California Fish and Game 101(3):165-177; 2015

A fortuitous mitigation for desert mule deer along the All-American Canal

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We studied mule deer (*Odocoileus hemionus*) presence associated with the All-American Canal (AAC) before, during, and after the U.S. Bureau of Reclamation and Imperial Irrigation District replaced a 36.8-km section of the earthen canal in Imperial County, California with a concrete-lined canal. The concrete-lined canal had steeper sides and higher water velocities than the unlined canal, increasing the risk of mule deer drowning in the canal. Our objective was to determine if the concrete-lined canal had an effect on the occurrence of mule deer along the AAC based on observations, aerial surveys, track plots, and camera traps. We examined deer presence at the AAC prior to lining (2004–2006), during lining (2007–2009), and post-lining (2010–2014). We monitored 1-m^2 track plots north and south of the AAC from 2004 to 2010. We did not find deer south of the canal and deer were rarely found north of the canal from December to April; thus, during 2011–2014, we monitored areas north of the canal from May to November. We also monitored deer at two mitigation catchments (established based on the first years of the study), one previously established catchment, and a sheet pile seam (i.e., 6-m wide gap or seam where the canal has a piece of sheet metal covered with rip-rap rock and dirt instead of cement) that deer used to access the canal. During the pre-lining phase, only one deer was reported near the canal. During the lining-phase we detected deer in a small area north of and adjacent to the canal. There were occasional observations of deer: three that drowned and two that were rescued from the canal. During the post-lining phase we documented continued deer presence at the canal and mitigation catchments. One deer drowned in the canal and one was rescued. The number of deer tracks at the canal remained consistent from 2008 to 2010 and from 2011 to 2014 as did the number of photos; thus, the mitigation catchments did not reduce deer use of the canal. We recommend that the sheet pile seam deer use to access the canal be maintained and kept free of vegetation. Further, we conclude the development of water catchments for this small population of deer crossing sand dunes to acquire water was not necessary. Deer use of the sheet pile seam was unanticipated and fortuitous for deer attempting to acquire water from the AAC.

Key Words: All-American Canal, California, drowning, mitigation, mule deer, *Odocoileus hemionus,* water catchments

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Population growth and infrastructure development in the western United States depend on the availability of water. Over 12,000 km of canals carry water from rivers and reservoirs to industrial, residential, and agricultural users in California. Unfortunately, animals can drown in canals while attempting to cross or drink from them. During the last survey of mortalities of ungulates in canals in the late 1980s, there were ≥21 canals in nine western states and one Canadian province where ≥10 deer (*Odocoileus* spp.) drowned/year (Rautenstrauch and Krausman 1986). In 1977 and 1978, an average of 259 deer and five elk (*Cervus elaphus*) drowned in 22 U.S. Bureau of Reclamation (USBR) canals. More than 95% of ungulates that drown in USBR canals are deer (Latham and Verzuh 1971, Rautenstrauch and Krausman 1986). Other native ungulates that drowned in canals include pronghorn (*Antilocapra americana*), including endangered Sonoran pronghorn (*A. a. sonoriensis*; Arizona Game and Fish Department 1981), and bighorn sheep (*Ovis canadensis*). Ungulates also drown in concrete-lined canals in Europe (Peris and Morales 2004).

Besides causing additional mortalities, canals interfere with ungulate populations because they disrupt seasonal dispersal or daily movements and are attractive nuisances that can result in death (Busch et al. 1984, Fry 1984, Krausman and Hervert 1984). Deer have been entrapped in canals when dispersing (Menzel 1966, Shult 1968), or moving between agricultural fields (Gatz et al.1984), forage plots (Michny and McKevitt 1982), or to canals for water (Guenther et al. 1979, Michny and McKevitt 1982, Krausman and Hervert 1984).

Deer drown more often in canals during summer (Krausman 1985), although some investigators have reported high mortality rates from canals in November and December (Furlow 1969). Busch et al. (1984) reviewed canal design features and operation procedures that prevent trapped deer escaping from canals. Most canals in which deer drowned had concrete-lined side slopes of 2:1 or greater. Mud and algae on concrete canal walls often make it difficult for deer to escape, even when the water level is high (E. A. Seaman, U.S. Bureau of Reclamation, in litt., 1977). Deer also have trouble escaping from concrete-lined canals when the water velocity is too fast or too slow (Menzel 1966, Guenther at al. 1979, Busch et al. 1984, Fry et al. 1984). Further, water depth influences survival of deer that fall into canals (Boulders and Bailey 1980). Due to mortalities, biologists have worked with irrigation districts to minimize drownings.

