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MULE DEER ASSOCIATIONS WITH THE ALL AMERICAN CANAL, EASTERN CALIFORNIA, USA

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Abstract

Concrete-lined canals can interfere with native ungulate populations because they have the potential to disrupt dispersal, seasonal or daily movements, or they are an attractive nuisance. The All American Canal (AAC) is immediately north of the US-Mexico border and transports water from the Colorado River to western California. Because it traverses the Algondone Sand Dunes in eastern California, a significant amount of water is lost each year due to evaporation and seepage. To minimize this water loss the AAC was lined for 36.8 km beginning at Pilot Knob, Imperial County, California. The concrete lining changed the dynamics of the canal from a more natural riparian area to a steep sided, faster flowing waterway. We monitored the landscape adjacent to the AAC that was lined with concrete to determine the extent of deer usage of the area prior to the lining (November 2004-December 2006), during the lining (2007-2008), and after the lining was complete (2009-present). We monitored deer with track and road plots, weekly ground, and monthly aerial surveys. Deer use of the canal was limited and concentrated along a 1 km section (i.e., deer use area) of the canal. Only 1 deer was reported in the area during the pre-lining phase but activity increased during the warm months during the lining phase. At least one deer drowned and 2-3 crossed the canal during the lining phase. Tracks continued to be reported along the deer use area after the lining was completed, and were highest in hot months. Although, deer use of the area is limited and the habitat is marginal for deer, mitigation to eliminate any mortality includes the addition of water catchments and fencing. Deer in this part of the desert are rare and management agencies want to minimize any unnecessary reduction in the population.

Key Words: California, desert mule deer, habitat use, water.

Resumen

Asociaciones del ciervo mulo con el Canal Americano, en el extremo este de California (USA)

La canalización de los cursos de agua pueden interferir con las poblaciones de ungulados al ser elementos que pueden interrumpir los movimientos de dispersión diarios y estacionales y no son atractivos. El Canal Americano (ACC) se localiza al norte de la frontera entre USA y México y transporta agua desde el rio Colorado hasta el oeste de California. Este canal atraviesa la zona de

Dunas Algodonales, al este de California, por donde se pierde cada año una cantidad significativa de agua debido a la evaporación y filtración. Para minimizar esta pérdida de agua, el ACC fue canalizado mediante revestido de hormigón en 36,8 km en el Condado Imperial, California. Esta canalización ha cambiado la fisionomía del canal, de una zona natural ribereña ha pasado a ser un cauce lineal y uniforme , donde el agua fluye más rápido. Hemos monitorizado el paisaje adyacente al canal para determinar el uso por parte de los ciervos, antes del revestimento (noviembre 2004-diciembre 2006), durante el revestimento (2007-2008) y cuando la obra finalizó, de 2009 hasta la actualidad. Hemos monitorizado a los ciervos mediante itinerarios semanales por carretera y reconocimientos aéreos mensuales. El uso del canal por los ciervos es limitado y se centra en 1 Km (a esta zona la hemos llamado área de uso por el ciervo). Sólo se observo un animal durante la fase previa a las obras en el canal, pero la actividad se incremento en los meses de calor durante la ejecución de las mismas. Por lo menos un ciervo se ahogo y 2-3 cruzaron el canal durante la fase de canalización. Las pistas dejadas por los ciervos siguieron apareciendo después de finalizar los trabajos, siendo estás más numerosas en los meses de calor. Si bien el uso de este área por los ciervos es limitado y el hábitat es marginal, para reducir la mortalidad es necesario crear puntos de agua accesibles y cercar el canal. El ciervo en esta parte del desierto es raro por lo que los organismos de gestión deben reducir al mínimo cualquier interferencia en la población.

Palabras clave: Agua, California, ciervo mulo, hábitat.

Introduction

Growth and development in the western United States depends on the availability of water. Over 12,000 km of canals carry water from rivers and reservoirs to industrial, residential, and agricultural users. Unfortunately, animals can drown in concrete-lined canals while attempting to cross or drink from them. There are ≥21 canals in 9 western states and 1 Canadian province where ≥10 deer drown in them in 1 year (Rautenstrauch & Krausman 1986; Table 1). In 1977 and 1978, an average of 259 deer (*Odocoileus* spp.) and 5 elk (*Cervus elaphus*) drowned in 22 U.S. Bureau of Reclamation (USBR) canals; 51% were in the Pacific Northwest (Rautenstrauch & Krausman 1986). Over 95% of ungulates that drown in USBR canals are deer (Latham & Verzuh 1971, Rautenstrauch & Krausman 1986); most are mule deer (*Odocoileus hemionus*). White-tailed deer (*O. virginianus*) were found in the Ainsworth Canal, Nebraska (Shult 1968). Other native ungulates that drowned in canals include elk, pronghorn (*Antilocapra americana*) including endangered Sonoran Pronghorn (*A. americana*

Table 1. Reports of deer dying in canals in the western United States, 1940-1985.

Canal	State	Minimum no. drowned	Time period	Comments	Source
Central Arizona Project	Arizona	21	1979-1983	During construction	Krausman (1985)
		33	1985	After construction	USBR unpublished data
Welton-Mohawk	Arizona	>40	9/1968-1/1969		Furlow (1969)
		170	1977-80		USBR unpublished data
Coachella	California	29	1980	During construction	Rorabaugh and Garcia (1983)
		18	1981-82	After construction	Rorabaugh and Garcia (1983)
Delta-Mendota	California	13	1954-55		Gubser (1960)
		10	1958-59		Gubser (1960)
Friant-Kern	California	12	1950's	Annual X	Gubser (1960)
Hamilton Branch	California	13	1967-81	Annual X	Fry et al. (1984)
Robles-Casitas	California	>100	1957	Total includes all big game species	Gubser (1960)
Tehama-Colusa	California	360	1974-81		Michny and McKevitt (1982)
Tiger Creek	California	15-30	Early 70's	Annual X	Fry et al. (1984)
		340	1960-76		Seaman (1977)
Willows Project	California	29	1977		USBR unpublished data
Charles Hansen Feeder	Colorado	491	1957-68		Lathan and Verzuh (1971)

Table 1. Reports of deer dying in canals in the western United States, 1940-1985. (cont.).

