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Survival and cause-specific mortality of translocated female mule deer in southern New Mexico, USA

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Abstract

Context. Many mule deer (*Odocoileus hemionus*) populations in New Mexico have failed to recover from previous population declines, while some populations near urban areas have increased, resulting in more frequent human–wildlife conflicts. Translocations were used in an effort to simultaneously reduce an urban mule deer population and augment two low-density populations in south-western New Mexico, USA.

Aims. Because of insufficient monitoring, the efficacy of many ungulate translocations is unknown. Our goal was to monitor cause-specific mortality and 1 year post-release survival of mule deer translocated during 2013 and 2014. We compared survival rates of mule deer released with a hard- versus soft-release during the 2014 translocation.

Methods. . We translocated 218 mule deer in 2013 and 2014 into the Peloncillo Mountains (PM) and San Francisco River Valley (SFRV); 106 adult female mule deer were fitted with telemetry collars to determine cause-specific mortality and estimate survival 1 year post-release. All deer were hard-released in 2013. In 2014, translocated mule deer were either held in a soft-release pen (0.81 ha) for approximately 3 weeks or hard-released into their new environment. We used a Kaplan–Meier approach to estimate survival of translocated mule deer at each release area and to compare survival of mule deer translocated using each release method (i.e. hard- versus soft-release).

Key results. In 2013–14, survival of hard-released deer in the PM was 0.627 (s.e. = 0.09), compared with 0.327 (s.e. = 0.10) in the SFRV. In 2014–15, survival of hard–released deer in the PM was 0.727 (s.e. = 0.13) and survival of soft-released deer was 0.786 (s.e. = 0.11). In the SFRV, survival of hard- and soft-released deer was 0.656 (s.e. = 0.14) and 0.50 (s.e. = 0.16), respectively. Causes of mortality were predation (51%), potential disease (9%; blue tongue or epizootic haemorrhagic disease), accident (5%), poaching (5%) and unknown (20%).

Conclusions. Translocations can be an effective management tool to augment populations of mule deer while reducing overabundant urban populations. Soft-released mule deer did not have higher survival than hard-released mule deer, although the length and conditions of the acclimation period were limited in our study.

Implications. Overabundant mule deer populations in urban areas may serve as sources of animals to bolster declining populations. Soft-release pens of smaller size and short period of acclimation did not influence survival.

Additional keywords: hard-release, *Odocoileus hemionus*, soft-release, translocation.

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Introduction

Many mule deer (*Odocoileus hemionus*) populations across the western USA have either declined in recent years or have failed to recover from previous range-wide population declines. The causes of these mule deer population declines are not known definitively, but disease, predation, over-harvest and declines in habitat quality (i.e. nutritional quality) have all been proposed as potential mechanisms (Marshal *et al*. 2002; Mule Deer Working Group 2014, 2015). However, changes in habitat conditions (resulting in diminished nutritional carrying capacity of areas inhabited by mule deer) and predation have been the most widely implicated causes of these declines across the western USA (Ballard *et al*. 2001; deVos *et al*. 2003; Bishop *et al*. 2009; Hurley *et al*. 2011).

Mule deer in New Mexico have declined since the late 1960s (Snyder 1968), and many populations remain below historical levels of abundance (Mule Deer Working Group 2014, 2015). Conversely, mule deer populations in some urban areas of New Mexico have increased in abundance, leading to increased human–wildlife conflicts (e.g. property damage and vehicle collisions; New Mexico Department of Game and Fish (NMDGF), unpubl. data). The frequency of human–deer conflicts has escalated and will likely increase further in the near future in affected urban areas. Traditionally, nuisance wildlife was managed through lethal methods such as culling or sport harvest. However, some segments of the public are averse to lethal removal, citing concerns of humaneness and human safety in urban settings (Beringer *et al*. 2002; Massei *et al*. 2010). As a result, some wildlife management agencies have turned to translocation to reduce human–wildlife conflict caused by overabundant urban wildlife populations (Messmer *et al*. 1997; Beringer *et al*. 2002; Massei *et al*. 2010).

Wildlife managers regularly use translocations as conservation actions for species of concern and to resolve human–wildlife conflicts (Beringer *et al*. 2002; Parker *et al*. 2008; Foley *et al*. 2008; Massei *et al*. 2010). However, translocation efforts often lack adequate post-release monitoring to assess efficacy (Griffith *et al*. 1989; Fischer and Lindenmayer 2000; Cook *et al*. 2009). To maximise the efficient use of public resources, it is important to collect data that will allow managers to (1) quantify the efficacy of a particular translocation effort and (2) refine techniques to improve efficacy of future translocations. For example, soft releases generally involve construction of an enclosure at the translocation area and allow managers to provide food, water and protection from predation for a period of time, while translocated animals acclimate to their new environment. The use of soft-release methods may increase survival rates, fidelity to release sites and translocation success compared with hard-release methods (i.e. animals released immediately and unassisted after capture; Bright and Morris 1994; Fischer and Lindenmayer 2000; Wanless *et al*. 2002; Parker *et al*. 2008; Massei *et al*. 2010). However, few studies have compared post-translocation survival between these two release methods (Bright and Morris 1994; Parker *et al*. 2008; Nelson and Theimer 2012).

