Consensus on Criteria for Potential Areas for Wolf Reintroduction in Mexico

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Abstract: *Given the conflict with human interests that in many cases results in the extirpation of large carnivores, acceptance of their reintroduction is a considerable challenge. By the 1980s Mexican wolves (*Canis lupus*) were extinct in the wild. In 1998 a population was reintroduced in the Blue Range Mountains of New Mexico (U.S.A.). Efforts to reintroduce the species in Mexico have been ongoing since the late 1980s. Four teams working independently identified 6 areas in northern Mexico in the historic range of Mexican wolves, where reintroductions could potentially be successful. Each team used different methods and criteria to identify the areas, which makes it difficult to prioritize among these areas. Therefore, members of the different teams worked together to devise criteria for use in identifying priority areas. They identified areas with high, intermediate, and low potential levels of conflict between wolves and humans. Areas with low potential conflict had larger buffers (i.e., distance from human settlement to areas suitable for wolves) around human settlements than high- and intermediate-conflict areas and thus were thought most appropriate for the first reintroduction. High-conflict areas contained habitat associated with wolf presence, but were closer to human activity. The first reintroduction of Mexican wolves to Mexico occurred in October 2011 in one of the identified low-conflict areas. The identification of suitable areas for reintroduction represents a crucial step in the process toward the restoration of large carnivores. Choice of the first reintroduction area can determine whether the reintroduction is successful or fails. A failure may preclude future reintroduction efforts in a region or country.*

Keywords: *Canis lupus baileyi*, large carnivore, Mexican wolf, prioritization, species reintroduction

Consenso en Criterios para Áreas Potenciales para la Reintroducción de Lobos en México

Resumen: *Debido al conflicto con intereses humanos que en muchos casos resulta en la extirpación de carnívoros mayores, la aceptación de su reintroducción es un reto considerable. En la década de 1980 los*

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lobos mexicanos (Canis lupus *) estaban extintos en vida libre. En 1998 una población fue reintroducida en las Montañas Blue Range, Nuevo México (E.U.A.). Los esfuerzos para reintroducir la especie en México han sido continuos desde fines de la década de 1980. Cuatro equipos trabajando independientemente identificaron 6 áreas en el norte de México en el rango de distribución histórico de lobos mexicanos, en los que la reintroducción potencialmente tendría éxito. Cada equipo utilizó diferentes métodos y criterios para identificar las áreas, lo cual dificulta la priorización de estas áreas. Por lo tanto, integrantes de los diferentes equipos trabajaron conjuntamente para diseñar criterios para la identificación de áreas prioritarias. Identificaron áreas con alto, intermedio y bajo nivel de conflicto entre lobos y humanos. Las áreas con bajo potencial de conflicto tenían mayores zonas de amortiguamiento (i.e., distancia entre asentamientos humanos y áreas adecuadas para lobos) alrededor de los asentamientos humanos que las áreas con niveles altos e intermedios de conflicto y por lo tanto se pensó que eran más apropiadas para la primera reintroducción. Las áreas con nivel de conflicto alto contenían hábitat asociado con la presencia de lobos, pero estaban cerca de actividades humanas. La primera reintroducción de lobo mexicano en México se llevó a cabo en octubre de 2011 en uno de los sitios identificados con nivel de conflicto bajo. La identificación de áreas adecuadas para la reintroducción representa un paso crucial en el proceso hacia la restauración de carnívoros mayores. La elección del área de la primera reintroducción puede determinar si la reintroducción es exitosa o fracasa. Un fracaso puede impedir futuros esfuerzos de reintroducción en una región o país.*

Palabras Clave: *Canis lupus bailely*, lobo mexicano, priorización, reintroducción de especies

Introduction

Ecosystem structure and function have been reported to vary after either the extirpation or reintroduction of wolves (*Canis lupus*). For example, wolf populations limit abundance of coyotes (*Canis latrans*) (Fuller & Keith 1981; Carbyn 1982; Crabtree & Sheldon 1999), and absence of wolves may have contributed to the southward and eastward expansion of coyotes in Canada and the United States (Gier 1975; Nowak 1978; Dekker 1989). Wolf extirpation has also been linked to changes in vegetation composition and structure (McLaren & Peterson 1994; Ripple & Larsen 2000) and changes in abundance and species richness of other animals (Berger et al. 2001; Hebblewhite et al. 2005). Furthermore, after the reintroduction of wolves in Yellowstone, ungulate behavior changed (Laundré et al. 2001; Ripple et al. 2001) and vegetation is recovering from intensive grazing by ungulates (Ripple & Beschta 2003). Accordingly, restoration of ecosystems is being used as an argument for the restoration of carnivores, including wolves, to ecologically functional densities and distributions (Parsons 2003; Ripple & Beschta 2003; Soulé et al. 2003; Soulé et al. 2005).

