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30 January 2024

Regional Forester, U.S. Forest Service
1220 SW 3rd Avenue
Portland, OR 97204
https://cara.fs2c.usda.gov/Public//CommentInput?Project=64745

Subject: Summary of Current Ecological and Conservation Science, NWFP Amendment, National Forests in Klamath Ecoregion (Scoping Comments, Project 64745)

Dear Regional Forester:

Attached please find a summary of current scientific understanding about the frequent-fire forests in the Klamath Ecoregion, which constitute the majority of Forest Service landscapes in northwestern California. These comments are submitted specifically to inform the development of the Northwest Forest Plan (NWFP) amendment elements that affect the five National Forests in the Klamath ecoregion (four in California's Region 5 and the Rogue-Siskiyou NF in southwestern Oregon). The ecological dynamics of the 'dry, frequent-fire forest' landscapes of the Klamath ecoregion are substantively different from those of the mesic forests in western Washington, Oregon, and coastal northwestern California that otherwise are likely to dominate the NWFP amendment, and the Forest Service must incorporate the scientific framework in the attached summary into the amendment in order to address the 'dry forest' dynamics in the interior of northwestern California and southwestern Oregon.

While these interior landscapes differ from the mesic, coastally influence forests in numerous ways, there are two overarching differences that really must be addressed in order to achieve landscape resilience as climate and fire dynamics in the Pacific Northwest continue to unwind.

- The first major difference is that the dynamics of fire and fuels management in the region require that management be directed at reducing fuels loadings throughout the forests, and that this changed focus must include a restoration of 'good fire' (i.e., prescribed fire or managed wildfire) to an active role in land management. The Regional Bioassessment and the Science Synthesis prepared as supporting documents for the amendment both recognize the altered dynamics that make this change necessary in these 'dry' forests, although it seems likely that this change should occur broadly throughout much of the Pacific Northwest.
- The second difference with respect to the Klamath ecoregion is an acknowledgment that forested landscapes in the region demonstrate a fundamentally different ecological dynamic when compared to the 'moist forest' dynamics that misinformed the 1994 NWFP. Landscapes in the ecoregion occur in a dynamic mosaic in which alternative (i.e., non-conifer-dominated) landscapes are naturally favored by disturbance processes that have formed and continue to affect the landscapes in the region. The dynamics in this ecoregion are similar to the dynamics identified for the 'eastside' forests in the Region 6 of the Pacific Northwest, and similar management guidance is needed in order to address the frequency and magnitude of landscape dynamics here.

The attached summary also addresses several changes in scientific understanding that post-date the adoption of the 1994 NWFP, which need to be included in and addressed by the NWFP amendment, and then included in and addressed by the amended Land Management Plans of the National Forests in the ecoregion. The most significant change is certainly the increased understanding of landscapes as dynamic mosaics that need to be managed as systems that change through time as disturbance events occur in different places. That is, landscapes need to be managed as time-varying rather than static. In addition, scientists now understand substantially more about the dynamic processes that occur in ecological communities and ecosystems (including subsurface ecohydrological processes in the Critical Zone), and this improved understanding needs to be reflected in the NWFP.

Climate change is a significant driver of ecological changes in federally managed lands in northern California, but the full range and scope of the potential changes in landscape dynamics aren't yet known, and retention of some future management flexibility at local levels is likely to be beneficial. Changes in the socioecological patterns in the federally managed lands in northwestern California are underway, including potential restorations of salmonid fisheries following flow restorations in two major river basins, for which conditions in managed National Forest landscapes must play a major role. For the Forest Service to meet those obligations fully will require that management plans be based on a continuing commitment to obtain and follow the best available science, as required by the 2012 Planning Rule (36 CFR § 219.3). The attached summary document is hereby submitted in the hope that it will help frame the agency's management approaches during coming decades.

Thank you for caring about our public lands and environmental resources.

Sincerely,

Chad Roberts

Chad Roberts, Ph.D.
Conservation Ecologist

Attached: Adapting to Climate Change & Fire in the Klamath Ecoregion - Incorporating the Best Available Science into Amendments of the Northwest Forest Plan and Individual Land Management Plans

ADAPTING TO CLIMATE CHANGE & FIRE IN THE KLAMATH ECOREGION

Incorporating the Best Available Science into Amendments of the Northwest Forest Plan and Individual Land Management Plans

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Davis, California

January 2024

A Short Summary

The Klamath ecoregion in northwestern California includes substantial parts of four Forest Service (FS) National Forests and portions of at least three Bureau of Land Management (BLM) field offices. Existing planning documents for these federal lands will soon be amended, including the Northwest Forest Plan (NWFP), the Land Management Plans (LMPs) for the National Forests, and the Resource Management Plans (RMPs) for the BLM field offices. For the National Forests, the plans will be developed pursuant to the 2012 Planning Rule, which directs that planning focus on processes occurring at landscape scales, on ecological processes leading to services from these public lands, and on adapting to the effects of climate change, a focus that differs in substantive ways from the focus in the existing management plans for these public landscapes.

Science summaries recently prepared for these plan updates show that substantial parts of these landscapes are dominated by 'dry' 'frequent-fire' forests, conditions which were not addressed in the existing NWFP and the existing unit management plans. The effects of increased fire and other disturbances, and of the aridity that results from warming climate, will exert significant stresses on these federally managed landscapes, and amended management plans must address responses to those changes. New scientific information and better understanding of ecological processes in northwestern California landscapes, summarized in this report, address many of those questions.

Responding to climate change and fire requires adaptational responses at a stand or patch level. Increased fuels in many mixed-conifer stands in the Klamath ecoregion must be addressed by including a restoration of fire to forested landscapes, returning its historical occurrence patterns. Existing stand structures must be adapted to increased fire and aridity by reducing stand densities. Restoration of a more natural stand structure identified in frequent-fire forests, the individuals/clumps/openings ('ICO') structure, and the intentional retention of large and old trees will increase stand resilience. Stand compositions in the Klamath ecoregion may shift toward more hardwood dominance with increased fire, because hardwoods and shrubs are ecologically selected vegetation types in the ecoregion. Nonetheless, climate change and more active fire regimes may cause the development of

‘no-analog’ stand compositions unlike those currently present. This report summarizes these effects.

Responding to climate change and fire also requires adaptational responses at landscape levels. Landscapes are large areas that combine many stands, and landscape-level management must include considerations about the joint status of multiple resources across stands as those resources are affected at the scale of the entire landscape. Landscapes are ‘mosaics’ of multiple patch or stand types, and landscape-scale responses include shifts in the both the locations of and the conditions in individual stands through time. Landscape-scale management requires an understanding of how those large-area dynamics occur and how they may be used to plan for the land and address public concerns. Landscape-based management also helps frame potential considerations about ‘no-analog’ future communities that may be better adapted and more resilient to future climates.

Landscape-scale considerations are already a significant part of many conservation planning frameworks, and incorporating scientific concepts developed for conservation purposes helps frame landscape management options. ‘Connectivity’ is fundamentally a landscape-scale concept that’s essential in conservation contexts, and will guide development of landscape-scale plans for other resource concerns. In the Klamath ecoregion a fundamental consideration for the future is the relative importance of coniferous trees with respect to increased fire, because the Klamath ecoregion is well understood to include hardwood tree and shrub species that are adapted to the region’s frequent-fire ecosystems. Hardwoods, shrublands, and coniferous forests are ‘alternative stable states’ in the ecoregion. An improved focus on riparian areas within the ecoregion will enhance both conservation outcomes and landscape-scale management.

This summary includes references for the described scientific concepts, providing an avenue to recent scientific literature most relevant for the processes underlying the application of the 2012 Planning Rule to National Forest landscapes in the ecoregion.

I. Bioregional Science, Climate Change, and Fire Assessment in the Klamath Ecoregion

Northwestern California’s four National Forests [the Klamath (KNF), Six Rivers (SRNF), Shasta-Trinity (STNF), and Mendocino (MNF)] are the southernmost National Forests included in the range of the Northern Spotted Owl (*Strix occidentalis caurina*), and as such their current Land and Resource Management Plans (LRMPs) are constrained to be consistent with the requirements of the 1994 Northwest Forest Plan (NWFP). In July 2020, the Forest Service (FS) regional offices for California (Region 5; R5) and Washington and Oregon (Region 6; R6) issued a document entitled the *Bioregional Assessment of Northwest Forests* (*BioA*; USFS 2020) for public review. The BioA has a formally identified status as a ‘pre-decisional’ document on the FS’s ‘Forest Plan Revision Process’ under the 2012 Planning Rule, where it accompanies the *Science Synthesis* (Spies et al. 2018b) as a document on which the forest plan revision processes for each of 19 identified National Forests in Washington, Oregon, and northwestern California are to be based. Like the Science Synthesis, the BioA is part of a formal process intended to identify public concerns as an element in public engagement regarding the development of those amended plans.

