Articles

Effects of Drought on Western Pond Turtle Survival and Movement Patterns

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Abstract

Drought has the ability to affect the persistence of small animal populations, especially those tied to aquatic habitats. We studied the response of western pond turtles *Actinemys marmorata* to California's worst drought on record. From 2009 through 2015 we used telemetry to track movements and assess survival of 19 western pond turtles in a stock pond at the San Joaquin Experimental Range in the western foothills of the Sierra Nevada, in Madera County, California. In 2013 the pond dried in late summer and winter rains were insufficient for pond formation. The pond remained dry through the end of the study in March 2015. In years with below average precipitation the pond often dried completely in late summer; however, the lack of a pond forming in winter and spring had not been previously documented. We observed no mortalities of radiotagged western pond turtles in years with normal precipitation. All observed mortalities occurred in drought years and in years when the pond completely dried up in the summer or never formed. Results from known-fate survival models revealed that survival decreased with increasing drought. Model results also indicated that male survival was slightly higher than female survival (19.1% vs. 11.5%), although the 95% confidence intervals overlapped. We observed high variability in western pond turtle movement distances from the pond in the final 2 y of the study. Two individuals that survived to the end of the study showed unique movement patterns. One young male moved frequently, accumulating a large total distance, moved into new areas, and eventually found his way into a livestock water trough. The other, a young female, moved 2.6 km from the pond (a minimum total distance traveled of 3.3 km based on telemetry locations) and emigrated to a pond on a neighboring ranch. Turtles that died exhibited no distinctive behaviors. After the pond dried western pond turtles remained terrestrial for long periods, with one surviving individual remaining out of water for 617 consecutive days, which is an unprecedented finding for this species to our knowledge. Our findings suggest that increased frequency and severity of droughts can affect the resiliency of small, isolated western pond turtle populations, especially those in ephemeral aquatic environments. These small populations are essential to the long-term survival of the species because of the current fragmented distribution of the species.

Keywords: *Actinemys marmorata;* climate change; drought; movement; population viability; survival; western pond turtles

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Introduction

The severity of California's most recent drought is well-documented (Griffin and Anchukaitis 2014; Mann and Gleick 2015; Seager et al. 2015). Although paleoclimate records reveal that similar droughts have occurred in the region's distant past (Griffin and Anchukaitis 2014; Diaz and Wahl 2015), the current drought episode (beginning in 2012) is the most severe in >100 y of instrumental record (Swain et al. 2014; Robeson 2015). The 3-y period from 2012 to 2014 was characterized by below average precipitation and record high temperatures, creating what could be the most severe drought experienced in California in hundreds of years (Griffin and Anchukaitis 2014), especially in California's southern Central Valley (Williams et al. 2015). Such environmental extremes present major challenges to wildlife and their habitats. Though all wildlife species may experience problems related to drought conditions, species that rely on aquatic habitats are especially vulnerable. When a seasonal wetland dries, aquatic species must either estivate under dry conditions or seek out more favorable or wetter habitat. Both options pose risks of starvation, dehydration, and increased predation. Understanding how wildlife responds to climate-induced stress is crucial to the development of effective conservation and management strategies.

The western pond turtle *Actinemys marmorata* is native to the Pacific states and northern Baja California and is declining throughout its range (Jennings and Hayes 1994), primarily due to loss of habitat related to urbanization and agricultural encroachment (Hays et al. 1999; Germano and Bury 2001). In Washington, western pond turtles are considered state-endangered; they are on the Oregon state's sensitive species list; and in California they are a species of special concern (Jennings and Hayes 1994; Hays et al. 1999; Oregon Department of Fish and Wildlife 2016). They have been petitioned for listing under the Endangered Species Act and are currently under review by the U.S. Fish and Wildlife Service (U.S. Endangered Species Act [ESA 1973, as amended]) based on a 90-d finding issued in April 2015 (USFWS 2015).

The western pond turtle is the only extant freshwater turtle native to California. The species is dependent on both upland and aquatic environments, because it requires water for foraging and mating, but nests on land and uses upland habitat to varying degrees for overwintering (Reese and Welsh 1997). Western pond turtles can live >40 y (Bury and Germano 2008), and Bury et al. (2012) note that a few may survive >55 y in the wild, although it is unlikely that most live that long. They fill a wide variety of aquatic niches in rivers, streams, ponds, vernal pools, reservoirs, agricultural ditches, sewage treatment ponds, and estuaries (Holland 1992; Stebbins 2003; Germano 2010). Each of these habitats presents a unique set of environmental conditions and challenges that can impact the ability of a population to survive and recover from disturbance. Western pond turtles can maintain viable populations in small, ephemeral habitats (Germano and Riedle 2015); however, prolonged drought conditions have the potential to pose a serious threat to isolated turtle populations, especially small populations that lack alternative habitats (Anthonysamy et al. 2013; Rowe et al. 2013).