There are two ways to prevent deer from drowning in canals: exclude them from the canal or provide a way for them to escape from the canal after entering. Some authors have concluded that excluding deer from entering canals is the most effective way to prevent drowning (Gubser 1960, Shult and Menzel 1969, Krausman 1985), but this is not always possible. Busch et al. (1984) identified three ways to prevent and discourage deer from entering canals: fencing, building crossing structures, and providing alternate water sources. Each of these options presents challenges. Fencing is expensive to construct and maintain, and may prevent deer from crossing canals, thereby disrupting migratory movements. Deer crossings have been constructed at many canals to prevent movements from being disrupted and are often successful (Gubser 1960, Latham and Verzuh 1971, Boulders and Bailey 1980, Krausman 1985). Alternate water sources built adjacent to some canals may also have contributed to decreased losses of deer (Rorabaugh and Garcia 1983).

Where methods used to prevent deer from entering a canal have failed or were impractical to implement, structures (i.e., metal grates, ladders, ramps) have been developed to help deer escape from canals, but with limited success (Gubser 1960, Shult and Menzel 1969, Boulders and Bailey 1980). With few exceptions (Richmond ramps; Fry et al. 1984), all of these examples demonstrate the importance of keeping deer out of canals.

The All-American Canal (AAC) is an important water delivery system for agriculture and power generation in the Imperial and Coachella Valley, California (Schaefer and O'Neill 2001). The AAC was built when the Boulder Canyon Project of 1928 was signed into law. It is owned by the USBR but the Imperial Irrigation District (IID) is responsible for maintenance and operation. To conserve water in the AAC (approximately 83,500,000 m^3/year), the USBR and IID replaced the existing earthen canal with a concrete-lined canal parallel to

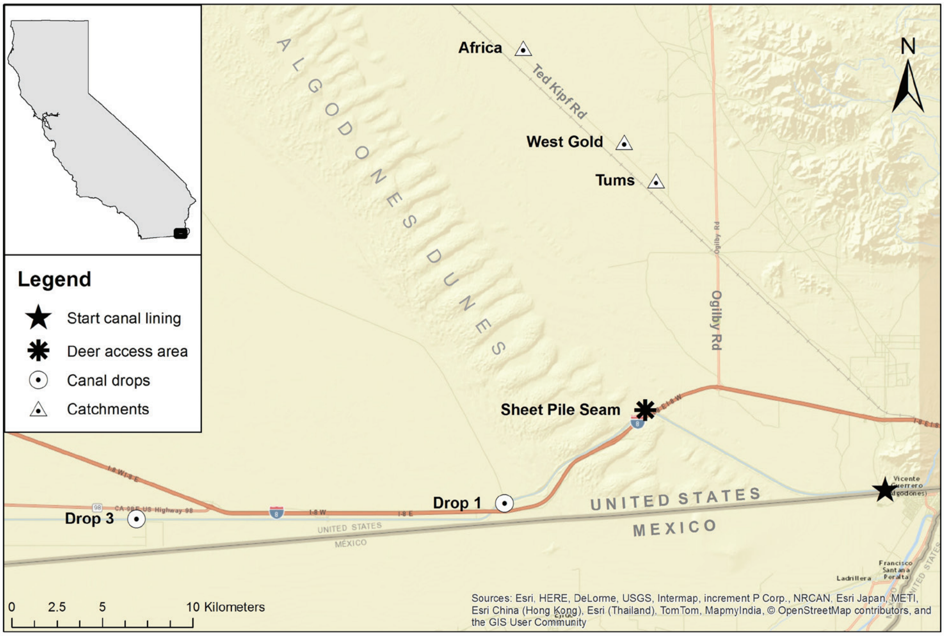

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FIGURE 1.—Section of the All-American Canal, Imperial County, California that was concrete-lined from Pilot Knob to Drop 3, including locations of the sheet pile seam (used by deer to access the canal for water), mitigation catchments (Africa and Tums), and West Gold, a previously established catchment.

the existing canal (Figure 1). In June 2004, the IID issued an Environmental Commitment Plan and Addendum to the 1994 Environmental Impact Statement-Environmental Impact Report that included provisions to minimize deer mortality, as required by law.

The new concrete-lined canal has steeper sided slopes and water moves at higher velocities than in the unlined canal. Both conditions could cause higher risk of drowning to mule deer (*Odocoileus hemionus*) that attempt to drink from or attempt to cross the canal (Imperial Irrigation District 2004) and could be problematic because the population of deer in the Sonoran Desert of southeastern California is one of low density and is popular with hunters and recreationists (Thompson and Bleich 1993). Our objectives were to determine the presence of deer in the area where the canal was lined and if mitigation catchments minimized deer approaches to the AAC because of the added sources of water.

Materials and Methods

Study area.—The AAC lining project was in the Sonoran Desert, Imperial County, California, near the international border with Mexico (Figure 1). The AAC was lined for 36.8 km from 1.6 km west of Pilot Knob (32°43’04.6” N, 114°45’15.3” W) to Drop 3 (32°42’19.3”N, 115°07’30.8”W). The AAC originates at Imperial Dam on the Colorado River and flows westward into the Imperial Valley (Bransfield and Rorabaugh 1993). In the nearly 90 years since the canal’s construction, deer have likely been in the general area, albeit in small and fluctuating numbers (Marshal et al. 2002, Marshal 2005, Marshal et al. 2006b).

