



MEETING REVIEWS

Global Change and the Vulnerability of Chaparral Ecosystems

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Introduction

The Mediterranean-type climate (MTC) regions of the world—the Mediterranean Basin, southwestern South Africa, southwest Australia, coastal central Chile, and the California Floristic Province—support remarkable plant diversity and convergent vegetation communities that share similar physiognomies and functional characteristics (Rundel 2018). In California, chaparral vegetation, typified by evergreen sclerophyllous shrubs that are ubiquitous in the MTC regions, dominates the wildland vegetation of the southern coastal region of California, accounting for approximately 70% of the vegetation cover on federal national forest lands in the region.

Like the world's other Mediterranean-type ecosystems, California is a global biodiversity hotspot (Cowling et al. 1996, Myers et al. 2000). Much of this diversity is centered in sage- and chaparral-dominated shrublands found in the coastal and interior mountains. Since Euro-American settlement, these shrubland types have been undervalued and underappreciated, and repeated attempts have been made to “improve” them via clearing or afforestation. For decades, science focused on how chaparral might be most efficiently transformed to grasslands that were more useful for grazing and providing

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water runoff, or to forests that might be more profitably harvested. Today, public underappreciation of chaparral continues, largely as a byproduct of the unfortunate insertion of poorly planned housing developments in landscapes dominated by chaparral's highly flammable foliage (Syphard et al. 2018). As the human landscape expands, chaparral's extent is progressively diminished and fragmented, and frequent anthropogenic fires emanating from roads and communities threaten its very existence. Current fire return intervals in many of the southern California foothills are <15 years, a threshold beyond which chaparral—adapted to infrequent, high intensity fires—is often transformed into weedy grassland (Safford et al. 2018).

After intensive, internationally collaborative comparative research on MTC region vegetation in the 1970s and 1980s (e.g., Davis and Richardson 1995), a subsequent lull in interest has recently reversed owing to a number of developments which have refocused attention on chaparral and related shrublands. One of these has been the occurrence of multiple huge fire events that have burned millions of combined hectares, killed dozens of people, and destroyed thousands of homes. Another is the conservation emergency which has emerged as human development and pyrophilia have cleared large areas of diverse shrublands in MTC regions. Deriving from these negative developments, a more positive development has been the recent initiation of a quasi-biannual Chaparral Symposium in southern California, a meeting connecting resource managers, conservation practitioners, research scientists, and the public. The meeting, organized by the US Forest Service Pacific Southwest region and the California Fire Science Consortium, is held every 2 or 3 years at the Angeles National Forest Training and Conference Center, in Arcadia, California, just east of Los Angeles.

The first Chaparral Symposium (June, 2013) included a discussion that centered on *Chaparral Restoration* issues related to the restoration of degraded chaparral, including sessions on biological and landscape assessments, restoration implementation, monitoring, and restoration planning and coordination, and finishing with field trips to restoration areas in the San Gabriel Mountains. A Forest Service-published proceedings from this event is currently unpublished (Narog *unpublished*).

The second Chaparral Symposium (June, 2015) focused on the *Ecological Value of Chaparral*, addressing the ecosystem services provided by chaparral such as water provision, recreational opportunities, reduction of soil erosion, native American use, biodiversity, and the importance of developing educational programs centered on chaparral value and conservation. Several presentations aimed to quantify chaparral ecosystem services and associated economic values. Another set of presentations showed how spatial mapping of multiple services can be used to identify high value areas during wildfire suppression or to prioritize locations for post-fire restoration. Insights from the second symposium were compiled into a recently published book from Springer, *Valuing Chaparral: Ecological, Socio-Economic and Management Perspectives* (Underwood et al. 2018).

Here we report on the most recent Chaparral Symposium on *Global Change and the Vulnerability of Chaparral Ecosystems*, attended by over 200 people in May of 2018. Chaparral is increasingly threatened by a wide variety of interacting stressors and disturbances. These include human population growth and expanding urban areas (Syphard et al. 2018), warming temperatures and multi-year droughts (Swain 2015, Molinari et al. 2018), air pollution, invasion of non-native annual plants (Allen et al. 2018), unmanaged recreation (Safford et al. 2018), and increasingly more frequent fire (Keeley and Safford 2016). Presentations at the 2018 symposium addressed all of these themes. Here we review highlights

and distill major findings from the 2018 symposium. In addition, using the results of the three symposia, we present a set of future research priorities focused on chaparral, its ecological and economic values, and its long-term conservation.

