rodent remains were the most frequently occurring item in kit fox scats (88.4%), followed by remains of insects (18.4%), other arthropods (11.6%), leporids (8.7%), human-derived items (6.3%), and birds (1.9%). Rodent species occurring in kit fox scats included the house mouse (*Mus musculus;* 34.3%), deer mouse (*Peromyscus maniculatus;* 17.9 %), Botta's pocket gopher (*Thomomys bottae;* 9.7%), California vole (*Microtus californicus;* 3.9%), Western harvest mouse (*Reithrodontomys megalotis;* 3.4%), and San Joaquin pocket mouse (*Perognathus inornatus;* 1.5%). In addition, 27.0% of the scats contained murid rodents that could not be identified to species, and 4.8% of the scats contained nonmurid rodents that could not be identified to species. Insects in scats included field crickets (9.7%), grasshoppers (4.4%), ants (4.4%), and beetles (2.9%). Other arthropods included species that were not identifiable. Bird remains in scats typically consisted of a few feathers and were not identified to species. Human-derived items included plastic (1.9%), string (1.9%), paper (1.5%), and rubber (1.0%).

Prey Availability

During 900 trap-nights in December 1998, 183 individuals of 6 species of small mammals were captured 219 times for an overall trapping success of 24.3%. Deer mice were captured most frequently (63.4% of individuals), followed by house mice (31.1%), pocket mice (1.6%), Heermann's kangaroo rats (*Dipodomys heermanni;* 1.6%), short-nosed kangaroo rats (*Dipodomys nitratoides brevinasus;* 1.6%), and harvest mice (0.6%).

The average number of rodents captured per trapline differed among habitats ($F_{2,\,27} = 6.52$, $P < 0.01$) and varied from 9.3 ($s_{\bar{x}} = 1.77$, range 0–21) in the ROW to 2.2 ($s_{\bar{x}} = 0.48$, range 0–3) in cotton fields and 0.5 ($s_{\bar{x}} = 0.34$, range 0–2) in almond orchards. The average number of rodents captured per trapline was higher ($P = 0.04$) within the ROW than within the almond orchards. Average number of rodents captured per line did not differ between the ROW and cotton fields ($P = 0.12$) or between cotton fields and almond orchards ($P = 0.88$).

All 6 species of rodents were captured along the ROW, whereas only deer mice and house mice were captured within cotton fields and only house mice were captured within almond orchards. The average number of species captured per line differed among habitats ($F_{2,\,27} = 7.57$, $P < 0.01$) and varied from 1.8 ($s_{\bar{x}} = 0.21$, range 0–3) within the ROW to 1.2 ($s_{\bar{x}} = 0.31$, range 0–2) in cotton fields and 0.3 ($s_{\bar{x}} = 0.21$, range 0–1) in almond orchards. The average number of species captured per trapline was higher within the ROW than within almond orchards ($P = 0.01$). Average number of species captured per trapline did not differ between the ROW and cotton fields ($P = 0.40$) or between cotton fields and almond orchards ($P = 0.19$).

In December 1999, all traplines within the ROW and 3 traplines within almond orchards were placed in the same locations as in 1998. However, because of access problems, 3 traplines in almond orchards were moved to new locations. Also, traplines were not set within the cotton fields, because the fields had been plowed under. During 840 trap-nights in December 1999, 16 individuals (13 deer mice and 3 Heermann's kangaroo rats) were captured 17 times for an overall trapping success of 2.0%. Because all captures were within the ROW habitat, results were not statistically compared.

DISCUSSION

Habitat Use

Our sample size (7 foxes) was comparatively small, as was our study area, but our results indicated that natural lands along the ROW were very important to kit foxes in this mostly agricultural setting. The ROW made up approximately 5% of the available habitat, yet >48% of the nocturnal locations and 98% of the diurnal locations occurred in this type. The importance of the ROW to foxes probably was due to the presence of den sites and the relatively abundant and diverse prey base found within this habitat. Small mammal abundance within the ROW was several times higher than in orchards and cotton fields, and kit foxes almost exclusively denned within the ROW during this study. Nonetheless, because the ROW only provided a thin strip of natural habitat, kit foxes may have been compelled to explore and forage within adjacent farmlands.