An overabundance of mule deer in Silver City, New Mexico (Fig. 1), and the associated human–wildlife conflicts, prompted the NMDGF to initiate a translocation effort to simultaneously reduce the abundance of mule deer in Silver City and bolster two mule deer populations that have not recovered from previous population declines in the Peloncillo Mountains and San Francisco River Valley. Our goal was to evaluate survival and cause-specific mortality of translocated mule deer to assess the efficacy of translocating mule deer from urban areas. In addition, we sought to compare survival of animals translocated with soft- versus hard-release methods to determine if it is cost effective to expend additional resources required when using soft releases for translocations.

Materials and methods

Study sites – source populations

Silver City (32.78044; -108.27394) is located at 1828 m elevation in south-western New Mexico, USA (Fig. 1). Average annual rainfall is 40.9 cm (s.d. = 9.4 cm) and average annual snowfall is 42.7 cm (s.d. = 9.57 cm; period of record 1960–2013; Western Regional Climate Center (WRCC 2015*a*). The lowest temperatures occur in December, with an average daily low of –2.7 °C; high temperatures occur in June with an average daily high temperature of 31.9 °C (WRCC 2015*a*). Vegetation types in Silver City include piñon–juniper (*Pinus* and *Juniperus* spp.) woodlands, oak (*Quercus* spp.) woodlands, grassland areas and non-native, residential landscaping.

Arabela (33.58724; –105.17291) is located in east central New Mexico near the Captain Mountains. Elevations range from 1663 to 1698 m. The majority of the lands were managed as a working cattle ranch that included private, state trust and lands managed by the Bureau of Land Management. Average annual rainfall is 37.1 cm (s.d. = 11.7 cm) and average annual snowfall is 36.6 cm (s.d. = 24.9 cm; period of record 1980–2016; WRCC 2015*b*). The lowest temperatures occur in December, with an average daily low of –4.2 °C; high temperatures occur in June with an average daily high temperature of 31.9 °C (WRCC 2015*b*). Vegetation types are primarily grasslands interspersed with rolling hills covered with juniper and oak woodlands.

Study sites – translocation areas

The Peloncillo Mountains (32.02531; –108.95099, PM) are located in south-western New Mexico and extend northwest from the international border with Mexico for approximately 120 km. Elevations range from 1219 m to over 2743 m (Sandoval 1979). The Bureau of Land Management manages most of the lands in the translocation area. Mean annual rainfall is 26.6 cm (s.d. = 8.9 cm) and mean annual snowfall is 11.8 cm (s.d. = 13.3 cm; period of record 1909–2015; WRCC 2015*c*). More than half of its rainfall occurs during July–September. Low temperatures occur in January, with an average daily low of –2.7 °C (WRCC 2015*c*). June is typically the warmest month with an average daily high temperature of 34.9 °C (WRCC 2015*c*).

Vegetation types in the PM include Chihuahuan desert shrub, grasslands, piñon–juniper woodland and mountain shrub (Brown 1982; Sandoval 1979). Dominant plants in the desert shrub include sotol (*Dasylirion wheeleri*), yucca (*Yucca baccata*, *Y. schotti*), mesquite (*Prosopis glandulosa*), whitethorn (*Acacia constricta*), ocotillo (*Fouquieria splendens*), prickly pear (*Opuntia* spp.) and cane cholla cacti (*Cylindropuntia spinosior*). Perennial grama grasses (*Bouteloua* spp.) and a variety of forbs are prevalent. On the moderately steep slopes in the desert scrub, oak, mountain mahogany (*Cercocarpus montanus*), and cliff fendler-bush (*Fendlera rupicola*) are common. Mexican piñon (*Pinus cembroides*) and juniper (*Juniperus monosperma*, *J. deppeana*) are found on the north and west slopes.

Other ungulates in PM include desert bighorn sheep (*Ovis canadensis mexicana*), Coues white-tailed deer (*Odocoileus virginianus couesi*), collared peccary (*Pecari tajacu*) and domestic cattle. Predators of mule deer in the PM include mountain lion (*Puma concolor*), bobcat (*Lynx rufus*) and coyote (*Canis latrans*). Water is available mostly in ephemeral potholes or man-made impoundments.