The role of the wolf in Mexican landscapes has not been studied. The riparian areas of northern Mexico have been heavily grazed and degraded by cattle, and wolves are likely to use these areas, especially in the relatively dry Sierra Madre Occidental. The presence of wolves in riparian areas could change native and domestic ungulate behavior and reduce their level of use of these areas (e.g., Brown et al. 1999; Laundré et al. 2001; Hernández & Laundré 2005; Beschta & Ripple 2010).

The Mexican wolf (*Canis lupus baileyi*) is the most distinct subspecies in North America (Nowak 1983; Moreno et al. 1996). Originally, it was distributed from the southwestern United States to central Mexico (Leopold 1959; Hall 1980), but by the 1980s it was considered extinct in the wild (McBride 1980; Brown 1992; Secretaría del Medio Ambiente y Recursos Naturales 2010). In 1978 a binational captive-breeding program was launched to prevent the extinction of the subspecies (Ames 1982; Bernal Stoopen et al. 2009). Public interest in the reintroduction of the wolf in Mexico started in 1989, when a group of individuals and organizations started working collaboratively toward that goal. In 2000 the group became an advisory entity to the Mexican Ministry of the Environment (Secretaría del Medio Ambiente y Recursos Naturales [SEMARNAT]) as the Consultative Subcommittee for the Recovery of The Mexican Wolf (Comité Consultivo para la Recuperación del Lobo Mexicano).

From 2000 until 2005, 4 research teams conducted independent studies to identify potential areas for wolf reintroduction in Mexico. The teams used different criteria and approaches and identified 6 areas for reintroduction, 4 in the Sierra Madre Occidental (northwestern Mexico), and 2 in the Sierra Madre Oriental (northeastern Mexico). Araiza (2001), Caroll et al. (2006), Sánchez and Guevara (2006), and Martínez-Gutiérrez (2007) evaluated northern Mexico. Only Martínez-Gutiérrez (2007) considered the full historic range of the wolf in Mexico.

In April 2006, the Consultative Subcommittee organized the Mexican Wolf (*Canis lupus baileyi*) Reintroduction Workshop. Thirty people from Mexico and the United States participated in this experts' workshop. The goals of the workshop were to identify the most suitable areas for reintroduction in Mexico and to develop a release protocol that would profit from the experience gained from wolf reintroductions in the United States (Araiza et al. 2007). The areas identified by each team were presented to the experts. However, each team used different methods and examined different spatial extents, so it was not possible to reach a consensus on prioritization of different areas for reintroduction. Thus, reintroduction plans slowed down because it was difficult to agree on an area where efforts and fundings should be focused. The primary conclusion of the experts at the workshop was that there is a need to unify and refine the criteria and methods used to identify potential areas for reintroduction of the Mexican wolf and that the criteria should include a consensus on habitat quality and probability of anthropogenic mortality. Our goal was to generate such consensus on the criteria and methods with respect to the already identified potential regions for wolf reintroduction in Mexico.

Methods

We conducted a spatial analysis of each of the 6 regions potentially suitable for wolf reintroduction (Fig. 1). We identified and quantified the area of potential habitat on the basis of museum and literature records for wolves in Mexico. For our purposes and the scale of analyses, the number of records of wolves in different vegetation types and distance to human-populated places and roads were indications of high, intermediate, and low habitat quality. First, we evaluated wolf associations with vegetation types by spatially overlaying 264 occurrence records on a map of potential primary vegetation (pine forest, pine-oak forest, oak forest, oak-pine forest, grasslands, Douglas fir [*Pseudotsuga menziesii*]-spruce forest, mesquite shrubland, fir forest, desert shrubland, subtropical thorn scrub) produced by the National Institute of Geography and Statistics between 1999 and 2000 (INEGI 2003). Occurrence data came from 219 interviews with elders who provided data from 1915 to the 1970s (J.S., unpublished data), 30 records from the literature, and 29 museum specimens (Martínez-Gutiérrez 2007). We used the 1999–2000 map of potential primary vegetation rather than a current land-cover map because we did not have information on the degree of land-cover change at the time the wolves were recorded and because we believed it was reasonable to assume that the extent of natural vegetation and intensity of land use were less in the past than today (Lammertink et al. 1997; INEGI 2003; Martínez-Gutiérrez 2007) (Table 1). Historically, wolves likely had stronger associations with open vegetation types such as grasslands. Today, these areas are grazed by cattle and the resulting potential for conflict with humans makes them less suitable for wolves.