The climate is arid with daytime summer temperatures >45° C and low annual rainfall ($\bar{x}$ = 70 mm in Imperial County, California; Marshal 2006b). Vegetation is typical of the Lower Colorado River Valley Subdivision of Sonoran Desert Scrub (Brown 1994). There are three main vegetation associations: creosote bush (*Larrea tridentata*) scrub, psammophytic scrub, and microphyll woodland. Creosote bush scrub is the most common, and additional typical plant species include brittlebush (*Encelia farinosa*) and burrobush (*Ambrosia dumosa*). Psammophytic scrub occurs in the dune system and the vegetation is adapted to shifting sand. Typical vegetation includes Mormon tea (*Ephedra nevadensis*), buckwheat (*Eriogonum deserticola*), desert twinbugs (*Dicoria canescens*), sandpaper plant (*Petalonyx thurberi*), desert panicgrass (*Panicum urvilleanum*), and fanleaf crinklemat (*Tiquilia plicata*). Microphyll woodland occurs on the alluvial fan along or within drainages from the East Chocolate Mountains and Cargo Muchacho Mountains that are north of the canal. Typical vegetation includes blue palo verde (*Parkinsonia florida*), desert ironwood (*Olneya tesota*), and smoke tree (*Psorothamnus spinosus*; Andrew 1994, RECON Environmental 2009).

Methods.—Our surveys consisted of track and road plot preparation and inspection, aerial surveys, camera traps, and contacts with regular users of the area (e.g., canal maintenance personnel, Border Patrol personnel, California Fish and Game wardens, Bureau of Land Management personnel). Additionally, we examined IID files related to deer in the project area.

The study was conducted in three phases: pre-lining (November 2004 through 2006), lining (2007–2009), and post-lining (2010–November 2014). The post-lining phase began when lining was complete and water had been transferred to the lined canal. During the pre-lining and lining phases, we surveyed the project area weekly for deer using road surveys and track plot surveys, and monthly aerial surveys from a Cessna 172 (Krausman and Etchberger 1993). We surveyed the project area weekly using 1-m^2 track plots (Popowski and Krausman 2002) set ≤3 km north and south of the AAC that were randomly selected but adjacent to roads (i.e., all roads were numbered and then selected from a random number generator). We checked for any tracks or pellets present, and cleared the plots by raking. We conducted observations of the landscape from the top of Pilot Knob (267 m; the highest elevated peak in the study area) to detect deer. We conducted road surveys by driving <25 km/hr along >56 km of roads (all of which had sandy substrate suitable for detecting tracks) to detect deer or deer sign (i.e., tracks or pellets). The roads were also dragged with tires by the Border Patrol to detect illegal border crossing activity in the area; dragged roads were also useful for detecting animal tracks.

Aerial surveys were conducted with a pilot and two observers flying 150 m above ground level at 130 knots. The area surveyed by air included Pilot Knob along the AAC west to Drop 3 as the southern boundary, then west along the Algodones Dunes, north to the railroad tracks north of the AAC that run parallel to Ted Kipf Road, and east to Ogilby Road (Figure 1). Deer tracks could easily be observed on sand dunes in the morning; thus, we also looked for deer and deer tracks when flying over the dunes.

There was a patch of vegetation (1 km × 0.5 km in size; hereafter referred to as the deer use area [DUA]) north of the AAC and west of the Interstate Highway 8 (I-8) bridge (32°44’59.9” N, 114°52’09.8” W) crossing the AAC. We surveyed the DUA because it became clear in the first few years of study that deer only crossed at this small patch when travelling from the north to the canal.

We established a road survey immediately adjacent to the AAC 0.64 km east of the I-8 bridge and continuing for 0.96 km west of the bridge on the road above the canal. This embankment above the canal was not as disturbed as the road immediately adjacent to the canal, which was used by canal workers on a near daily basis. We also searched for deer tracks along the canal to Test Hill, 3.0 km west of the bridge, by driving <25 km/hour with an observer verifying and counting the number of times tracks crossed the road. We used the number of tracks as an index of deer presence across years.

We could not maintain the same track plots and road surveys throughout the study because of AAC construction activity, illegal border crossing activity, recreationists (i.e., off-road vehicles), and we obtained a better understanding of areas used by deer as the project progressed. Thus, we ceased observations from Pilot Knob and weekly track plot inspections in April 2010 during the post-lining phase when many plots could not be maintained or it had been determined that they were in areas not used by deer. We also ceased monthly aerial surveys in April 2010 because of our increased knowledge of deer use of the project area.