The BioA does not incorporate site-specific results for any National Forest. What it does is identify general concepts or approaches that the FS should consider and may employ in developing updated LRMPs for the National Forests identified in the BioA. Many of the concepts (and the altered planning process required under the 2012 Planning Rule) also support strategic options that have been identified for adapting National Forest landscapes to the effects of climate change, which is an existential concern for the long-term conservation of forests throughout the region.

Incorporating climate change into ongoing management programs represents a fundamental challenge for the Forest Service (as it does for most organizations) in several ways. Perhaps most importantly, for most of its history the FS has been guided by a concept that landscapes were 'stationary' through time, and that management should be based on maintaining or restoring landscape conditions that existed at the time the USFS was established, or even on the conditions that existed prior to the colonization of North America by Europeans. However, it's already clear scientifically that climate change is altering dynamic processes in federal landscapes that will likely take them beyond the range of known historical conditions, and that alternative management approaches are needed that incorporate effects of altered climate on the landscapes.

Box 1. Ecosystem Services

The Millennium Ecosystem Assessment (2005) identified four categories of ecosystem services, 'the benefits people obtain from ecosystems.'

Provisioning Services
Provisioning services address benefits that people receive directly from nature, including food, water, timber, and fiber, among others.

Regulating Services
Regulating services address ecosystem controls on climate, floods, disease, wastes, and water quality, among others.

Cultural Services
Cultural services reflect how nature affects people, including effects on their aesthetic, spiritual, educational, and recreational well-being.

Supporting Services
Supporting services underlie all the categories above, reflecting ecosystem processes such as nutrient cycling, soil formation, and primary production, among others.

The assessment noted that 'people are integral parts of ecosystems and that a dynamic interaction exists between them and other parts of ecosystems, with the changing human condition driving, both directly and indirectly, changes in ecosystems and thereby causing changes in human well-being.'

Potential effects of climate change on USFS lands and resources will affect the ecosystem services provided by these landscapes (Box 1); this is an explicit consideration for plan amendments in the 2012 Planning Rule. National Forest landscapes provide many ecosystem service, and a primary consideration for the NWFP amendment will be the potential for sequestering carbon in living (and/or retained dead) biomass. Forested landscapes in northwestern California have historically acted as major reservoirs for stored carbon, a service of significant management concern in an era of climate change, but one that is affected adversely by recently increased fire occurrence and severity in the region. Projections of future landscape dynamics in the region (e.g., Peeler et al. 2023) indicate significant vulnerability of carbon stocks in National Forests to increased fire; reducing the vulnerability of these landscapes to future fires must be a principal concern for the NWFP and forest LMP amendments.

Climate exerts a major influence in the evolution of plant and animal species; variations in temperature and moisture patterns are particularly important. Ecological research has long documented the importance of moisture gradients for California vegetation: both precipitation and species richness decline from north to south in this region's Mediterranean-type climate, and from the coast toward the Sierra Nevada (Richerson & Lum 1980; Hawkins et al. 2003). Fluctuations in precipitation are related to coupled ocean-atmosphere systems that vary over periods of a few months to a few years to several decades, and are linked to dynamic processes in vegetation growth and fire occurrence and severity in California (Trouet et al. 2006; Skinner et al. 2009, 2018; Wahl et al. 2019).

Vegetation in northwestern California's mountains is a significant element underlying the designation of California as a global biodiversity hotspot. Similar concerns exist for ecological diversity in other ecoregions in northwestern California which are also affected by the guidance provided by the NWFP. The climate, geography, and geological composition in northwestern California support high richness and endemism in numerous plant families, including conifers (Stebbins & Major 1965, Raven & Axelrod 1978, Briles et al. 2008, Kauffmann & Garwood 2022), as well as high species richness among native wildlife and fish species (CDFW 2003, 2015).

The ambient Mediterranean-type climate (cool, wet minters and warm, dry summers) in northwestern California interacts with elevation, localized ecohydrology, soil composition, long-term California Indigenous land management practices, and other factors to influence recurring vegetation patterns in California. Fire is one of the most significant factors resulting in patterns in patterns in fire-return frequency, fire intensity and severity, and plant reproductive strategies characterized as *fire regimes*; these co-evolved relationships are reflected in the dominant vegetation patterns in California's landscapes (Sugihara et al. 2018, Collins et al. 2018, Oddi 2018; other chapters in van Wagtendonk et al. 2018). These fire regime patterns are major contributing factors to the genesis of geographic *ecoregions* (Griffith et al. 2016), which reflect intrinsic patterns in underlying biophysical factors and ecological interactions, and in the resulting landscapes; fire regimes have been, and still are, a significant factor shaping California's landscapes.

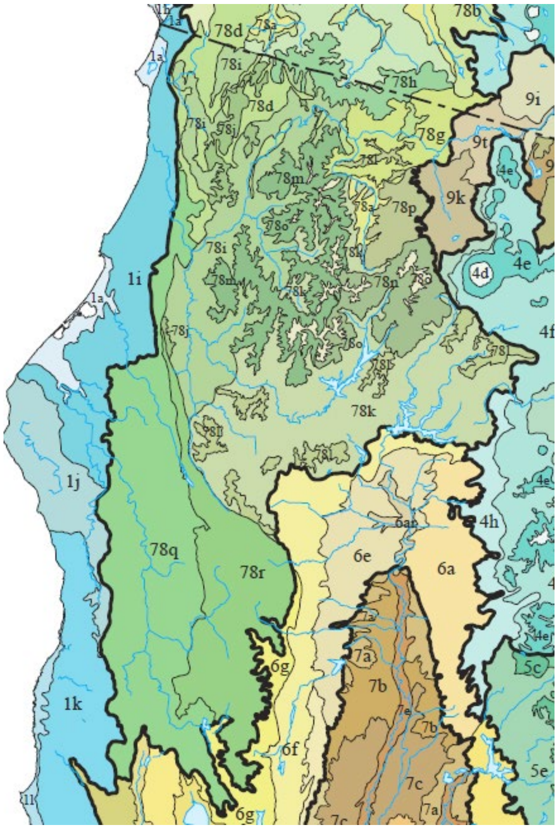

Figure 1. 'The Klamath Mountains/California High North Coast Range Ecoregion (78) *encompasses the highly dissected ridges, foothills, and valleys of the Klamath and Siskiyou Mountains. It extends south into California to include the mixed conifer and montane hardwood forests that occur on mostly mesic soils in the North Coast Range mountains. ... The ecoregion's diverse flora, a mosaic of both northern Californian and Pacific Northwestern conifers and hardwoods, is rich in endemic and relic species. The mild, subhumid climate of this ecoregion is characterized by a lengthy summer drought.' (Ecoregion 78 map and text excerpted from Griffith et al. 2016.)*

Most of the public landscapes within the four NW California National Forests that the focus here are included within the '*Klamath Mountains/High North Coast Range*' ecoregion (Griffith et al. 2016; Figure 1). This ecoregion encompasses the geologically defined Klamath Mountains (including the Siskiyou region in southwestern Oregon) together with higher-elevation conifer-forested landscapes in the interior northern Coast Ranges. (i.e., <u>*not*</u> including the coastal ecoregion dominated by cooler and wetter landscapes); hereafter this report refers to these interior, higher-elevation landscapes collectively as "the Klamath ecoregion". The Klamath ecoregion generally incorporates forested landscapes above 3000 feet in elevation, higher elevations generally above 6,000 to 7000 feet, and the highest peaks in the ecoregion above 9,000 feet. The ecoregion incorporates a wide range of geological substrates, soils, aspects, and other underlying physical variables, a range of variability that exceeds the coverage of this memorandum, but the ecological communities are similar enough throughout the ecoregion that USEPA geographers combine the various vegetation communities into the same ecoregion.[1]

A significant thread throughout the BioA is the identification of ecological differences in the forested landscapes covered by the NWFP that were not recognized when the NWFP was formulated in the early 1990s. The most significant regional difference is the existence of 'dry' or 'frequent-fire' landscapes in most of the four National Forests in northwestern California (Figure 2). As synopsized in the BioA, these inland forested landscapes developed, and continue to exist, under significantly different moisture, temperature, and fire regimes than occur in 'moist forests' closer to the Pacific Ocean. In the existing NWFP, the conditions in the 'moist' forests were effectively presumed to exist in all forested landscapes in the region. In the intervening three decades, abundant scientific evidence has accrued supporting the distinctions among forests that have developed under differing fire regimes (summarized in van Wagtendonk et al. 2018, as well as in hundreds of individual scientific publications covering forests throughout the western US).

