Cattle Grazing Mediates Climate Change Impacts on Ephemeral Wetlands

CHRISTOPHER R. PYKE*‡ AND JAYMEE MARTY†

*National Center for Ecological Analysis and Synthesis, 735 State Street, Suite 300, Santa Barbara, CA 93101-5504, U.S.A.
†The Nature Conservancy, Cosumnes River Preserve, 13501 Franklin Boulevard, Galt, CA 95632-9014, U.S.A.

Abstract: *Climate change impacts depend in large part on land-management decisions; interactions between global changes and local resource management, however, rarely have been quantified. We used a combination of experimental manipulations and simulation modeling to investigate the effects of interactions between cattle grazing and regional climate change on vernal pool communities. Data from a grazing exclosure study indicated that 3 years after the removal of grazing, ungrazed vernal pools dried an average of 50 days per year earlier than grazed control pools. Modeling showed that regional climate change could also alter vernal pool hydrology. Increased temperatures and winter precipitation were predicted to increase periods of inundation. We evaluated the ecological implications of interactions between grazing and climate change for branchiopods and the California tiger salamander (*Ambystoma californiense*) at four sites spanning a latitudinal climate gradient. Grazing played an important role in maintaining the suitability of vernal pool hydrological conditions for fairy shrimp and salamander reproduction. The ecological importance of the interaction varied nonlinearly across the region. Our results show that grazing can confound hydrologic changes driven by climate change and play a critical role in maintaining the hydrologic suitability of vernal pools for endangered aquatic invertebrates and amphibians. These observations suggest an important limitation of impact assessments of climate change based on experiments in unmanaged ecosystems. The biophysical impacts of land management may be critical for understanding the vulnerability of ecological systems to climate change.*

Key Words: *Ambystoma californiense*, branchiopod, California Central Valley, California tiger salamander, impact assessment, land management, vernal pools

El Apacentamiento de Ganado Influye en los Impactos del Cambio Climático sobre Humedales Efímeros

Resumen: *Los impactos del cambio climático en buena medida dependen de decisiones de gestión de tierras; sin embargo, raramente se han cuantificado las interacciones entre los cambios globales y la gestión de recursos. Utilizamos una combinación de manipulaciones experimentales y modelos simulados para investigar los efectos de las interacciones entre el apacentamiento de ganado y el cambio climático regional sobre comunidades en charcas primaverales. Los datos de un estudio de exclusión de apacentamiento indicaron que, 3 años después de eliminar el apacentamiento, las charcas primaverales no apacentadas se secaban 50 días por año en promedio antes que las charcas control con apacentamiento. El modelado mostró que el cambio climático regional también podía alterar la hidrología de las charcas primaverales. Se predijo que el aumento de temperatura y de precipitación invernal incrementaría los periodos de inundación. Evaluamos las implicaciones ecológicas de las interacciones entre apacentamiento y cambio climático sobre braquiópodos y la salamandra tigre de California (*Ambystoma californiense*) en cuatro sitios a lo largo de un gradiente latitudinal. El apacentamiento jugó un papel importante en el mantenimiento de condiciones hidrológicas adecuadas para la reproducción de braquiópodos y salamandras en las charcas. La importancia ecológica de*

‡*Current address: Global Change Research Program, U.S. EPA—ORD (MC 8601 N), 1200 Pennsylvania Avenue NW, Washington, D.C. 20460-0001, U.S.A., email pyke.chris@epa.gov*
Paper submitted May 11, 2004; revised manuscript accepted November 16, 2004.

Conservation Biology 1619–1625

DOI: 10.1111/j.1523-1739.2005.00233.x

la interacción varió no linealmente en la región. Nuestros resultados indican que el apacentamiento puede enmascarar los cambios hidrológicos derivados del cambio climático y jugar un papel crítico en el mantenimiento de la aptitud hidrológica de las charcas primaverales para invertebrados acuáticos y anfibios en peligro de extinción. Estas observaciones sugieren una importante limitación de las evaluaciones de impactos del cambio climático basadas en experimentos en ecosistemas en los que no hay actividades de gestión. Los impactos biofísicos de la gestión de tierras puede ser críticos para el entendimiento de la vulnerabilidad de los sistemas ecológicos al cambio climático.