The effects of consecutive years of drought are cumulative; therefore, several years of data are needed to address drought impacts. We studied the effects of drought on survival, movement patterns, and duration of time out of water of western pond turtles in a small population in central California from 2009 to 2015. We collected data during years of normal precipitation and during an extreme multiyear drought, providing a valuable opportunity to examine how severe fluctuations in environmental events can impact species that reside in ephemeral lacustrine environments.

Study Site

The study was done at the San Joaquin Experimental Range (SJER) in Madera County, California (Figure 1). Resting in the western foothills of the Sierra Nevada between 210 and 520 m (700–1,700 ft), SJER occupies 1,806 ha of open woodland. This woodland landscape is dominated by blue oak *Quercus douglasii,* interior live oak *Q. wislizeni,* and foothill pine *Pinus sabiniana,* and has been grazed by cattle since the early 1900s. The climate is Mediterranean, with cool, wet winters and hot, dry summers. Most precipitation falls as rain during the winter months and rain is rare throughout the summer months. Based on long-term weather data collected at SJER since 1934, the long-term average for precipitation is 45 cm but is highly variable from year to year. Reservoirs that serve as stock ponds within the study area are dependent on surface runoff from rain that falls during the winter months. These small aquatic habitats are relatively isolated from other lotic or lentic ecosystems, leaving aquatic species few alternatives during the dry season.

Western pond turtles are believed to have been introduced to three stock ponds created shortly after SJER was established in the mid-1930s (Figure 1). No data exist on past population sizes but anecdotal observations show that numbers have clearly declined and western pond turtles are now limited to just one stock pond (K. Purcell, personal observation). The pond that still accommodates a small western pond turtle population at SJER is not fed by springs or streams but by rainfall runoff only and is strongly influenced by precipitation and evaporation. This pond and the one on the neighboring ranch measure just over half a hectare in size when full, but were generally smaller during the study period because of an extended period of below average precipitation. The length of time the ponds held water over the study period was closely linked to the amount of rainfall during the previous year.

Methods

Each spring we captured western pond turtles (Figure 2; Table S1, *Supplemental Material*) using primarily basking traps, hoop nets, and baited wires. We notched marginal

Figure 1. Map of western pond turtle *Actinemys marmorata* range within California (green dashed area). Inset map shows the San Joaquin Experimental Range (SJER), Madera County, California, where western pond turtles were studied from spring of 2009 through spring of 2015, and the adjacent ranch where one individual emigrated to another pond. Three reservoirs occur at SJER; however, only the pond in the lower portion of the map was occupied by pond turtles during the study. Aerial imagery acquired from National Agriculture Imagery Program (NAIP 2014).

scutes for individual identification beginning in spring 2012. Prior to 2012 we used various marking techniques (e.g., paint, bee dots) that proved unsuitable for long-term identification. We determined sex of western pond turtles based on morphological traits. We assigned an age category of juvenile or adult based on a combination of characteristics. Age, size, and the number of growth rings are all correlated in this species (Bury and Germano 1998; but see Germano and Bury 2009) and all should be taken into account when assigning age classes. Western pond turtles with a carapace length >120 mm are generally considered adults, and in some populations by carapace length >110 mm (Bury and Germano 2008; Ashton et al. 2012). We counted growth rings on the plastral shield to determine age. We were generally not able to count growth rings on western pond turtles over the age of 9 y as the plastron was worn smooth (Figure 3). The number of growth rings corresponds well to age in western pond turtles up to ≥10 y of age (Bury and Germano 1998). Finally, adults exhibit signs of sexual dimorphism. We weighed all western pond turtles, recorded shell measurements, recorded body condition, and noted any injuries. We radiotagged western pond turtles with carapace length >110 mm with 12- or 24-mo transmitters (generally model RI-2B, Holohil Systems Ltd). The weight of the transmitter plus epoxy was not >5% of the western pond turtle's body weight (Ashton et al. 2012). All individuals that received transmitters were sexually dimorphic, supporting their classification as adults. We applied transmitters to 20 individuals over the course of the study using nonexothermic epoxy, blackening the epoxy with copier toner, and leaving the whip antenna

Figure 2. Western pond turtles *Actinemys marmorata* were studied at the San Joaquin Experimental Range (SJER), Madera County, California, from spring of 2009 through spring of 2015. Photo on left shows basking at typical lentic habitat at SJER, middle photo show a western pond turtle captured for radiotagging, and photo on right shows a turtle with a radiotag.

free (Figure 2). One western pond turtle disappeared soon after capture and we did not include this individual in analyses. We replaced transmitters prior to battery failure when western pond turtles were in terrestrial locations and on aquatic western pond turtles upon recapture.

From April 2009 through March 2015, we tracked and located western pond turtles at least weekly except for a brief hiatus from October 2010 through January 2011 (Table S2, *Supplemental Material*). To locate turtles, we used hand-held receivers (Communications Specialist R1000) and 3-element Yagi antennas. We disturbed turtles in terrestrial sites only to the extent necessary to establish location. We used a Garmin Vista HCx GPS (3-m accuracy) to collect Universal Transverse Mercator coordinates. We calculated distances from the pond and turtle movements using ESRI ArcGIS 10.2.2 (ESRI 2015) software and Geospatial Modelling Environment (Beyer 2012) tools. We measured the distance from the edge of the pond at capacity for each terrestrial location.