The ecological patterns underlying the 'dry'/'moist' differentiation are described more fully in the Science Synthesis than in the BioA. However, the Synthesis (and therefore the BioA) describes plant associations in California using a classification framework developed for Region 6 that doesn't translate well to vegetation categories normally used in California. The Science Synthesis presents a crosswalk to the CALVEG classification developed for USFS Region 5, but the potential for misinterpretation of vegetation patterns in California based on the Region 6 classification system is a concern for the amended NWFP.[2]

Much of the forested landscape in northwestern California is identified in the BioA as 'Douglas-fir' forest or 'White Fir-Grand Fir' forest, grading into 'Tanoak' forest on the coastal side and 'Ponderosa Pine' forest near the Central Valley, but managers (and the public) in California are familiar with, and normally utilize. a different vegetation categorization system. Other summaries exist for vegetation patterns in NW California (e.g., Küchler 1977, Sawyer 2006, Griffith et al. 2016), and the variability in these forest types is amplified in site descriptions included in hundreds of published and unpublished research reports. A poor characterization of northwestern California forest ecosystems will be a substantive issue for the amendment process of the NWFP if the USFS planning team fails to appreciate the importance of the differences among forest ecosystem dynamics throughout the NWFP plan area, as happened in the early 1990s.

In northwestern California, 'dry' forests generally include many of the mid-elevation forests typically identified as 'mixed conifer' or 'yellow pine' forest in California's Sierra Nevada and southern Cascades ecoregions. Dominant conifer species in mixed-conifer forests include Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), ponderosa pine (*Pinus ponderosa*), and sugar pine (*P. lambertiana*). California black oak (*Quercus kelloggii*) is frequently a co-dominant species in California's mixed-conifer forests. Incense cedar (*Calocedrus decurrens*) is also a common mixed-conifer dominant, but varies locally in abundance. Jeffery pine (*P. jeffreyi*) often occurs in mixed-conifer (and yellow pine) stands on mafic substrates.

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[1] Some historical ecological treatments limit the Klamath Mountains ecoregion (aka the 'Klamath-Siskiyou region') to the geological region identified as the Klamath Mountains, placing the forested landscapes of the inner northern Coast Range in other ecoregions. The Griffith et al. (2016) classification places all the higher-elevation forested landscapes in northwestern California into the same ecoregion, based on their ecological similarities. As will be evident from considerations of 'dry' 'frequent-fire' forests in this summary, the Griffith et al. (2016) classification generally reflects the ecological patterns in NW California.

[2] See https://www.fs.usda.gov/detail/r5/landmanagement/resourcemanagement/?cid=stelprdb5347192.

These are also dominant species in Sierra Nevada mixed-conifer landscapes, although Douglas-fir is less dominant in the Sierra, and is absent from the Sierra south of Yosemite NP. In most Sierra Nevada National Forests, ponderosa pine is considered to be the dominant conifer species in mixed-conifer landscapes; however, in the mixed-conifer landscapes in the Klamath ecoregion (and elsewhere in northwestern California), Douglas-fir has long been identified as the ecologically dominant conifer species. This difference reflects differing evolutionary dynamics in California, but it should also be noted that Douglas-fir ecology in the Klamath ecoregion has been described as also different from Douglas-fir ecology in the Cascades of Oregon and Washington.[3]

In northwestern California's 'dry' mixed-conifer forests, canyon live oak (*Q. chrysolepis*) and madrone (*Arbutus menziesii*) are frequently important hardwood species. In addition, Oregon white oak (also known as Garry oak, *Q. garryana*) may be a dominant hardwood in successional patches following fires, and is more common in northern and western parts of the ecoregion and the *Central California Coastal and Foothill Mountains* ecoregion to the south. Forests at low elevations on the west side of the Klamath ecoregion include 'dry' subareas of mixed-evergreen forests, with Douglas-fir as the dominant conifer and tanoak (*Notholithocarpus densiflorus*), madrone, and canyon live oak as codominant broadleaved species.

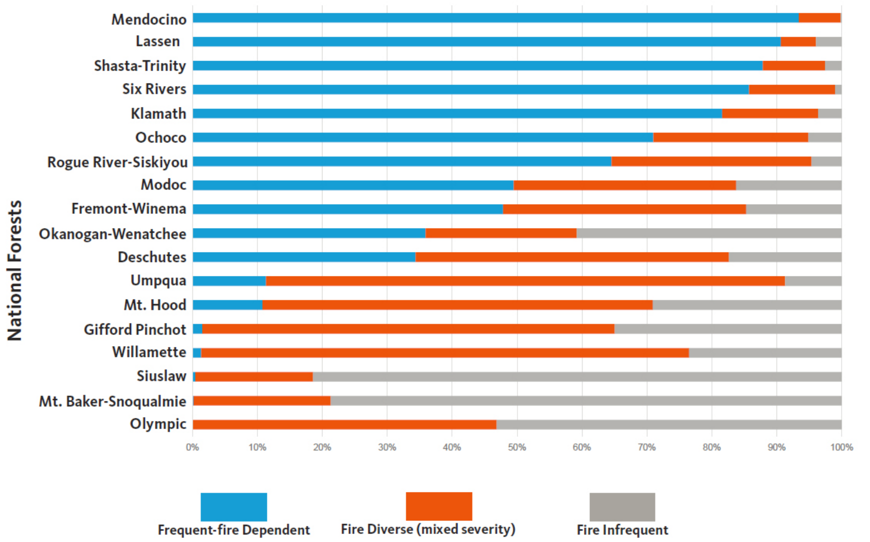

Figure 2. The BioA includes this figure (as Fig 4-4) identifying generalized fire regimes for national forests covered by the NWFP. The four northwestern California forests all exhibit at least 80% landscape dominance by 'frequent-fire dependent' forests, which are not currently addressed by either the NWFP or the individual forest LRMPs. The NWFP amendment needs to identify the management strategy that the FS will use to address climate change, habitat values, increased fire, and fuels management in these forested landscapes.

Because each of the dominant plant species responds to its own set of required environmental conditions, local composition of forest plant alliances varies throughout the ecoregion, and the forest types typically occur in a patchy mosaic. The north-facing side of a ridge (the north '*aspect*') may support a dense conifer forest, while the south aspect of the same ridge may be an open ponderosa pine forest, a black oak woodland, a chaparral-covered slope, or a grassland/savanna. Mixed-conifer forests throughout the ecoregion frequently include shrubby understories, which are generally continuous at lower elevations with mixed chaparral, generally considered by California ecologists to dominate the largest total percentage of the state's landscapes. In a general sense, 'dry forests' in NW California resemble forested landscapes in the eastern/inland parts of

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[3] Some ecologists working in Klamath ecoregion forests have concluded that these landscapes are unique in the United States, perhaps worldwide. "(I)t is readily apparent that, although the Klamath Mts. maintain many species in common with other western mountain areas, local populations are not ecologically equivalent to those of the Sierra Nevada or the Cascades. Additionally, the roles played by some environmental factors may be unique. For example, the fire ecology of the Klamath region seems to be intermediate between that of the Pacific Northwest and the Sierra Nevada, and therefore distinctive." (Sawyer & Thornburgh 1977:730).

the Pacific northwest, with less rain/snow and higher summer temperatures than closer to the coast. These landscapes, in consequence, tend to exist in a different fire regime than do coastal ‘moist’ forests.

The BioA (correctly in my judgement) identifies the four northwestern California National Forests as virtually all dominated by ‘dry’ ‘frequent-fire dependent’ forests (Figure 2). The BioA identifies the overarching dominance of ‘frequent-fire’ landscapes in much of the region as having significant implications for the NWFP amendment, with ‘climate change’ and ‘disturbance restoration’ as high-priority management concerns (designations shared with ‘dry’ forests in the Rogue-Siskiyou NF in southwestern Oregon).[4] Forest ecologists have generally concluded that climate change will increase the significance of fire in all western forest landscapes during the 21st Century and beyond (e.g., Stephens et al. 2020). These landscapes require a management emphasis that restores and recognizes appropriate roles for fire and regular disturbance.

Box 2. Climate Facts

From an evolutionary perspective, climate is a primary driver of change in plant and animal species. The following climate conditions and processes have affected ecosystems in California landscapes today (all statements in italics are quoted from Millar 2014). See text and Figure 7 for additional information.

“*Climates have been changing constantly through the history of life on Earth; this includes dramatic changes throughout the periods of evolutionary history of species we manage today*.

“Climates are expressed at hierarchic levels, with interannual regimes nested in decadal modes, nested within multicentury modes, and these are nested within even longer-term multimillennial cycles.

“*Different physical mechanisms drive modes at the different scales. While these are quasi-independent, drivers interact. Climate at any one moment in history is expressed as the cumulative effect of all modes acting together. Ecosystems respond at all scales of climate variability and change*.”