Canal	State	Minimum no. drowned	Time period	Comments	Source
Horsetooth	Colorado	138	12/1949-2/1955		Miner in Shult (1968:5)
Heart Mountain	Wyoming	15	1977-78		USBR unpublished data
Ainsworth	Nebraska	253	1965-69		Menzel in Seaman (1977)
		95	1973-75		Menzel in Seaman (1977)
		22	1978		USBR unpublished data
Navajo Irrigation Project	New Mexico	38	1969-75	During construction	Boulders and Bailey (1980)
		26	1977-79	After construction	Boulders and Bailey (1980)
Howard Prairie	Oregon	55	7/21/59-8/3/31/59		Gubser (1960)
		190	1961-1968		Lathan and Verzuh (1971)
		29	1977-78		USBR unpublished data
Toketee Project	Oregon	57	1952-59		Gubser (1960)
Spanish Fork	Utah	10	1978		USBR unpublished data
Columbia Basin Project	Washington	171	1977-78		Gubser (1960)
		42			USBR unpublished data
Yakima Project	Washington	184	1977-78		USBR unpublished data
Southern Okanagan	British Columbia	8-12	1940's		Blair in Seaman (1977)
		4-6	1970s		Blair in Seaman (1977)

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).

Causes of Ungulate-Canal Interactions

Concrete-lined canals interfere with ungulate populations because they disrupt seasonal, dispersal or daily movements, or they are an attractive nuisance (Busch *et al.* 1984).

Movement barriers. The Pacific Gas and Electric Company's Hamilton Branch Canal transects a migration route of California's Tehama black-tailed deer (*O.h. columbianus*) herd. Deer become entrapped in the canal while attempting to cross between their summer and winter ranges (Fry *et al.* 1984).

Eighty-three percent of the deer found in the Ainsworth Canal in 1966 and 1967 were yearlings (Menzel 1969). Sixty-seven percent of the deer-canal interactions (DCI= any observation of ≥1 deer or deer track in or along a canal right-of-way [ROW]) they observed occurred from June through August, during the fawning period. Shult (1968) and Menzel (1969) concluded that this canal may disrupt the dispersion of yearling deer that have recently left family groups.

The Charles Hansen Feeder Canal, Colorado, may prevent deer from moving between bedding sites on one side of this canal and agricultural forage on the other (Haegele & Blevins 1980). The Central Arizona Projects' Hayden Rhodes Aqueduct may also prevent movements to foraging sites. Eight of 22 mule deer captured and radiocollared near the Hayden Rhodes aqueduct crossed this canal while it was under construction. Some of these deer crossed to feed in agriculture fields south of the canal (Krausman & Hervert 1984).

Attractive nuisance. Deer may be attracted to forage and cover in canal ROW's and adjacent agricultural fields or to water in a canal. During a winter aerial survey in North Dakota, Gatz *et al.* (1984) found 6.3 white-tailed deer/10 km in the McClusky Canal ROW, and only 0.4 deer/10 km in an adjacent control area. They believed that the deer were attracted to the cover and forage along the canal ROW.

Michny & McKevitt (1982) stated that mule deer were attracted to small game food and cover plots and other vegetation next to the Tehama-Colusa Canal. In the arid regions of the southwest U.S., mule deer are attracted to canals to drink. To get to parts of the Coachella Canal where they were drowning, deer had to cross <1-5 km of bare sand dunes. Deer have also drowned while attempting to drink from the Mohawk Canal (Guenther *et al.* 1979) and the Central Arizona Project (Krausman & Hervert 1984).

Deer drown more often in most canals during summer. All deer drownings in the Coachella Canal occurred in summer. Thirty-nine of 42 deer trapped in the Central Arizona Project during construction were found during summer (Krausman 1985). Deer tracks were found along the Navajo Indian Irrigation Project during all months, but track counts increased during late summer (Boulders & Bailey 1980). Deer drowned in the Tehama-Colusa Canal in all months, but drownings were highest from May through November (Michny & McKevitt 1982). However, Furlow (1969) reported that although deer drowned in the Mohawk Canal, Arizona during all months, "November and December were the worst months".

Canal Design and Operation Features Influencing Drownings

Busch *et al.* (1984) reviewed the canal design features and operation procedures that prevent trapped deer from escaping from canals. Most canals with deer drownings had concrete-lined side slopes of 2:1 or greater. Mud and algae on these canal walls often make it difficult for deer to escape, even when the water level is high (Seaman 1977).

Deer have trouble escaping from concrete-lined canals when the water velocity is too fast or too slow. When the velocity is too fast, deer may become exhausted from fighting the current before they have a chance to escape. Seventy-four percent of the deer trapped in the Ainsworth Canal drowned when the flow rate was >1.5 m^3/sec; 19.4% drowned when the flow rate was <1.5 m^3/sec (Menzel 1969). High water velocity made it difficult for deer to use escape structures at the Tiger Creek Canal (Fry *et al.* 1984). When water velocities are too low, deer may exhaust themselves attempting to escape at the point they entered and may never be forced toward an escape structure (Guenther *at al.* 1979, Busch *et al.* 1984).

Water depth also influences deer survival in canals. When a canal is filled to the top of the lining, deer can drink without falling in, and those that enter to cross can easily escape. When the depth of water at the Mohawk Canal is >31 cm, deer cannot escape without assistance (Guenther *et al.* 1979). However, when the water level is below a certain point, deer may hesitate to drink or enter the canal to cross. Fourteen of 15 deer found in the Navajo Indian Irrigation Project entered the canal where the water was checked to within 0.9 m of the top of the canal lining (Boulders & Bailey 1980).