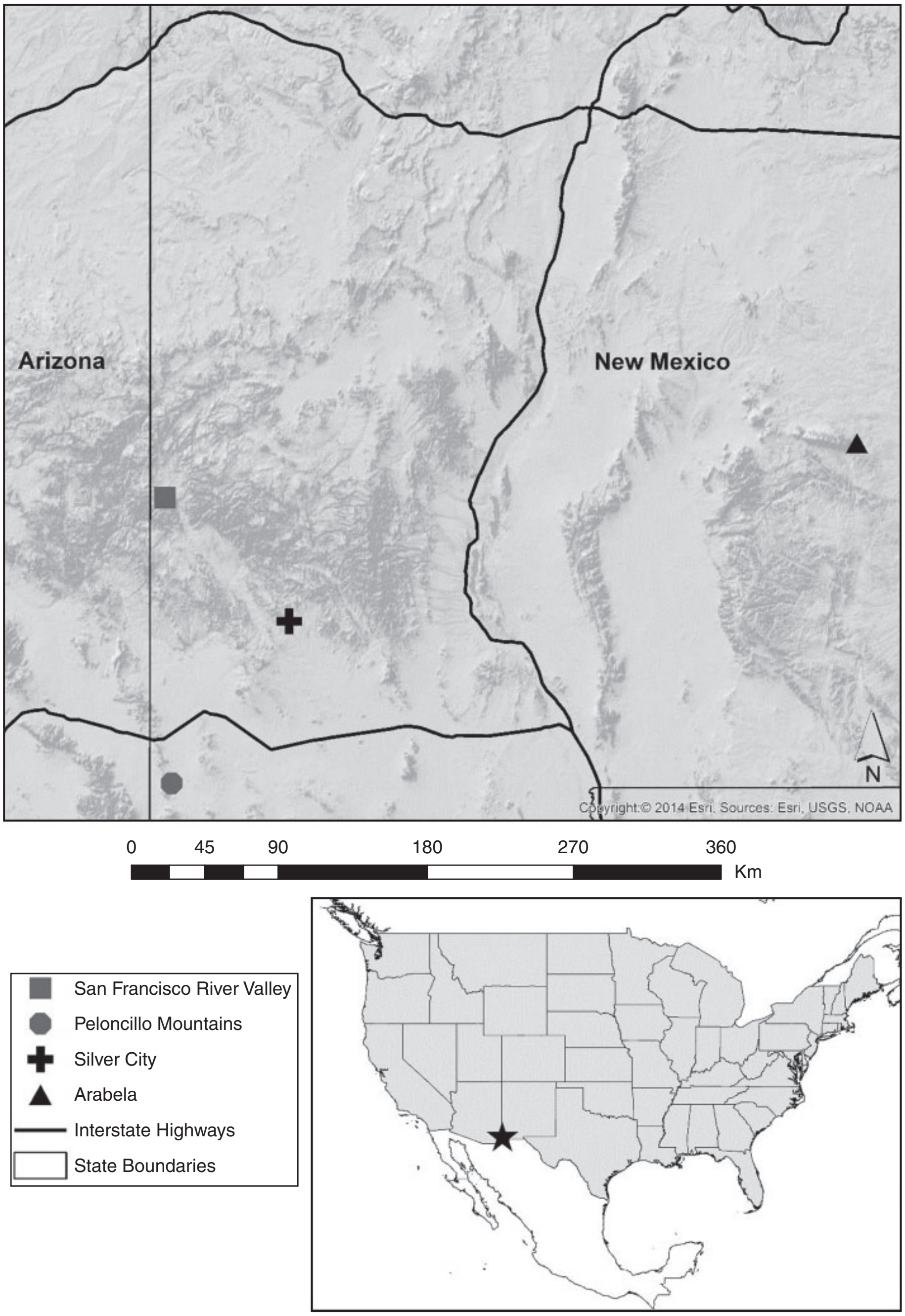

Fig. 1. Locations of the source populations in Silver City and Arabela, New Mexico and the two release locations in the San Francisco River Valley and Peloncillo Mountains, New Mexico.

The San Francisco River Valley (33.35512; -108.98117, SFRV) is located in west-central New Mexico and east-central Arizona within the Gila and Apache National Forests (Fig. 1). Elevations range from 1219 m to 3352 m (USFWS 1996). The US Forest Service manages the majority of the land in the SFRV. Average annual rainfall is 42.4 cm (s.d. = 10.9 cm; period of record 1939–2013; WRCC 2015*d*). Most rainfall occurs between mid-July and September, and snow falls in the higher elevations from December through March (USFWS 1996). Maximum temperatures typically occur in July, with an average daily high of 33.3 °C (WRCC 2015*d*). December and January are the coldest, with an average daily minimum temperature in January of –4.1 °C (WRCC 2015*d*).

Vegetation types include Petran montane and Great Basin conifer forests, plains, Great Basin grasslands, Madrean evergreen woodland and semi-desert grasslands (USFWS 1996). Dominant species include ponderosa pine (*Pinus* *ponderosa*), aspen (*Populus tremuloides*), Douglas fir (*Pseudotsuga menziesii* and *Abies* spp.), juniper, piñon, mesquite, oaks and a variety of grasses and forbs (USFWS 1996).

Common ungulates include domestic cattle, elk (*Cervus canadensis*), Coues white-tailed deer, Rocky Mountain bighorn sheep (*O. canadensis*) and collared peccary (USFWS 1996). Potential predators of mule deer in the SFRV include mountain lion, coyote, black bear (*Ursus americanus*) and Mexican gray wolf (*Canis lupus baileyi*; USFWS 1996). Water is widely available as natural springs, streams and the San Francisco River, supplemented with man-made sources constructed for livestock and wildlife.

Study sites – mountain lion removals

Mountain lions were removed from translocation areas through a combination of public hunter harvest and removal by contractors hired by NMDGF. Mountain lion removal efforts by hired contractors were intended to benefit management of sympatric bighorn sheep populations in the translocation areas. During our study, nine mountain lions were removed from PE and 17 from SFRV. Prior to the first translocation, eight mountain lions were removed from the SFRV and four from the PM (Fig. 2). In addition, four lions were removed from SFRV and four from PM during the first translocation year. During the second translocation (February 2014 to March 2015), five mountain lions were removed from the SFRV and one was removed from the PM (Fig. 2).

Capture and translocation

Vehicle-based ground surveys by NMDGF in 2010 resulted in a total count of 498 deer in the affected area in Silver City (65 km^2), and in 2011, surveyors counted 757 deer; densities were 7.7 and 11.6 deer per km^2 in 2010 and 2011, respectively (NMDGF, unpubl. data). Estimates of sightability are not available for these surveys, but given that detectability is likely substantially <100%, due to restricted visibility caused by housing, fences and terrain features, these estimates likely underestimate the deer population in Silver City. The high deer abundance is associated with damage to both native and ornamental vegetation, vehicle–deer collisions and in some instances, aggressive behaviour towards residents (NMDGF, unpubl. data). Additional deer were sourced from a population inhabiting a cattle ranch near Arabela, New Mexico (Fig. 1). Deer captured in Silver City and Arabela were translocated to the Peloncillo Mountains and the San Francisco River Valley (Fig. 1).