II. Climate Science Concepts for Plan Amendments

Current regulations applicable for USDA Forest Service forest plan amendments (the “2012 Planning Rule”; 36 CFR §219) explicitly direct that amendments address the effects if climate change on these federally managed landscapes. The Forest Service research and planning communities have addressed incorporating climate change into land management plans in a variety of publications (not addressed here), but my experience has been that most on-the-ground Forest Service managers are not familiar with either climate science or suggested approaches to address it within management. However, maintaining ecosystem functions and services from National Forest lands (Box 1) requires identifying and implementing measures to adapt to climate-related changes in these landscapes. The proposed amendment for the NWFP, as well as the environmental assessment documents prepared pursuant to the National Environmental Policy Act (NEPA) for the amendment, must assure a sufficient discussion about the dynamics of, and effects on landscapes from, climate processes sufficiently that managers and the public can understand the need to address these effects.

Climate is a primary factor in the evolution of plant and animal species; every native (and most naturalized) species in the western US has experienced numerous changes in ambient climate during its evolutionary history, and these exposures shaped the species’ tolerances of (or

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[4] BioA Table 5-1 identifies ‘large, high-severity fire impacts’ as high-priority concerns for the Six Rivers and Rogue-Siskiyou National Forests, but as low-priority concerns for the Mendocino, Klamath, and Shasta-Trinity NFs. Based on recent fire occurrences (including the 2018 Ranch Fire, the 2020 August Complex, and other recent fires) and the projections of future fire resulting from climate change, large, high-severity fire impacts should also be identified as a major concern for all National Forests in northwestern California.

requirements for) the ecological conditions in which it occurs today. Climate itself has been variable, on multiple scales, during the periods in which California plant species evolved (Box 2). As current climate conditions are altered, each species will adapt its occurrence pattern to the new ambient conditions in order to experience, to the degree possible, conditions like those that shaped its evolutionary past. Often this will involve geographic range shifts, although most species retain enough genetic flexibility to accommodate altered climatic conditions to some degree, and some may respond to changing environments by evolving new genetic variations better adapted to the new ecological conditions. Describing the ecological and evolutionary responses to changing environments exceeds the scope of this summary.

Most plant and animal species in California today evolved within the past few million years, although ancestral clades (continuous genetic lineages from ancestors to descendants) for most California plant families originated in North America before the early Miocene Epoch (i.e., by about 20 million years ago). During the evolutionary history of California clades, global temperatures and precipitation patterns differed significantly from current conditions, exposing California lineages to a vast range of local climate (Figure 3). Many California plant lineages have been shaped to a significant degree by the development of a summer-dry Mediterranean-type climate in California since the middle Miocene Epoch; i.e., within about the last 15 million years (Ackerly 2004; Rundel et al 2016, 2018).

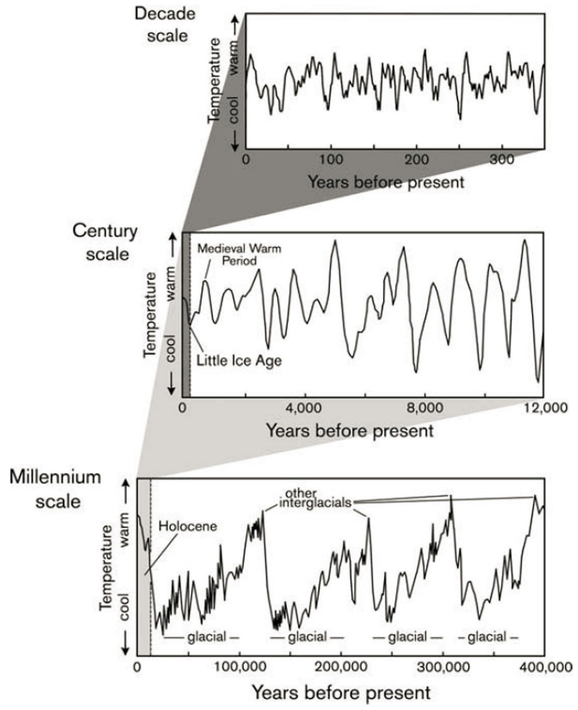

Figure 3. Millar's (2014) representations of global temperature cycles showing the nested nature of climate modes at different temporal scales. Top: Multidecadal cycles are related to ocean circulation and sea temperatures. Middle: Century cycles result from variability in solar activity. Bottom: Millennial cycles result from variations in several aspects of Earth's orbit relative to the sun. These and other cycles interact continually and, in combination, result in ongoing changes in earth's natural climate system.

The climate variations summarized in Figure 3 have resulted from long-term cyclic changes in the interactions of primary physical factors (orbital variations and the inclination of the Earth's axis) with shorter-term variability resulting from changes in the sun's internal thermonuclear dynamics, and from changes in physical responses in the Earth's energy-transport systems. The short-term cycles in Earth's processes (periodicities of decades to centuries) are nested with cycles that operate over periods of thousands of years, which are in turn nested within orbitally driven cycles of multiple tens of thousands of years. Dynamics occurring at all these scales affected the evolution of plant and wildlife species in California today, because adaptations developed in response to one periodicity are carried over into processes of adapting to other periodicities, both longer and shorter. While the sources of evolutionary dynamics in living organisms are both numerous and variable, some genetic ability to respond to ranges of climatic conditions often remains within each species' genome rather than being lost, which may affect the species' subsequent responses to varying climate.

Changing climate is often accompanied by adjustments in the interrelationships among species and changes in the ecological communities in each landscape. Prior climate-driven ecological changes are well documented in North America's geological record. Paleoecological assessments of vegetation and wildlife patterns from the late Pleistocene to the present (e.g., Overpeck et al 1992, Whitlock 1992, Graham et al. 1996, Davis & Shaw 2001, Briles et al. 2008, Millar 2014) have documented vast ecological transformations in ecological communities in western North America as a consequence of climate warming with an extent similar to what's projected for the late 21st Century.[5] The short-term internal ecosystem dynamics that led to past ecological transformations can never be known with certainty, but there's no reason to expect that they differed substantially from the ecological processes observed in today's landscapes, particularly those related to altered moisture regimes and altered fire regimes. It should be noted that climate fluctuates at scales of centuries and decades as well as at longer intervals, and a general consensus exists among climate scientists that the period between approximately 1700 and 1950 CE was a period in which Earth's climate was generally wetter and cooler than during the Holocene as a whole. Such conditions are not expected to return during the active lifetime of the pending plan amendments, and landscapes compositions, structures, and dynamics established under those conditions are not expected to be typical of conditions under future climate.

Increased ambient air temperature results in the atmosphere's increased ability to hold water vapor. The atmosphere gets additional moisture by increasing the evaporation rate from soil and through increased vegetation evapotranspiration. This effect is generally identified as an increasing atmospheric 'vapor pressure deficit'. An ecologically relevant form of this vapor pressure deficit is the *Climate Water Deficit* (CWD), in which atmospheric water demand exceeds readily available moisture in soils and vegetation. Defined empirically when actual evapotranspiration exceeds potential evapotranspiration (PET<AET), such conditions typically exist in California landscapes in summer and early fall (see Stephenson 1998 for a full explication of the dynamic process and its effect on dominant vegetation types). Measures of CWD are now readily available from several climate data repositories for most locations in the western US.

In essence, warmer air is 'a bigger sponge,' pulling more moisture out of vegetation and the substrate. Increased CWD results in accelerated fuels drying and increased ignition probability from natural sources (i.e., lightning), and has been identified as a primary contributing factor in the altered fire regimes and increased wildfire occurrences in National Forest landscapes during the 21st Century, when compared to those of the late 20th Century (Bachelet et al. 2007; Westerling & Bryant 2008; Allen et al. 2010, 2015; Westerling et al. 2011; Liang et al. 2017; Restaino & Safford 2018; Westerling 2018; Keyser & Westerling 2019; Martinuzzi et al. 2019; Wahl et al. 2019).

The significance of increased CWD to climate-change stress for western US forested landscapes in the 21st Century has been widely identified by forest ecologists (McKenzie et al. 2004; van Mantgem et al. 2009; Allen et al. 2010, 2015; Abatzoglou & Williams 2016; Tepley et al. 2017; Restaino & Safford 2018; Hessburg et al. 2016, 2019, 2021; Spies et al. 2018a; North et al. 2019; Wahl et al. 2019; Larson et al. 2022; Gaines et al. 2022). Increased CWD is an unavoidable consequence of climate change, which depends solely on physical processes, and the primary driver of those processes is increased air temperature, an irrefutable consequence of climate change. Recent climate-change assessments for California, based on widely used global climate models, improved hydrological assessment methodology, and now-standardized methods for computing CWD, demonstrate an uneven increase in CWD, with lower elevations throughout

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[5] Average global temperature rose approximately 5ºC (8ºF) between the end of the last glacial maximum in the Pleistocene Epoch (about 17,000 years ago) and the beginning of the Holocene (about 12,000 years ago). This is roughly the same increase in global average temperature expected during the 21st Century under current socioeconomic trends (see publications of the International Panel on Climate Change for additional information).