Empty canals are also a hazard to ungulates. Thirty-eight deer and 2 pronghorn died in, and 150 deer were rescued from, the empty Navajo Indian Irrigation Project during construction. They may have been attracted to water in the siphons (Boulders & Bailey 1980). About 10% of the 171 deer mortalities in the Columbia Basin Project between 1952 and 1959 occurred in dry canals (Latham & Verzuh 1971). Twenty-one deer died in, or shortly after, being removed from the empty Central Arizona Project during 4 years of construction. These deer either drowned in pools of standing rain water or of exposure to extreme heat; temperatures exceeded 54°C in the canal bottom during summer (Krausman 1985).

Preventing Ungulate Drownings in Concrete-lined Canals

There are two ways to prevent deer from drowning in canals: prevent them from entering the canal or provide a way for them to escape from the canal after entering. Some authors have concluded that preventing deer from entering canals is the most effective way to prevent drowning (Gubser 1960, Shult & Menzel 1982, Krausman 1985), but this is not always possible.

Preventing deer from entering canals. Busch *et al.* (1984) identified three ways to prevent deer from entering canals: fencing, building crossing structures, and providing alternate water sources.

Michny & McKevitt (1982), Busch *et al.* (1984), and Marcy (1986) reviewed the use of fences to prevent drowning. Deer-proof fences should be at least 2.4 m tall and should have no gaps or holes.

Deer drowning in the Tiger Creek Canal decreased from 15-30/year prior to fencing to 8 the first year after fencing (Fry *et al.* 1984). A 2 m fence along the Tehama-Colusa Canal was not effective because there were too many gaps, low gates, and short cattle guards (Michny & McKevitt (1982).

There are many problems associated with fencing canals. The average construction cost for upright deer-proof fence was $8,200 (US)/km in 1984 (Marcy 1986). The cost of fencing the Central Arizona Project was $47,800/km in 1984 (Busch *et al.* 1984). The New Mexico Department of Game and Fish estimated that the annual maintenance cost of a proposed fence along the Navajo Indian Irrigation Project was $155/km in 1976 (Seaman 1977). Costs are certainly higher in 2009. If there are any gaps in a fence, deer finding them will be trapped between the fence and the canal. More than 57 deer entered the Central Arizona Project through open gates or incomplete sections of fence during the summers of 1984-85, and the same problem occurred in 1986 (USBR, unpublished data). Deer have also jumped the 2.4 m fence along the Central Arizona Project (USBR, unpublished data). Building fences may prevent deer from crossing canals and disrupt migratory movements.

Deer crossings have been constructed at many canals to prevent movements from being disrupted. There were 235 wooden bridges (1/300 m) built on the Talent Division Project (Gubser 1960). A number of bridges built over the Charles Hansen Canal were used extensively by deer, but there was no decrease in drowning after their construction (Haegele & Blevins 1980). Deer crossed 2 1.8 m wide concrete bridges over the Navajo Indian Irrigation Project 13 times in 1978-79 (Boulders & Bailey 1980). Deer crossings have also been used in the Colorado Big Thompson, Rouge River (Latham & Verzuh 1971), Central Arizona Project (Krausman 1985), and other canals (Gubser 1960, Seaman 1977). Crossings should be at least 2.5 m wide and covered with dirt (Latham & Verzuh 1971).

Deer will also use other structures to cross canals. Krausman (1985) created track plots in 3 siphons, 11 road bridges, 10 dirt plugs, 15 overchutes, 2 livestock crossings, and 2 deer bridges crossing the Central Arizona Project. During the summer of 1982, 235 sets of tracks were recorded: 53% at siphons, 19% at road bridges, 19% at dirt plugs, 7% at overchutes, and 2% at the deer bridge. Deer may have used some of these structures more than the deer bridge because they were built along major drainages that deer travel and the deer bridge may not have been located near a travel corridor. Michny & McKevitt (1982) recommended that specially designed deer crossings were not needed on the Tehama-Colusa Canal because there were enough roads bridges and other crossings.

Alternate water sources have been built at the Coachella and Mohawk Canals. Nineteen windmills and drinkers built near the Coachella Canal were used by deer, and may have contributed to the decrease in deer losses at that canal (Rorabaugh & Garcia 1983). Water troughs temporarily installed along the Mohawk Canal prior to 1960 may have prevented some drowning (Gubser 1960), but a later effort to divert water into a ditch next to the Mohawk Canal did not decrease drowning (Furlow 1969).

Deer escape structures. Where methods used to prevent deer from entering a canal have failed to work or were impractical to use, structures have been developed to help deer escape from canals. Many devices have been attached to canal walls to help deer gain a footing on the steep, slippery sides. Metal grates and ladders, snow fences, wooden slats, asphalt pads, and grooves and steps cut into the canal walls have all been tested, but none have reduced deer losses (Gubser 1960, Shult & Menzel 1969, Seaman 1977, Boulders & Bailey 1980). These escape structures are either too steep and slippery (Seaman 1977), or deer do not recognize that they are a way to escape.

Guenther *et al.* (1979) described steps cut into the concrete wall of the Mohawk Canal that were ineffective because deer could not locate them or recognize them as escape structures. To solve this problem, directors such as cables, pipes, and wooden booms have been used in many canals to direct swimming deer toward escape structures and prevent them from swimming further downstream.

Semi-tame deer were put in the Ainsworth Canal to test 2 types of escape structures (Shult 1968). One structure had A-frame pipe directors that extended from the top of the canal to the bottom, and 5x10 cm boards attached to the canal wall for steps. Five of the 6 times deer made it to the structure they were able to escape; the other time a deer slipped through the pipes and had to be rescued. A seventh deer, placed in 0.3 m of water, walked away from the escape structure and drowned in a drop structure pool. The second escape structure had a diagonal pipe director that could be raised or lowered when the water level changed and angle iron steps attached to the canal wall. Deer were swept under this director in 4 of 5 tests. Although Shult (1968) concluded that deer could use the first type of escape structure, both types were removed because they interfered with the water flow.

Richmond ramps, named after the person who designed them, have been used successfully on the Okanagan Canal of the southern Okanagan Lands Irrigation District since 1960 (Seaman 1977). These ramps have a slope of 4:1; are set perpendicular or diagonal to the canal wall; and have a floating, triangular, wooden director attached to the canal wall. Modified ramps that extend to the canal bottom so that small trucks can enter the canal for maintenance have been constructed on the canal.