Presentation highlights

Climate-related change in chaparral characterized one-quarter of the presentations at the 2018 symposium, with a suite of presentations reporting on the physiological effects of drought on chaparral plants. Stephen Davis (Pepperdine University) drew on a series of long-term studies to show that non-sprouting chaparral species known for their exceptional dehydration tolerance (e.g., *Ceanothus* and *Arctostaphylos*) nonetheless experience high mortality during acute, intense drought, whereas deep-rooted resprouting species (e.g., *Malosma*) experience exceptionally low mortality because of roots extending deeper than 13 m (Venturas et al. 2016). In contrast, chronic drought recently experienced in southern California between 2012 and 2016 has predisposed *Malosma laurina* and other deep-rooted species to opportunistic endophytic fungi that cause high mortality (Aguirre et al. 2018). This dispels one of our longest held beliefs that the long tap roots of some native mixed chaparral species are resilient to protracted drought over many years. Evidently, chronic drought gradually reduces carbon stores that normally defend against fungal invasion of tissue. Findings presented by Alex Pivovarov (Whittier College) show that during extreme heat events ($>35^{\circ}\text{C}$), carbon gain of chaparral shrubs is greatly reduced, but latent cooling provided by high transpiration rates may protect leaves from damage to allow fast recovery. The relevance of these findings is notable when considering that parts of southern California are projected to have a 10-fold increase in extreme heat days by the end of the century (Sun et al. 2015). Aaron Ramirez (Reed College) also illustrated the vulnerability of chaparral to extreme drought by comparing hydraulic safety margins of plants from contrasting environments. The work identifies California's Channel Islands as potential drought refugia within the southern California landscape and suggests these sites are priorities for future research and management.

Another important climate-related change affecting chaparral is the effect of changing climate on fire. Hugh Safford (US Forest Service and University of California, Davis) provided a regional context, contrasting natural fire regimes, fuel structures, and fire management of southern California chaparral with higher elevation forested landscapes. Max Moritz (University of California Cooperative Extension) reported on the impact of climate change on chaparral fire regimes, with an emphasis on modeling fire frequencies using mechanistic relationships involving both climate and land development variables. Two presenters reported on the relationship between climate change and 'type conversion' from native shrubland to non-native annual grasslands, which has consequences for chaparral biodiversity and the provision of ecosystem services. Jon Keeley (US Geological Survey) described how climate change will impact post-fire recovery by favoring annual plants, limiting chaparral persistence, and favoring type conversion, while Alexandra Syphard (Conservation Biology Institute) reported that over one-third of the Santa Monica Mountains has converted from woody to herbaceous cover over the last 70 years. Short intervals between fires have been a primary driver of this change, with conversion most likely in highly disturbed or water-limited portions of the landscape. Janet Franklin (University of California, Riverside) elaborated on climate–fire interactions with the addition of land use factors, reporting that iconic chaparral functional types, e.g., long-lived obligate seeders dependent on extensive fire-free intervals for regeneration, are particu-

larly vulnerable to the synergies among climate change, urban growth, and human-caused increases in fire frequency.

The vulnerability of chaparral to post-fire debris flows was considered by Dennis Staley (US Geological Survey) in an analysis of the feedback between stand age and post-fire debris-flow magnitude and likelihood. Using the Thomas fire (2017) and Station fire (2009) as examples, a weak statistical relation between stand age and fire severity was identified, where older stands tend to burn at higher severity, therefore are more susceptible to debris flow and likely to produce larger flow events than younger stands. In addition, stand age was theoretically linked with sediment storage, whereby the amount of sediment available for transport by flow-driven processes is greater following combustion of older stands.