We used baited drop nets to capture deer in Silver City in February 2013 and January–March 2014 (Fig. 3; Ramsey 1968). Once captured, we tagged each deer with an individually numbered and coloured ear tag, administered an antibiotic

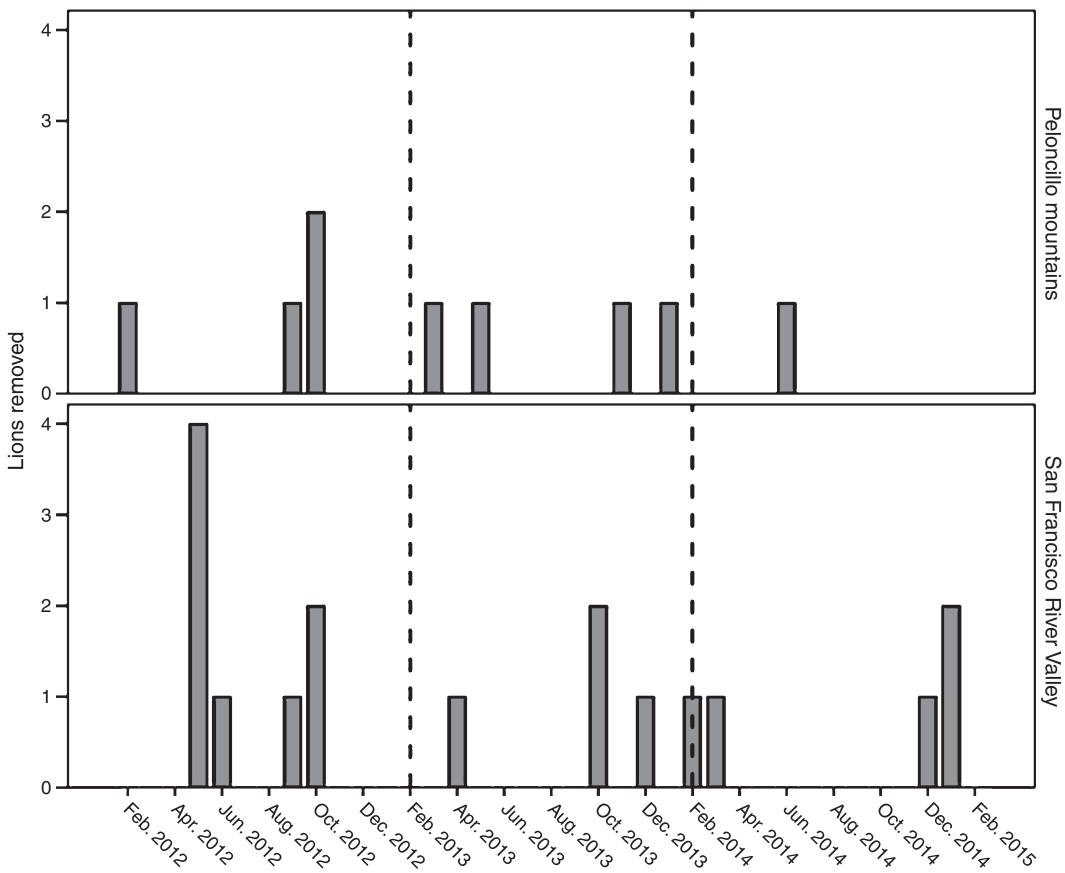

Fig. 2. Monthly mountain lion removals from the Peloncillo Mountains and San Francisco River Valley, New Mexico relative to mule deer translocations. Dashed vertical lines indicate approximate translocation date in 2013 and 2014.