Kit foxes in this study often entered the margins of farmland at night and traveled up to 1.5 km into some orchards. However, we found no evidence that kit foxes were able to occupy farmland. This contrasts with recent studies, which demonstrated that the closely related swift fox occupied and reproduced within croplands of western Kansas (Jackson and Choate 2000, Matlack et al. 2000). This dissimilarity in fox use of croplands in the 2 regions could result from differences in farming practices. Methods of cropping in western Kansas rarely include irrigation, and most fields are left fallow every other year to allow moisture to accumulate (Matlack et al. 2000). This regime differs from practice within the southern San Joaquin Valley, where farmlands are irrigated and rarely left fallow for more than a few months. The frequent ground disturbance associated with the intensive farming methods in the San Joaquin Valley allows for only a sparse prey base and leaves little room for den sites. Kit foxes commonly create dens by expanding the burrows of other species, such as ground squirrels; and flooding and ground disturbance damage or destroy dens. Low prey availability, few burrowing animals, and low den persistence probably limit the ability of kit foxes to occupy agricultural fields in this region.

Our results indicated that kit foxes used orchards more intensively than annual croplands. Kit foxes used orchards either in proportion to or more than expected based on availability. In contrast, kit foxes rarely used annual croplands during the 3 years, even though this type encompassed >50% of the available habitat. Orchards offer less ground disturbance and probably a more consistent food supply than annual crops such as cotton. Plowing and flooding of land that is used to produce cotton and other annual crops probably severely limit the abundance of small mammals at some times of the year. Although prey may be more plentiful in orchards, we did not find any kit fox dens in orchards. Thus, use of orchards appeared to be limited to foraging.

Kit foxes traveled further into orchards compared to annual croplands. The structure of some annual croplands may impede kit fox movement. A mature cotton field is a dense thicket of approximately 1-m-tall plants in which kit foxes may have trouble hunting prey or avoiding predators. In contrast, orchards provide a more open landscape, especially at lower levels (<1.5 m), and movement in orchards may be easier for foxes.

Diet

Although heteromyid rodents are a frequent prey item for kit foxes, murid rodents usually are not an important food source (Logan et al. 1992, White et al. 1995, Cypher et al. 2000). However, kit foxes in this study were able to take advantage of the relatively high numbers of deer mice and house mice at this site. A similar reliance on nontraditional food sources by kit foxes also occurred in an intensively developed oil field (Spiegel et al. 1996). Murid rodents were the most commonly captured small mammals in December 1998 (95%) and December 1999 (81%), and they were found in 79% of the kit fox scats collected in 1999. Botta's pocket gophers and California voles were the only 2 species of rodents found in kit fox scats that were not captured during the trapping sessions. However, mounds and digging by pocket gophers were seen within almond orchards. Voles are also known to inhabit agricultural areas, so it is probable that kit foxes preyed on both these species while foraging in farmlands.

Conservation Implications

Although our results indicated that kit foxes were unable to occupy farmland on a long-term basis, it is possible that farmland can be made more suitable for movement and dispersal of kit foxes. One idea for facilitating the movement of kit foxes through agricultural lands is to provide small islands of habitat as “stepping stones” between otherwise isolated patches of natural land (U.S. Fish and Wildlife Service 1998). Another idea that may have merit is to provide or improve habitat along canals in areas where increased movement by kit foxes is needed. This study demonstrated that kit foxes frequently used the ROW of the California Aqueduct, and that kit foxes also travel along canals in some urban areas (Cypher unpublished data). Likewise, irrigation canals could serve as corridors for kit foxes within farmland, especially if they are enhanced. Canals that pass through orchards or fragmented natural land may be particularly suitable for enhancement. Because this study and others (Cypher unpublished data) have demonstrated that kit foxes readily use culverts and artificial dens, these structures also could be established along irrigation canals to provide needed cover for kit foxes. Creating strips or islands of habitat along canals could provide a more stable source of prey for foxes, and further enhance their ability to disperse through agricultural lands.

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