We used precipitation records and the Palmer Drought Severity Index (PDSI) to relate western pond turtle survival and movements to drought conditions.

Figure 3. Western pond turtles *Actinemys marmorata* were studied at the San Joaquin Experimental Range (SJER), Madera County, California, from spring of 2009 through spring of 2015. Photo on left shows the plastron of a young western pond turtle with evident growth rings. Photo on right shows an older western pond turtle with growth rings worn smooth.

Local weather data have been collected at SJER since 1934. We calculated annual precipitation from daily records. We obtained monthly bias-corrected PDSI data from the National Climatic Data Center for California division five (NCDC 2015; based on California division 5 from http://www1.ncdc.noaa.gov/pub/data/cirs/). Precipitation as well as temperature is used to calculate PDSI. It also takes into account precedent conditions and can be computed at high spatial resolution. Negative PDSI values represent dry conditions with high potential evaporation (i.e., high temperatures), which have important implications for the persistence of aquatic habitats.

Throughout the paper we use the terms "turtle year" and "water year." To reduce confusion associated with these time intervals we provide explicit explanations here. We defined turtle year as 1 April through 31 March based on timing of reproduction and upland movements. We refer to a given turtle year using only the year in which it began. For example, turtle year 2009 designates the period from 1 April 2009 to 31 March 2010. Similarly, we defined the water year as 1 July through 30 June. July is a logical starting point for the water year at SJER because virtually no rain occurs in July and August. We specify a given water year using the year in which it began (e.g., water year 2009 designates the period from 1 July 2009 to 30 June 2010).

We used known-fate modeling in Program MARK (White and Burnham 1999) to derive monthly and yearly survival probability estimates from encounter histories. We created monthly encounter histories from the weekly telemetry data for 19 western pond turtles. Each western pond turtle was given a status of alive, dead, or missing for each of the 72 mo of the study. We censored from analysis any western pond turtles missing for ≥ 1 mo while they were missing. There were 20 censoring events that were 1 mo in duration and 5 prolonged censoring events (>2 mo) where we subsequently relocated turtles (range $=$ 3–22 mo). Our a priori set of candidate models was based on variables we hypothesized might affect survival, including variables for drought, sex, and year. Our model set included all combinations of PDSI, sex, and turtle year along with a null model, for 8 total models. We evaluated models using Akaike's Information Criterion adjusted for small sample size (AIC_c) and Akaike weight (Burnham and Anderson 2002).

Results

Precipitation and impacts on the San Joaquin Experimental Range stock pond

Water year 2013 was the driest recorded at SJER since recordkeeping began in 1934. If we define a drought as any period of ≥ 2 years with annual precipitation $\leq 75\%$

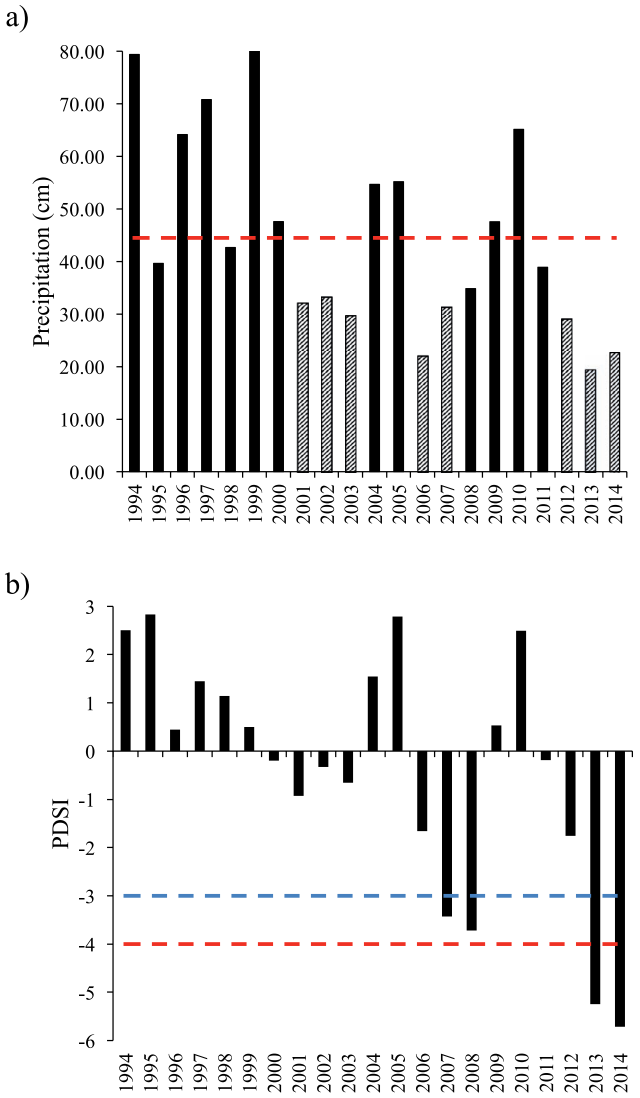

Figure 4. Western pond turtles *Actinemys marmorata* were studied at the San Joaquin Experimental Range (SJER), Madera County, California, from spring of 2009 through spring of 2015. **(a)** Annual precipitation at the SJER for the 1994 through 2014 water years (July through June of the following year). Drought years are shown in hashed bars. Average precipitation at SJER is indicated by dashed line. **(b)** Palmer Drought Severity Index (PDSI) for July through June of 1994 through 2015. Values from -3.0 to -3.9 are classified as severe drought (blue dashed line shows beginning of severe class); values below -4.0 are classified as extreme drought (red dashed line; Heddinghaus and Sabol 1991).