During the post-lining phase, we changed our methods to detect mule deer use of the canal due to information obtained during the previous stages. Because evidence of deer was not observed south of the AAC during the pre-lining or lining phases we concentrated our searches north of the canal during the post-lining phase. We continued monitoring the road survey route near the I-8 bridge crossing that had been established in September 2007 after identifying deer tracks in the area from track plot surveys, and maintained those surveys throughout the duration of the study. We used ANOVA to compare the number tracks detected from 2008 to 2010 and from 2011 to 2014.

We also created track plots at two water catchments constructed during summer 2010, Tums (32°50’47.5”N, 114°52’04.0”W) and Africa (32°54’06.3”N, 114°56’01.4”W) in response to concerns regarding deer presence at the AAC. Those catchments were established in an effort to reduce movement of deer to the AAC by providing alternate sources of water. We also monitored another catchment constructed in 2000, West Gold (32°51’45.0”N, 114°53’01.2”W), which was between the two newly installed water catchments (Figure 1). We created track plots by raking the substrate around water catchments that deer would have to move through when going to water.

In addition to counting tracks on roads and determining deer presence at the catchments, we set up camera traps (DV-7SS, Leaf River Outdoor Products, Taylorsville, MS; Stealth Cam STC-AD3, Stealth Cam, Bedford, TX; Bushnell XLT Model 119456, Bushnell Outdoor Products, Overland Park, KS; Reconyx Hyperfire PC850, Recoynx, Holmen, WI) at the mitigation catchments and a sheet pile seam (i.e., a 6-m wide gap or seam where the canal has a piece of sheet metal covered with rip-rap rock and dirt instead of concrete; 32°45’03.2”N, 114°52’23.6”W) along the AAC. Cameras were set up 10 m from the water sources and were programed to take 1–3 photos each time a deer approached water; we could not distinguish between individual deer except on two occasions. We used the number of deer counted in photos as an index to compare across sites and time. We used ANOVA to compare deer presence based on photos between years at water sources (i.e., the AAC and catchments) and between water sources.

We continued weekly track surveys the first year of post-construction until 31 December 2010. We documented most deer presence from May to November from 2007 to 2010; beginning in 2011 we reduced weekly surveys to biweekly surveys from May to November that continued until the end of the project in November 2014.

RESULTS

During the pre-lining phase (November 2004 to December 2006), only one deer was observed in the study area. A deer was photographed by IID personnel on the AAC roadway at Drop 1 (32° 42’ 43.0” N, 114° 56’ 34.9” W) in July 2006. This was the first documentation of deer near the canal during this study. We observed no other deer from the air or ground. We found no tracks or pellets present in our track plots or during road surveys, and we did not receive any reports of deer from other individuals working in the study area.

We first detected deer near the AAC on track plots north of the AAC and I-8 in the DUA beginning in June 2007 (during the lining phase). From June 2007 through 2008, we observed deer or deer tracks and sign in the DUA with the exception of December 2007 to May 2008 (Table 1). In 2009 we first documented deer tracks in February but, overall, we did not find deer or deer sign in the area until May. More deer tracks were observed from August to November than other months, with the most recorded in November 2009 (n = 533). We did not detect an annual difference in the number of tracks counted from 2008 to 2010 ($F_{2,33}$ = 0.78, SE = 118.43, P = 0.47). We included 2010 because that was the last year of weekly monitoring throughout the year; thence, monitoring was performed twice each month from May to November.

Deer observations during the lining period were rare. We observed deer only four times in 2007, and one time each in 2008 and 2009. Deer were also occasionally seen near the mitigation catchments, and there were four other incidents involving deer that the AAC reported to us during the lining phase (P. R. Krausman and M. E. Bucci, Imperial Irrigation District, in litt., 2014).

Table 1.—Mule deer tracks and number of deer photographed located north of the All-American Canal (AAC), Imperial County, California at the junction of the canal and Interstate Highway 8 bridge. Tracks were counted 0.64 km east of the I-8 bridge along the canal, and 0.96 km to the west on the embankment above the canal. Photographs were taken at a sheet pile seam (32° 45’ 03.2” N, 114° 52’ 23.6” W).

	Lining phase			Post-lining phase								
Month	2007	2008	2009	2010	2011 Tracks	2011 Deer	2012 Tracks	2012 Deer	2013 Tracks	2013 Deer	2014 Tracks	2014 Deer
January		0	0	56								
February		0	4	0								
March		0	0	0								
April		0	0	0								
May		25	30	0	0		6	9	7	14	6	0
June	N/A[a]	83	45	0	0		32	37	0	2	66	31
July	N/A	227	149	129	2		45	52	21	22	43	56
August	N/A	332	159	291	218	28[b]	0	0	152	189	4	19
September	13	150	110	13	89	80	0	0	11	4	0	1
October	74	144	27	0	13	42	2	3	1	3	38	58
November	99	151	533	0	0		2	0	12	6	0	6
December	0	10	51	0								

[a] Deer tracks and pellets first observed north of I-8 where the canal goes under the freeway the first time west of Pilot Knob. There was no standardized method for counting tracks adjacent to the canal until September 2007.