The symposium aimed to bridge science and management, with presentations addressing the practicalities of managing chaparral to address key vulnerabilities. Marti Witter (National Park Service) illustrated the challenges of managing wildfire risk and conservation objectives using the Santa Monica Mountains as an example. The Wildland Fire Resilient Landscape Collaborative is a partnership among fire agencies, parks, and local cities and counties that aims to slow or stop the increasing social and natural costs of wildfires. Their strategic plan focuses more on measures such as ignition prevention and house-out fire resistance, rather than on chaparral fuels treatments. Katie VinZant (US Forest Service) and Arlee Montalvo (Riverside-Corona Resource Conservation District) discussed important challenges to chaparral restoration and offered solutions to insure project success. VinZant notes the importance of using best management practices to grow pathogen-free plants for restoration after finding *Phytophthora* infections at restoration sites and in contract-grown plants. Montalvo presented tools to aid seed sourcing decisions under changing climates.

Two presentations focused on the utility of plant traits for maximizing ecosystem resilience. Carla D'Antonio (University of California, Santa Barbara) reported that the most likely chaparral sites to be degraded are low elevation, with warmer winter and summer temperatures, lower mean annual precipitation, and closer to roads. To address the challenges of restoring these degraded sites, D'Antonio used a trait-based approach to assemble communities of species that are redundant or complimentary in terms of their drought tolerance and competitive traits, and best-suited to survive harsh conditions and competition from non-native grasses. Marko Spasojevic (University of California, Riverside) highlighted the utility of data on plant traits for understanding and maximizing ecosystem resilience, where communities with greater functional diversity in resproutability, fire tolerance, and fire resistance may be able to recover more quickly after a fire.

Presentation sessions concluded with the demonstration of a tool in development for resource managers that quantifies ecosystem services pre- and post-fire, and a discussion of the methods used (Eric Rounds [US Forest Service], Emma Underwood [University of California, Davis], and Nicole Molinari [US Forest Service]). Subsequent presentations by Frank Lupi (Michigan State University) and Lorie Srivastava (University of California, Davis) described approaches to assess the economic and monetized value of some of these services, including recreation, carbon storage, and water provision. Finally, Rick Halsey's (California Chaparral Institute) provocative presentation challenged listeners to appreciate the mental and physical health benefits of being in nature and use the existing community resource of nature and visitor centers to link the large urban communities of southern California to the chaparral-dominated landscapes that surrounds them.

The Symposium concluded with a fieldtrip to the County of Los Angeles Department of Public Works' Santa Anita Oak Woodland Project (led by Marc Blain and Richard B. Lewis III of Psomas, Fig. 1)—a habitat creation program that includes strictly local native plants, salvaged coarse woody debris/boulders, and placed natural snags, to naturalize a sediment placement site; and a restoration site in Big Tujunga Canyon on the Angeles National Forest that supported an abundance of non-native species following the Station fire (2009; Billy Sale of the Rancho Santa Ana Botanical Garden, and Edward Belden of the National Forest Foundation, Fig. 2).

Future research priorities to address vulnerability in chaparral

Consideration of the presentations given at the three symposia, as well as the extended discussions that followed them, led us to identify four major information and research gaps that should be addressed to better understand and mitigate chaparral vulnerability to global change:



Fig. 1. Symposium field trip to the Los Angeles County Department of Public Works' Santa Anita Oak Woodland Project, a highly effective effort to create native oak woodland and shrubland; the fence aids in reducing deer predation on native plants (photo by J. Franklin).



Fig. 2. Restoration field crew in Big Tujunga Canyon on the Angeles National Forest where restoration efforts are aimed at reducing abundance of non-native species that established after the 2009 Station fire and replacing them with native perennials (photo by J. Franklin).

1. Develop a toolbox of reliable and efficacious techniques for chaparral restoration

Given that severely disturbed chaparral is slow or unable to recover naturally, developing successful restoration techniques is a fundamental first step. Techniques such as using container stock, preserving topsoil, and suppressing non-native species are key to success (VinZant *in press*), as is ensuring adequate monitoring of restoration efforts. The quality of nursery stock, improved nursery practices, and species selection are also key considerations (Vallejo et al. 2012). Decision support tools can also greatly assist in allocating limited restoration resources by prioritizing restoration areas post-fire and identifying which species are likely to have the highest survival given specific stressors, as highlighted in the talk by D'Antonio using the plant trait database REST (Ostertag et al. 2016).

