Mule Deer Demographic Responses to Select Climatic Variables in Arizona

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Abstract: To determine what effect climate has potentially had on recent demographic shifts and population declines of mule deer in Arizona, I studied the relationship of monthly precipitation and Palmer Drought Severity Index (PDSI) values with Arizona Game and Fish Department winter mule deer (*Odocoileus hemionus*) survey fawn:doe (FDR) and buck:doe (BDR) ratio data. Seven of 37 Game Management Units (GMUs) had no relationship between measured climatic variables and FDR, while 22 other GMUs had relationships with adjusted R^2 of < 0.350. Thirteen of 37 GMUs had no relationship between measured climatic variables and BDR, while 19 GMUs had relationships with adjusted R^2 of < 0.350. Pooling GMUs into similar habitats did not improve the modeled fit of relationships between demographic parameters and climatic variables. Habitats at climatic extremes (i.e., desertscrub and montane conifer habitats) demonstrated a predictable and superior model fit with FDR, more so than other habitats (i.e., Mohave desertscrub, chaparral and desertscrub, and grassland-woodland habitats), suggesting climate has a greater influence on recruitment in less moderate climates.

Statewide mule deer population estimates showed a relationship with PDSI data with an adjusted R^2 of 0.446. This apparent weak explanatory ability is probably the result of some combination of: (1) mule deer demographics responding to other confounding factors such as predation, habitat alterations or succession, or sport harvest, (2) climatic variation not driving population declines across Arizona, (3) other climatic variables, such as temperature, having a greater influence than precipitation or PDSI, (4) demographic parameters responding to a combination of climatic factors in addition to those I evaluated either directly or through vegetative influences (nutrition or cover), or (5) survey data is not accurately representative of the population. However, the explanation of 40-50% of the variation in statewide mule deer population numbers does suggest that climatic variables do have a strong influence in determining deer numbers throughout the state.

Key words: Arizona, climate, mule deer, *Odocoileus hemionus*, Palmer Drought Severity Index, precipitation.

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Introduction

Mule deer in Arizona have suffered population declines during the past two decades (Arizona Game and Fish Department, unpub. data). Resource managers have attributed much of this decline to either ultimate or proximate causal agents. In fact, the decline in mule deer numbers has occurred across the West, and the Western Association of Fish and Wildlife Agencies (WAFWA) established an ad hoc committee in June 1998 specifically to examine this phenomenon. At their initial meeting, this committee identified climatic changes as one of eight factors (climatic changes, habitat alterations or succession, nutrition, disease, competition, predation, sport harvest, or urbanization) that likely has had substantial influence on mule deer populations across the West (WAFWA Mule Deer Ad Hoc Committee, unpub. data). Connolly (1981*a*, *b*) identified similar putative causes for a West-wide decline in the 1960s and 1970s.

Various climatic factors influence ungulate populations. Precipitation in desert regions may influence mule deer productivity (Leopold and Krausman 1991, Smith and LeCount 1979) and movements (Kucera 1992, Rautenstrauch and Krausman 1989). Low temperature may influence habitat occupation, as certain habitats provide needed thermal cover (Parker and Gillingham 1990). High temperatures influence mule deer during summer, and deer respond by altering activity patterns (Leopold and Krausman 1987). Yet the impact of many climatic variables on ungulates is realized through vegetative influences on nutrition and carrying capacity (Feldhamer et al. 1989, Langvatn et al. 1996, Leopold and Krausman 1991, Smith and LeCount 1979). Winter snow accumulations can also dramatically influence survival (Mech et al. 1987, Picton 1984).

Because climate has the potential to influence mule deer populations, I studied climatic relationships in regard to demographic parameters measured routinely by the Arizona Game and Fish Department (AGFD). My objective was to compare mule deer demographic components with monthly precipitation data and Palmer Drought Severity Index (PDSI) (Palmer 1965), in an attempt to determine if these climatic variables had an influence on Arizona's mule deer population.