To determine the type of vegetation associated with wolf occurrences within their historical range in Mexico, we determined the proportion of wolf occurrences (use) in each primary vegetation type and the proportion of each potential primary vegetation type within that range. We tested the null hypothesis that the wolves used the vegetation types in proportion to the amount available with a chi-square test. We calculated Bonferroni confidence intervals ($\alpha = 0.05$) to evaluate whether the expected use of each vegetation type was significantly different from actual use (Neu et al. 1974; Byers et al. 1984) (Table 1).

We identified patches of habitat for the Mexican wolf within its historical range on a map of current vegetation (Instituto de Geografía 2001). We classified the quality of vegetation types in these patches from 1 (highest quality) to 6 (lowest quality) on the basis of results of the vegetation-association analysis and the current status of land-cover transformation. For example, an area of a given vegetation type that was unaffected by human activity would be more suitable than an area where primary and secondary (i.e., affected by human activity) vegetation types were mixed.

On the basis of human population size, we delineated circular buffer areas around populated areas within a geographic information system (GIS). Buffer area was the distance between human settlement and areas considered suitable for wolves. Human settlements are represented as points in our source data (INEGI 2002) regardless of their population size. The width of the buffer increased as human population size increased and was up to 4500 m for settlements with $>15,000$ people (Table 2). For example, we assumed that an area would be unsuitable for wolves (i.e., high probability of human-caused mortality) if it were within 1000 m of a human settlement with 1–20 inhabitants, which is the distance at which wolves avoid buildings (Kaartinen et al. 2005), and that wolves would have low probability of mortality if they were within 5000 m of a human settlement of that size. The minimum and maximum distances for the intermediate probability of mortality, depending on size of the human population, were 2500 and 6000 m, respectively. The maximum distance for low probability of mortality was 12,000 m (Table 2). We followed a similar approach to buffer areas around roads, which are represented as single lines in our source data (INEGI 2000). At the high probability of mortality, buffers along roads extended 250 m on each side, the distance at which wolves avoid roads (Kaartinen et al. 2005). At the intermediate and low probabilities of mortality, buffers along roads extended on each side 500 and 750 m, respectively.

We combined the maps of vegetation associated with wolf occurrence, buffer areas around settlements, and buffer areas around roads to identify the largest patches (i.e., contiguous polygons of the same or different vegetation type) of the highest habitat quality to prioritize areas for potential reintroduction and to identify where prey availability and potential social attitudes toward wolf reintroduction should be assessed. We assumed that potential release patches were those with habitat qualities of 1 and 2 that were $>150\ km^2$, which is the smallest home range of a wolf pack in Arizona (Arizona Game and Fish Department et al. 2008).