California experiencing greater atmospheric drying (Thorne et al 2015, 2016), although localized conditions (e.g., increasing CWD with upper slope positions and western and/or southern aspect) affect CWD on a landscape scale in northern California forestlands (JH Thorne, *in seminar* 2021). Increased CWD results in increased competition among trees in a stand for water and nutrients, reduced tree growth and increased competitive mortality, reduced resistance to and increased mortality from insects and diseases, and similar effects (Abatzoglou & Williams 2016, Schoennagel et al. 2017, Crockett & Westerling 2018, Restaino & Safford 2018, Vose et al. 2018, Fettig et al. 2019, Gaines et al. 2022).

The combination of altered fire regimes and altered climate (increased temperatures, intensified CWD, and altered precipitation patterns) increases the likelihood of altered ecological communities and landscape patterns for California wildlands. For example, increased CWD was identified as a fundamental cause of excessive tree mortality in the Sierra Nevada during the 2014-2017 drought, both directly and as a major factor underlying deaths of weakened trees because of bark beetle attacks (Young et al. 2017, Fettig et al. 2019). Region-wide studies (e.g., van Mantgem et al. 2013) have indicated that increased climatic stress results in increased tree mortality across the gradient of wildfire energy release because of stress effects on tree physiology.

In the Klamath ecoregion, interactions among drought (as increased CWD) and fire have also been identified as a factor in determining dominant stand conditions, including the patchworks of stand conditions for which the region's landscapes are well-known, and are the most likely cause of potential climate-related conversions of mixed-conifer forest to hardwood- and shrub-dominated landscapes in the future (Whitlock et al. 2003, Briles et al. 2008, Colombaroli & Gavin 2010, Tepley et al. 2017, DeSiervo et al. 2018, Skinner et al. 2018, Shive et al. 2018, Stephens et al. 2018, Coop et al. 2020, McCord et al. 2020, Jules et al. 2022; see Attachment 1).

III. Ecological Community Dynamics in NW California Dry Forests

Conifer-Dominated Vegetation Types. Dry mixed-conifer and mixed-evergreen forests in northwestern California are generally understood to have exhibited a *frequent-fire, mixed-severity regime* prior to the 20th Century (Halofsky et al. 2011; Perry et al. 2011; Hessburg et al. 2016; Skinner et al. 2018; Stephens et al. 2018a, 2018b; Spies et al. 2019). While a mixed-severity regime is also the dominant fire regime for mixed-conifer forests throughout the southern Cascades and the Sierra Nevada (Mallek et al. 2013; Safford and Stevens 2017), there are ecological differences among the mixed-conifer forests in NW California, the inland Cascades, and the Sierra Nevada that must be considered when applying insights from one region to other regions.

Within the coniferous forests in the Klamath ecoregion in NW California, Douglas-fir exhibits a larger ecological amplitude than in the Sierra Nevada and southern Cascades, or in other regions of North America (Sawyer & Thornburgh 1977; Sawyer et al. 1977; Uchytil 1991; Atzet et al. 1996; Taylor & Skinner 1998, 2003; Shatford et al. 2007; Tepley et al. 2017; Skinner et al. 2018). Douglas-fir in mid-elevation forests in northwestern California is a shade-tolerant species adapted to frequent fires, an adaptation pattern that includes germinating under established shrub or hardwood canopies and tolerating competition until trees can grow through and overtop the shrub or hardwood canopy (Sawyer et al. 1977, Hunter & Barbour 2001, Taylor & Skinner 2003, Shatford et al. 2007, Tepley et al. 2017, Skinner et al. 2018, Stephens et al. 2018b). Douglas-fir also germinates well from bare mineral soil following fire; regeneration success is greatest in the years immediately following a fire and declines through time. However, regeneration declines with distance from a living-tree seed source and with increasing climate water deficit (Tepley et al. 2017, Meyer et al. 2021, Long et al. 2023).

Mixed-conifer forests in all four NW California National Forests apparently evolved within a *fire return interval* typically less than 25 years (often significantly less, particularly in areas influenced for millennia by California Indigenous human management), characterized as a *very-frequent fire, low-severity regime* (Halofsky et al. 2011; Spies et al. 2018, 2019). The frequent fires tended to maintain low levels of accumulated fuels in these forested landscapes by removing shrubs and smaller trees, while the dominant tree species (particularly large Douglas-firs and ponderosa pines) were relatively resistant to low-intensity fire. The only conifer taxon in this region known to sprout if top-killed by fire is California torreya (*Torreya californica*), although knobcone pine (*P. attenuata*) and several native cypresses (*Hesperocyparis* spp.) are serotinous (i.e., with cones that open and shed seeds after a fire). Dominant hardwood species [particularly black oak, madrone, and canyon live oak, but also bigleaf maple (*Acer macrophyllum*)] show adaptations to resist being killed by low-intensity fire and/or abundant sprouting by top-killed trees (see Attachment 1).

‘Old Growth’ Has Different Meanings, and Different Structures, in Different Forests. The context in which the NWFP was developed was a reaction to what was at the time widely recognized as a FS program to convert ‘old’ forests to younger, faster-growing plantations. A major outcome of the NWFP development was the general adoption of the concept of an ‘old-growth forest,’ something having intrinsic biological value as a desired part of public landscapes. Old-growth forests were to be recognized by having a combination of old and/or large trees, the presence of other legacy features like down logs and snags, and structural characteristics relating to canopy layering and closure percentages. At the time, the Northern Spotted Owl came to represent a focus for old-forest activism, one result of which was the identification of one conception of Spotted Owl habitat (i.e., ‘old growth forest’ with large and/or old trees, abundant coarse woody down material, and multiple canopy layers) as a central element in the 1994 NWFP.

In June 2023, the Forest Service requested input from agencies and members of the public regarding definitions for ‘mature’ and ‘old growth’ forest with respect to National Forests (and to some extent, BLM lands) in response to Executive Order 14072. Consequently, in December 2023 the Forest Service issued a proposal to amend all National Forest land management plans in the United States with respect to what “old growth” and “mature” means with respect to land management. Clearly, such an amendment cannot be developed or implemented separately from the amendment process for the NWFP and the individual forest LMPs.

The Science Synthesis and the BioA recognize that the ‘frequent-fire dependent’ forests in the interior Klamath ecoregion lacked many of the ‘moist forest’ conditions the original NWFP stipulated. This recognition stems from a general recognition in the Final Recovery Plan for the Northern Spotted Owl (USFWS 2011), in which the FWS formally recognized the ecological difference presented by the ‘dry’ forests and directed the Forest Service (and the BLM) to develop a management approach that addresses the sustainability of owl habitat in the ‘dry’ forests. It’s clear that most ‘dry’ forests lack the capability to provide habitat that consistently conforms to the ‘old-growth’ concept as defined in the 1994 NWFP, are even less likely to be able to do so in a climate-altered future, and that an alternative set of stand structural objectives are needed for the NWFP and LMP updates.

Ecological studies in the Pacific Northwest have documented that a range of ‘old’ forest types exists, differing in different parts of the region (Reilly & Spies 2015). ‘Old-forest’ conditions regularly develop through different successional sequences, involving different plant species associations in different locations, with different substrates and different climatic conditions. Each combination may generate stand conditions providing elements of the habitat conditions for wildlife species that respond to ‘old-forest’ elements. However, different forest stands with large and/or old trees often don’t conform to the ‘old-growth’ concept defined in the NWFP, even though each forest type includes ‘old-tree’ habitat attributes. Among these alternatives are ‘dry’ conditions in which large and/or old trees occur in stands that lack closed canopies, lack multiple canopy layers, and lack relictual coarse woody debris levels required to satisfy the NWFP definition.

The pre-EuroAmerican 'dry' forests in the Klamath ecoregion likely were structurally composed of scattered large/old trees and groups of trees (likely varying regionally in size, species composition, and age), alternating with intervening areas supporting grasses, shrubs of varying ages, and/or hardwoods. Extensive ecological research within the Klamath ecoregion during the past quarter-century has documented a regional vegetation dynamic in which non-coniferous vegetation occupies significant parts of the regional landscape, where shrublands and hardwoods occupy as much as, or more of, the landscape than do conifers (Sawyer & Thornburgh 1977, Sawyer et al. 1977, Atzet et al. 1996, Hunter & Barbour 2001, Taylor & Skinner 2003, Shatford et al. 2007, Donato et al. 2009, Skinner et al. 2009, Odion et al. 2010, Halofsky et al. 2011, Tepley et al. 2017, Schriver et al. 2018, Skinner et al. 2018, Shive et al. 2018, Stephens et al. 2018b, Coop et al. 2020, McCord et al. 2020, Jules et al. 2022). Maintaining a "moist forest" stand structure of large and/or old trees in 'dry' Klamath ecoregion landscapes, especially in stands of conifers with multiple canopy layers and large volumes of down large logs, may be among the more problematical elements to be addressed in an NWFP amendment, as it's unlikely that such stand conditions are compatible with the consequences of climate change and increased fire in the ecoregion.