Methods

The AGFD conducts winter deer surveys from ground (foot, vehicle, or horseback) or air (helicopter or fixed-wing) during winter (months of December and January). During these surveys, observers record the number of observed male, female, and young. Population estimates are then derived using annual buck:doe ratios (BDR), fawn:doe ratios (FDR), harvest estimates from mail out questionnaires, estimates of mean annual non-hunt mortality based on change-in-ratio estimates, and an initial estimate of the population size (Fig. 1). Sampling efforts were not equal among years. Consequently, I did not search for relationships in non-ratio data (raw counts) despite acknowledged inherent problems with ratio data (Atchley et al. 1976, Packard and Boardman 1988). I was also unable to separate survey data by technique.

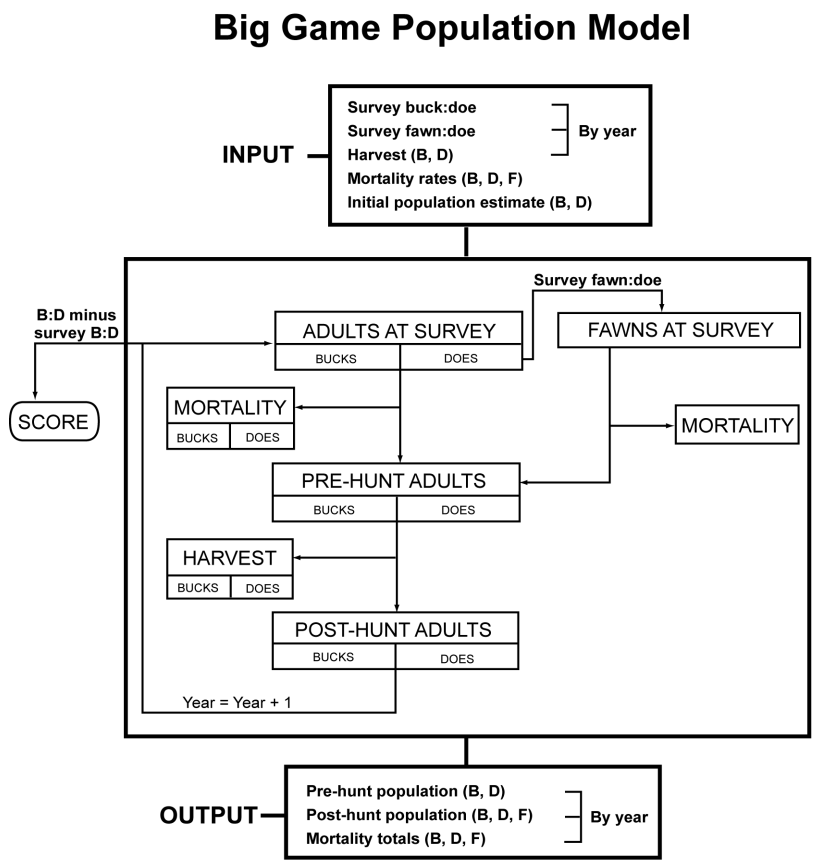

Figure 1. Conceptual framework of the Arizona Game and Fish Department model for estimating mule deer population numbers in Arizona.

I examined relationships between mule deer demographic parameters using data from the AGFD, and climatic variables from the National Oceanic and Atmospheric Administration data base. Specifically, I calculated FDR and BDR from AGFD winter surveys from 1957 to 1996. Monthly precipitation and Palmer Drought Severity Index (PDSI) data were taken from the most central and representative weather station of each individual GMU. I also included monthly weather data, including two years prior to mule deer surveys, to examine lag effects on populations. Because GMUs have been changed over the years, all surveys were pooled to the largest common unit (i.e., GMUs 1-10, 12, 13, 15-24, 27-45). I used these data in an exploratory, forward step-wise, multiple linear regression (*P* to enter = 0.05, *P* to remove = 0.10) analysis to determine which climatic factors best predicted mule deer demographic parameters and population responses.

Cluster analysis was used to group similar GMUs based on proportions of habitat associations (Brown et al. 1979). I then pooled mule deer observations across similar GMUs and recalculated FDR and BDR. Climatic data were averaged across similar GMUs. Each pooled group of GMUs with similar habitat was then reanalyzed using forward step-wise, multiple linear regressions.