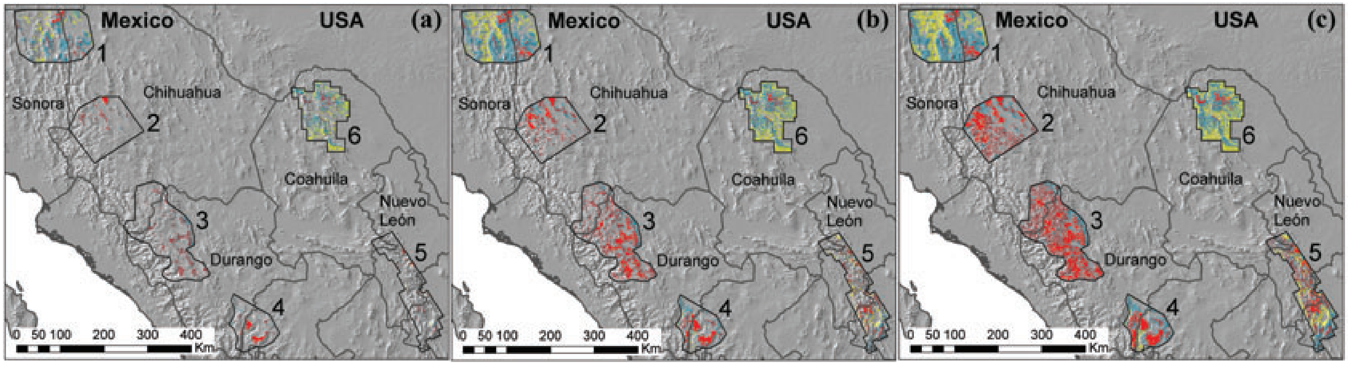

Figure 1. Patches of Mexican wolf habitat within potential reintroduction areas in northern Mexico (1, Sonora-Chihuahua; 2, Central Chihuahua; 3, Chihuahua-Durango; 4, Durango-Zacatecas; 5, Nuevo León-Tamaulipas; 6, Coahuila): (a) areas where wolves have a low probability of anthropogenic mortality, (b) areas where probability of anthropogenic mortality is intermediate, and (c) areas where probability of anthropogenic mortality is high (light red, patches of high habitat quality [categories 1 and 2, Table 1] >150 km ^{2}; dark red, patches of high habitat quality [categories 1 and 2] <150 km ^{2}; blue, patches of intermediate habitat quality (categories 3 and 4); yellow, patches of low habitat quality (categories 5 and 6)).

Results

Results of the habitat-association analyses indicated wolf occurrences were not proportional to the area of vegetation types ($\chi^2 = 13651.96$, df $= 10$, $p < 0.001$). A greater proportion of occurrences were associated with pine forest, pine-oak forest, and oak-pine forest than expected. Occurrences in oak forest, fir forest, and mesquite shrubland were proportional to the relative area of these vegetation types, whereas there were a lower proportion of occurrences in native grasslands, desert shrubland, and subtropical thorn scrub than expected (Table 1). Thus, on the basis of these results and the current vegetation (considering transformation) within the area historically occupied by the wolf, the order, from highest to lowest habitat quality, of vegetation types was pine forest and pine-oak forest; pine forest and pine-oak forest with secondary vegetation; oak forest, fir forest, and mesquite shrubland; oak forest, fir forest, and mesquite shrubland with secondary vegetation; desert shrubland and subtropical thorn scrub; desert shrubland and subtropical thorn scrub with secondary vegetation; and native grasslands (Table 3). Native grasslands were classified as of the lowest quality because these are open areas where wolves would be highly visible to humans and therefore more likely to be killed.

Table 1. Bonferroni confidence intervals of historic wolf-vegetation associations in Mexico derived from a map of potential primary vegetation (INEGI 2003) and proportion of historical records.

Primary vegetation	*No. of records*	*Occurrence (%)*		*Bonferroni intervals*[a]		*Proportion availability*[b]	
		expected	*observed*	*upper*	*lower*		
Pine forest	173	65.53	0.033	0.655	0.572	0.738	obs > exp
Pine-oak forest	57	21.59	0.005	0.2160	0.144	0.288	obs > exp
Oak forest	11	4.16	0.034	0.042	0.007	0.077	obs = exp
Oak-pine forest	10	3.78	0.004	0.038	0.005	0.071	obs > exp
Grasslands	5	1.89	0.270	0.019	−0.005	0.043	obs < exp
Douglas-fir, spruce forest	3	1.13	0.000	0.011	−0.007	0.030	obs = exp
Mesquite shrubland	2	0.75	0.002	0.008	−0.008	0.023	obs = exp
Fir forest	1	0.37	0.000	0.004	−0.007	0.015	obs = exp
Desert shrubland	1	0.37	0.256	0.004	−0.007	0.015	obs < exp
Subtropical thorn scrub	1	0.37	0.021	0.004	−0.007	0.015	obs < exp
Other	0	0	0.375	0.000	0.000	0.000	obs < exp

Note: Historical records from interviews with elders who provided data from 1915 through the 1970s, the literature, and museum specimens.
[a] *An expected proportion smaller than the interval indicates the number of records of wolves in the vegetation type was greater than expected if the proportion of records was equal to the proportional cover of each vegetation type; an expected proportion larger than the interval indicates the number of records of wolves in the vegetation type was smaller than expected. When the expected proportion lies within the interval, we assumed the number of records in the vegetation type was expected (Neu et al. 1974; Byers et al. 1984).*
[b] *Abbreviations: obs, proportion of observed records; exp, proportion of expected records.*

Table 2. Habitat quality of different vegetation types for the Mexican wolf.