[b] Start of camera monitoring.

Table 2.—Track observations (T; Y = deer tracks present, N = no deer tracks present) and number of deer (D) photographed at the Tums (Tu; 32° 50’ 47.5” N, 114° 52’ 04.0” W) and Africa (Af; 32° 54’ 06.3” N, 114° 56’ 01.4” W) water catchments north of the All-American Canal, Imperial County, California, 2010–2014.

	2010		2011				2012				2013				2014			
Month	T Tu	T Af	T Tu	D Tu	T Af	D Af	T Tu	D Tu	T Af	D Af	T Tu	D Tu	T Af	D Af	T Tu	D Tu	T Af	D Af
January																		
February																		
March																		
April																		
May			N		N		Y	7	Y		Y	10	Y	6	Y	45	Y	12
June	N[a]	N[a]	Y		Y		Y	17	Y		Y	13	Y	4	Y	75	Y	35
July[c]	N	N	Y	3[b]	Y		Y	3	N		Y	3	Y	31	Y	15	Y	34
August	N	Y	Y	1	Y	5[b]	N	0	Y	2	Y	0	Y	168	Y	25	Y	33
September	N	Y	N	1	Y	76	N	0	N	2	Y	9	Y	8	Y	22	Y	16
October	N	Y	N	0	Y	78	N	0	Y	36	Y	9	Y	35	Y	26	Y	209
November	N	Y	Y		Y		Y	0	Y		Y	0	Y	13	Y	126	Y	161
December	Y	Y																

[a] First track observations made.

[b] Start of camera trap monitoring.

[c] Africa catchment was broken and empty 11 July-26 July 2010.

Deer presence generally started off slow, gradually increased until August and then decreased until November. We found no annual difference in the number of tracks counted from 2011 to 2014 ($F_{3,24}$ = 0.52, *SE* = 52.01, *P* = 0.68). We obtained a similar result with the number of deer photos captured at the AAC from 2012 to 2014 ($F_{2,18}$ = 0.36, *SE* = 43.86, *P* = 0.70).

Based on the number of photos from the Tums catchment, deer presence increased in 2014 from 2012 and 2013 ($F_{2,18}$ = 7.65, *SE* = 23.58, *P* = 0.004; Table 2). Deer presence remained consistent in 2013 and 2014 at the Africa catchment ($F_{1,12}$ = 0.81, *SE* = 69.77, *P* = 0.39; Table 2). Deer presence was similar between Tums catchment and the AAC in 2012 ($F_{1,12}$ = 1.60, *SE* = 15.68, *P* = 0.23) and also between Tums and Africa catchments and the AAC in 2013 ($F_{2,18}$ = 2.03, *SE* = 60.63, *P* = 0.16).

We suspected that the West Gold catchment received more use than the mitigation catchments because we observed more tracks surrounding West Gold than the newer Tums or Africa catchments. We observed tracks at West Gold from April 2009 (when we began to monitor the West Gold catchment) to January 2010 and again beginning in June 2010 through the end of the year. From 2011 to 2014, we observed tracks during every month that we monitored except May 2011. In 2014 we documented 1,267 deer from photos ranging from 109 (September) to 294 (November). We also photographed more deer at West Gold than at the other two catchments and the AAC ($F_{3,24}$ = 7.71, *SE* = 63.56, *P* = 0.001) in 2014.

The cameras also took photos of one uniquely marked deer at the catchments and at the canal, demonstrating that some deer continued to use the both the canal and catchments as water sources. Furthermore, a collared female was photographed at the Africa catchment in September and October of 2011. The only known investigator that collared deer in the area was Marshal (2005) and deer using the AAC and mitigation catchments were likely from the same population.

DISCUSSION

During the first two years of the study, only one deer was observed along the canal that was to be lined. This was not unusual as the canal traversed sand dunes that are not considered deer habitat. Mule deer occupy washes (Krausman et al. 1985) in desert habitats and bajadas east of the Algodones Dunes and occupy mountain ranges and riparian zones along the Colorado River (Marshal et al. 2006a). However, in a recent study of mule deer in the Sonoran Desert of southeastern California (33° 00’ N, 114° 45’ W) none of the >34 deer that were captured and radio-collared in the East Chocolate and Cargo Muchacho mountains north of the AAC ever approached closer than 5 km of the ACC (Marshal 2005, Marshal et al. 2002, Marshal et al. 2006b). Deer in the project area likely come from the mountains north of the AAC as we occasionally obtained photographs of collared deer from studies by Marshal (2005) and Marshal et al. (2002, 2006a, 2006 b). Deer use of the study area is likely minimal because, in general, it does not contain the habitat components required by mule deer.