<u>Non-Conifer Vegetation Types</u>. Projections of potential climate-change consequences for hardwood-dominated plant associations in the western US are uncommon. Some recent studies have identified low-elevation landscapes that are expected to be under severe 'climate stress' as the century unwinds, including oak woodlands around the Central Valley (Thorne et al. 2016, 2017). Projections of climate-change effects on region-scale vegetation in northwestern California, however, suggest future transformations in which some mixed-conifer forests may become conifer-hardwood or hardwood-dominated community types, a transformation resulting from climate change and increased fire (Bachelet et al. 2007, Lenihan et al. 2008, McIntyre et al. 2015, Shafer et al. 2015); such projections have also been made for increased hardwood dominance in current mixed-conifer stands in the Sierra Nevada (e.g., Liang et al. 2017). It should be noted, however, that such vegetation projections mostly have not addressed shortened fire regimes, which could further alter ecological dynamic processes toward shrub- or grass-dominated plant communities.

Some oak species dominant in low-elevation woodlands and savannas (e.g., blue oak and valley oak) are relatively resistant to being killed by low-intensity surface fires (Plumb 1980; Horney et al. 2002; Fry 2008). Black oak, whether part of mixed-conifer forests or in woodlands and savannas, exhibits a similar adaptation pattern and responds vigorously to available light and moisture following fire (Cocking et al. 2012, Nemens et al. 2018, Skinner et al. 2018). Other oak species, particularly thin-barked live oaks, are readily top-killed by surface fires. However, almost all oaks and many other hardwood species readily sprout if top-killed, and individuals that avoid top-kill may regenerate leaves soon after a fire. Most hardwood species in the Klamath ecoregion exhibit adaptations to frequent-fire regimes, but if fire-return intervals are not sufficiently long to allow at least some individuals to reach reproductive age and produce fruits between events, changes in stand composition are likely.

Historical fire return intervals in shrublands near mixed-conifer forests in the southern Cascades and northern Sierra Nevada have been noted to have been longer than those in adjacent conifer forests (e.g., Nagel & Taylor 2005, Airey-Lauvaux et al. 2016, 2022). In the southern Cascades, shortened fire-return intervals in mixed-conifer forests have been observed to be associated with forest replacement by shrublands (Coppoletta et al. 2016). A similar dynamic exists in mixed-conifer landscapes in the Klamath ecoregion, in which hardwood trees and/or shrubs are dominant species in a variety of community types (Sawyer et al. 1977, Atzet et al. 1996, Hunter & Barbour 2001, Taylor & Skinner 2003, Sawyer 2006, Shatford et al. 2007, Donato et al. 2009, Odion et al. 2010, Halofsky et al. 2011, Tepley et al. 2017, Schriver et al. 2018, Skinner et al. 2018, Stephens et al. 2018b, Coop et al. 2020, McCord et al. 2020, Jules et al. 2022; see Attachment 1 for additional considerations of the evolutionary and ecological significance of these "alternative states" in the Klamath ecoregion).

In southwestern Oregon, shrublands (dominated by the many of the same shrub species as in 'mixed chaparral' in NW California) apparently can be a self-replacing community type that may not experience fire for a century or more (Duren & Muir 2010, Airey-Lauvaux et al. 2016). Scientists who study shrubland ecosystems (e.g., Keeley 2002, Halsey and Keeley 2016) have cautioned that shrublands in northern California may exhibit dynamic relationships that are different from the better-studied chaparral dynamics in southern California. Authors of studies carried out in forested landscapes in northwestern California and southwestern Oregon (e.g., Odion et al. 2010, Tepley et al. 2017) have identified hardwood-dominated Klamath ecoregion landscapes as fire-influenced or fire-maintained 'alternative stable states' that do not change for long periods.

Dominant plant species in shrublands typically exhibit traits (e.g., sprouting from lignotubers or roots, or germinating from long-lived seeds in soil seedbanks) that are adaptations for recovering from fire (Keeley & Zedler 1978); many chaparral species also show traits that indicate adaptations to burn at very hot temperatures when a fire occurs, indicating that recurring fire has likely been an evolutionarily significant element in the fire regimes sustaining these shrublands. However, in much of California a fire return interval shorter than the period required to allow the dominant shrub species to reach reproductive age can result in type conversions to grass-dominated communities, which subsequently tend to be maintained by frequently recurring fires. Moreover, fires (or fuel-reduction treatments in lieu of fires) in shrublands may lead to colonization (and to dominance) by exotic plant species that may predispose the communities to future fire (Potts & Stephens 2009, Halsey & Keeley 2016, Guiterman et al. 2022).

As a general summary, species in the hardwood tree- and shrub-dominated vegetation types in the Klamath ecoregion demonstrate adaptations for surviving and reproducing in habitats that are regularly burned. The prevalence of shrubs in the understories of many mid-elevation conifer stands represents a 'pre-colonization' of these stands by shrubs, and indicates a high potential for stand conversions from forest to shrubland if fire-return intervals in conifer stands are shortened by climate change, representing a potential 'tipping point' into regional shrubland and hardwood dominance driven by increased aridity and fire (Tepley et al. 2017). However, fires that recur at intervals shorter than the generation time of the dominant hardwoods and shrubs are likely to be associated with further conversions of these vegetation types, such as from hardwood woodlands to shrublands and shrublands to grasslands. In addition, increased fire frequency may be associated with increased colonization of these vegetation types by exotic plant species.

The amended NWFP and the LMPs for the National Forests in the region must address these factors, as they represent a substantial change in environmental conditions and landscape dynamics with respect to the focuses in the 1994 NWFP and the individual forest LMPs.

An Evolutionarily Stable Stand Structure for 'Dry' 'Frequent-Fire' Forests. Current ecological interpretations of evolutionary dynamics in frequent-fire forests emphasize that periodic fires in these landscapes removed most accumulated fuels, and an absence of abundant fuels meant that most fires shaping the evolution of those landscapes were low- or mixed-severity fires. Middle-elevation 'dry' forests in these landscapes developed a general structure in which stands developed large individual conifers, different-sized clumps of confers, and intervening 'open' areas lacking conifers (i.e., an 'ICO' structure; Larson & Churchill 2012, Kane et al. 2019; Figure 4). That is, most frequent-fire forests in California (including those in the Sierra Nevada and other mountainous areas south as far as northern Baja California) are now believed to have exhibited a widespread ICO structure under Pre-EuroAmerican fire regimes, where periodic low- and mixed-severity fires removed much of the fuels that accumulated between fires, creating stands with a few relatively large trees that would resist being killed by those fires. Periodic fires created landscapes in which periodic fires maintained the dominant forest structure, resulting in a self-reinforcing dynamic.

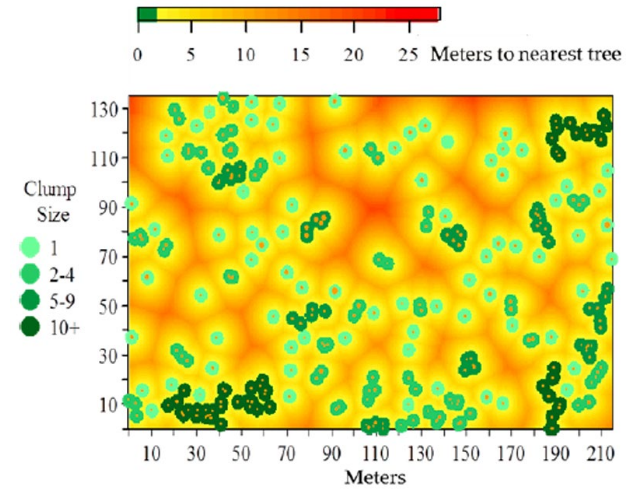

Figure 4. A 'stem map' of a reconstructed forest stand circa 1900 in the Fremont-Winema NF that displays a spatial pattern of individual trees, clumps, and openings (the natural ICO stand structure). Orange dots are tree boles scaled to dbh. All trees are ponderosa pine. Green circles are a fixed 3m (10') crown radius around each tree, showing interlocking crowns and clump formation. Clump size is the number of trees in the clump; larger clumps are shown in darker green. Color ramp and background coloration in the plot indicate distances to nearest tree or gap edge. Original map by D. Churchill; adapted from Franklin et al. (2013).