Palabras Clave: *Ambystoma californiense*, braquiópodo, charcas primaverales, evaluación de impacto, gestión de tierras, salamandra tigre de California, Valle Central de California

Introduction

Cattle grazing is a global enterprise with far-ranging economic and environmental impacts. In 2001 approximately 26% of the world's land base was allocated to permanent pastures (FAO 2003). Consequently, large-scale grazing is the dominant land-management activity in many ecosystems (Fleischner 1994). Grazing has sparked controversy that has been caricatured as a fight between landowners interested in maintaining unsustainable grazing regimes and environmentalists determined to curtail or eliminate a destructive land use. A growing body of work belies this false dichotomy and suggests that land-management decisions are more complicated (Freilich et al. 2003; Asner et al. 2004). Climate change may add a new dimension to this land-management debate. Grazing has significant impacts on the biophysical properties of land surfaces (Gerlanc & Kaufman 2003), and assessments of the compatibility of grazing with conservation goals must explore the potential for interactions between climate change and grazing regimes.

We investigated interactions between climate change and grazing for vernal pool wetlands in the Central Valley ecoregion of California. Ephemeral wetlands are common features of ecosystems in which seasonal climates allow water to periodically accumulate in topographic depressions (Hanes & Stromberg 1998). In the Central Valley, vernal pools occur over more than 376,000 ha (Holland 1998). The majority of vernal pools in this region are currently grazed, and grazing practices are a central issue for the management of sensitive species in biological reserves and lands protected by conservation easements. Cattle grazing has dominated the landscape since European settlement in the nineteenth century. Before that, Central Valley grasslands were grazed by native ungulates; the relative intensity of grazing between these regimes, however, is unknown (Marty 2005). Frequently, there is pressure to remove grazing from conservation lands based on a perception that grazing is uniformly detrimental to local biodiversity. This perception ignores many factors that influence the ecological impact of grazing, such as the biophysical effects of removing grazing on vernal pools and their obligate organisms.

Vernal pools provide habitat for a rich flora of endemic plant species and several threatened and endangered animal species in the Central Valley. Branchiopods, including fairy (*Branchinecta* spp.), tadpole (*Lepidurus packardi*), and clam shrimp (*Cyzicus californicus*) (Helm 1998), and the California tiger salamander (*Ambystoma californiense*) are sensitive to changes in wetland hydrology and central to regional conservation efforts. *A. californiense* and four branchiopods are listed under the U.S. Endangered Species Act (USFWS 1994, 2003). Branchiopod species differ somewhat in their responses to hydrologic conditions, but for the purposes of this study their tolerances are similar enough for us to treat them as a group and average their hydrologic requirements (Helm 1998). Population dynamics for these endangered species are strongly regulated by vernal pool hydrology, particularly the longest continuous ponding event each year (King et al. 1996). Branchiopods endemic to California vernal pools require an average of 47 days to reproduce (Helm 1998), and *A. californiense* are believed to require at least 90 days to mature sufficiently to leave the aquatic environment (Shaffer & Trenham 2004). Shorter ponding events may have negative ecological consequences because changes in the duration of inundation affect population processes (Morey 1998), alter community composition (Schneider 1997), and increase vulnerability to invasion by non-native species (Gerhardt & Collinge 2003).