Deer eventually were documented at the AAC at a single site that offered access to the canal from which to drink, the sheet pile seam. Deer in deserts often have home ranges >90 km^2 (Krausman and Etchberger 1993, 1995) that include numerous sources of water and other resources (McNab 1963, Krausman 1985, Rautenstrauch and Krausman 1989, Hayes and Krausman 1993); deer using the AAC surely used other sources of water, and the area is likely used for short periods to obtain water from the AAC. We did not collect any data on the movements of deer or of their use of surrounding parts of the landscape, so our conclusions are based only on evidence of deer presence at the DUA, sheet pile seam, the mitigation catchments, and the West Gold Catchment. The West Gold catchment, established in 2000, was probably more familiar to deer than either of the mitigation catchments (Tums and Africa), which did not reduce deer use of the canal from 2011 to 2014. We were able to determine presence of deer near the AAC and the mitigation catchments, but could not measure the importance of those catchments to the deer using them. Based on photographs and tracks, we concluded the mitigation catchments were not effective in reducing deer use of the canal.

We collected data in the same manner in the lining and post-lining phases. Some plots had to be moved due to safety concerns associated with illegal border activity, but were replaced with others. During the lining phase, however, heavy equipment precluded systematic data collection because plots were often destroyed by construction activity and, thus, were relocated to different areas. Deer crossing the canal came from the north and, to our knowledge, are the only deer that have been reported south of the AAC during this study. It is unlikely deer entered the study area from the south because of the fence along the international border between the United States and Mexico that parallels the ACC in the study area.

The study began in 2004, but deer were not detected until 2007. Although we have no information to suggest why deer apparently did not use the area, we suggest they were never abundant even if present. Presence of deer was, however, detected later in the lining phase as well as during the post-lining phase of the study. During 2008, no evidence was recorded until May; use peaked in August and remained consistent from September through November, but declined again in December. More tracks were detected in November 2009 than in any other month. Our track results in 2009 paralleled the number of drowning deaths reported by Furlow (1969) in the Mohawk Canal, Arizona but were not consistent with our later results. Overall, more deer visited the canal from July to November than in other months.

There was very little rainfall in 2009 compared to other years. For example, there were approximately 7, 2, and 8 cm of rain in 2008, 2009, and 2010, respectively (National Climatic Data Center; http://www.necd.noaa.gov/). The high number of tracks recorded likely reflects increased movement to the canal for water by ≥1 group of deer, but not necessarily by additional deer. There was also intense construction activity at this time that may have caused increased rates of movement to and away from the AAC.

Why we began to detect deer near the AAC during the lining phase is unknown. One possibility was the limited scope of the study. We were interested only in deer that were present in areas adjacent to the canal. Because we did not know how many deer were in the area, where the population obtained water, the availability of water for deer outside of this limited study area, or the home ranges of deer using the AAC, we did not have the information necessary to make broader inferences.

Mortality from deer falling in the canal and drowning was not a major issue during this study. During 10 years of monitoring, four deer drowned and three were rescued from the canal. The mitigation waters were used, but some deer that used those catchments also used the canal. Photographs of naturally marked deer at the canal and at the catchments supported our conclusion that the mitigation catchments did not “short-stop” deer movements to the AAC during this study.

Marshal et al. (2006b) estimated that population densities from 1999 to 2004 ranged from 0.05–0.13 deer/km^2. Ungulate populations in deserts are generally small and additional mortality (e.g., from drowning) is usually additive (Krausman 1985, Krausman and Leopold 1986). Nevertheless, creating additional water sources to mitigate for the loss of the AAC as a water source was not supported by our data. Deer used the mitigation catchments but continued to use the AAC as well. Because biologists do not want deer to use the area adjacent to the AAC, establishing water catchments near or adjacent to the canal was not recommended (Krausman 2009, Imperial Irrigation District Interim Report, in litt. 2009). The creation of the mitigation water sources between the AAC and the mountains to the north likely did not serve the intended purpose of precluding deer from travelling to the AAC, as several existing water sources that were used by deer already were available. Indeed, some deer continued to use the AAC and use of the canal did not decrease significantly once the two new water catchments were constructed.

In summary, deer use the AAC north of I-8 and some have died accessing the canal, albeit only a few. To eliminate mortality from the canal, the canal would have to be fenced from Test Hill to Ogilby Road (Figure 1). We do not think this is a reasonable management approach if managers are willing to accept mortalities from time to time as documented herein. It is important, however, to maintain the design feature (referred to as the sheet pile seam) that deer use to access the AAC.