The BioA and the NWFP Science Synthesis emphasize a future with fires in western US forested landscapes that are more frequent, larger in area, and more severe. The BioA and the Synthesis also consider strategies to increase the ability of the forested landscapes to 'resist' the effects of climate change, or to become 'resilient' to those effects, by adapting to altered stand composition or structure. Strategies to restore resilience to 'dry' forests involve recreating the 'mixed-severity' fire regimes and natural stand structures (primarily variations of the ICO structure) that shaped the evolution of these forests, by reintroducing periodic fire (as managed wildfire or as prescribed fires) (Perry et al. 2011; Franklin et al. 2013; Hessburg et al. 2016, 2019, 2021; Kane et al 2019; North et al. 2019; Taylor et al. 2021; Larson et al. 2022). These science-based strategies clearly need to be elements in an essential set of "core" practices in the amended NWFP and individual forest LMPs. However, in the Klamath ecoregion, the 'open' areas are likely to be vegetated with broadleaved shrubs and/or hardwood, which evolved with and are well-adapted to the 'very-frequent-fire' regimes in the region.

__Stand-level Considerations for Climate Change and Fire Adaptation__. Much of traditional Forest Service land management is focused on developing and maintaining conditions within "stands", which are generally identified as land areas where conditions (including vegetation type, slope, aspect, etc.) are generally similar enough that the entire area can be managed with one silvicultural prescription. These traditions are part of the foundation for much of what the Forest Service considers to be its "mission". However, over-reliance on traditional management approaches in an age of climate change and increased fire raises a strong likelihood that management will fail to recognize a necessity for changes. The Forest Service must be aware of the risk in stand-based management in amending the NWFP and the forest LMPs, particularly given the emphasis in the 2012 Planning Rule on adopting landscape-based approaches for planning and management.

Stand management approaches nonetheless can help provide resilience to stressors like fire and climate change will vary across publicly owned landscapes. This variability is related to variations in air and land temperatures, soil composition and depth, 'Critical Zone' ecohydrology (e.g., Dralle et al. 2023), annual precipitation amount and timing, and other physical and biological parameters. While the same factors will clearly affect future forests, they're likely to be altered, potentially substantially, from the ranges of conditions under which existing stands developed in recent decades (Millar 2014). Past management policies, particularly fuels management and treatment methodology and the amount and type of biological legacy retention across stand development sequences (e.g., Franklin & Johnson 2012, Franklin et al. 2018), will also affect the resilience of stands to fire in a climate-altered future.

Forest scientists in California have addressed these dynamics in recent decades. For example, conditions known to affect forest stand development have been incorporated into a proposed approach for managing mixed-conifer forests in the Sierra Nevada (the 'GTR-220' strategy; North et al. 2009); in my opinion, this approach is also relevant for stand dynamics in the Klamath Mountains, and the Forest Service should consider how it might be implemented as part of the NWFP amendment. For example, upper slopes, particularly those with southern or western aspects, have historically experienced higher fire severities than lower slopes and those with northern or eastern aspects (Taylor & Skinner 1998), one of the parameters identified in the GTR-220 strategy. Approaches to forest planning like the GTR-220 strategy harness natural ecosystem processes for management purposes, an approach likely to enhance ecosystem resilience under increased stress from changing climate (West et al. 2009, North et al. 2019).

'Reforestation', which is required after major stand disturbances by the National Forest Management Act (P.L. 94-588) and the 2012 Planning Rule, can be demonstrated as successfully with hardwoods as with conifers (White & Long 2019). Climate change can drive forest ecosystems in the Klamath ecoregion toward uncertain future compositions, and many projections (e.g., Lenihan et al. 2008) suggest that hardwood-dominated forests will be prominent in future landscapes in northwestern California. 'Standard' reforestation practices for conifer forests on National Forests in the region in recent decades have involved planting conifers at closely spaced intervals across varying landscapes, typically at densities significantly higher than are expected to be sustainable through the stand-development and self-thinning processes (often referred to as 'pines in lines,' although planted seedlings are not always pines).

Management strategies for the Klamath ecoregion might be better-adapted to future conditions by incorporating other approaches. *Variable-density planting*, for example, incorporates an understanding of ecosystem dynamics such as those recommended by forest scientists in the past decade (North et al. 2009, Stephens et al. 2010, North et al. 2019). Rather than adopting a 'standard' reforestation program for all or most stands in an entire landscape or region, future management likely should include flexibility that enables the application of stand reforestation strategies adaptively tailored to specific locations. Diversity in stand conditions is likely to be a desirable hedge against the unknown stressors that will emerge as climate change unwinds.

Variability in stand structure can also be introduced by thinning treatments, where thinning is intended to reduce the biomass and/or stem density in a stand to provide a hedge against increased future stand-level stressors. Thinning can and probably should occur in combination with prescribed fire. However, prescribed fire without prior thinning may still be used to remove smaller stems as a form of density reduction. Thinning treatments reduce the increased moisture deficit resulting from CWD, reducing mortality from competition among the trees in the stand and augmenting the likelihood of survival and increasing the growth rates of the remaining trees. Silvicultural practices have long existed that relate stand density to stand health and resilience (see North et al. 2022 for a recent discussion indicating that these silvicultural guidelines also are important for climate-change adaptation).

Prescribed fire is characteristically judged to be a necessary treatment component to address the increased coverage of shrubs that were favored by thinning; the effect of opening canopies in conifer stands that result in increased shrub growth is a concern described in numerous studies (e.g., McGinnis et al. 2010, Collins & Roller 2013, Mallek et al. 2013; Coppoletta et al. 2016, Stephens et al. 2018, Richter et al. 2019). Logging, fire, or high mortality because of insects or forest diseases can result in major increases in surface-level fuels, from an accumulation of fallen dead stems a decade or more following death of the trees from fire, insect attack, or disease, a combination that leads to an increased potential for high-severity follow-on fires (e.g., Thompson et al. 2007, Hicke et al. 2012, Stephens et al. 2018).

An important element in forest management prescriptions for 'dry' forest stand management is *legacy retention*, focused primarily on retaining large and/or old trees (Franklin & Johnson 2012; Franklin et al. 2007, 2013). Forest management that focuses on keeping large trees as legacy elements has an essential effect of adding 'old forest' structure to these landscapes, as was intended in the 1994 NWFP. Legacy retention can also be a significant management element in adapting larger forested landscape regions to climate-change effects by maintaining 'old forest legacy' elements in stands across patchy ecosystems. Removing most of the larger and/or older trees is clearly not consistent with restoring 'old forest' structure to 'dry' 'frequent-fire dependent' forests.[6] Legacy retention concepts should be incorporated into the management of 'dry' forests (e.g., Franklin et al. 2013) where creating an ICO structure and retaining large and old trees become primary objectives.

An element identified repeatedly in the BioA with respect to stand-scale restoration should, however, be considered as clearly inapplicable for Klamath ecoregion forests in the 21st Century. The BioA identifies reestablishing stand conditions within the 'natural range of variation' (NRV; sometimes known as the 'Historical Range of Variation' or HRV) as basic guidance for future landscape composition, structure, and processes (a continuation of recommendations from the early days of the NWFP; e.g., Beschta et al. 2004). However, as an adaptive focus for forests responding to climate conditions likely to occur outside known historical ranges, restoring historical conditions is not a scenario that will assure stand composition, structure, and processes that can address the altered future. Because it does not include the potential for establishing communities outside the historical range, managing stand conditions to fall within the 'natural range of variation' has been rejected by many forest scientists as being an unsuitable response for climate adaptation (e.g., Millar et al. 2007, West et al. 2009, Stephens et al. 2010, Millar 2014, Millar & Stephenson 2015). Attempting to maintain or return stand conditions to the 'natural range of variation' in northwestern California forests is not a credible planning objective for climate change adaptation in the NWFP amendment, or for the individual forest LMP amendments, regardless of its identification as a planning focus in the 2012 Planning Rule.

IV. Fire and Fuels Management in a Climate-Altered Future

A relative historical lack of accumulated fuels in 'dry' mixed-conifer forests in the Klamath ecoregion is now considered by most forest ecologists to have supported low-severity or mixed-severity fires (i.e., fire with few to moderate impacts on the biological forest structure), in which most large and/or old trees were not killed in most fires, although many (or most) shrubs and small trees in the forest understory were eliminated (Taylor & Skinner 1998, 2003; Skinner et al. 2009, 2018; Halofsky et al. 2011; Perry et al. 2011; Hessburg et al. 2016; Spies et al. 2018; Taylor et al. 2021; Larson et al. 2022; Steel et al. 2022). That is, recurring fires removed much of the surface-

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[6] Research in the 'dry' forests east of the Cascades in Oregon and Washington, which are not within the range of the Northern Spotted Owl and are not covered by the NWFP, has indicated that many of the larger trees in these forests are not necessarily old, and older trees are not necessarily large (Franklin et al. 2013; Hessburg et al. 2020). Modifications to the 'Eastside Screens' in these forests (Hessburg et al. 2020) have emphasized the retention of older trees because they impart 'old growth' character to the stands regardless of their size, and it's likely that similar reasoning should apply for 'dry' 'frequent-fire' forests in the Klamath ecoregion.

level and ladder fuels that would have increased the heat energy released in crown fires, with the resulting high mortality levels.