Finally, I used statewide mule deer population estimates from 1970-1996 and climatic factors to examine larger scale relationships. For statewide climatic data, I averaged climatic data across the state. Again, I used forward step-wise multiple linear regression to evaluate this relationship. Because these analyses were exploratory in nature, I consciously ignored the potential for autocorrelation among climatic variables.

RESULTS

Monthly precipitation and PDSI values explained little of the variation in FDR and BDR data (Table 1). In addition, I found little consistency among GMUs in climatic factors that explained variation in demographic parameters. Seven of 37 GMUs demonstrated no relationship with FDR and weather variables. Adjusted R^2 on FDR models ranged from 0.148-0.562, although 22 models had adjusted R^2<0.350. Thirteen of 37 GMUs demonstrated no relationship with BDR and weather variables. Adjusted R^2 on BDR models ranged from 0.096-0.520, although 19 models had adjusted R^2<0.350 (Table 1).

Cluster analysis grouped GMUs into 5 categories: (1) montane conifer GMUs (1-14, 19, 23, 25-27), (2) Mohave desertscrub GMU (15), (3) chaparral and desertscrub GMUs (17, 18, 20-22, 24, 37), (4) grassland-woodland GMUs (28-36), and (5) desertscrub GMUs (16, 38-46) (Figs. 2 and 3). Multiple linear relationships from the analysis of pooled GMUs yielded dissimilar relationships among categories, with relatively low adjusted R^2 values. These relationships were generally dissimilar from many of the individual GMUs within each category (Table 2). The statewide mule deer population estimate was best described by greater PDSI values in the September before surveys and greater PDSI values in the October 2 years before surveys. The adjusted R^2 value for this relationship was 0.446.

DISCUSSION

Relatively little variation in mule deer population parameters measured by AGFD was explained by multiple linear relationships with monthly precipitation or PDSI values. Several possible explanations exist for this lack of explanation: (1) mule deer demographics are responding to other confounding factors such as predation, habitat alterations, or sport harvest, (2) climatic variation is not driving population declines across Arizona, (3) other climatic variables, such as temperature, might have a greater influence than precipitation or PDSI, (4) demographic parameters might respond to a combination of climatic factors in addition to those that I evaluated, either directly or through vegetative influences (e.g., nutrition or cover), or (5) survey data does not accurately represent the true mule deer population numbers.

Table 1. Significant climatic variables and adjusted R^2 values for multiple linear regression equations explaining fawn:doe ratios (FDR) and buck:doe ratios (BDR) in each Arizona Game Management Unit (GMU).