The sheet pile seam is the only section of the canal where we documented any use during this investigation. Although it was not planned to offer deer safe passage to the cement-lined AAC, it has been a design element that has minimized deer drownings and may be useful in other canals. Because the sheet pile seam is not concrete-lined, however, vegetation that grows through the rip-rap must be continually trimmed to offer safe access to the AAC. Finally, and in the interest of conserving limited dollars for conservation, our results suggest that mitigation to offset impacts to deer be considered in the context of population-level impacts rather than out of concern for the loss of individual animals.

ACKNOWLEDGMENTS

V. Bradshaw, K. Hutchinson, R. Powell, and M. Remington of the IID assisted with technical advice and direction. L. Franks assisted with administration of the contract. C. P. P. Reid and E. Sanders provided the opportunity for us to work on this project while at the University of Arizona and P. Brown and J. Birchfield provided the opportunity to work on the project while at the University of Montana. L. Lesicka generously provided us with several cameras for use during the study. R. Ethington expertly maneuvered the fixed wing aircraft during aerial surveys. Keiwit Construction generously provided us with information and assistance while in the field. J. Derbridge assisted with the figure and helping us in the field. E. Loft, V. Bleich, and an anonymous referee provided valuable insight to an earlier version of this paper. This study was funded by the IID, the University of Arizona, and the Boone and Crockett Program at the University of Montana.

LITERATURE CITED

ANDREW, N. G. 1994. Demography and habitat use of desert-dwelling mountain sheep in the East Chocolate Mountains, Imperial County, California. M.S. Thesis, University of Rhode Island, Kingston, USA.

ARIZONA GAME AND FISH DEPARTMENT. 1981. The Sonoran pronghorn. Special Report No. 10. Arizona Game and Fish Department, Phoenix, USA.

BOULDERS, J., AND J. BAILEY. 1980. Big game loss monitoring study: Navajo Indian Irrigation Project. Final Report contract number 7-07-50-VO959. U.S. Bureau of Reclamation, Amarillo, Texas, USA.

BRANSFIELD, R., AND J. RORABAUGH. 1993. Final Fish and Wildlife Coordination Act Report, All-American Canal lining project, Imperial County, California. U.S. Bureau of Reclamation, Lower Colorado Region, Boulder City, Nevada, USA.

BROWN, D. E. (EDITOR). 1994. Biotic communities: southwestern United States and Northwestern Mexico. University of Utah Press, Salt Lake City, USA.

BUSCH, D. E., J. C. RORABAUGH, AND K. R. RAUTENSTRAUCH. 1984. Deer entrapment in canals of the western United States: a review of the problem and attempted solution. Pages 95-100 *in* P. R. Krausman and N. S. Smith, editors. Deer in the southwest: a symposium. School of Renewable Natural Resources, University of Arizona, Tucson, USA.

FRY, E. M., V. L. WYMAN, AND E. H. YOEMAN. 1984. A method for evaluating the effectiveness of a deer protection system on a concrete-lined canal with comments on planning these systems. Pages 647-658 *in* A. F. Crabtree, editor. Third international symposium on environmental concerns in rights-of-way management. Mississippi State University, Mississippi State, USA.

FURLOW, B. 1969. The Wellton-Mohawk Canal incident. Arizona Wildlife Views 12(2):22-25.

GATZ, T., G. BRUCKER, W. OTTO, S. ROTHE, AND D. ORTHMEYER. 1984. Wildlife use of an irrigation canal rights-of-way in the prairie pothole region of North Dakota. Pages 630-639 *in* A. F. Crabtree, editor. Third international symposium on environmental concerns in rights-of-way management. Mississippi State University, Mississippi State, USA.

GUBSER, C. E. 1960. An inquiry into the effects of reservoirs and canals on big-game migrations. Proceedings of the Annual Conference of the Western Association of State Game and Fish Commissioners 40:42-52.

GUENTHER, H. R., F. P. SHARPE, AND P. STRAUSS. 1979. Mule deer losses—Mohawk Canal, Arizona: a problem identified—a solution sought. Pages 642-644 *in* G. A. Swanson, editor. The mitigation symposium: a national workshop on mitigating losses of fish and wildlife habitats. General Technical Report RM-65. U.S. Forest Service, Fort Collins, Colorado, USA.

HAYES, C. L., AND P. R. KRAUSMAN. 1993. Nocturnal activity of female desert mule deer. Journal of Wildlife Management 70:197-201.

IMPERIAL IRRIGATION DISTRICT. 2004. Environmental commitment plan and addendum to the All-American Canal Lining Project EIS-EIR. California State Clearinghouse Number SCH90010472. Imperial Irrigation District, Imperial, California, USA.

Krausman, P. R. 1985. Impacts of the Central Arizona Project on desert mule deer and desert bighorn sheep. Contract Number 9-07-30-X069. U.S. Bureau of Reclamation, Phoenix, Arizona, USA.