2. Identify and map potential chaparral refugia

Refugia provide species locations to which they may retreat and persist under changing environmental conditions, and can function as an expansion nucleus under the resumption of regionally favor-

able conditions. Potential chaparral refugia include mesic areas (e.g., canyons, north-facing slopes, and deeper soils), sites with complex topography, areas with relatively few non-native species, and areas protected from excessive anthropogenic fire. Work is needed to map the occurrence of such locations and to better understand other factors that may be beneficial to chaparral persistence under global change. Maps of potential refugia could prove important to many aspects of resource management, conservation, and restoration decision-making. In addition, it is important to develop a clearer idea of where and why chaparral lands might experience high climate exposure and higher susceptibility to mortality from drought.

3. Measure and monitor biomass and carbon sequestration in chaparral and related shrublands

Biomass inventories on US Forest Service lands are used to offset 10-20% of US carbon emissions each year (<https://www.fs.usda.gov/ccrc/topics/forests-carbon>). The primary source of biomass data on public lands is the USDA Forest Service Forest Inventory and Analysis (FIA) program (*available online*)¹; however, biomass measurements in shrublands are not collected on the national forests. Chaparral lands thus appear as a carbon void in the FIA carbon maps. Recently, Bohlman et al. (2018) summarized the extant sources of biomass/carbon data for chaparral, but the data are scarce and additional, larger efforts to estimate chaparral carbon are imperative. Furthermore, monitoring biomass in shrublands over time will contribute to understanding post-disturbance biomass recovery and how carbon storage on public lands is affected by management actions.

4. Better understand the drivers of vegetation type conversion in chaparral and the effects of type conversion on chaparral and neighboring ecosystems

Southern California counties are among the most biodiverse in the United States (Safford et al. 2018), largely due to landscapes dominated by chaparral and related shrublands. There are various information gaps affecting our ability to maintain chaparral and chaparral biodiversity at the landscape scale. For example, (1) What are the impacts of vegetation type conversion from chaparral to non-native annual grassland on the below-ground mycorrhizal community (Allen et al. 2018)? As type conversion occurs, will changes in the mycorrhizal community affect recovery of native shrubs and can mycorrhizal inoculum increase restoration success?; (2) What are the interactions between post-fire chaparral environments and downstream freshwater ecosystems, such as the effect of sediment erosion or nutrient enhancement on amphibians and other freshwater taxa?; (3) What are the consequences of atmospheric nitrogen deposition on chaparral landscapes and does this predispose chaparral to non-native annual grass invasion and reductions in native diversity (Allen et al. 1998)?; (4) How do ground-disturbing activities like grazing, mining, vegetation clearing to aid fire suppression efforts, and heavy recreational use (e.g., with Off-road Highway Vehicles [OHV]) affect time to recovery in chaparral?

Future management and policy implications

Bringing together scientists, resource managers, and the public at the Chaparral Symposia has been an important forward step toward shaping management and policy to promote chaparral persistence and resilience in the face of environmental change. Three key areas have been identified as important targets for this effort:

¹ <https://www.fia.fs.fed.us/>

1. Integrate science and our understanding of chaparral vulnerability into community planning

One of the reasons for the lack of appreciation of chaparral is its perceived fire hazard, particularly in the Wildland Urban Interface (WUI). Given that the WUI contains sufficient people to start fires and sufficient wildland areas to encourage the spread of fire, fire ignition frequencies are generally high (Syphard et al. 2018). Each year large fires in the WUI destroy hundreds of homes and impact many lives. Integrating our understanding of chaparral into community planning, as well as enhancing fire prevention and education, improving the arrangement of houses so they are less fire-prone, and encouraging home retrofitting will all help reduce fire risk in these communities.

2. Encourage small-scale investments to ensure sustained provision of ecosystem services

In some cases, a relatively small amount of funding on public lands can have a substantial positive impact on chaparral conservation. For example, improved signage in multiple languages on the sensitivity of the natural environment could help relieve pressure from recreational use. For example, areas where chaparral vegetation has been removed can further become damaged by user-created OHV trails. Groups like the American Conservation Experience (ACE) have worked with the Angeles National Forest to blockade and restore these user-created trails. Reducing illegal use of these features prevents erosion and allows for post-fire recovery of chaparral vegetation.