Similar ramps have been built on the Pacific Gas and Electric Company's Tiger Creek and Hamilton Branch Canals (Seaman 1977, Fry *et al.* 1984). These ramps have "flasher" type directors (15 cm wide aluminum strips attached to a cable suspended over the water at one end and to a cable suspended at water level at the other end). The water flow shakes the strips, which drives deer toward the ramps (Seaman 1977). Tests with captured deer showed that these are effective escape structures (Fry *et al.* 1984).

Three types of directors were tested on the Mohawk Canal (Guenther *et al.* 1979). Flashers similar to those used on the Tiger Creek Canal accumulated too much debris behind them. Wooden booms became water logged and sunk. Three cm diameter cables with swimming pool floats worked well because they did not interfere with water flow and were easy to install and maintain (USBR, unpublished data). However, because it appeared that deer could easily swim over or under them, it was not known if these cable directors would prevent drowning.

Escape structures should be placed just upstream from all check dams, siphons, and other obstructions. If deer are entering a canal to cross, escape structures should be placed on both sides of the canal. The Hamilton Branch Canal has ramps on both sides and the angle of the directors is changed seasonally so deer can only exit in the direction they are migrating (Fry *et al.* 1984).

Most of the escape structures and directors designed for full canals will not work in dry canals. Richmond ramps modified to extend to the canal bottom may work, but only if deer recognize them as a way to escape. Deer used dirt plugs to escape from the Coachella and Central Arizona Project Canals during construction (USBR; unpublished data; Krausman & Hervert 1984). However, these plugs collect rainwater behind them, which may attract deer into the canal.

Deer and the All American Canal

The All American Canal (AAC) is an important water delivery system that converted Imperial and Coachella Valley, California into one of the most productive agricultural regions in the state (Schaefer & O'Neill 2001). The canal also delivers water for residential and commercial development and power generation. Construction of the 130 km AAC began in 1934 and began delivering water in 1940. The AAC irrigates nearly 202,500 ha of farmland (Schaefer & O'Neill 2001).

The AAC was built by the USBR when the Boulder Canyon Project of 1928 was signed into law. It is still owned by the USBR but the Imperial Irrigation District (IID) is responsible for its maintenance and operation. The Boulder Canyon Project Act authorized the construction of Boulder Dam (now Hoover Dam), Imperial Dam (480 km downstream of the Colorado River), the AAC, and the Coachella Branch of the AAC. A detailed account of the history of the AAC is provided by Schaefer & O'Neill (2001).

To conserve water in the AAC (approximately 67,700 acre-feet/yr) the USBR and IID are replacing a 36.8 km section of the canal (i.e., 1.6 km west of Pilot Knob to Drop 3) with a concrete-lined parallel canal. Lining this portion of the AAC may have adverse impacts on air quality, wetlands habitat, terrestrial habitat and special status species, large mammal escape, canal fishery, cultural resources, recreation, geodetic survey monuments, sand and gravel supplies, transportation, public safety, and immigration from Mexico (Imperial Irrigation District 2004). The remainder of this report will examine the adverse impacts on large mammal (e.g., mule deer) escape.

The proposed parallel canal will have steeper sided slopes (i.e., 1-1/2:1) and water will move at higher velocities than the present unlined canal. Both conditions could cause high risk of drowning to large mammals that attempt to drink from or cross the canal (Imperial Irrigation District 2004). Our objective is to determine the presence of large mammals in the area where the canal will be lined, determine any interactions they have with the canal, and propose measures that minimize or eliminate adverse impacts of the canal on large mammals. The study will examine deer-canal interactions prior to lining, during the lining phase, and post-lining. This study covers the pre-lining phase and part of the lining phase only.

Study area

The AAC lining project is in Imperial County, California, immediately north of the international boarder. The AAC will be lined for 36.8 km from 1.6 km west of Pilot Knob to Drop 3. The AAC originates at Imperial Dam on the Colorado River and flows into Imperial Valley (Bransfield and Rorabaugh 1993).

The canal is in the Sonoran Desert of southeastern California. The climate is arid with daytime summer temperatures >45ºC and low annual rainfall ($\bar{x}$= 70 mm) in Imperial County, California (Imperial Irrigation District, unpublished data). Plant species in the project area are common to the Lower Colorado River Valley Subdivision of Sonoran Desert scrub. Desert scrub can be divided into sand dune associations and creosote (*Larrea tridentate*) scrub. Several plant species in the sand dune association have limited distribution but are adapted to the dunes including Peirson's milk vetch (*Astragalus magdalanae peirsonii*), sand food (*Pholisma sonorae*), and desert sunflower (*heliantus niveus tephrodes*), which are also sensitive species. Dominant plants include creosote and bursage (*Ambrosia dumosa*) in the creosote scrub association. Areas adjacent to the AAC contain cattails (*Typha domingensis*), Goodding willows (*Salix gooddingii*), salt cedar (*Tamarix shinensis*), honey mesquite (*Prosopis glandulosa*), screwbean mesquite (*Prosopis pubescens*), and arrowweed (*Pluchea sericea*).

There are over 50 mammal species in the project area but mule deer (*Odocoileus hemionus eremicus*) are the only native large mammal. Mountain lions (*Felis concolor*) are rare in this desert (Bransfield & Rorabaugh 1993).

The seasons for this report will follow Marshal *et al.* (2002): hot-dry (April-June, hot-moist (July-September), and cool (October-March). We will examine weather throughout the study, which may alter season designation for the final report following post construction monitoring.