of the long-term mean, three droughts have occurred in the past 20 y at SJER (Figure 4a). The last of these, from 2012 through 2014, was the most severe and occurred during our study. Similarly, PDSI data indicated three periods of drought conditions in the region. Of the three periods with negative PDSI values shown in Figure 4b, the first (2000-2003) was near normal. By the end of the second period (2006–2008) PDSI values were categorized as severe according to categories defined by Heddinghaus and Sabol (1991), and in the most recent period (2011–2014) values considered extreme were achieved (Figure 4b).

Pond duration is a function of the previous water year's precipitation. In general, the pond lasted throughout the year if above average precipitation occurred in the previous year and the pond dried if below average precipitation occurred during the previous year. In the first year of the study the pond dried by 31 July 2009. This reflects below average precipitation during the 2008 water year, and residual effects of the mild-to-severe drought that occurred from 2006 to 2009 (Figure 4). The pond held water year-round throughout the second and third years of the study (2010 and 2011), both of which were preceded by above average rainfall (48 cm and 63 cm, respectively). The 2012 and 2013 water years both were preceded by below average rainfall, and by 1 July in both years the pond was dry. After the pond dried in the summer of 2013, it remained dry through the winters of 2013 and 2014. To our knowledge, this has never been observed since SJER was established in 1935.

Western pond turtle mortalities and survival

We captured 35 western pond turtles throughout the course of the study (Table 1). Of those 35, we fitted 20 with radiotransmitters. We did not put transmitters on western pond turtles that were too small for transmitters ($n = 12$) or adults captured when we were out of transmitters in the early years of the study ($n = 4$). We dropped nine western pond turtles from the database when their transmitters failed, we did not recapture them before their transmitter batteries died, or we lost track of them (Table 1). We refitted western pond turtles with new transmitters upon recapture but we did not always recapture them before their batteries died. We trapped no new individuals in 2014 because there was no standing water to accommodate trapping efforts. We did not follow any western pond turtles for the full duration of the study. The longest any individual was monitored was from April 2009 through March 2014, which included a 19-mo lapse in data collection in 2010 and 2011.

We observed no mortalities of radiotagged western pond turtles in the first 3 y of the study (Table 1). Two individuals died in the fourth year of the study, four in the fifth year, and three western pond turtles died in the last year of the study (Table 1). We also found a dead nonradiotagged (but previously captured and notched) juvenile in the last year of the study (not included in mortality calculations). All observed mortalities occurred in drought years and in years when the pond completely dried up in the summer or never formed. All but one mortality occurred in warm or hot months (June through Oct; Figure 5a). Western pond turtle mortality was highest in years with low precipitation and annual survival decreased as the drought intensified ($R^2 = 0.674$, $P = 0.045$ for precipitation; $R^2 = 0.903$, $P = 0.004$ for PDSI). At the end of the 72-mo study period only two live western pond turtles with transmitters remained. All

Table 1. Data on western pond turtles *Actinemys marmorata* captured and radiotagged at the San Joaquin Experimental Range, Madera County, California, from spring of 2009 through spring of 2015. Turtle year is defined as 1 April through 31 March (only the first year is given). Only adults were fitted with radiotransmitters, and not all adults were radiotagged each year because of a lack of transmitters in some years. Total captured includes recaptures from previous years, # new transmitters is the number of new adults captured that received transmitters, mortalities is the number of turtles tracked via telemetry that died, and percent mortality is the percent of turtles that died of those tracked each year.

Turtle year	Total captured	New captures	Recaptures	Total # adults captured	# new transmitters	# tracked from previous years	Total # tracked	Mortalities	% mortality
2009	11	11	0	10	8	0	8	0	0
2010	11	6	5	9	0	4	4	0	0
2011	3	3	0	3	3	0	3	0	0
2012	19	12	6	13	7	5	12	2	16.7
2013	11	3	8	9	1	8	9	4	44.4
2014	5	0	5	5	0	5	5	3	60.0
Total		35			19				

mortalities appeared to have occurred during transit between terrestrial sites except for one that appeared to have been dug from its burrow by a predator. All carcasses had missing limbs, most had all or nearly all of their flesh consumed, and about half had obvious scratch or bite marks.

Overall survival across all years of the study was 14%, all of which was accounted for during the last 3 y of the study (Figure 5b). The most supported model included PDSI and accounted for 70.3% of the Akaike weight (Table 2). Survival decreased with drought (Figure 5c). The only other competitive model included PDSI and sex. Male survival was slightly higher than female survival (19.1% vs. 11.5%) although the 95% confidence intervals overlapped.