GMU	FDR[a]	R^2	BDR[a]	R^2
1	No relationship	--	+Oct ppt, +P Oct ppt., -P Oct PDSI	0.395
2	-Jul PDSI	0.235	-Jan ppt, -P Jan ppt	0.392
3	+Jul PDSI, -Aug PDSI	0.224	-PP Jan PDSI	0.108
4	-P Jun ppt	0.148	No relationship	--
5	-Feb ppt, -Sep ppt, +P Jul ppt	0.360	-Feb PDSI	0.164
6	+Jan PDSI, -Aug ppt, -Feb ppt, +PP Jan ppt	0.382	+P Aug ppt, -May PDSI	0.244
7	No relationship	--	+P Apr ppt, -Mar ppt, +P Aug PDSI	0.299
8	+Jul ppt, +P Jul ppt, +Nov PDSI, -P Dec ppt, -Mar ppt, -P Jun ppt	0.562	-P Aug PDSI	0.255
9	+Nov ppt, +P Apr ppt, +P May ppt	0.276	-Aug PDSI	0.236
10	-Feb ppt, -P Feb PDSI	0.319	No relationship	--
12	+P Dec PDSI, -Jan PDSI	0.246	-P Jul PDSI	0.116
13	+Dec ppt, +P Apr ppt	0.375	-Dec ppt, -P Oct PDSI	0.297
15	-P Jan ppt	0.171	+Jan ppt, +Feb ppt, +P Nov ppt, -Apr PDSI	0.520
16	+Nov PDSI, -P Jan ppt	0.342	+P Sep ppt	0.252
17	+Nov PDSI	0.171	No relationship	--
18	+P Jun ppt, -Mar PDSI	0.235	+P Dec ppt, -P Apr ppt, -May PDSI	0.319
19	+Jul ppt	0.136	-Feb ppt	0.150
20	+Jul ppt	0.083	No relationship	--
21	+Jul PDSI, -May PDSI	0.271	+Jul PDSI, -P Dec ppt	0.372
22	+Oct ppt, +P Dec ppt	0.217	-P Jul PDSI	0.183
23	+Sep ppt, +P Jun ppt, +P Jan PDSI, -Aug PDSI	0.392	No relationship	--
24	+Mar ppt, +P Apr ppt, +Jan PDSI, -Apr ppt, -May ppt, -P Aug ppt	0.554	No relationship	--
27	+Jul PDSI, +P Jul PDSI, -P Aug PDSI	0.297	+P Oct ppt, +P Nov ppt, -Jul PDSI	0.464
28	+Dec ppt, +P Apr ppt	0.278	No relationship	--
29	No relationship	--	+P Sep ppt	0.135
30	No relationship	--	-May ppt	0.126
31	+Oct ppt, -P Apr PDSI	0.153	No relationship	--
32	+Jan PDSI, -Aug ppt, -P Aug PDSI	0.329	No relationship	--
33	No relationship	--	-P Apr PDSI	0.205
34	No relationship	--	-Jan PDSI	0.127
35	+Aug ppt, +Sep PDSI	0.259	No relationship	--
36	-Oct ppt, -Apr ppt, -P Nov ppt, -P Apr ppt, -P Mar ppt	0.447	-Apr PDSI	0.254
37-38	+Oct ppt, -Jun ppt, -P Jul ppt, -P Apr ppt	0.370	+P Sep ppt	0.133
39-40	No relationship	--	No relationship	--
41	-Jan ppt, -P Sep ppt, -P Feb PDSI	0.341	No relationship	--
42	+Nov ppt, -P Mar PDSI	0.184	No relationship	--
43-44-45	-P May PDSI	0.159	+P Sep PDSI	0.096

[a] Abbreviations: ppt refers to precipitation, PDSI refers to Palmer Drought Severity Index, + refers to positive effect of factor, - refers to negative effect of factor, no modifier on month refers to data from during or immediately preceding the survey, P as a modifier on month refers to the year prior to the survey, and PP as a modifier on month refers to 2 years prior to the survey.