Mule Deer

The density of mule deer in the study area is unknown. Mule deer occupy washes (Krausman *et al.* 1985*b*) in desert habitats and bajadas east of the Algondones Dunes and occupy mountain ranges and riparian zones along the Colorado River. Harvey & Stanley Associates (undated; cited in Bransfield & Rorabaugh 1993) estimated there were 900 to 2,000 mule deer from the Algondones Dunes to the Colorado River. These are likely high estimates. Reports of deer drowning near Pilot Knob along the AAC are rare but deer have been reported in the area specifically on Quechan Indian Reservation land at Pilot Knob (Imperial Irrigation District 2004). Mule deer inhabiting deserts have large home ranges (>90 km^2) (Krausman & Etchberger 1993, 1995). Some biologists assume that deer along the study portion of the AAC "… roamed south from the Chocolate Mountain and Picacho Peak ranges along the Colorado River to the Knob area of the AAC" (Imperial Irrigation District 2004). However, in a recent study of mule deer in the Sonoran Desert of southeastern California (33°00'N, 114° 45'W) >34 deer were captured and radio collared in the East Chocolate and Cargo Muchacho mountains north of the AAC. The mean home-range size for 34 deer was 153.4 km^2 (range= 43.2-615.1 km^2) and only 6 females approached (within 5 km) the AAC. These 6 females had a mean home-range size of 285.8 km^2 (range= 117.3-615.1 km^2). The southern portion of their home range was within 5 km of the AAC in all seasons but they were closer to the canal during hot-dry and hot-moist seasons. None of these deer were reported south of Interstate 8 and not closer than 5 km to portions of the AAC; they were north and east of Pilot Knob and not in the project area. Although mule deer in deserts have large home ranges, the deer in the Cargo Muchacho and Chocolate mountains did not appear to use the project area (Marshal 2005). However, these movement data were collected with Very High Frequency technology and it is likely they could have approached the canal closer than the reported 5 km without detection. Deer in the project area likely come from the mountains north of the AAC. Currently, deer use of the study area has been to obtain water from the AAC.

Methods

The study was conducted in 2 phases depending on the construction schedules: pre-lining and lining. The pre-lining phase included November 2004 through 2006. The concrete lining phase began in 2007 and is on-going. During the pre-lining phase, we surveyed the project area for deer using a combination of track plots (Popowski & Krausman 2002), road surveys for sign (i.e., tracks pellets, observations of deer), and aerial surveys from a Cessna 172 (Krausman & Etchberger 1993). We also contacted people who used the area on a regular basis (i.e., Border Patrol, California Fish and Game employees, and interested citizens knowledgeable about the area wildlife (e.g., L. Leisca). We examined IID files and others that may indicate the number of deer that entered the project area along the AAC.

Road and track plot surveys were conducted at least weekly (Figure 1) and aerial surveys east of Pilot Knob to Drop 3 were conducted monthly with a pilot and 2 observers. Surveillance of the landscape was made from Pilot Knob, and

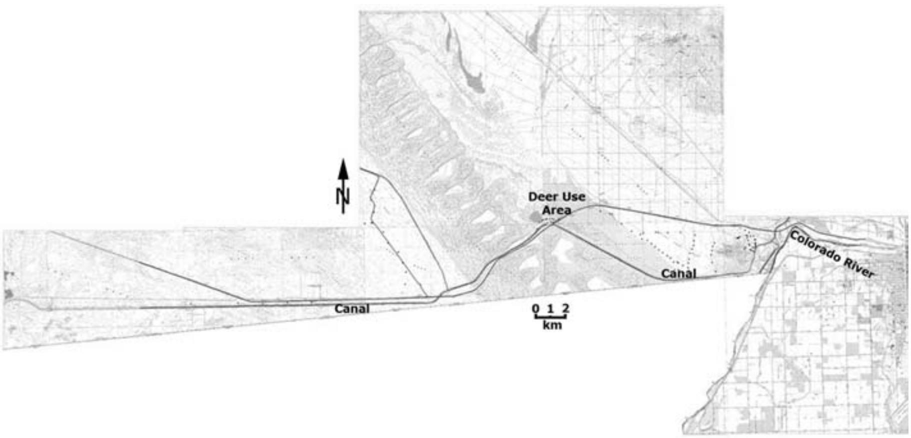

Figure 1. Deer track plots (dots), deer use area, and the All American Canal (canal), Eastern California, USA, 2004-2008.

by driving along >56 km of authorized roads that had sandy substrate suitable for reading tracks. The availability of the substrate varied because the Border Patrol dragged the roads to detect illegal aliens. The dragged roads were useful to detect animal tracks also. Most observations and plots were established south of the AAC. However, there was a patch of vegetation north of the AAC (north of I-8 at the junction of the canal and I-8 west of Pilot Knob) that was surveyed from the air and on ground. This area is primarily sand dunes with scattered shrubs and trees and tracks are easily detectable. We used systematic observation, examination of roads and track plots, and aerial surveys to indicate the extent of use of the project area by mule deer.

We estimated site occupancy using track plots and site occupancy models (i.e., PRESENCE; MacKenzie *et al.* 2003). Occupancy models have been successfully used with an array of taxa from butterflies in Finland to tigers (*Panthera tigris*) in India (MacKenzie & Royle 2005). Occupancy models are applicable to studies of species occurrence and distribution, habitat selection and modeling and, metapopulation studies (MacKenzie & Royle 2005). We used the model to detect occurrence and distribution during the concrete lining phase when deer were detected.

In 2008, we established 11 additional plots adjacent to the AAC on the north side of I-8. The only area that was regularly accessible was a 1.6 km strip from the I-8 bridge to the west. This area could not be regularly surveyed due to construction activity and sand dunes. However, construction activities created a road that was functional in 2008. We classified the 11 plots as those central to the strip, east (toward Olgilby), and west (toward the dunes) for occupancy modeling.

Results

Preliminary Phase (2004-2006)

During the pre-lining phase (November 2004-December 2006), only 1 deer was observed in the study area. A deer was photographed by IID personnel on the AAC roadway at the beginning of Reach 1B in July 2006. Although it is likely deer used the study area to acquire water since canal construction, this was the first documentation of deer use of the canal during this study. No other deer were observed from the air or ground, no tracks were recorded, and no other sign of deer were recorded by me or reported by the U.S. Border Patrol or others working in the study area.

Lining Phase (2007-2008)

We began to consistently document deer north of the AAC and I-8 in a patch of vegetation approximately 1 km x 0.5 km (i.e., deer use area; Figure1) during the hot-dry season 2007. From May 2007 through 2008, we observed deer, deer tracks and signs in the study area except from December 2007 until May 2008. (Tables 2, 3).