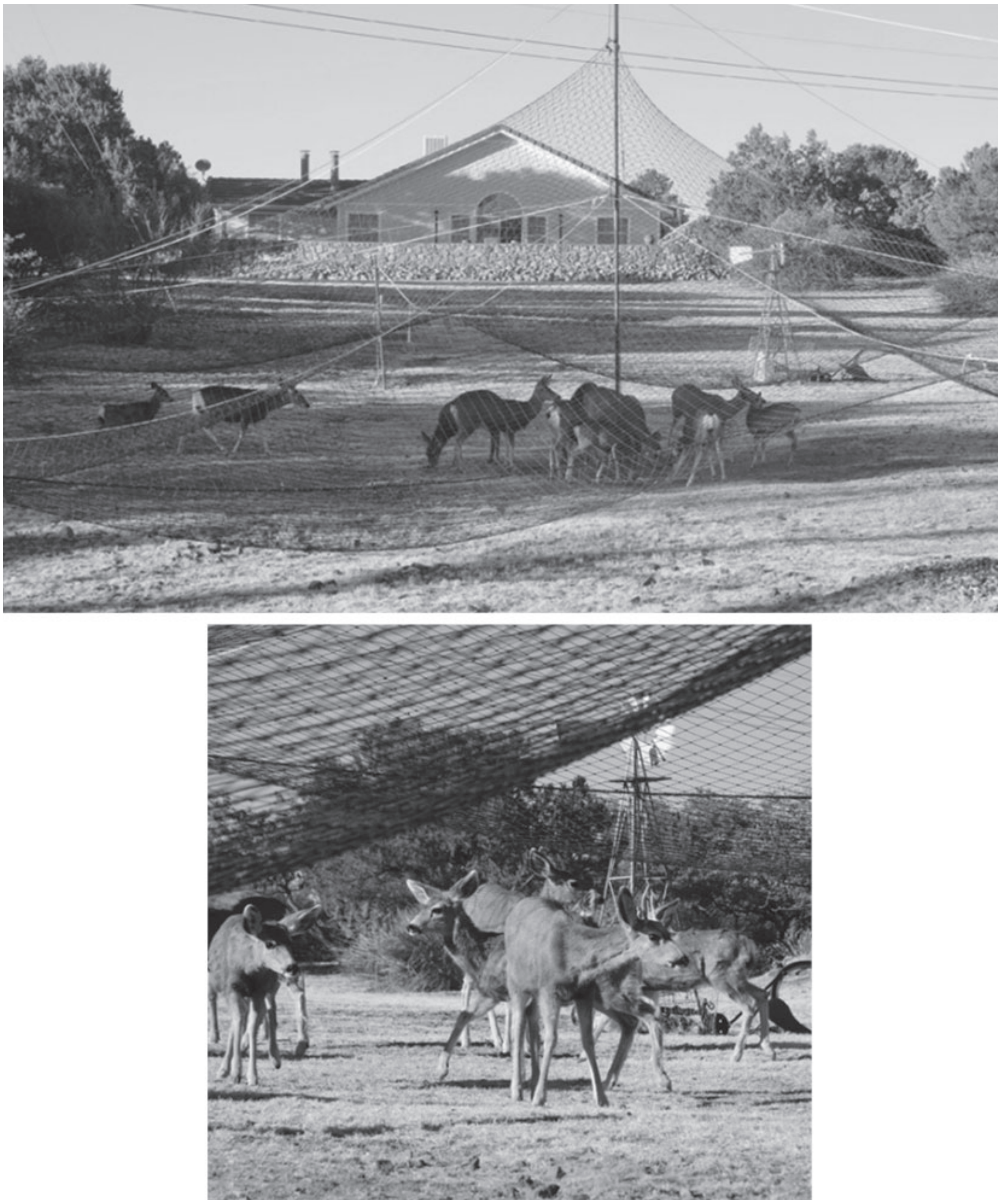

Fig. 3. Mule deer under drop net in Silver City, New Mexico. Photo by New Mexico Department of Game and Fish.

(Oxytetracycline, 8 mg kg), an antiparasitic (Ivermectin, 0.2 mg per kg), and gave most deer a neuroleptic tranquiliser (either Haloperidol: 0.25 mg per kg or Azaperone: 0.5 mg per kg, depending on holding times in the trailers), except when they were to be released <6 hours after capture (e.g. the last deer to fit in a single trailer). We sexed, weighed and classified all deer as adult or juvenile, and visually assessed deer for injuries and external parasites.

In February 2013, we translocated 107 deer (76 females and 31 males). In total, 55 adult females were randomly selected and fitted with either VHF (model V5C 176A, Sirtrack, Hawkes Bay, New Zealand) or GPS telemetry collars (model G2C 181 range, Sirtrack or model G2110B/D, Advanced Telemetry Systems, Isanti, MN, USA); all collars were equipped with a 6-h mortality sensor. When the mortality sensor does not detect collar movement for 6 h, the sensor triggers a doubling of the pulse rate of the VHF transmitter, indicating a potential mortality. As deer were processed, we randomly assigned all sex and age classes to release sites. Only adult females were fitted with telemetry collars, given their importance for population growth. We then transported deer by trailer to either the PM (56 total deer; 27 adult females collared) or SFRV (51 total deer; 28 adult females collared) release areas. Trailers used for translocation were standard livestock trailers with roofs (approximately 6.1 m × 2.1 m × 2.4 m), modified to prevent animals from seeing through the sides of the trailer while still allowing airflow from the top of the trailer sides; the floors of the trailers were padded with straw. Up to 20 unrestrained mule deer were transported in each trailer. In 2013, all deer were hard-released into both translocation areas.

From January to March 2014, an additional 111 mule deer were translocated using the same methods. In total, 64 deer (20 males and 44 females) were captured in Silver City. We caught and translocated an additional 47 (15 males, 32 females) deer from Arabela, New Mexico. In total, 51 adult females (28 in PM and 23 in SFRV) were randomly selected for monitoring and fitted with VHF telemetry or GPS collars. All captured mule deer from Silver City were randomly assigned to a translocation area based on sex and age class. However, deer captured in Arabela were only released in the SFRV. To compare the effects of a soft- versus hard-release on survival, we placed half of each group of deer transported to each release area in a 0.81-ha holding pen enclosed with predator-proof fencing for approximately 3 weeks. We located the holding pens in areas where there was native browse to acclimate the deer to the surrounding location, and provided water and pelleted alfalfa while the deer were in the holding pens. After release, we removed all feed, water and fencing. We immediately hard-released the other half of the translocated deer. All animal capture and handling procedures were approved by New Mexico State University's Institutional Animal Care and Use Committee (protocol #2012-030).

Post-release monitoring and mortality assessment

We monitored collared deer from the ground ≥1 time per week using a vehicle-mounted omni-directional antenna or a hand-held antenna from high points in the translocation areas. We conducted aerial telemetry ≥1 time per month to locate animals whose signals were difficult to hear from the ground, and to locate animals whose collars had not been detected for ≥2 weeks.