Western pond turtle movements

Western pond turtles remained fairly close to the pond in years following near normal or nondrought conditions, when rains were sufficient to fill the pond (Table 3; Figure 4). Distances moved in 2009 and 2013 and associated variability were similar, likely reflecting dry conditions in the preceding years (Table 3; Figure 4). In the final 2 y of the study we observed high variability in western pond turtle movement distances from the pond, with some remaining close to the dry pond and others moving long distances as the drought persisted (Table 3). Most of the turtles that died did not move far from the pond or exhibit distinctive behaviors. The two surviving western pond turtles tracked through March 2015 exhibited unique movement patterns in terms of locales visited and either straight-line distance moved from the pond or cumulative distances moved (Figure 6). Turtle 23, a young male, made movements into areas not previously used and moved frequently, so his total distance moved was unusually high. Based on the 29 unique locations from our approximately weekly telemetry observations, he traveled a minimum cumulative distance of 847 m in 2013 and 956 m in 2014. He was often found unconcealed rather than completely burrowed, indicating that he was in transit. In March 2015 he found his way into a livestock water trough and remained there to the end of the study period. Turtle 60, a young female, made progressively more distant movements and was able to find alternative aquatic habitat. She moved 2.6 km (straight-line) from the SJER pond, and emigrated to a pond on a neighboring ranch to the northeast (Figure 6). The minimum total distance moved was 3.3 km (based on telemetry locations). She remained in this pond until the end of the study.

Time in terrestrial habitat

The five western pond turtles that survived into the final year of the study spent unusually long periods of time out of water, far exceeding the number of consecutive days out of water during previous years (Table 4). On average these five individuals spent 423 consecutive days out of water. This is a conservative estimate because three of the five turtles died by early July 2014. Turtle 23, a survivor, spent 617 consecutive days out of water (Table 4).

Discussion

We documented high mortality of western pond turtles during an extreme drought event in California. The effects of drought on survival of western pond turtles have been previously reported by Holland (1994) and unpublished data from Patterson and Stafford (L. Patterson and R. Stafford, California Department of Fish and Wildlife, personal communication) documented large-scale die-offs in California in 2015. Drought-related mortality has been reported in other turtle species as well. Lindeman and Rabe (1990) documented high mortality of western painted turtles *Chrysemys picta belli* during a 2-y drought in Washington, with up to 20–25% of the total population succumbing to predation; and high mortality of Blanding's turtles *Emydoidea blandingii* was documented in wetlands subject to drawdown, with increasing mortality as water levels receded (Hall and Cuthbert 2000).

Western pond turtle mortalities observed in this study appeared to be due to predation, although scavenging cannot be ruled out. Documented predators of western pond turtles that occurred at SJER include coyotes *Canis*