Krausman, P. R., and R. C. Etchberger. 1993. Effectiveness of mitigation features for desert ungulates along the Central Arizona Project. Final Report 9-C5-32-00350. U.S. Bureau of Reclamation, Phoenix, Arizona, USA.

Krausman, P. R., and R. C. Etchberger. 1995. Response of desert ungulates to a water project in Arizona. Journal of Wildlife Management 59:292-300

Krausman, P. R., and J. J. Hervert. 1984. Impacts of the Granite Reef Aqueduct on desert ungulates. Pages 640-646 *in* A. F. Crabtree, editor. Third international symposium on environmental concerns in rights-of-way management. Mississippi State University, Mississippi State, USA.

Krausman, P. R., and B. D. Leopold. 1986. The importance of small populations of desert bighorn sheep. Transactions of the North American Wildlife and Natural Resources Conference 51:52-61.

Krausman, P. R., K. R. Rautenstrauch, and B. D. Leopold. 1985. Xeroriparian systems used by desert mule deer in Texas and Arizona. Pages 144-149 *in* R. R. Johnson, C. D. Ziebell, D. R. Patton, P. F. Ffolliott, and R. H. Hamre, editors. Riparian ecosystems and their management: reconciling conflicting uses. General Technical Report RM-120. U.S. Forest Service, Fort Collins, Colorado, USA.

Latham, H. S., and J. M. Verzuh. 1971. Reducing hazards to people and animals on Reclamation canals. Engineering and Research Center Report Number REC-ERC-71-36. U.S. Bureau of Reclamation, Denver, Colorado, USA.

Marshal, J. P. 2005. Interactions of mule deer, vegetation, and water in the Sonoran Desert. Ph.D. Dissertation, University of Arizona, Tucson, USA,

Marshal, J. P., V. C. Bleich, P. R. Krausman, M. L. Reed, and N. G. Andrew. 2006a. Factors affecting habitat use and distribution of desert mule deer in an arid environment. Wildlife Society Bulletin 34:609-619.

Marshal, J. P, P. R. Krausman, V. C. Bleich, W. A. Ballard, and J. S. McKeever. 2002. Rainfall, El Niño, and dynamics of mule deer in the Sonoran Desert, California. Journal of Wildlife Management 66:1283-1289.

Marshal, J. P., L. M. Lesicka, V. C. Bleich, P. R. Krausman, G. P. Mulcahy, and N. G. Andrew. 2006b. Demography of desert mule deer in southeastern California. California Fish and Game 92:55-66.

McNab, B. K. 1963. Bioenergetics and the determination of home range size. American Naturalist 97:133-140.

Menzel, K. 1966. Deer and the Ainsworth Canal. Nebraska Game and Parks Commission, Bassett, USA.

Michny, F., and J. J. McKevitt. 1982. Tehama-Colusa Canal deer study. Final report. U.S. Bureau of Reclamation, Mid-Pacific Regional Office, Sacramento, California, USA.

Peris, S., and J. Morales. 2004. Use of passages across a canal by wild mammals and related mortality. European Journal of Wildlife Research 50:67-72.

Popowski, R. J., and P. R. Krausman. 2002. Use of crossings over the Tucson Aqueduct by selected mammals. The Southwestern Naturalist 47:363-371.

Rautenstrauch, K. R., and P. R. Krausman. 1989. Influence of water availability and rainfall on movements of desert mule deer. Journal of Mammalogy 70:197-201.

Rautenstrauch, K. R., and P. R. Krausman. 1986. Preventing desert mule deer drownings in the Mohawk Canal, Arizona. Contract Report 9-07-30-X0069. U.S. Bureau of Reclamation, Boulder City, Nevada, USA.

RECON Environmental, Inc. 2009. Biological Assessment for the Imperial Sand Dunes Draft. Recreation Area Management Plan-Draft Environmental Impact Statement. Prepared for U.S. Department of the Interior. San Diego, California, USA.

Rorabaugh, J., and J. R. Garcia. 1983. An evaluation of wildlife response to windmill wells at the Coachella Canal and Algodones Sand Dunes, Imperial County, California. California Department of Fish and Game and U.S. Bureau of Reclamation, Long Beach, California, USA.

Schaefer, J., and C. O'Neill. 2001. The All-American Canal: an historic properties inventory and evaluation. ASM Affiliates, Encinitas, California, USA.

Shult, M. J. 1968. Incidence of deer in the Nebraska concrete-lined Ainsworth Irrigation Canal. M.S. Thesis, Iowa State University, Ames, USA.

Shult, M. J., and K. E. Menzel. 1969. Some observed deer behavior in relation to an irrigation canal in Nebraska. Iowa State Journal of Science 43:335-340.

Thompson, J. R., and V. C. Bleich. 1993. A comparison of mule deer survey techniques in the Sonoran Desert of California. California Fish and Game 79:70-75.

Received 6 May 2015
Accepted 19 July 2015
Associate Editor was J. Villepique