The duration of inundation in vernal pools is controlled by the relationship between inputs of precipitation and water loss to overflow, infiltration, open-water evaporation, and evapotranspiration (Hanes & Stromberg 1998; Pyke 2004*b*). Although both grazing and climate change can modify this water balance, their relative contributions have not been quantified or considered together for this system. The major features of seasonal inundation are defined by climate, but cattle grazing can change wetland hydrologic regimes by altering soil properties (Daniel et al. 2002) and modifying the rate of evapotranspiration from plants (Bremer et al. 2001). Climatic change can influence the amount and timing of precipitation inputs to pools and the rate of loss through evaporation and evapotranspiraton (Pyke 2005*a*). The reproductive requirements of branchiopods and *A. californiense* can create nonlinear relationships between the duration of ponding and habitat suitability (Pyke 2005*a*, 2005*b*). We hypothesized that the ecological importance of these interactions may vary as a function of the absolute amount of water available in the system, and we investigated the effect of grazing and climate across a regional precipitation gradient. Our goal was to determine the role of grazing in mediating the impact of regional climate change and evaluate net changes in the availability of hydrologically suitable vernal pool habitat for branchiopods and *A. californiense*.

Methods

The grazing experiment included 36 vernal pools on two different geologic formations on a 5000-ha ranch in eastern Sacramento County, California. Cattle are currently and have historically (about 150 years) grazed the area seasonally from October through June at a stocking rate of 1 animal unit (cow-calf pair)/2.4 ha. A total of 18 pools were excluded from cattle grazing for 3 years with electric fencing, and 18 pools were grazed at historical levels. We assigned grazing treatments randomly to groups of 3 (nested) pools, and treatment plots were blocked by proximity across the site (3 pools × 2 treatments × 6 blocks = 36 pools). Grazing treatments were replicated across a representative set of pool areas, volumes, and soil substrates. We excluded cattle from a subset of pools for 3 years with electric fencing and collected data on hydrology, vegetation, and aquatic invertebrates throughout the winter and spring growing seasons each year. We collected hydrologic data (pool depth, period of inundation) each week throughout the rainy season. We sampled vegetation in permanent plots in the pool basins, edges, and adjacent uplands and used Daubenmire classes to estimate cover values for each plant species occurring within the 35 × 70 cm quadrats (Barbour & Major 1990). We converted cover class values to midpoint cover values to estimate absolute percent cover (see Marty 2005 for details).

We evaluated the effects of climate change on water balance in vernal pools with the PHYDO hydrologic model (Pyke 2004*b*). We simulated the response of a representative set of 100 vernal pools to daily meteorological data for four reference locations in the Central Valley over 100 years. From north to south, the sites included Red Bluff (mean annual precipitation, 58.6 cm/year), Sacramento (43.6 cm/year), Merced (31.2 cm/year), and Bakersfield (15.7 cm/year). Mean annual temperature is relatively constant across the region, ranging from 16° (Red Bluff) to 18° C (Bakersfield) (Table 1). We assumed that the 100 pool populations were grazed historically and designed the synthetic population to proportionally represent the range of size, shape, soil, and vegetation characteristics found in a reference area in the southern Sacramento Valley (Pyke 2005*a*). Using a reference set allowed the impacts of grazing and climate interactions to be modeled without regard to site-specific variation in pool characteristics. The four sites spanned the range of the valley's climatic gradient, which ranges from semiarid in the south to more continental conditions in the north.

Our goal was to evaluate the sensitivity of vernal pools to potential climate and grazing interactions, so for illustrative purposes we present data from only one climate-change scenario with a warming of +3° C and an increase in winter precipitation of 30%. These changes are roughly equivalent to projections from the Hadley CM2 (run 1) global climate model that was used in a series of regional impact assessments (Miller et al. 2003). This scenario lies within the range of recent regional projections for 2100 (Synder et al. 2002). In previous publications, we considered the hydrologic impacts of a wider range of climatic conditions such as cooler temperatures and lower precipitation (Pyke 2004, 2005*a*). Results of these studies suggest that the effect of a wide range of climate conditions can be directly inferred from those evaluated here.

We used PHYDO to simulate vernal pool hydrologic conditions for both historical and warmer, higher-precipitation climate at each reference site. The average

Table 1. Changes in maximum annual ponding for rain-fed Central Valley ecoregion vernal pools under combinations of grazing and climate change.