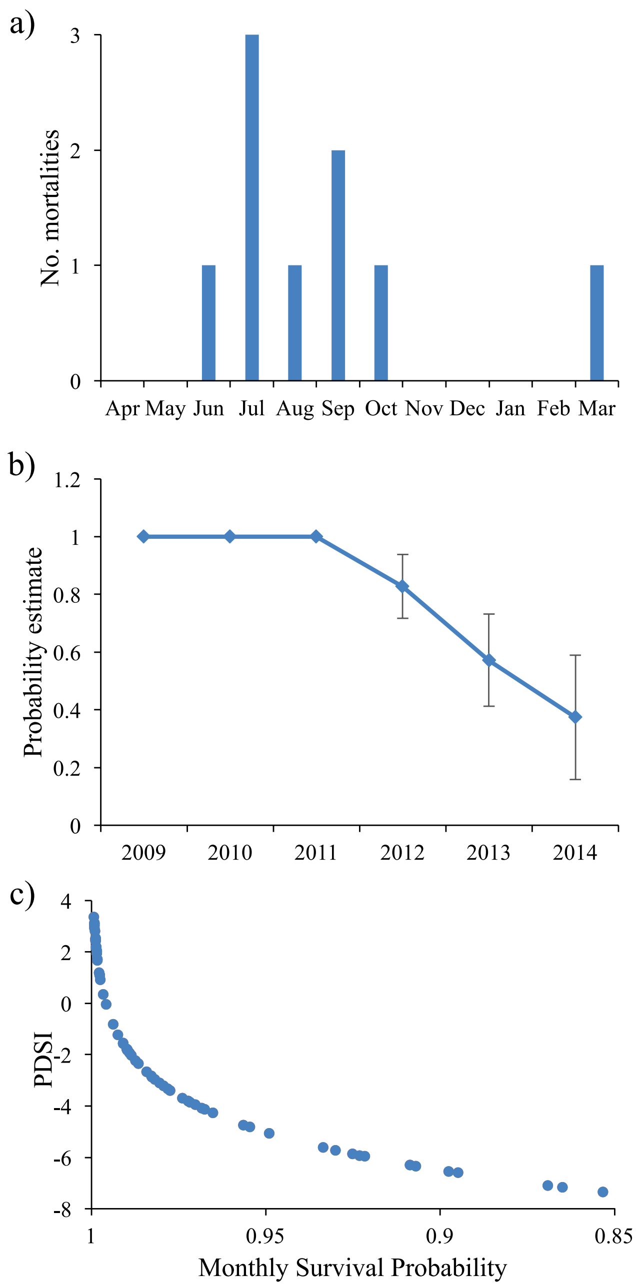

Figure 5. Mortality patterns and survival estimates for western pond turtles *Actinemys marmorata* studied at the San Joaquin Experimental Range (SJER), Madera County, California, from spring of 2009 through spring of 2015. **(a)** Number of mortalities of western pond turtles by month. **(b)** Annual survival estimates based on Program MARK. Error bars represent 95% confidence intervals. **(c)** Relationship between PDSI and monthly survival rates.

latrans and raccoons *Procyon lotor*. Coyotes were common and frequently sighted at SJER (Purcell et al. 2007). Raccoons were commonly seen around stock ponds and documented on a game camera overlooking a water trough; and raccoon DNA was isolated from swabs taken from one carcass (G. Wengert, Integral Ecology Research Center, unpublished data). Some apparent predation could have been scavenging of individuals that died from other causes, although some individuals were known to be healthy with no sign of emaciation within 1 wk (1 case) or 1 mo of death (2 cases) based on capture data, and all carcasses were at least partially consumed. Conversely, carcasses found during the 1986–1991 drought in California were mostly intact, including soft parts, and showed no obvious signs of predation as a cause of death; body condition therefore was consistent with death by starvation (Holland 1992). Whatever the ultimate cause of death, the extended occupancy of upland sites and increased movement prompted by drought conditions likely resulted in increased predation risk.

After the pond dried and failed to reform because of lack of winter rains, western pond turtles remained terrestrial without access to food or water for long periods, with one individual surviving >20 mo out of water. To our knowledge, this finding exceeds published records for continuous time out of water for this species. Other individuals in this study were documented in terrestrial sites for >400 consecutive days. Western pond turtles must ingest their prey in water (Bury 1986), so they are fasting while on land and on land do not drink. Little is known regarding how long aquatic turtles can survive in upland locations. Maximum periods (~200 d) of terrestriality reported in other studies of western pond turtles were much shorter than our observations(Reese and Welsh 1997; Rathbun et al. 2002; Pilliod et al. 2013). Turtle species clearly vary in their ability to survive without food and water. Long-necked turtles *Chelodina longicollis* survived a maximum of 480 d out of water (Roe and Georges 2008), and survival as long as 2 y without water has been recorded in yellow mud turtles *Kinosternon flavescens* (Rose 1980, cited in Ligon and Peterson 2002). Extensive periods out of water as a consequence of drought undoubtedly increase physiological stress to animals.

We observed unusually long movements among some individuals in response to drought, and movement into areas not used previously. Western pond turtles in seasonal ponds in Central California moved a maximum distance of 345 m from water, and a summary of 13 studies showed a range of 8–500 m from water in both permanent and ephemeral habitats (Pilliod et al. 2013). In the last year of our study, distances traveled were well outside that range, with one individual moving 2.6 km from the pond (straight line distance between ponds). Of >1,200 turtles marked, Holland (1992) reported a maximum linear distance between capture and recapture locations of 2.5 km, although the majority of individuals were relatively sedentary with only 8% moving out of the capture area. This finding highlights that at least some western pond turtles were responding to drought by venturing outward. However, this was not the response of all individuals, because some remained close to the dry pond even as the drought persisted.

Decisions to move or remain in terrestrial habitats depend on the ability of individuals to weigh the costs and benefits of moving vs. staying (Anthonysamy et al. 2013). Responses likely depend on local landscape

Table 2. Candidate models and results of model testing for survival of western pond turtles *Actinemys marmorata* from April 2009 through March 2015 at the San Joaquin Experimental Range, Madera County, California. PDSI is the Palmer Drought Survival estimate for April through March for the water year. Turtle year (turtleyear) is defined as 1 April through 31 March. *K* is the number of parameters in the model.

Model	*K*	AIC_c	ΔAIC	Akaike weight
PDSI	2	77.4506	0	0.70303
PDSI sex	3	79.3369	1.8863	0.27376
Constant (null)	1	86.6339	9.1833	0.00713
PDSI turtleyear	8	87.0745	9.6239	0.00572
Turtleyear	7	87.9337	10.4831	0.00372
sex	2	88.5155	11.0649	0.00278
PDSI sex turtleyear (global)	9	88.878	11.4274	0.00232
sex turtleyear	8	89.6934	12.2428	0.00154

factors such as distance between wetlands, the physiological state of individuals, and predation risk (Roe and Georges 2008). The costs of remaining include depletion of energy and water stores. The costs of movement include increased mortality from predators and roads and the likelihood that a suitable wetland may not be found. The costs of terrestrial movement are well-recognized (Christiansen and Bickham 1989; Hall and Cuthbert 2000; Rathbun et al. 2002; Gibbs and Steen 2005; Roe and Georges 2008).