The detection probabilities (Ψ; i.e., the probability that a site is occupied) calculated in 2008 for the deer use area are useful to determine the probability of deer using various sections (Table 4). After a number of surveys (e.g., weekly), when deer have not been detected the species is considered absent from the sampling unit and $\Psi = 0$. These probabilities are similar to the track plot data from 2007 that reveal that deer approach the canal during hot periods (Table 4). August 2008 had the highest probability of deer for all months examined and the central portion of the deer use area had the highest probability of detecting deer in July and August (Table 4). In addition, the west and east sections had the highest probabilities at any time for their respective sections; the east section had the highest probability of detecting deer for the entire year (Table 4).

Observations of deer were rare but were seen 3 and 18 July 2007, 7 September 2007, and 4 deer were observed during aerial flights on 28 September 2007 (Table 2). Deer did not use the area from January-April 2008 but returned in May and were recorded through December 2008.

No deer were detected south I-8 from plots. However, there were 2-3 deer that crossed the canal and I-8 to the south and died in the canal or on I-8 (verbal reports; i.e., 1 died in the canal south of I-8 in September 2008, and mortalities occurred on I-8 in July 2007, June 2008, and November 2008). These deer came from the north and to my knowledge are the only deer that have been reported south of the AAC during this study. It is highly unlikely deer could enter the study area from the south due to the fence being constructed by Homeland Security along the border.

TABLE 2
Deer tracks recorded in 1X1 m sand plots adjacent to the All American Canal from Pilot Knob to Drop 3, Imperial County, California, 2004-2008.

	Pre-lining phase			Lining phase	
Month	2004	2005	2006	2007	2008
January		0	0	0	0
February		0	0	0	0
March		0	0	0	0
April		0	0	0	0
May		0	0	0	2[f]
June		0	0	0[a]	9[f]
July		0	0	0[b,c]	15[f]
August		0	0	0[b]	23[f]
September		0	0	0[b,d,e]	13[f]
October		0	0	0[f]	7[f]
November	0	0	0	0[f]	8[f]
December	0	0	0	0[f]	1[f]

a Located deer tracks 26 June and pellets north of I-8 where the canal goes under the freeway the first time west of Pilot Knob.

b Located deer tracks and pellets in a patch of vegetation 2 km x 0.5 km (i.e., deer use area) north of I-8 at the junction of the canal and I-8 west of Pilot Knob.
Observed ≤3 deer >500 m north of the canal at the west end of the deer use area at the edge of the dunes, 3 July.

c Observed 1 adult male deer foraging 100 m northeast of the canal at sunrise, 18 July. California Fish and Game Department reported 1 female deer hit and killed by a vehicle in eastbound lane of I-8 near Olgilby Road, 22 July.

d Observed 1 female with fawn 250 m north of the canal at the junction of the canal and I-8 west of Pilot Knob, 7 September.

e Observed 3 females and 1 male mule deer during aerial survey, northeast of the canal and west of Olgilby Road, 28 September.

f Located deer tracks in the deer use area.

Table 3
Sets of mule deer tracks (e.g., 1 line of tracks= 1 set) located in the deer use area (e.g., the 1 km x 0.5 km patch of vegetation north of I-8 at the junction of the canal and I-8 west of Pilot Knob).

	Pre-lining phase			Lining phase	
Month	2004	2005	2006	2007	2008
January		0	0	0	0
February		0	0	0	0
March		0	0	0	0
April		0	0	0	0
May		0	0	0	25
June		0	0	>1[a]	83
July		0	0	≥9	227
August		0	0	≥8	332
September		0	0	≥7	150
October		0	0	98	144
November	0	0	0	95	151
December	0	0	0	0	10

a First time any tracks were recorded in this area.

Discussion

During the pre-lining phase, data collection was consistent. Some plots had to be moved due to safety concerns (i.e., high use areas by illegal aliens), but were replaced with others. However, during the lining phase, heavy equipment precluded data collection from plots in a systematic manner.

Deer use of the desert north and adjacent to the AAC, north of I-8 has increased from no use from November 2004 through the pre-lining phase into the lining phase (May 2007). Since then, deer use of the area increased through November 2007 (Table 3). There was no use recorded in 2008 until May when use peaked in August then remained consistent from September through November and declined again in December.

TABLE 4
Detection probability (Ψ) of desert mule deer along 1.6 km of the All-American Canal north of I-8 (from the first bridge west of Pilot Knob to the edge of the dunes), 2008, eastern California. The 1.6 km section is divided into 3 areas: central (central 0.5 km), west (0.3 km west of central), and east (0.3 km east of central).

Season and month	Monthly Ψ	West Ψ	Central Ψ	East Ψ
Cool				
February	0.0000	0.0000	0.0000	0.0000
March	0.0000	0.0000	0.0000	0.0000
Hot-Dry				
April	0.0000	0.0000	0.0000	0.0000
May	0.0130	0.0000	0.0000	0.0476
June	0.1202	0.0000	0.1533	0.0417
Hot-Moist				
July	0.1690	0.0000	0.2133	0.0417
August	0.1882	0.1111	0.1556	0.3234
September	0.0099	0.0046	0.1000	0.0000
Cool				
October	0.0739	0.000	0.0889	0.0000
November	0.0909	0.0417	0.0750	0.0000
December	0.0130	0.0000	0.0286	0.0000

Why deer started to approach the AAC during the lining phase is unknown. Possible explanations for the increase in use of the AAC include a reduction of functional catchments, temperature increases, or deer population increases. According to some (G. P. Mulcahy, California Game and Fish Department, personal communication, 19 November 2008) deer will use landscapes adjacent to the AAC for several years, then may not use the area for several years before they return. However, deer have started using the AAC (or at least approach it) and soon will likely fall in and drown if the canal is accessible.