	Location[b]			
Variable[a]	*Bakersfield*	*Merced*	*Sacramento*	*Red Bluff*
MAT_{max} (°C)	25.4	24.8	23.1	24.2
MAT_{min} (°C)	11.4	8.4	8.9	10.2
MAP (cm)	15.7	31.3	43.6	60.3
Max. ponding (days/year)				
historical climate + grazing	9	56	108	127
historical climate + no grazing	0	6	58	77
climate change + grazing	11	75	126	142
climate change + no grazing	0	25	76	92

[a]*Abbreviations: MAT_{max}, annual average maximum daily air temperature; MAT_{min}, annual average minimum daily air temperature; MAP, mean annual precipitation.*
[b]*Locations are arranged from south (Bakersfield) to north (Red Bluff).*

observed changes resulting from release from grazing were then subtracted from the ponding duration predicted for each individual pool. We averaged model predictions across the 100-year simulation period to provide information about the average duration of continuous ponding for each pond of the 100 simulated ponds in each of the four landscapes under four scenarios of grazing and climate change. We present data as frequency distributions for each site under each scenario.

Results

Removal of grazing reduced the maximum annual duration of ponding. The mean change in the third year after the removal of grazing was −50 days/year, and it was associated with significant changes in soil compaction and grass cover (Fig. 1). All differences in inundation were significant at $\alpha = 0.01$ in a two-way nested analysis of variance. The results of the F tests included significant changes in maximum ponding duration (F[numerator df 1, denominator df 4] $= 44.76, p = 0.0026$), soil resistance to penetration ($F[1,4] = 29.17, p = 0.0057$), and absolute grass cover ($F[1,4] = 23.40, p = 0.008$). The nested effect was not statistically significant for any of these analyses. Marty (2005) describes changes in vegetation and hydrology in more detail, including results for specific grazing treatments (e.g., seasonal exclosures).

The warmer, higher-precipitation climate scenario was projected to cause longer periods of vernal pool inundation during cool, winter months and an average increase in the maximum duration of ponding of +13 days/year. Hydrologic sensitivity of pools to climate change alone varied along the valley's climate gradient with peak responses in the Merced region (+18 days/year) (Table 1).

The ecological importance of combinations of grazing and climate varied between sites. At Bakersfield neither grazing nor climate change improved hydrologic conditions for branchiopods or *A. californiense*. These southern pools were limited by an absolute lack of water. Climate change alone pushed the most hydrologically responsive vernal pools into a range suitable for the fastest maturing branchiopods, but the majority of pools remained unsuitable across all scenarios.

Pools at Red Bluff were more responsive to combinations of grazing and climate change. On average, Red Bluff's climate allowed reproduction by both branchiopods and *A. californiense* in the majority of pools. Removing grazing shifted fewer than half the currently suitable pools below the 90-day *A. californiense* requirement, but climate change pushed the distribution back toward longer flood durations. In either case, many pools were available with periods of inundation exceeding *A. californiense* and branchiopods requirements.