Long-lived species such as western pond turtles may use previous experience to adjust their behavior to drought conditions (Anthonysamy et al. 2013). In our study, age and experience did not appear to provide a benefit. Both of the western pond turtles that survived through the end of the study were too young (6–8 y of age) to have experienced a previous drought. Six of the nine turtles that died were old enough to have smooth plastrons (>9 y). Similarly, Roe and Georges (2008) found that responses of long-necked turtles in Australia to wetland drying were not related to age, sex, body size, condition, or experience.

Drought, coupled with increasing temperatures that result in high rates of evapotranspiration, is likely to negatively impact the already imperiled western pond turtle populations in California. With sustained drought, the isolated aquatic habitats in our study area disappeared for an extended period of time, and negatively impacted the western pond turtle population at SJER. Although there is considerable uncertainty regarding projections for changes in precipitation in California during the next century, some simulations suggest decreases in winter precipitation of 15–30%, centered in the Central Valley and along the northern Pacific Coast (Hayhoe et al. 2004). Increased length, frequency, and severity of droughts are predicted, with increasing temperatures contributing to this trend (Hayhoe et al. 2004). In years of low precipitation, especially when they are consecutive, any small but persistent water sources can be crucial to the survival of turtles and many other wildlife species. We observed use of livestock water troughs by western pond turtles to survive an exceptional drought. A wide variety of wildlife species also used this trough as a water source during this period. The importance of wildlife escape structures in livestock water troughs to prevent drowning has been well-documented (Wilson 1977; Taylor and Tuttle 2012). Although nutrients are often limiting to growth of individuals attempting to live in troughs, they may promote survival sufficient to sustain the population through hard times.

The reproductive strategy of freshwater turtles is typified by long life span, delayed sexual maturity, and low recruitment. Population persistence is dependent on high adult survival. These life-history traits make recovery from population declines slow (Reese and Welsh 1998; Hall and Cuthbert 2000; Dodd et al. 2006). Especially when population sizes are low, catastrophic events can drastically alter extinction probabilities (Dodd et al. 2015). Furthermore, when habitats are isolated, emigration is less likely to serve as a rescue mechanism. Our findings have important conservation implications for western pond turtles. Extirpation of local populations can affect the overall health of imperiled species. The small size, isolation, and tenuous state of western pond turtle populations in the Pacific states indicate the need for conservation action.

This small population of western pond turtles may not survive the drought and the resulting lack of habitat needed for foraging and reproduction. We tracked only adults, so we have no information on survival rates of younger age classes, which are generally lower because

Table 3. Straight line distances moved from the pond edge by western pond turtles *Actinemys marmorata* at the San Joaquin Experimental Range, Madera County, California, from 2009 through 2014. Turtle year is from 1 April through 31 March of the following year. Distances are the mean, minimum, and maximum distance from the perimeter of the pond at capacity. Number of turtles is the number included in distance measurements. Number of locations is the number of unique locations included in distance measures. There are no distance observations for 2010 because the turtles were in the pond for the most part except for one foray, and telemetry observations ended in September 2010.

Turtle year	Mean (m; SD)	Min. (m)	Max. (m)	Number of turtles	Number of locations	Pond dry-by date
2009	184 (146)	1	696	8	73	31 July 2009
2010	NA	NA	NA	NA	NA	Water all year
2011	83 (68)	9	212	3	5	Water all year
2012	90 (42)	39	364	10	67	1 July 2012
2013	179 (150)	25	455	9	67	1 July 2013
2014	412 (645)	32	2651	5	43	Never formed