Vegetation type [a]	*Quality* [b]
Pine forest	1
Pine-oak forest	1
Pine forest with secondary vegetation	2
Pine-oak forest with secondary vegetation	2
Oak forest	3
Fir forest	3
Mesquite shrubland	3
Oak forest with secondary vegetation	4
Fir forest with secondary vegetation	4
Mesquite shrubland with secondary vegetation	4
Desert shrubland	5
Subtropical shrubland	5
Subtropical shrubland with secondary vegetation	6
Desert shrubland with secondary vegetation	6
Grasslands	6

[a] *Classified on the basis of potential primary vegetation types (INEGI 2003) and current vegetation types in Mexico (Instituto de Geografìa 2001). Secondary vegetation means forests or vegetation established naturally after a dramatic disturbance (e.g., clear cutting); secondary species account for more than 70% of the vegetation cover.*
[b] *Habitat quality decreases as numbers increase: (1) observed proportion of records of wolves greater than expected if the proportion of records was equal to the proportion cover of the vegetation type within the study area (highest habitat quality); (2) observed proportion greater than expected with secondary vegetation; (3) observed proportion equal to expected frequency; (4) observed proportion equal to expected with secondary vegetation; (5) observed proportion lower than expected; (6) observed proportion lower than expected frequency with secondary vegetation (lowest habitat quality).*

Prioritization of areas for reintroduction differed at different probabilities of anthropogenic mortality. Participants in the experts' workshop agreed that areas >10,000 km^2 should be considered suitable for reintroduction; however, no single habitat patch in the 6 areas participants considered was >10,000 km^2 (Fig. 1). The largest patch with low probability of mortality was 354 km^2 along the northern boundary of the states of Sonora and Chihuahua (Sonora-Chihuahua area); the largest patch with intermediate probability of mortality was 877 km^2 along the boundary of the states of Durango and Chihuahua (Chihuahua-Durango area); and the largest patch with high probability of mortality was 1636 km^2 in the Chihuahua–Durango area. The largest clusters of habitat patches were in the Sonora–Chihuahua area. Sizes of these clusters assigned low, intermediate, and high probabilities of mortality were 7,828, 15,705, and 20,716 km^2, respectively (Fig. 1). The largest cluster of patches with habitat quality 1 or 2 was in the Chihuahua-Durango area. In this cluster, areas of 2,175, 8,344, and 15,308 km^2 were assigned low, intermediate, and high probabilities of mortality, respectively (Fig. 1).

Discussion

There are 2 extremes to the options available for the prioritization of potential reintroduction areas. Reintroduction areas where the probability of anthropogenic wolf mortality is low are relatively small and few; thus, relatively fewer wolf populations can potentially be established in these areas. However, there is an increased possibility of survival in such areas given their greater distance from roads and human settlements. Reintroduction areas where the probability of mortality is high are relatively close to roads and human settlements, but the potential reintroduction area and thus the potential size of the wolf population is larger.

Table 3. Width of buffer around center of human settlements in potential areas for wolf reintroduction with high, intermediate, and low probabilities of anthropogenic mortality.

Number of people	*Buffer width (km)*		
	low probability	*intermediate probability*	*high probability*
1–20	5	2.5	1
21–100	6	3	1.5
101–500	7	3.5	2
501–1500	8	4	2.5
1501–3000	9	4.5	3
3001–7500	10	5	3.5
7,501–15,000	11	5.5	4
15,001–25,000	12	6	4.5

Note: Area of increased mortality risk, defined as the distance between a human settlement at the center of a circle and the area considered as suitable for reintroduction at the periphery of the circle

Priority areas for reintroduction identified on the basis of all habitat patches regardless of habitat quality were very different from priority areas identified only on the basis of different probabilities of mortality. When we considered all habitat patches, the Sonora–Chihuahua area was of the highest priority for reintroduction. This area included the largest habitat patch of quality 1 or 2 (Fig. 1). Use of only habitat patches with intermediate probability of mortality did not add new priority areas or change the ranking of areas with the high and low probabilities of mortality.