3. Promote chaparral-focused educational efforts and recognition

There is an old and oft-repeated myth that chaparral needs to burn frequently for its persistence. Although this has been debunked thoroughly in the literature, the myth persists, leading to “ecologically based” proposals to frequently burn large areas of chaparral to reduce fuels and theoretically protect ex-urban subdivisions. However, young chaparral stands can support wind-blown fires within a few years of burning, making such landscape-scale treatments of dubious effectiveness under extreme fire weather conditions. In addition, frequent burning can lead to type conversion over time, increase erosion and non-native species invasion, reduce native species habitat, and facilitate illegal OHV entry. As highlighted by Halsey et al. (2018), the roles of naturalist programs, nature centers, and other educational efforts are paramount to ensuring that southern Californians operate from a common base of understanding about chaparral, its ecology, and its importance. Furthermore, the explicit recognition of “shrubland” in addition to “forest” and “rangeland” as an ecosystem type in the State’s Fire and Resource Assessment Program’s (FRAP) 5-year assessments, would increase focus on shrubland and allow regular recording of key issues and trends (*available online*).²

Conclusion

Meetings dedicated to bridging scientific advances and resource implementation by convening researchers and practitioners in Mediterranean-type climate regions are not new. The Fynbos Forum in South Africa has met annually for the last 40 years to discuss the collaborative production of knowledge underlying regional conservation efforts in the fynbos biome, a spectacularly biodiverse Mediterranean-type climate shrubland. In the Mediterranean Basin, Mediterranean Forest Week occurs

² <http://frap.fire.ca.gov/assessment/2015/assessment2015>

biannually in a different country, focusing on the nexus between science, management, culture, and policy in Mediterranean Basin forest ecosystems. In California, the Chaparral Symposia are providing a multi-way information exchange for resource managers, researchers, and the public, where recent scientific and management advances can be highlighted and discussed, and where questions key to the conservation and management of chaparral can be debated.

Literature Cited

- Aguirre, N. M., et al. 2018. First report of *Botryosphaeria dothidea* causing stem canker and plant death in *Malosma laurina* in southern California. *Plant Disease* 102:1451.
- Allen, E. B., P. E. Padgett, A. Bytnerowicz, and R. Minnich. 1998. Nitrogen deposition effects on coastal sage vegetation of southern California. Pages 131–139 in A. Bytnerowicz, M. J. Arbaugh, and S. L. Schilling, editors. *Proceedings of the International Symposium on Air Pollution and Climate Change Effects on Forest Ecosystems, February 5-9, 1996, Riverside, California*. General Technical Report PSW-GTR-166. USDA Forest Service, Pacific Southwest Research Station, Albany, California, USA.
- Allen, E. B., K. Williams, J. L. Beyers, M. Phillips, S. Ma, and C. M. D'Antonio. 2018. Chaparral restoration. Pages 347–384 in E. C. Underwood, H. D. Safford, N. A. Molinari, and J. E. Keeley, editors. *Valuing chaparral: ecological, socio-economic, and management perspectives*. Springer Series on Environmental Management, Springer, Cham, Switzerland.
- Bohlman, G. N., E. C. Underwood, and H. D. Safford. 2018. Estimating biomass in California's chaparral and coastal sage shrublands. *Madroño* 65:28–46.
- Cowling, R. M., P. W. Rundel, B. B. Lamont, and M. T. K. Arroyo. 1996. Plant diversity in Mediterranean-climate regions. *Trends in Ecology and Evolution* 11:1035–1046.
- Davis, G. W., and D. M. Richardson, editors. 1995. *Mediterranean-type ecosystems*. Springer, Berlin, Germany.
- Halsey, R. W., V. W. Halsey, and R. Gaudette. 2018. Connecting Californians with the chaparral. Pages 295–322 in E. C. Underwood, H. D. Safford, N. A. Molinari, and J. E. Keeley, editors. *Valuing chaparral: ecological, socio-economic, and management perspectives*. Springer Series on Environmental Management, Springer, Cham, Switzerland.
- Keeley, J. E., and H. D. Safford. 2016. Fire as an ecosystem process. Pages 27–45 in H. A. Mooney and E. Zavaleta, editors. *Ecosystems of California*. University of California Press, Berkeley, California, USA.
- Molinari, N. A., E. C. Underwood, J. B. Kim, and H. D. Safford. 2018. Climate change trends for chaparral. Pages 385–409 in E. C. Underwood, H. D. Safford, N. A. Molinari, and J. E. Keeley, editors. *Valuing chaparral: ecological, socio-economic, and management perspectives*. Springer Series on Environmental Management, Springer, Cham, Switzerland.
- Molinari, N. A., E. C. Underwood, J. B. Kim, and H. D. Safford. 2018. Climate change trends for chaparral. Pages 385–409 in E. C. Underwood, H. D. Safford, N. A. Molinari, and J. E. Keeley, editors. *Valuing chaparral: ecological, socio-economic, and management perspectives*. Springer Series on Environmental Management, Springer, Cham, Switzerland.
- Myers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. B. da Fonseca, and J. Kent. 2000. Biodiversity hotspots for conservation priorities. *Nature* 403:853–858.
- Ostertag, R., et al. 2016. Restoring ecosystem services tool (REST) program user guide. <https://www.serdp-estcp.org/content/download/40043/384355/file/RC-2117%20User%20Guide.pdf>