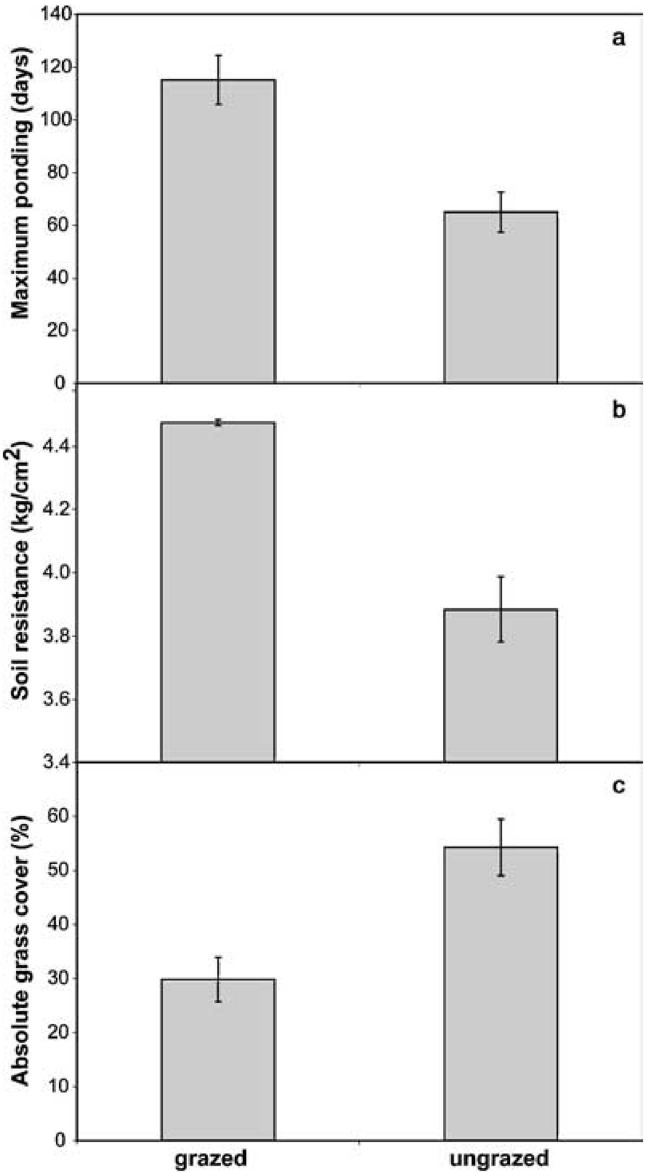

Figure 1. Effect of grazing on (a) maximum ponding duration (days/year), (b) soil resistance to penetration (kg/cm^2), and (c) absolute grass cover (percent). All differences were significantly different in a two-way nested analysis of variance.

Pools in the middle of the ecoregion (Merced and Sacramento) were most sensitive to combinations of grazing and climate change. In Sacramento almost all pools had sufficient periods of inundation for branchiopods, but under historical conditions a substantial percentage do not provide hydrologically suitable habitat for *A. californiense*.

We frequently observe pools drying up before *A. californiense* would be able to emerge in these areas. Climate change alone improved this situation for *A. californiense*. The resulting distribution, however, was close enough to the 90-day *A. californiense* threshold that reductions in