We examined mortalities immediately after detecting a mortality signal. We determined cause of death based on the carcass condition and characteristics of the mortality site, including predator sign. We performed a field necropsy if the cause of death was not apparent. We examined the carcass for subcutaneous haemorrhaging, external wounds in skin and soft tissues and inspected internal organs for gross abnormalities. We differentiated predation from scavenging based on presence of subcutaneous haemorrhaging. Characteristics indicative of mountain lion predation included: (1) carcass covered with debris; (2) mountain tracks or scat near the carcass; (3) drag marks; (4) uneaten rumen whether removed from carcass or not; and (5) canine puncture wounds on the neck or head with a canine spacing of approximately 3.8–5.7 cm (Halbritter *et al.* 2008). We distinguished coyote predation by tracks at the carcass site and smaller puncture wound spacing (2.9–3.5 cm; Bowns 1995). We classified mortalities as predation, accidents (e.g. being caught in a barbwire fence), poaching, potential disease or unknown. Characteristics of poaching included animals with bullet wound tracts, carcasses that were skinned and/or telemetry collars cut off (with or without an associated carcass). Animals assigned to the potential disease category were found dead, with no signs of trauma, predation or scavenging. Unfortunately, the mortalities were located 1–2 days after death, precluding collection of viable samples for laboratory analyses. All appeared to be in good body condition and these mortalities occurred during the same time of year (August–September), when blue tongue mortalities are commonly reported in sympatric desert bighorn sheep; confirmed mortalities of desert bighorn sheep due to blue tongue displayed similar characteristics (NMDGF, unpubl. data).

Statistical analyses

We monitored mule deer translocated in 2013 from 15 February 2013 to 15 February 2014, and those translocated in 2014 from 2 February 2014 to 7 April 2015. We used the Kaplan–Meier approach to estimate annual survival rates for each group of translocated adult female mule deer. We did not use staggered entry, because all deer within each translocation group were released at the same time. We censored mule deer that died of known capture myopathy and mortalities of unknown cause that occurred <3 weeks after translocation. We compared survival of mule deer between PM and SFRV in 2013 and 2014 and compared survival of hard- and soft-released deer in 2014 using the log-rank test.

Results

Cause-specific mortality

One deer died and two were euthanised due to injuries sustained during capture in 2013. Following the 2013 translocation, 11% ($n = 3$) of the radio-collared females translocated to the PM died from mountain lion predation, 7% ($n = 2$) died from unknown causes, 4% ($n = 1$) were caught in a fence, 15% ($n = 4$) were suspected to have succumbed to disease (i.e. blue tongue or epizootic haemorrhagic disease) and 4% ($n = 1$) were killed by poachers. In the SFRV, 52% ($n = 13$) of translocated deer were killed by mountain lions, 8% ($n = 2$) died from unknown causes and 4% ($n = 1$) from poaching. Mountain lion predation accounted for 27% of all mortalities in the PM and 81% in the SFRV.

During the 2014 captures, four mule deer died or were euthanised during captures, and three mule deer were censored due to capture myopathy. In 2014, 15% ($n = 4$) of the radio-collared deer died in the PM due to mountain lions and 8% ($n = 2$) died from unknown causes. In the SFRV, 9% ($n = 2$) died from mountain lion predation, 22% ($n = 5$) from unknown causes and 4% ($n = 1$) were caught in a fence. We detected only mountain lions at kill sites, despite the presence of other predators in the translocation areas. For deer translocated in 2014, mountain lion predation was the cause of 67% of the total mortalities in the PM and 25% of the mortalities in the SFRV.

Survival

Survival of mule deer translocated in 2013 was higher in the PM (0.627, s.e. = 0.09) than in the SFRV (0.327, s.e. = 0.10; $\chi^2_1 = 5.84$, $P = 0.016$; Fig. 4). Survival functions for mule deer translocated in 2014 were not different between the PM (0.760, s.e. = 0.09) and SFRV (0.584, s.e. = 0.11; $\chi^2_1 = 1.36$, $P = 0.239$). The survival function for mule deer translocated using a soft-release was not different from hard-released mule deer at either the PM (hard 0.727, s.e. = 0.13 versus soft 0.786, s.e. = 0.11) or SFRV (hard 0.656, s.e. = 0.14 versus soft 0.500, s.e. = 0.16; Fig. 5).

Discussion

Survival of translocated mule deer in our study was lower than that reported for resident mule deer by Forrester and Wittmer (2013) in their review of mule deer survival studies in the western United States (mean survival 0.84, 95%; CI 0.745–0.935). However, some of our higher survival estimates (e.g. 0.79 soft release in PM) were comparable to resident mule deer survival in regions with similar annual precipitation and land cover (0.62–0.91; Bishop *et al*. 2005; 0.59–0.91; Lawrence *et al*. 2004), but lower than reported for much of their range, including areas of northern New Mexico (0.73–0.91, Bender *et al*. 2007; 0.83, Sorensen 2015; see Forrester and Wittmer 2013). Unfortunately, we were unable to estimate survival for resident mule deer in our translocation areas.