The IID, California Fish and Game, and U.S. Bureau of Land Management have been in consultation to minimize mortality. To ensure deer do not drown, the canal north of I-8 should be fenced to prevent entry. Biologists have considered building the fence from Olgilby Road extending west >1.6 km beyond the beginning of the canal into the dunes.

We monitored roads and trails between Olgilby Road and the AAC and regularly found deer tracks when tracks were also found in the deer use area. In addition, the highest probability of site occupancy by desert mule deer was east of the deer use area (Table 4). These data suggest that fencing is necessary from the canal to Olgilby Road to minimize deer-canal interactions. Deer occupancy also extended into the dunes during hot months. The highest occupancy probability occurring west of the deer use area was in August 2008 indicating deer use of dunes. We could not measure the distance deer moved into the dunes but during aerial surveys, it was not uncommon to locate tracks in the dunes as far west as Test Hill. The AAC should be fenced beyond Test Hill to minimize deer drowning in the canal.

Two water catchments are also being considered to mitigate for the alterations being made to deer habitat north of the canal (i.e., mitigation for lost water source). In the arid southwestern United States, water catchments are commonly used to enhance habitat of deer and with increasing losses of water they will likely be more important with global warming. Management of all water is important and gaining in stature as global water shortages occur. Some consider limited water as the defining crisis of the 21st century (Pearce 2006). The crisis has been caused by limited drinking water for wildlife and humans. Reductions in water are being caused by increased global demand, altering climate, drawdown of aquifers (Jackson *et al.* 2001) and in the case of the AAC, diversions of water resources for irrigation and industry.

Management recommendations

The AAC has likely been used by deer intermittently as a source of water since canal development. Prior to the current study no one has examined deer use along this section of the AAC. However, deer were reported just north of the study site (Marshal 2005) and a deer was photographed by IID personnel at the beginning of Reach 1B in July 2006 during the pre-lining phase. We began to consistently detect deer presence north of the AAC in the deer use area (Figure 1) during the hot-dry season 2007. Deer use the AAC north of I-8. Based upon the literature, canals similar to the AAC in similar habitat, and expert opinion, unless this portion of the canal is fenced with a deer proof fence, deer will continue to use the canal and some will fall in and drown. At least 1 reportedly died in the AAC south of I-8. In addition at least 3 deer were killed by vehicles along I-8. In summary, we have documented the presence of mule deer along the AAC and interactions with the canal. Most of these data are from tracks and occupancy models and show a clear trend of deer approaching the AAC through the deer use area (Figure 1) from the north.

An array of actions could be initiated from doing nothing to fencing all or part of the canal. If no action is taken deer will fall into the canal and drown. Deer populations in deserts are generally small and additional mortality (e.g., from drowning) usually represents additive (not compensatory) mortality. Based on the literature, canals in similar habitats, and expert opinion, a second option would be to fence the entire canal north of I-8 to Olgilby Road with a deer proof fence. Deer will not be able to approach the AAC from the south due to the border fence constructed by Homeland Security. Furthermore, we never detected deer approaching the AAC from the south prior to the construction of the border fence. This option would minimize deer mortality by drowning.

A third option would be to fence part of the AAC that is north of I-8 (e.g., from Olgilby Road to Test Hill). This option would likely reduce mortality but eventually some deer would walk along the fence until they came to the open canal and could fall in. Because deer likely traveled >5-10 km to reach water in the AAC, they could be expected to travel a bit further by following a fenceline until they reached water.

To minimize mortality we recommend the second option. All deer sign observed occurred between Olgilby Road, the deer use area (Figure 1), and surrounding dunes. By reducing access to this area deer will not be able to interact with the canal north of I-8.

Another mitigation factor is the creation of additional water sources to mitigate for the loss of the AAC as a water source. Because biologists do not want deer to use the area adjacent to the AAC, establishing water catchments near the canal is not recommended. However, the creation of water sources between the AAC and the mountains to the north may not serve the intended purpose of short stopping deer because there are several existing water sources in the area used by deer. There are no data available to suggest that additional waters would be detrimental to the population and when water from the AAC is no longer available to deer (due to fencing) additional sources of water may be an appropriate mitigation.

In summary, deer use the AAC north of I-8 and have died trying to cross the freeway and in the canal. To minimize mortality from the canal we recommend that the entire canal north of I-8 be fenced to Olgilby Road. Deer use the area between Olgilby Road and the AAC and have used the dunes at least to Test Hill. If the decision was made to terminate the fence at, or prior to Test Hill, managers and administrators should be prepared and willing to accept occasional mortalities from deer moving west beyond the fence. The fence could be designed with additional fencing perpendicular to the main fence every 0.5 km that would extend ≥100 m to the north to direct deer away from the canal. However, due to the high human use of this area by off-road recreationists, it would be difficult to maintain. If any fence is constructed, we recommend that it will be immediately north and close to the service road associated with the AAC.

Postscript

This report covers 2004 through 2008. Since then, deer use patterns have remained similar to 2007 and 2008. They did not use the AAC in cool months (except once in February) and began using the deer use area in May 2009.

Between 2008 and 2009, algae grew on the canal walls below the water line, and when scraped, a distinctive mark is created. We recorded deer tracks going into the canal adjacent to the I-8 bridge and ≥2 deer fell in the canal and scraped marks in the algae with their hooves. One deer traveled 0.16 km before exiting the canal and a second deer traveled 2.56 km to Test Hill, where the canal is not lined, and escaped (as evidenced by deer tracks). This was an unique opportunity due to the undisturbed algae. Once this section of the canal is lined, deer will not be able to escape easily. Animals that are able to escape will likely damage their hooves in attempts to exit the AAC.

References

Arizona Game and Fish Department. 1981. *The Sonoran pronghorn*. Arizona Game and Fish Department Special Report No. 10, Phoenix, Arizona, USA.

Boulders J. & Bailey J. 1980. *Big game loss monitoring study: Navajo Indian Irrigation Project*. US. Bureau of Reclamation contract number 7-07-50-VO959. Final Report.

Bransfield R. & Rorabaugh J. 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.