Therefore, it was unclear whether criteria that we based on all vegetation types in which wolves occurred or only the types with the highest proportion of occurrences (habitat quality 1 and 2) would lead to identification of areas where the probability of reintroduction success would be higher. In Italy and Spain, wolves use areas in close proximity to human settlements, enter villages, and feed at garbage dumps (Boitani 1983; Ciucci et al. 1996). Therefore, by choosing the Chihuahua–Durango area—the largest area with highest quality habitat—we would expect a larger recovery area and hence a larger wolf population to be established. However, it would be advisable to conduct the first reintroduction effort in the Sonora–Chihuahua area because wolves tend to avoid roads (Kaartinen et al. 2005; Whittington et al. 2005) and humans have been the leading cause of deaths of

Mexican wolves reintroduced to Arizona (Paquet et al. 2001; Arizona Game and Fish Department 2009). Survival and reproduction of the released individuals is more important than the potential for expansion across the landscape because the latter is contingent upon the former. Although the interaction of environmental and anthropogenic factors with physiography may affect the quality of wolf habitat, in Mexico such interaction resulted from historical human actions within the geographic distribution of Mexican wolves. Mexican wolves persisted longer in rugged to very rugged habitat, where predator control was more difficult and hence less intense (Molina Bravo 1964; Brown 1992).

Releasing wolves far from roads and human settlements may also reduce the potential for disease transmission from domestic dogs. The level of inbreeding in the captive population may have made these wolves more susceptible to pathogens. Several young from the reintroduction program recaptured in Arizona died of canine parvovirus or canine distemper. It is suspected that contact with domestic dogs from towns in the area was the source of the disease (Hedrick et al. 2003). Canine parvovirus and distemper are commonly present in coyotes, foxes, and domestic dogs in the region (Araiza 2001).

Subsequently and independent of this study, another workshop with the wolf specialists, coordinated by SEMARNAT, determined methods to assess prey availability and perception of local people toward wolves and a potential reintroduction. Prey densities were estimated with camera-traps and perceptions evaluated with questionnaires. These assessments were done simultaneously in the 6 areas. Results showed that both the Sonora–Chihuahua and Chihuahua–Durango regions contain sufficient prey to sustain wolves, and perception toward wolves was such that with adequate education and attention to the concerns of stakeholders, a reintroduction may be possible (Subcomité Técnico Consultivo para la Recuperación del Lobo Mexicano et al. 2009). On the basis of this information, SEMARNAT will conduct the first reintroduction in the Sonora–Chihuahua region and use the Chihuahua–Durango region as a secondary reintroduction area conditioned on the identification of a wolf-like canid documented with a camera trap during the prey-abundance survey (J.S., unpublished data).

Male coyotes have been reported to breed with female gray wolves in areas with high coyote and low wolf densities (Lehman et al. 1991; Roy et al. 1994). Hybridization with coyotes is a major threat to a reintroduced red wolf (*Canis rufus*) population (Kelly et al. 1999; Adams et al. 2007; Hedrick & Fredrickson 2008). Domestic dogs (*Canis familiaris*) have also been reported to breed with gray wolves and Ethiopian wolves (*Canis simensis*) in the wild (e.g., Randi & Lucchini 2002; Vilà et al. 2003; Verardi et al. 2006). Because of the risk of genetic extinction of Mexican wolves through hybridization (Rhymer & Simberloff 1996; Adams et al. 2003), before considering a reintroduction in the Chihuahua–Durango region, we suggest the genetic identity of the wolf-like canid be documented. Although the objective of the present work was to determine where wolves should be reintroduced to increase the probability of establishing a wolf population, the areas we identified as suitable but less than ideal could be considered for later reintroductions as expertise is gained from the initial reintroduction, financial resources increase, and work is conducted to improve the habitat quality of the sites.

At the time of writing, attempts to trap or obtain fecal samples for genetic analyses of the wolf-like canid in the Chihuahua–Durango area had been unsuccessful, but a family group composed of an older female and 4 offspring from 2 separate litters was released in the Sonora–Chihuahua region on 11 October 2011. About 2 months later, one wolf was found dead close to a dirt road, and 3 others were found dead on a ranch in the Chihuahua side of the release region. Two of these wolves proved to have been poisoned. It is unknown whether they ingested poison intended for other carnivores or whether they were the targets. All wolves had satellite and VHF collars. This allowed the field workers to follow their movements, confirm that no livestock predation events took place since the reintroduction, and determine that they had been feeding on native prey (Naturalia 2012). The surviving female separated from the rest of the pack shortly after the reintroduction (Naturalia, unpublished data). There are plans to continue the release of wolves within this area in 2012. The monitoring of reintroduced individuals will continue.

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