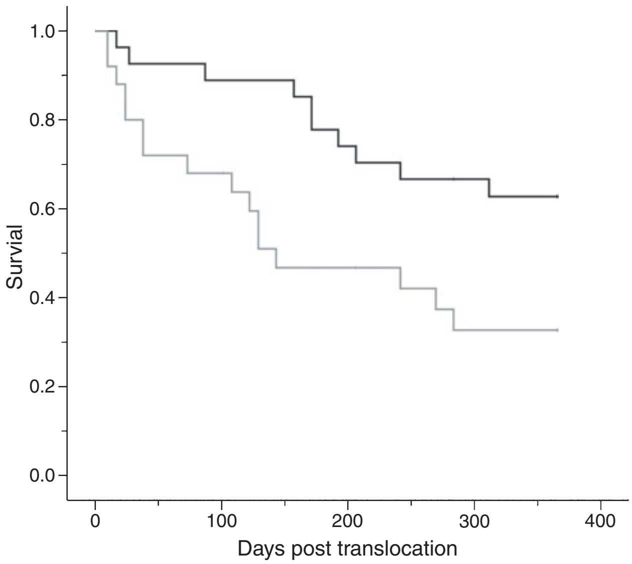

Fig. 4. Kaplan–Meier survival curves for translocated mule deer in the Peloncillo Mountains (black line) and San Francisco River Valley (grey line), New Mexico, 2013.

Some researchers have reported comparable survival rates between translocated and resident animals (Mosillo *et al*. 1999; Moehrenschlager and Macdonald 2003; Foley *et al*. 2008; Bell and George 2012; Woodford *et al*. 2013), whereas others have reported lower survival for translocated animals than for residents (Stussy *et al*. 1994; Reinert and Rupert 1999; Beringer *et al*. 2002; Pinter-Wollman *et al*. 2009). Translocated woodland caribou (*Rangifer tarandus caribou*) in the Selkirk Mountains, Idaho had 20% lower survival than residents (i.e. 0.94 and 0.74; Compton *et al*. 1995). Similarly, survival of translocated white-tailed deer (*Odocoileus virginianus*) in Illinois was less than 50% of resident deer (i.e. 0.34 versus 0.73; Jones and Witham 1990), and translocated elk in Oregon had survival rates 16% lower than residents (0.77 versus 0.92; Stussy *et al*. 1994). Although survival estimates in our study were lower than many estimates from resident mule deer populations, survival rates of our translocated mule deer were similar to or substantially higher than reported for other deer translocation efforts: 0.15 black-tailed deer (*O. h. columbianus*; O'Bryan and McCullough 1985); 0.30 white-tailed deer (*O. virginianus*; Beringer *et al*. 2002); and 0.72 white-tailed deer; Foley *et al*. 2008.

Translocated animals may be more susceptible to predation because they are unfamiliar with the translocation site. Mule deer translocated from urban areas may also have limited experience with these predators, leading to higher predation rates (Jones and Witham 1990; Pietsch 1994). Also, urban deer are not accustomed to locating resources in a more natural setting; they have learned to navigate and find food sources in a human-manipulated environment, potentially reducing their overall post-release survival. Similar to our study, mountain lion predation was the primary cause of mortality for translocated mule deer in Mexico (Ortega-Sanchez 2013) and desert bighorn sheep in New Mexico

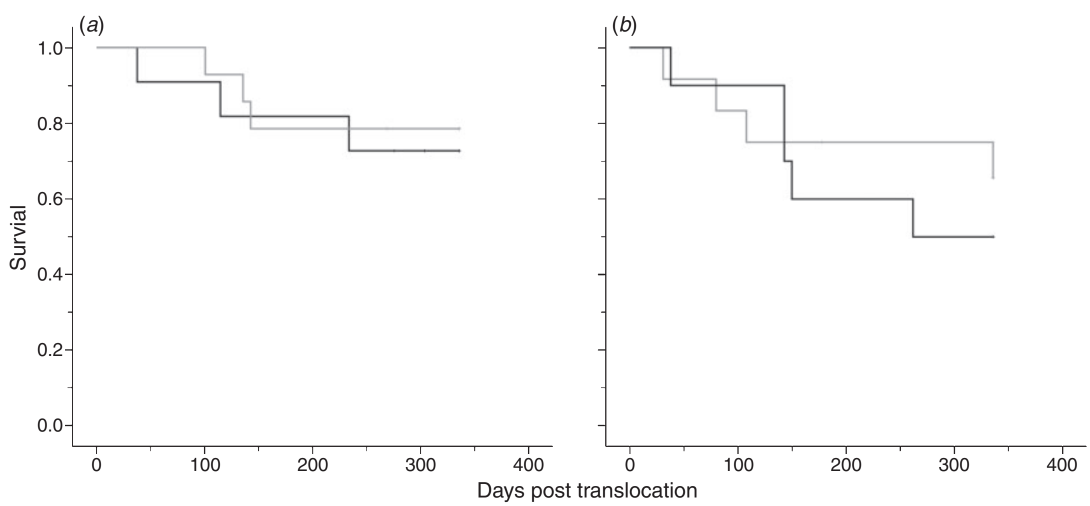

Fig. 5. Kaplan–Meier survival curves for mule deer translocated with a hard-release (black line) and soft-release (grey line) translocated mule deer in the (*a*) Peloncillo Mountains and (*b*) San Francisco River Valley, New Mexico, 2014.