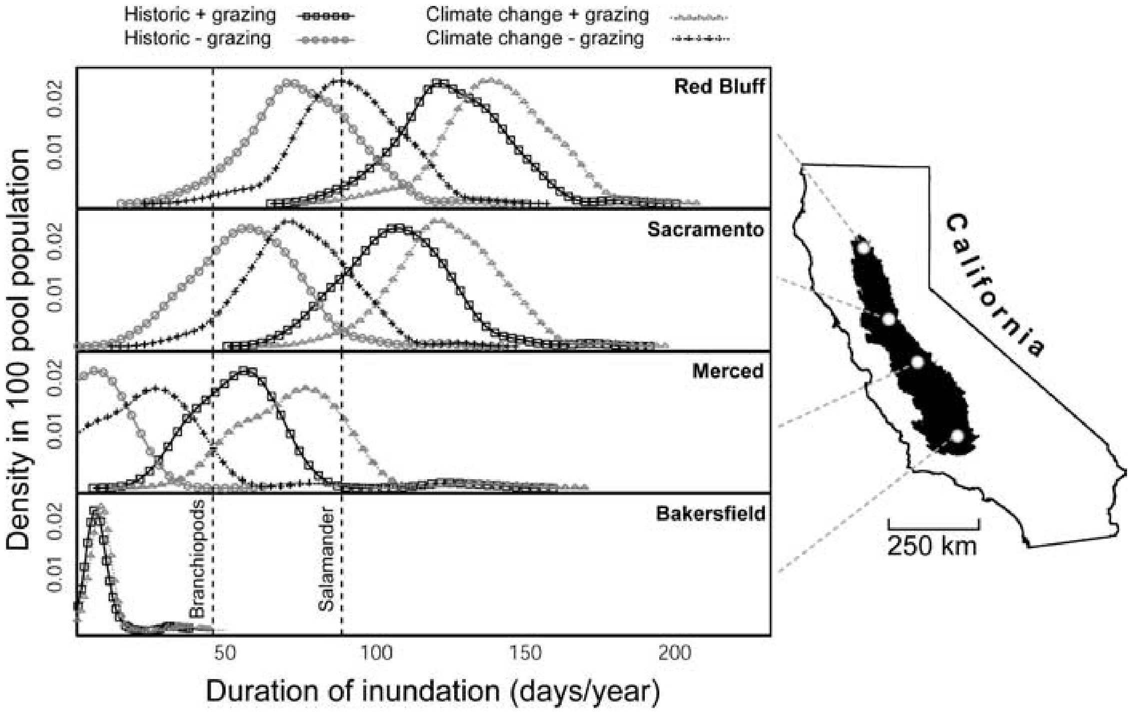

Figure 2. Nonparametric probability density functions of maximum ponding duration across four sites in the Central Valley ecoregion of California under combinations of grazing and climate change. Historical climate reflects conditions over the period of record for each station. Climate change reflects a single scenario of +3° C with precipitation increase of 30%. Vertical dashed lines indicate the minimum duration of inundation required for branchiopods (47 days) and California tiger salamander (90 days) reproduction (Helm 1998).

inundation duration accompanying the removal of grazing pushed the majority of pools below the minimum time required for *A. californiense* reproduction. Our warmer, higher-precipitation scenario did not increase the duration of inundation enough to offset these impacts, and the net result was a substantial loss of hydrologically suitable habitat.

We found similar hydrologic sensitivity at Merced, but in this case for branchiopods. The majority of pools near Merced did not regularly provide sufficient duration of inundation for *A. californiense* under historical or warmer, higher-precipitation climate. The situation for branchiopods was more sensitive and similar to that for *A. californiense* in Sacramento. Under historical conditions, a narrow majority of pools provided conditions suitable for branchiopod reproduction. Release from grazing drove a large percentage of these pools into the unsuitable range and, again, climate change was insufficient to make up the difference.

Discussion

Changes in climate are likely to alter the biophysical properties of habitats in ways that affect their suitability for species of conservation concern. These impacts, however, cannot be understood by focusing exclusively on physical dynamics of climate and unmanaged, model ecosystems. Rather, the ecological importance of climatic change will be mediated by interactions with land management practices and tolerances of individual species (Asner et al. 2004). Both land management and species' tolerances are likely to show plastic responses to environmental change (Ackerly 2003), and they are often even more poorly understood than the Earth's climate system.

Results from our field experiment and simulations suggest that grazing plays an important role in maintaining hydrologically suitable habitat for endangered branchiopods and *A. californiense*. Simply removing grazing from pools in the Sacramento or Merced regions is likely to reduce the amount of hydrologically suitable habitat available to these species. Similar actions in Bakersfield or Red Bluff, however, seem unlikely to change existing habitat distributions. Management practices must be adapted based on combinations of pool hydrology and species life-history traits across the Central Valley. The implementation of these practices is complicated by the need to balance the impacts of grazing inside and outside vernal pools. Marty (2005) provides a more extensive treatment of the implications of grazing for grassland uplands at this site, but in most cases, moderate grazing regimes appear compatible with both wetland and terrestrial conservation objectives.

Our project was primarily a sensitivity analysis based on limited experimental data, an average distribution of vernal pool characteristics, and a plausible, but generalized, climate-change scenario. Predicting the impacts of grazing and climate interactions on hydrologic conditions for specific vernal pools requires much more detailed information than is currently available for climate, soils, vegetation, and physiological requirements. There is no a priori reason, however, to suspect that site or species-specific variation would confound or contradict the general pattern of results.

