TWENTY FOUR

Epilogue

Future Directions

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The preceding chapters provide an understanding of our current knowledge of the ecological, evolutionary, and cultural forces influencing grasslands of the California floristic province and their conservation and management. Many of the chapters provide discussions that support or elaborate on some of the syntheses found in the first, and only other edited volume on California grasslands, published by Huenneke and Mooney in 1989. Other chapters provide wholly new approaches or syntheses of both basic and applied research. In this epilogue we discuss some of the ways in which our understanding of California grasslands has grown in the 18 years since the publication of this earlier synthesis. We conclude by speculating on some future areas of study.

With the advent of molecular techniques and the proliferation of approaches to delineating genetic relationships, there has been a dramatic increase in our information on systematic relationships among species and lineages. Hypothesized relationships among the grasses found in California have likewise changed, and new proposed phylogenies are presented by Peterson and Soreng (Chapter 2). Preliminary releases of the taxonomic treatment of these species in the *Flora of North America* reveal dramatic changes at both many generic and species levels (FNA 2007). We also now have a greater understanding of how the non-native and native grass floras' compare and are related to one another.

Other technological advances in the past 18 years have changed our ability to study broad aspects of grassland, such as their distribution and ecology. For example, recent advances in remote sensing, as well as more detailed mapping of vegetation units in selected sites (primarily grasslands purchased for conservation) have supported the original estimates of the area of grassland plant communities in California (Huenneke 1989). Huenneke's observations of the mosaic nature of grasslands as patches in the landscape have been supported by recent mapping at more detailed levels (Keeler-Wolf, in press).

Huenneke and Mooney's book, as well as Heady's (1988) description of Valley Grassland, focused on Eurasian annual species as dominants of vast areas of grassland. While this is clearly true, over the past 16 years there has been a dramatic rise the study of California native grasslands and an effort to find and restore sites where native species are still abundant. Yet we still have relatively little information on the overall distribution and abundance of native-species-dominated grasslands across the state. Although it was once stated that native California grasslands were restricted to uncommon, chemically unique soils (Murphy and Ehrlich 1989), we now understand that native grass stands occur as well on a wide variety of soils and climate zones (Reever Morghan et al., Chapter 7; Eviner and Firestone, Chapter 8; Jackson et al., Chapter 9; Harpole et al., Chapter 10; Harrison and Viers, Chapter 12) and that many native forbs remain within sites otherwise dominated by non-native annual species (Keeler-Wolf et al., Chapter 3).

Understanding factors limiting the distribution of native grasses has been a focus of research in the past 16 years, and we expect that interest to continue in the future. For example, competitive interactions between native perennial and non-native annual grasses have been extensively studied (Corbin et al., Chapter 13). The importance of land use history as a limitation on the distribution of native grasslands has become clearer (Stromberg and Griffin 1996; Steenwerth et al. 2002; Carmel and Flather 2004), although the mechanism behind the lack of recovery of native perennial grasses on formerly tilled soils is still poorly understood. Recent studies have supported the idea that native grasses are seed-limited in some circumstances (Hamilton et al. 1999; Seabloom et al. 2003a; Divittorio 2007). Recent developments in soil microbiology have led to new questions about soil conditions and the microbial and biogeochemical legacies of land use. These are described by Jackson et al. (Chapter 9), where the authors show that land use history leaves a clear imprint on the soil microbial community. The importance of this microbial "legacy" to future restoration or recovery is, however, not understood.

In addition to the rise in interest in native perennial grasses in California, there has been a rise in interest in studying non-native plant invaders into California grasslands. The documentation of waves of species invasion has gone on for decades (Burcham 1957; Heady 1958; Heady et al. 1991), but a recent emerging focus has been on understanding community susceptibility to particular invaders (Dukes 2001a; Reever Morghan and Rice 2005) and the impacts of certain plant invaders on grassland communities and ecosystem functioning. Intriguing new research suggests a potential role that plant viruses might play in mediating interactions between native and non-native species (Malmstrom et al. 2006). Indeed, it is notable how many of the studies cited by D'Antonio et al. (Chapter 6) have been published in the last 6–10 years. Whether these basic ecological studies can be applied to better manage and restore grasslands remains to be explored. Several chapters note the potential for invasive species to further dominate California grassland under future climate and chemical environmental change scenarios. Experimental studies suggest that certain ecologically and potentially economically significant invaders such as yellow starthistle *(Centaurea solstitialis)* will increase with rising CO_2 or that anthropogenic nitrogen deposition is already enhancing the abundance and persistence of invasive grasses (see Dukes and Shaw, Chapter 19). The latter situation is particularly threatening for the persistence of rare species on serpentine soils, which have otherwise served as refuges for native grassland species in the face of non-native invaders (see Harrison and Viers, Chapter 12). The recent expansion of unpalatable, noxious invaders such as barbed goatgrass *(Aegilops triuncialis)* onto serpentine raises the issue of whether we can predict what invaders will be here in another 16 years. Genetic changes within existing populations of non-native species that are not currently invasive or damaging to grassland habitat may cloud our ability to predict which species will be invasive in what settings.