Busch D.E., Rorabaugh J. C. & Rautenstrauch K.R. 1984. Deer entrapment in canals of the western United States: a review of the problem and attempted solution. Pp: 95-100. In: P.R. Krausman & N.S. Smith (eds). *Deer in the southwest: a symposium*. School of Renewable Natural Resources, Univ. of Arizona, Tucson, Arizona, USA.

Fry E.M., Wyman V.L. & Yoeman E.H. 1984. A method for evaluating the effectiveness of a deer protection system on a concrete-lined canal with comments on planning these systems. Pp: 647-658 In: A.F. Crabtree (ed). *Third international symposium on environmental concerns in rights-of-way management*. Mississippi State University, Mississippi State, Mississippi, USA.

Furlow B. 1969. The Wellton-Mohawk Canal Incident. *Arizona Wildlife Views,* 12 (2): 22-25.

Gatz T., Brucker G., Otto W., Rothe S. & Orthmeyer D. 1984. Wildlife use of an irrigation canal rights-of-way in the prairie pothole region of North Dakota. Pp: 630-639 In: A.F. Crabtree (ed). *Third international symposium on environmental concerns in rights-of-way management*. Mississippi State University, Mississippi State, Mississippi, 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 commissions*, 40: 42-52.

Guenther H.R., Sharpe F.P. & Strauss P. 1979. Mule deer losses-Mohawk Canal, Arizona: a problem identified-a solution sought. Pp: 642-644 In: G.A. Swanson (ed). *The mitigation symposium: a national workshop on mitigating losses of fish and wildlife habitats*. U. W. Forest Service General Technical Report RM-65.

Haegele M.A. & Blevins Z.C. 1980. Experimental animal escape ramps for concrete-lined canals. *Unpublished paper presented at the Colorado Wildlife Society Meeting*, Glenwood Springs, Colorado, USA.

Hooge P.N. & Eichenlaub B. 1997. *Animal movement extension to Arc View, Version 2.0*. Alaska Biological Science Center, U. S. Geological Survey, Anchorage, Alaska, USA.

Imperial Irrigation District. 2004. *Environmental commitment plan and addendum to the All American Canal Lining Project EIS/EIR*. California State Clearinghouse Number SCH90010472.

Jackson R.B., Carpenter S.R., Dahm C.N., McKnight D.E., Naiman R.J., Pastel L.L. &. Running S.W. 2001. Water in a changing world. *Ecological Applications,* 11: 1027-1045.

Kenward R.E. 2001. *A manual for wildlife radio tagging*. Academic Press, London, United Kingdom.

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

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

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

Krausman P.R. & Hervert J.J. 1984. Impacts of the Granite Reef Aqueduct on desert ungulates. Pp: 640-646 In: A.F. Crabtree (ed). *Third international symposium on environmental concerns in rights-of-way management.* Mississippi State University, Mississippi State, Mississippi, USA.

Krausman P.R. Hervert J.J. & Ordway L.L. 1985*a*. Capturing deer and mountain sheep with a net gun. *Wildlife Society Bulletin,* 13: 71-73.

Krausman P.R., Rautenstrauch K.R. & Leopold B.D. 1985b. Xeroriparian systems used by desert mule deer in Texas and Arizona. Pp: 144-149 In: R. Johnson *et al.* (eds). *Riparian ecosystems and their management: reconciling conflicting uses*. U. S. Forest Service General Technical Report RM-120.

Latham H.S. & Verzuh J.M. 1976. *Reducing hazards to people and animals on reclamation Canal.* U. S. Bureau of Reclamation, Engineering and Research Center Report Number REC-ERC-71-36. Denver, Colorado, USA.

Marcy L.E. 1986. *Impassable wire fences*. U. S. Department of the Army Corp of Engineers, Wildlife Resource Management Manual Technical Report EL-86-7.

Marshal J.P. 2005. *Interactions of mule deer, vegetation, and water in the Sonoran Desert*. Dissertation, University of Arizona, Tucson, USA, Marshal J.P, Krausman P.R., Bleich V.C., Ballard W.A. & McKeever J.S. 2002. Rainfall El Niño, and dynamics of mule deer in the Sonoran Desert, California. *Journal of Wildlife Management,* 66: 1283-1289.

MacKenzie D.I., Nichols J.D., Hines J.E., Knutson M.G. & Franklin A.B. 2003. Estimating site occupancy, colonization, and local extinction when a species is detected imperfectly. *Ecology,* 84: 2200-2207.

MacKenzie D.I. & Royle A. 2005. Designing occupancy studies: general advice and allocating survey effort. *Journal of Applied Ecology,* 42: 1105-1114.

Menzel K. 1969. *Deer incidence in the Ainsworth Canal, March 1, 1968 through February 28, 1969*. Nebraska Game and Parks Commission Job A-7.

Michny F. & McKevitt J.J. 1982. *Tehama-Colusa Canal deer study*. U. S. Bureau of Reclamation, mid-Pacific region. Final report.

Mohr C.O. 1947. Table of equivalent population of North American mammals. *American Midland Naturalist*, 37: 223-249.

Pearce F. 2006. *When the rivers run dry: water, the defining crisis of the twenty-first century.* Beacon Press, Boston Massachusetts, USA.

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

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

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

Rorabaugh J. & Garcia J.R. 1983. *An evaluation of wildlife response to windmill wells at the Coachella Canal and Algodones Sand Dunes*. Imperial County, California, USA.

Seaman D.E. & Powell R.A. 1996. An evaluation of the accuracy of kernel density estimators for home-range analysis. *Ecology,* 77: 2075-2085.

Seaman E.A. 1977. *Wild and domestic mammal control in concrete-line canals.* U. S. Bureau of Reclamation, unpublished report.

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

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

Swihart R.K. & Slade N.A. 1985. Influence of sampling interval on estimates of home-rang size. *Journal of Wildlife Management,* 49: 1019-1025.

White G.C. & Garrott R.A. 1990. *Analysis of wildlife radio-tracking data.* Academic Press, San Diego, California, USA.

Worton B.J. 1989. Kernel methods for estimating the utilization distribution in home-range studies. *Ecology,* 70: 164-168.