Our results support an increasingly general conclusion: the biophysical impacts of land use, cover, and management will be an important component of climate change at local (Wan et al. 2002), regional (Roy & Avissar 2002), and global scales (Milly & Dunne 1994). These processes are considered confounding factors in the search for evidence for climate change driven by atmospheric emissions (Kalnay & Cai 2003). It is clear, however, that these issues are more than noise in the climate-change signal (Pielke et al. 2002). These processes are acting to change biophysical conditions available to organisms and ecosystems with particularly important implications for threatened and endangered species. The biophysical implications of many land-management activities suggest mechanisms through which local and regional actions can either mitigate or exacerbate the effects of climate change (Asner et al. 2004). These actions, such as grazing, may eventually be assembled into a set of biophysical tools for climate adaptation and mitigation. Before we can apply these tools, however, we must identify them and determine how they work in the context of a changing climate.

Acknowledgments

C.R.P. was supported by The Nature Conservancy's David H. Smith fellowship program, the National Center for Ecological Analysis and Synthesis, and Thomas Lacher from the Ceasar Kleberg Chair in Wildlife Ecology at Texas A&M University. Support for J.M. came from The Nature Conservancy and grants from the Elizabeth and Stephen Bechtel Jr. Foundation, Bernard Osher Foundation, and the Anderson Grassland Research Fund. The manuscript benefited from comments from S. Andelman and P. Kareiva.

Literature Cited

Ackerly, D. D. 2003. Community assembly, niche conservatism, and adaptive evolution in changing environments. International Journal of Plant Sciences **164:**S165–S184.

Asner, G. P., A. J. Elmore, L. P. Olander, R. E. Martin, and A. T. Harris. 2004. Grazing systems, ecosystem responses, and global change. Annual Review of Environmental Resources **29:**261–299.

Barbour, M., and J. Major, editors. 1990. Terrestial vegetation of California. California Native Plant Society, University of California, Davis.

Bremer, D. J., L. M. Auen, J. M. Ham, and C. E. Owensby. 2001. Evapotranspiration in a prairie ecosystem: effects of grazing by cattle. Agronomy Journal **93:**338–348.

Daniel, J. A., K. Potter, W. Altom, H. Aljoe, and R. Stevens. 2002. Long-term grazing density impacts on soil compaction. Transactions of the American Society of Agricultural Engineers **45:**1911–1915.

FAO (Food and Agriculture Organization). 2003. Statistical databases. FAO, Rome.

Fleischner, T. L. 1994. Ecological costs of livestock grazing in western North America. Conservation Biology **8:**629–644.

Freilich, J. E., J. M. Emlen, D. J. J., D. C. Freeman, and P. J. Cafaro. 2003. Ecological effects of ranching: a six-point critique. BioScience **53:**759–765.

Gerhardt, F., and S. K. Collinge. 2003. Exotic plant invasions of vernal pools in the Central Valley of California, USA. Journal of Biogeography **30:**1043.

Gerlanc, N. M., and G. A. Kaufman. 2003. Use of bison wallows by anurans on Konza Prairie. American Midland Naturalist **150:**158–168.

Hanes, T., and L. Stromberg. 1998. Hydrology of vernal pools on non-volcanic soils in the Sacramento Valley. Pages 38–49 in E. Bauder, D. Belk, W. Ferren Jr., and R. Ornduff, editors. Ecology, conservation, and management of vernal pool ecosystems. California Native Plant Society, Sacramento.

Helm, B. P. 1998. Biogeography of eight large branchiopods endemic to California. Pages 124–139 in C. W. Witham, E. T. Bauder, D. Belk, W. R. Ferren Jr., and R. Ornduff, editors. Ecology, conservation, and management of vernal pool ecosystems. California Native Plant Society, Sacramento.