(Rominger *et al*. 2004) and Arizona (Kamler *et al*. 2002; McKinney *et al*. 2006). Despite mountain lions being removed from both study areas, mountain lion predation remained the leading proximate cause of mortality of translocated mule deer. Survival rates of translocated deer were higher the second year, which may be related to cumulative mountain lion removals from both translocation areas, or to the fact that the removal of several lions more closely coincided with the time of the deer translocation in 2014, particularly in the SFRV. Unfortunately, estimates of mountain lion abundance pre- and post-translocation are not available for our study areas, so it is unclear if mountain lion removals reduced lion abundance or if mountain lions immigrating from nearby areas quickly filled vacant home ranges. However, removal of mountain lions in this region has been associated with enhanced survival of sympatric desert bighorn sheep. Mean annual cause-specific mortality rates from mountain lion predation in the sympatric desert bighorn sheep population in PM was 0.22 during periods (1997–99 and 2000–02) without management removal of mountain lions and declined to 0.05 during periods with an active mountain lion removal program (1999–2002 and 2002–11; Goldstein and Rominger 2012).

Survival of translocated animals depends on individuals finding critically important resources such as food, cover and water, and their ability to successfully compete for these resources with resident animals while evading predators in their new environment (Letty *et al*. 2003; Moehrenschlager and Macdonald 2003; Owen-Smith 2003). Forage productivity and nutritional quality are driven by rainfall in arid and semiarid environments (Wallmo 1981; Marshal *et al*. 2005*a*, 2005*b*, Cain *et al*. 2017). During our study, there was considerable variability in annual rainfall at both translocation areas. In 2011 and 2012, the 2 years prior to the first translocation, both areas were in the midst of a drought, with precipitation 41–46% below the long-term average. Both areas experienced average rainfall during 2013 and 2014 (National Oceanic and Atmospheric Administration (NOAA) 2015). A notably wet monsoon season (July–September) occurred in 2013, with a seasonal rainfall 44% (21.4 cm) above the long-term average (14.5 cm). The growing seasons ended several months before the translocations in February and March. Drought conditions during the growing season prior to the first translocation (i.e. 2012) would have resulted in lower forage production, and animals released in February 2013 would have had to survive the remainder of the winter (December – February) and spring (March –April) until the next growing season on the limited forage that was produced during drought in 2012. An above-average monsoon season in 2013 would have resulted in higher levels of forage abundance. Animals released in February and March 2014 would likely have access to better foraging conditions than deer released the first year. The increase in rainfall likely increased availability and nutritional quality of forage, potentially contributing to the higher survival of translocated deer following the second translocation.

Use of a soft-release pen did not enhance survival of translocated mule deer in our study, in contrast to reports from other translocation efforts. Mule deer translocated to northern Coahuila, Mexico, were reported to have higher survival (S = 0.84) when soft-released compared with those that were hard-released (S = 0.57; de la Luz Martinez Garcia 2009). Parker *et al*. (2008) also reported a relatively high survival rate (S = 0.80) for Florida Key deer (*Odocoileus virginianus clavium*) following a soft- release. Similar results have been reported for translocations of other species including dormice (*Muscardinus avellanarius*), wild rabbits (*Oryctolagus cuniculus*), burrowing owls (*Athene cunicularia*) and collared peccary (Bright and Morris 1994; Letty *et al*. 2000; Porter 2006; Mitchell *et al*. 2011). However, other studies did not demonstrate an effect of release method on survival (Armstrong and Seddon 2008; Teixeira *et al*. 2007; Woodford *et al*. 2013; de Milliano *et al*. 2016).

Few studies have investigated the effects of holding time or pen size on survival of translocated animals (Franzeb 2004; Jenni *et al*. 2015; Sasmal *et al*. 2015). Thus, optimal pen sizes or holding times for most species is largely unknown. The increased survival among soft-released deer reported elsewhere may be related to the size of the pen and/or the length of time in the holding pen. Our soft-release pens were smaller (i.e. 0.81 ha) and our holding times were shorter (i.e. 3 weeks) than those used for other deer translocation efforts (e.g. 8–11 ha for 12–24 weeks, Parker *et al*. 2008; 16 ha for 12 weeks, Ortega-Sanchez 2013), which may have minimised any potential positive effects of soft-release on survival.

By bolstering populations, translocation of adult females can provide additional opportunities for hunting, through production of male offspring (harvest of female mule deer is prohibited in most of New Mexico), and may contribute to continued persistence of mule deer populations, despite moderate survival rates of translocated animals. Many urban mule deer populations are increasing and this trend is likely to continue due to changes in climate and land-use practices. These urban populations create numerous human–wildlife conflicts, ranging from minor nuisances to public safety issues. The ability to use these overabundant populations to augment declining resident populations is advantageous for wildlife managers.

Management implications

When translocating mule deer in southern New Mexico, a soft-release method using short acclimation period and small pen size did not influence survival. If resources are not available to construct large soft-release pens, management agencies could forgo construction of smaller soft-release pens, thereby saving funds, which could then be used to capture more animals for translocation. Further research is needed to measure differences in survival between local and translocated population segments to determine if survival of translocated animals is lower than that of residents, and to see if there are differences in the causes of mortality. In addition, further studies on how the length of time in soft-release pens affects survival are needed. Differences in the success of the release method may be related to subtleties that we did not assess, such as pen size and duration in captivity.

Conclusions

Translocations of overabundant urban mule deer offer an opportunity to reduce human–wildlife conflict and bolster declining populations outside urban areas. In our study, the confounding influences of cumulative lion removals and increasing precipitation made it difficult to determine the independent and interactive effects of forage conditions and predation pressure on survival of translocated deer. However, translocations may be more successful during periods of average-to-above-average rainfall, with short-term predator removals coincident with translocations, consequently providing good forage conditions while allowing translocated animals to gain knowledge of their new environments with a reduced risk of predation.

Conflicts of interest

The authors declare no conflicts of interest.

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