- Rundel, P. W. 2018. California chaparral and its global significance. Pages 1–27 *in* E. C Underwood, H. D. Safford, N. A. Molinari, and J. E. Keeley, editors. *Valuing chaparral: ecological, socio-economic, and management perspectives*. Springer Series on Environmental Management. Springer, Cham, Switzerland.
- Safford, H. D., E. C. Underwood, and N. A. Molinari. Managing chaparral resources on public lands. 2018. Pages 411–448 *in* E. C. Underwood, H. D. Safford, N. A. Molinari, and J. E. Keeley, editors. *Valuing chaparral: ecological, socio-economic, and management perspectives*. Springer Series on Environmental Management. Springer, Cham, Switzerland.
- Sun, F., D. B. Walton, and A. Hall. 2015. A hybrid dynamical–statistical downscaling technique. Part II: end-of-century warming projections predict a new climate state in the Los Angeles region. *Journal of Climate* 28:4618–4636.
- Swain, D. L. 2015. A tale of two California droughts: lessons amidst record warmth and dryness in a region of complex physical and human geography. *Geophysical Research Letters* 10.1002/2015GL066628. <https://doi.org/10.1002/2015gl066628>
- Syphard, A. D., T. J. Brennan, and J. E. Keeley. 2018. Chaparral landscape conversion in southern California. Pages 323–346 *in* E. C. Underwood, H. D. Safford, N. A. Molinari, and J. E. Keeley, editors. *Valuing chaparral: ecological, socio-economic, and management perspectives*. Springer Series on Environmental Management. Springer, Cham, Switzerland.
- Underwood, E. C., H. D. Safford, N. A. Molinari, and J. E. Keeley, editors. 2018. *Valuing chaparral: ecological, socio-economic, and management perspectives*. Springer Series on Environmental Management. Springer, Cham, Switzerland.
- Vallejo, V. R., A. Smanis, E. Chirino, D. Fuentes, A. Valdecantos, and A. Vilagrosa. 2012. Perspectives in dryland restoration: approaches for climate change adaptation. *New Forests* 43:561–579.
- Venturas, M. D., E. D. MacKinnon, H. L. Dario, A. L. Jacobsen, R. B. Pratt, and S. D. Davis. 2016. Chaparral shrub hydraulic traits, size, and life history types relate to species mortality during California’s historic drought of 2014. *PLoS ONE* 11:e0159145.
- VinZant, K. In press. Restoration in type converted and heavily disturbed chaparral: lessons learned. *In* M. Narog, technical coordinator. *Chaparral restoration: a paradigm shift*. Proceedings of the Chaparral Workshop, Arcadia, California June 17–20, 2013. General Technical Report. USDA Forest Service, Pacific Southwest Research Station, Albany, California, USA.