The word *genetics* did not occur in the index of the previous review of California grasslands (Huenneke and Mooney 1989a). Yet studies of the genetics of selected species of California grasses and selected non-native, invasive grassland plants have contributed important new understanding of compositional change, local adaptation, and mechanisms of evolution in grassland species (Rice and Espeland, Chapter 11). As climate change continues and grasslands potentially become more fragmented, genetics will play a role in determining which species will persist, which invaders will spread, and which genotypes will be used in restoration.

Another new index term since 1989 is *restoration* (Stromberg et al., Chapter 21), which denotes a field where both ecology and genetics have been critical. Although restoration arose initially as a practice and not as a science, ecological and genetic studies are increasingly being used as the basis for restoration decision making. California grassland restoration arose largely during the 1990s with the emergence of the California Native Grass Association and native grass industry. Today, it is a diverse field with projects being conducted from vernal pool grassland restoration to upland rangeland restoration. Nonetheless, although the linkages between scientific studies and the practice of restoration will help to achieve goals, particularly as they relate to species and landscape preservation, ecologists still tend to work on small-plot scales while restoration practitioners are increasingly tackling large-scale projects. It will be interesting to see how ecological experimentation and theory and ecological restoration interface in the coming decade.

Since 1989, new views of the interactions between people and California grasslands (Wigand, Edwards, and Schiffman, Chapter 4; Anderson, Chapter 5) have been published. Anderson's landmark book, *Tending the Wild* (Anderson 2005), as well as her chapter in this volume, explore the dominant effect of the original human occupants of California on grassland environments. From their contributions to the changing post-glacial megafauna (see Edwards, Chapter 4), to their impact using fire to manage large landscapes, evidence suggests that Native Californians created an anthropogenic grassland landscape throughout many regions of Sierran foothill, central valley, coastal range, and prairie environments. Europeans then tremendously altered these landscapes through their widespread use of agriculture and introduction of livestock and Eurasian plant species (Chapters 4–6). We can expect that the effects of humans will be equally important in the future. If the models of climate change are as dramatic as predicted for the California flora, the next 20 years will see significant changes in California grasslands (Dukes and Shaw, Chapter 19; S. R. Loarie et al., in review). Further, the human population of California is expected to increase to 45 million by 2020, and much of that growth will be in parts of California where grasslands occur (Public Policy Institute of California 2006). Thus, land conversion will diminish grassland area, and impacts from human populations such as nitrogen deposition, fragmentation, and altered movement of species will contribute to ongoing compositional and functional changes.

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Research on California grassland species or ecosystems has been an exceptionally dynamic field in the last 16 years. Research areas that might be particularly dynamic in the coming decade are those with applications to managing grasslands for the multiple values we gain from them. These likely include impacts of global environmental change on grassland ecosystems, the importance of genetics and further species invasions to structural and functional change, and the development of science based, context-specific tools to restore native biodiversity or ecosystem functioning.

Rising temperatures, altered precipitation patterns, and changes to the chemical systems of the earth will influence our ability to predict the condition of California grasslands over the coming decades. Some of these ongoing changes, such as atmospheric N deposition, appear to have fairly clear-cut effects, while others, such as climate change, are more difficult to forecast because of the uncertainty of future conditions and the interactions between various components (e.g., temperature, precipitation, and CO_2 concentrations) on grassland vegetation. Although Dukes and Shaw (Chapter 19) provide an up-to-date assessment of our knowledge of global change impacts and research in California grasslands, this is an area where our understanding could increase greatly in the coming decade. Existing climate models suggest either increased winter rainfall or increased spring and early summer rainfall in California over the coming decades, with potentially important consequences for grasslands (Dukes and Shaw, Chapter 19). Increased winter rainfall may enhance the growth of woody species within grassland settings, leading to a loss of grasslands. However, feedbacks and community interactions can reverse increases in individual species in response to a changing climate with additional summer rainfall (Suttle et al. 2007). There are considerable differences in predicted rainfall between climate models, and information available for new modeling efforts is growing rapidly (California Climate Change Center 2006).

The design of successful restoration strategies will require more effective tools to reduce the influence of non-native species and improve the establishment and persistence of native species. Grazing (Jackson and Bartolome, Chapter 17; Huntsinger et al., Chapter 20) and fire (Reiner, Chapter 18) are the only tools we currently have to manage grassland composition over large scales. Yet these are also two of the most complex and challenging issues and are ones that will require intensive, and long-term, observations because of the species-, year-, and site-specific nature of their effects. Effects of various grazing and/or fire treatments also will differ between the annual grasslands (largely non-native, introduced species) and existing or restored native grasslands, and there is much to learn about how to use these tools to manage composition within particular bounds or drive it toward specific goals. Use of either of these tools is controversial in many settings, for social and cultural as well as ecological reasons. A more clear understanding of how to interface grazing or fire with other management techniques and cultural constraints will become even more critical as human population growth continues its upward trajectory in California.

While the future of California grasslands is largely unknown, it is surely linked to an unprecedented human occupancy of the state. Management, conservation, and restoration will result both from increased scientific knowledge, such as has been reviewed in this book, and from how the people of California regard and invest in grasslands as a natural resource.