Holland, R. F. 1998. Great Valley vernal pool distribution, photorevised 1996. Pages 71–75 in C. Williams, E. Bauder, D. Belk, W. Ferren Jr., and R. Ornuff, editors. Ecology, conservation, and management of vernal pool ecosystems—Proceedings from a 1996 conference. California Native Plants Society, Sacramento.

Kalnay, E., and M. Cai. 2003. Impact of urbanization and land-use change on climate. Nature **423:**528–531.

King, J., M. Simovich, and R. Brusca. 1996. Species richness, edemism and ecology of crustacean assemblages in northern California vernal pools. Hydrobiologia **328:**85–116.

Marty, J. 2005. Effects of cattle grazing on diversity in ephemeral wetlands. Conservation Biology **19:**1626–1632.

Miller, N. L., K. E. Bashford, and E. Strem. 2003. Potential impacts of climate change on California hydrology. Journal of the American Water Resources Association **39:**771–784.

Milly, P. C. D., and K. A. Dunne. 1994. Sensitivity of the global water cycle to the water-holding capacity of land. Journal of Climate **7:**506–526.

Morey, S. 1998. Pool duration influences age and body mass at metamorphosis in the western spadefoot toad: implications for vernal pool conservation. Pages 86–91 in C. Witham, E. Bauder, D. Belk, W. Ferren Jr., and R. Ornduff, editors. Ecological, conservation, and management of vernal pool ecosystems. California Native Plant Society, Sacramento.

Pielke, R. A., G. Marland, R. A. Betts, T. N. Chase, J. L. Eastman, J. O. Niles, D. D. S. Niyogi, and S. W. Running. 2002. The influence of land-use change and landscape dynamics on the climate system: relevance to climate-change policy beyond the radiative effect of greenhouse gases. Philosophical Transactions of the Royal Society of London Series A–Mathematical, Physical, and Engineering Sciences **260:**1705–1719.

Pyke, C. R. 2004*a*. Habitat loss confounds climate change impacts. Frontiers in Ecology and the Environment **2:**178–182.

Pyke, C. R. 2004*b*. Simulations of vernal pool hydroregimes for two locations in California. Ecological Modelling **173:**109–127.

Pyke, C. R. 2005*a*. Assessing climate change impacts on vernal pool ecosystems and endemic branchiopods. Ecosystems **8:**95–105.

Pyke, C. R. 2005*b*. Interactions between habitat loss and climate change:

implications for fairy shrimp in the Central Valley of California. Climatic Change **68:**199–218.

Roy, S. B., and R. Avissar. 2002. Impact of land use/land cover change on regional hydrometeorology in Amazonia. Journal of Geophysical Research—Atmospheres **107:**8037.

Schneider, D. 1997. Predation and food web structure along a habitat duration gradient. Oecologia **110:**567–575.

Shaffer, H. B., and P. C. Trenham. 2004. *Ambystoma californiense*. Pages 1093–1102 in M. J. Lannoo, editor. Status and conservation of U.S. amphibians. Volume 2: species accounts. University of California Press, Berkeley.

Synder, M. A., J. L. Bell, L. C. Sloan, P. B. Duffy, and B. Govindasamy. 2002. Climate responses to a doubling of atmospheric carbon dioxide for a climatically vulerable region. Geophysical Research Letter **29:**1–4.

USFWS (U.S. Fish and Wildlife Service). 1994. Endangered and threatened wildlife and plants; determination of endangered status for the Conservancy fairy shrimp, longhorn fairy shrimp, and the vernal pool tadpole shrimp; and threatened status for the vernal pool fairy shrimp. Federal Register **59:**48136–48153.

USFWS (U.S. Fish and Wildlife Service). 2003. Endangered and threatened wildlife and plants; listing of the central California distinct population segment of the California tiger salamander. Federal Register **50:**28648.

Wan, S., Y. Luo, and L. L. Wallace. 2002. Changes in microclimate induced by experimental warming and clipping in tallgrass prairie. Global Change Biology **8:**754–768.