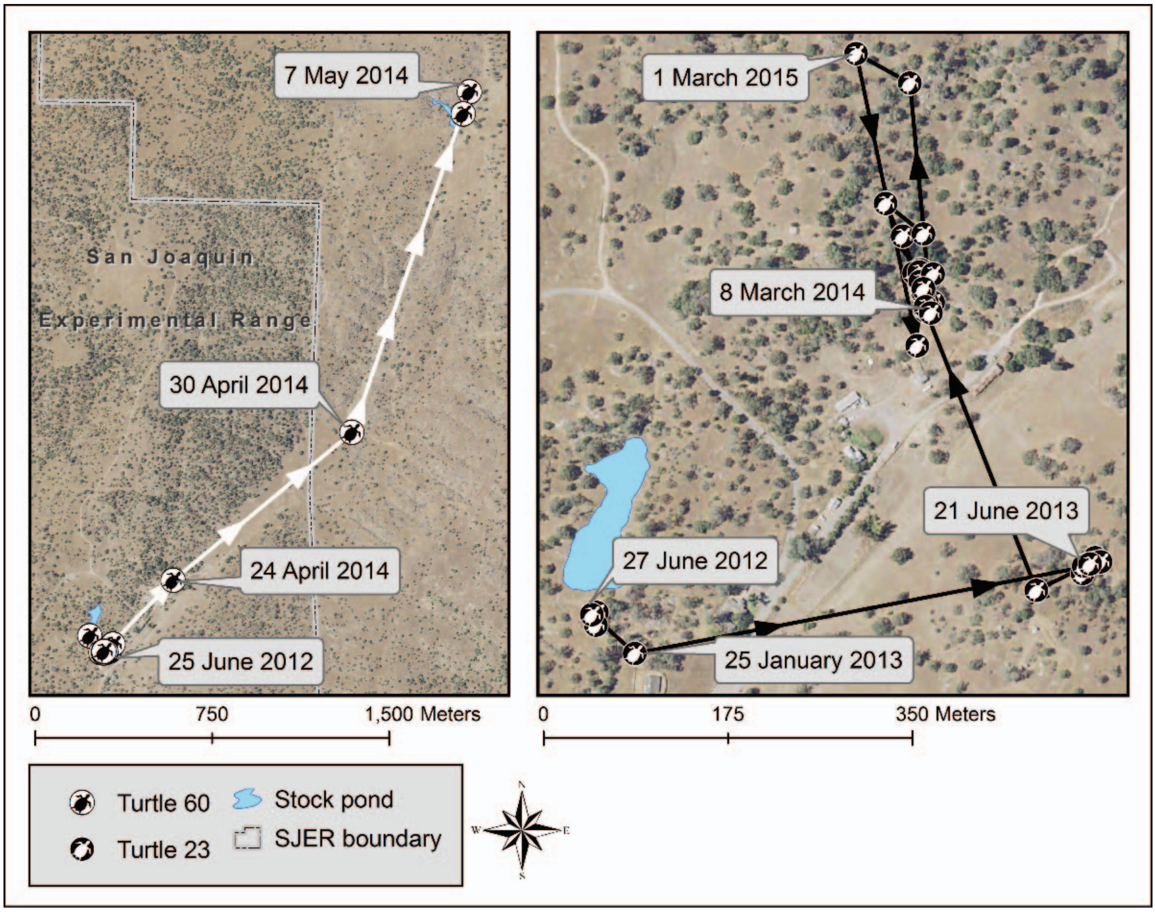

Figure 6. Movements of two western pond turtles *Actinemys marmorata* at the San Joaquin Experimental Range, Madera County, California in 2013 and 2014 (April through March of the following year in each case). Turtle 60 (left) was an adult female that made a long-distance dispersal movement to a neighboring ranch (white arrows). Map on right shows numerous smaller movements (black arrows) of Turtle 23, an adult male. Aerial imagery acquired from National Agriculture Imagery Program (NAIP 2014).

of increased vulnerability to predation and abiotic factors (Iverson 1991). Future work will entail conducting recapture efforts at this location at the next opportunity (when pond reforms) to estimate population size and impacts of what are now 4 y of drought. Additional spatial analyses are underway to look more closely at western pond turtle movement patterns in relation to available terrestrial habitat.

Table 4. Number of consecutive days on land for five western pond turtles *Actinemys marmorata* at the San Joaquin Experimental Range, Madera County, California, over 3 turtle years (April through March of the following year). Consecutive days on land indicates the maximum number of days each turtle spent out of water.

	Consecutive days on land		
Turtle ID	**2012**	**2013–14**	**Mortality date**
23	212	617	NA
24	289	405	8 July 2014
30	261	404	23 July 2014
31	265	368	8 July 2014
60	254	324	NA

Supplemental Material

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Table S1. Capture data for western pond turtles *Actinemys marmorata* at the San Joaquin Experimental Range (SJER), Madera County, California, from spring of 2009 through spring of 2015. 'Transmitter' (Y/N) is whether a western pond turtle was radiotransmittered. 'Growth rings' indicates the number of rings counted or whether the plastron was smooth and rings were obscured. 'Carapace length' was the midline carapace length from the tip of the nuchal to the cleft at the tail. 'Carapace width' is measured at the suture between the second and third vertebral shield. 'Plastron length' is the minimum plastron, measured at the clefts at each end of the plastron. Turtles that died during the study are listed in the 'Mortality' column. 'Found dead' and 'Last observed' are the date the carcass was found and the date the western pond turtle was last observed prior to mortality, respectively.
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Table S2. Telemetry data for western pond turtles *Actinemys marmorata* were studied at the San Joaquin Experimental Range (SJER), Madera County, California, from spring of 2009 through spring of 2015. 'Turtle year' is defined as 1 April through 31 March (only the first year is given). 'Telemetry date' and 'Telemetry time' are the date and time (24-h clock) the location was recorded, respectively. 'Observer' indicates the person recording the location data. 'UTM Easting' and 'UTM Northing' are the Global Positioning System coordinates collected in NAD 1983 Universal Transverse Mercator zone 11N for terrestrial locations. 'Habitat' indicates whether the location was in the pond (aquatic), terrestrial, or in the livestock trough (trough).

Found at DOI: http://dx.doi.org/10.3996/012016-JFWM-005.S2 (92 KB XLSX).

Reference S1. Holland DC. 1992. A synopsis of the ecology and status of the western pond turtle (*Clemmys marmorata*) in 1991. Report to National Ecology Research Center. San Simeon, California: U.S. Fish and Wildlife Service.

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