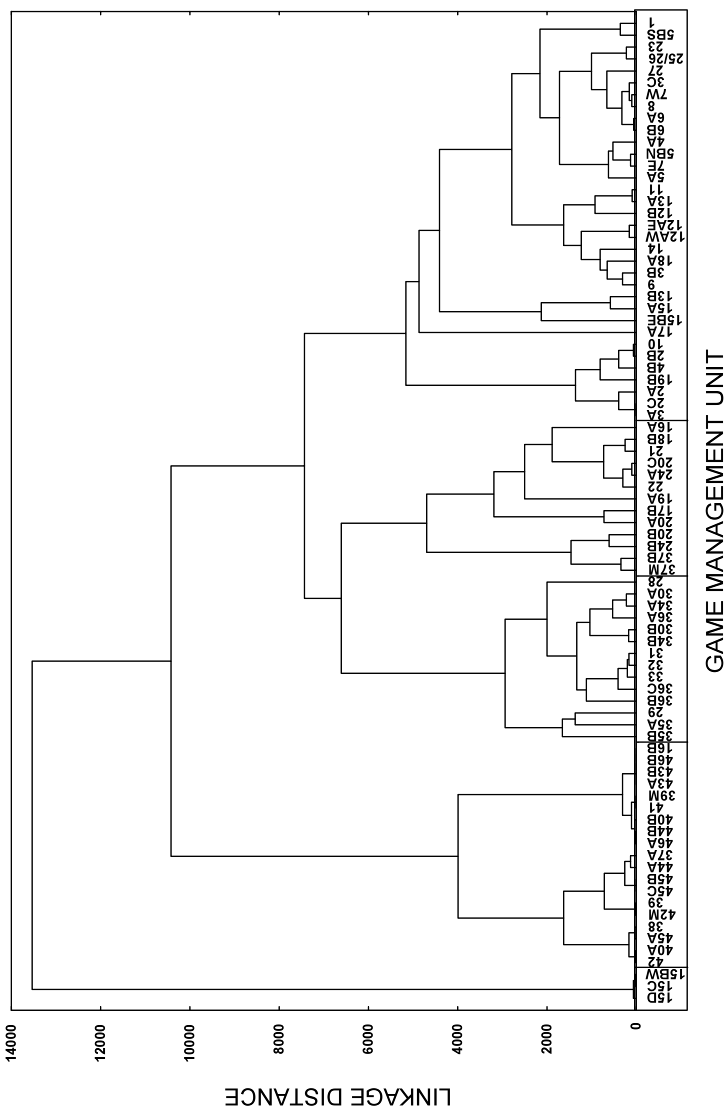

Figure 2. Cluster diagram of Arizona Game Management Units, based on similarities of habitat associations (Brown et al. 1979). Clusters (from left to right) are (1) Mohave desertscrub, (2) desertscrub, (3) grassland-woodland, (4) chaparrel and desertscrub, and (5) montane conifer habitats.

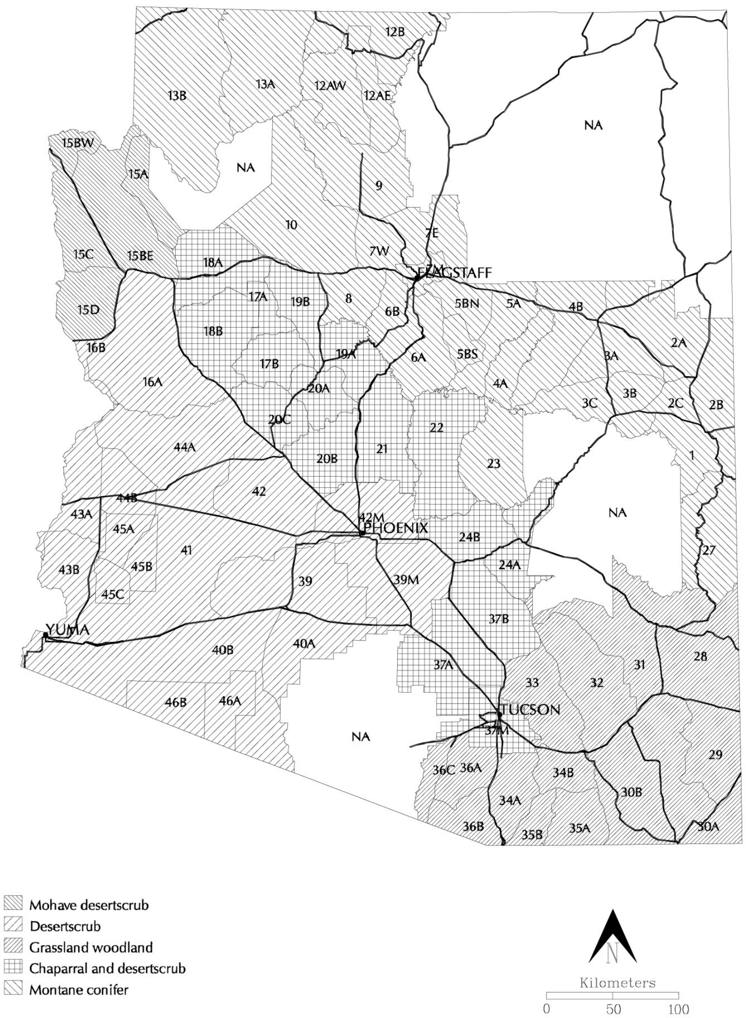

Figure 3. Arizona map indicating Game Management Units, pooled by cluster analysis, used in the evaluation of relationships among mule deer ratio and climatic data.

Mule deer populations, like most wildlife, probably respond both directly and indirectly to many climatic factors, although developing consistent predictive relationships across their occupied range is virtually impossible. However, PDSI may be an important factor influencing statewide mule deer populations. PDSI values can be more indicative of favorable conditions for forage growth and development of suitable fawn hiding cover. Precipitation may be favorable in some habitats, such as the warmer portion of the state, whereas it may be detrimental where snow accumu-

Table 2. Significant climatic variables and adjusted R^2 values for multiple linear regression equations explaining fawn:doe ratios (FDR) and buck:doe ratios (BDR) across similar Game Management Units in Arizona.

Category	FDR[a]	R^2	BDR[a]	R^2
Montane conifer	-Feb ppt, -Nov PDSI	0.312	-Jul PDSI, -P Jun PDSI	0.292
Mohave desertscrub	-P Jan ppt	0.171	+Jan ppt, +Feb ppt, +P Nov ppt, -Apr PDSI	0.520
Chaparral and desertscrub	-PP Jan PDSI	0.083	No relationship	—
Grassland-Woodland	+Dec PDSI, -P Jun PDSI	0.210	-Aug PDSI	0.115
Desertscrub	+Nov ppt, +Mar ppt, -P Feb PDSI, -P Jan PDSI	0.410	+P Sep ppt	0.092

[a] Abbreviations: ppt refers to precipitation, PDSI refers to Palmer Drought Severity Index, + refers to positive effect of factor, - refers to negative effect of factor, no modifier on month refers to data from during or immediately preceding the survey, P as a modifier on month refers to the year prior to the survey, and PP as a modifier on month refers to 2 years prior to the survey.

lations adversely impact mule deer populations. Rainfall in a given habitat is known to induce migration (Kucera 1992), whereas humidity may be the factor that induces movements in another habitat (McCullough 1964). In yet another ungulate species, increased rainfall can correlate with decreased population density (Latham et al. 1997). Each of these factors may be useful in understanding wildlife habitat relationships within a given community, however when applied to habitats beyond where the relationships were discovered, the relationships may be spurious. However, PDSI values may be better suited to indexing statewide populations.

Environmental relationships tend to be complex, although simple models may approximate our understanding of animal-environment relationships. Climatic variables, in addition to those I used in my evaluation, influence vegetative development, succession, nutritive quality, and cover components of the habitat (Singer et al. 1997, Post and Stenseth 1999). Mule deer densities in themselves have the potential to influence survival of young (Clutton-Brock et al. 1987). Prey densities influence predator densities, and ultimately habitat structure that both occupy. Neither habitat nor climate may be succinctly represented in a single, concise variable.

When examining population responses to climate, winter FDR may be a better variable than BDR because winter surveys occur after fall hunting seasons. Sport harvests influence BDR and may obscure, or be difficult to separate from, climatic effects. Yet, even with FDR, GMUs within each pooled habitat category did not exhibit consistent relationships among themselves or with pooled data sets.

Desertscrub habitats were favorably influenced by winter precipitation, probably for reasons elucidated by Smith and LeCount (1979). Similarly, decreased drought conditions and increased precipitation should create favorable forage and hiding cover within grassland-woodland and chaparral and desertscrub habitats. Conversely, explanations supporting the negative influence of winter precipitation in Mohave desertscrub are difficult to develop. Montane conifer habitats were negatively influenced by winter precipitation, presumably as a result of snow accumulations and resulting physiological stress. The superior fit of the regression models to the desertscrub and montane conifer habitats suggests that climate is more influential in determining FDRs within these potentially more extreme Arizona habitats.

Mule deer survey data may in itself be problematic, in that small sample sizes are not uncommon within GMUs, and misclassification of sex and age classes can substantially alter estimated ratios. The probability of misclassification can increase with observer inexperience, survey speed, distance, and inclement weather. However, explaining 40-50% of the variation within mule deer population estimates, using measured climatic variables, may be adequate for large-scale modeling. This is particulary true if climate is proven to have the largest influence on mule deer populations. Predation, habitat structure, and relation to carrying capacity may be unable to explain as much of the variation in Arizona's mule deer population as does the climatic variables that were analyzed in this paper.

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