The identified dominant ignition source for most wildfires during the pre-EuroAmerican history of California was lightning (Swetnam et al. 2016), although studies (e.g., Skinner et al. 2009) have indicated that Indigenous land management practices were associated with increased fire frequencies in some forested areas. While human-caused ignitions now dominate wildfire in much of California, lightning remains the dominant ignition source for wildland fires in northwestern California (Keeley & Syphard 2019), although recent studies indicate an increased dominance of ignitions by people in 'wildland urban interface' (WUI) areas (Safford & van de Water 2014, Keeley & Syphard 2019). Wildland fire incursion on developed areas is an identified concern for the Forest Service, and thus for the NWFP amendment, but current evidence from the Klamath ecoregion indicates that fuel and fire dynamics in the less-altered wildlands of northwestern California retain dynamics similar to those of Pre-EuroAmerican settlement conditions and differ from those in more densely developed WUIs elsewhere in the western US.

Whether agency fire-management should focus primarily on near-WUI areas in the Klamath ecoregion, or on general forest dynamics throughout the region, is likely to be a point of contention for the NWFP amendment. Given the relative importance of natural ignition sources in publicly owned landscape in the ecoregion, combined with the significance of natural landscapes for providing a great variety of ecological services that society gains from those landscapes (see Box 1), the NWFP amendment should avoid overcommitting agency resources to fuels management primarily in WUI areas. The NWFP amendment (and the individual forest LMP amendments) should focus on assuring a restoration of fuels dynamics consistent with low- to mixed-severity fires within forest landscapes as a whole, such that a restoration of low- and mixed-severity fire regimes can become a sustainable management outcome for the region.

Fuels Management is a Priority Concern in 'Dry' 'Frequent-Fire' Forested Landscapes. The BioA identifies fuels management as an issue of primary concern for northwestern California National Forests, because of its functional relationship with the historically recent under-representation of fire in these landscapes. 'Fuels' in this context is a term that includes all combustible biomass, including live and dead standing trees, down logs and branches, litter and duff: essentially any vegetation from the ground to the canopy that can burn in a fire. The BioA and the Science Synthesis, if anything, understate the importance of fuels management as a planning issue for these dry forests, which evolved with short fire-return intervals.

Accumulated fuels in 'dry' mixed-conifer forest stands in the Klamath ecoregion may be exemplified by abundant small trees of shade-tolerant conifer species (e.g., Douglas-fir and white fir), continuous fuels from ground level to the canopies of the larger trees, and/or abundant down material such as fallen dead stems, conditions that have resulted from a century of fire suppression in these landscapes. Accumulated fuels can result from past disturbances such as high-severity wildfires, insect or disease outbreaks, intense droughts, or adverse weather events in which the dead trees subsequently become fuels for future fires (e.g., Metz et al. 2011, Stephens et al. 2018, Wayman & Safford 2021).[7] Some forest management activities (including logging, which often results in accumulated slash and cull material) increase potential fire impacts in the residual forests.

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[7] The 2018 Ranch Fire on the Mendocino National Forest provides an example of this effect. The 1996 Fork Fire on the Upper Lake Ranger District burned within the footprint of the 2018 Ranch Fire. Some burned forest stands that were identified as important habitat under the NWFP following the Fork Fire were left without fuels-reduction treatments; the accumulated fuels created conditions during the Ranch Fire that incinerated several small ('100-acre') Late Successional Reserves (LSRs), obliterating both the desired habitat conditions and the LSR designations.

Current interpretations of dynamic ecological processes in frequent-fire landscapes in California emphasize that periodic fires in these landscapes in pre-EuroAmerican times removed most accumulated fuels, and most fires shaping the evolution of these landscapes were low- or mixed-severity fires. Under such dynamics, mid-elevation 'dry' forested landscapes are generally considered likely to have developed an 'ICO' stand structure (Figure 4; Larson & Churchill 2012, Kane et al. 2019). Stated a different way, most frequent-fire forests in California (including those in the Sierra Nevada and other mountainous areas south as far as northern Baja California) likely exhibited an ICO structure under natural fire regimes, where periodic low- and mixed-severity fires removed most of the fuels that accumulated between fires, creating stands with a few relatively large trees that would resist being killed by those fires. Thus, fuels management is clearly an essential consideration in planning for resilient stands in climate-altered future landscapes.

A primary element in most climate models is an expected climate change-driven future increase in fire occurrence (e.g., Figure 5), driven by the increased aridity resulting from a warmer atmosphere. Accumulated surface fuels are a concern when an essential element in successful adaptation to future fire regimes includes an intentional use of prescribed and/or 'managed' wildfire to reduce future fuel loads, because *existing* fuel loads must be reduced *before* prescribed fire can be used (e.g., Mallek et al. 2013, Richter et al. 2019, White & Long 2019). Climate-adaptation strategies for the Klamath ecoregion must address fuels by including actions to reduce both current and future fuels loading; i.e., fuels management is an essential and ongoing priority for forested landscapes in the Klamath ecoregion.

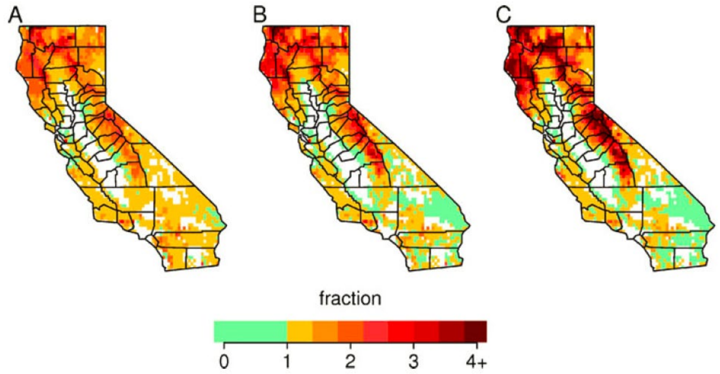

Figure 5. Burned area predicted by three climate models in the last third of the 21st Century as a multiple of burned area in the last third of the 20th Century; all model outcomes were based on Scenario A2 (extending current socioeconomic practices). A value of '1' indicates that burned area is unchanged, while '4+' indicates that burned area increases 300+% over late 20th Century reference conditions. Adapted from Westerling et al. (2011).

The amended NWFP likely should include options for reducing standing conifer snags whenever doing so is consistent with maintaining appropriate habitat conditions for desired wildlife. Extensive and widespread "complex early successional (snag) forests" in the footprints of recent wildfires are unlikely to be consistent with climate-resilient fuels management in Klamath ecoregion, although early-successional patches must be included as elements in the region's managed landscapes. In addition, reducing shrub presence in future stands may be necessary if those stands are to be protected from high-intensity surface fires that would consume regenerating stands before trees in the stand have grown large enough to resist being killed (e.g., Tepley et al. 2017, Meyer et al. 2021, Long et al 2023).

Managing accumulated fuels has become a sometimes-contentious issue, (e.g., with respect to 'salvage logging'), but in terms of creating and maintaining future forest resiliency the need to reduce fuels loading in order to be able to reintroduce fire to these landscapes is a *conservation* issue of significant concern. The NWFP amendment should clearly characterize this set of concerns; scientifically, the amendment should clearly indicate the need for fuels management as a critical climate-change and increased-fire adaptation throughout the 'dry forest' landscapes in the ecoregion.

Fuels-related issues also arise for the NWFP amendment with respect to riparian-zone management (addressed further in Attachment 2). In brief, while riparian areas tend to be more resistant to higher-severity fire when they're wet, they tend to accumulate greater fuels loading than may occur in adjacent upland areas. In 'dry forests' in Mediterranean-type climates, late-summer conditions can result in then-dry riparian areas being subject to high-intensity fire, burning hotter than adjacent uplands and increasing the potential for fire spread into unburned areas elsewhere in the managed landscapes (van de Water & North 2010, 2011; Dwire 2010, 2016). The NWFP and LMP amendments need to consider whether additional guidance should be provided for riparian-area management in the 'frequent-fire' landscapes in the Klamath ecoregion.

'Tools' that are available to managers to address fuels in these landscapes include multiple kinds of thinning projects, timber sales, salvage logging after disturbances, mastication, and/or selective fuels-reduction projects conducted to create or maintain desired habitats (e.g., oak woodlands). It's necessary that the NWFP and LMP amendments address habitat conditions needed by sensitive wildlife species or to meet other management goals (e.g., recreation, visual effects, and Native American priorities), and the amendments must include appropriate standards and guidelines to protect these resources. However, the NWFP must retain the availability of measures/practices that can be used for fuels reduction in order to manage these landscapes to address climate change and the future effects of enhanced drought and increased numbers, sizes, and intensities of fires.

It should be noted that some conifer species in the Klamath ecoregion may gain increased range and local abundance with increased fires. These include knobcone pine (*P. attenuata*), one or more uncommon cypress (*Hesperocyparis*) species, and higher-elevation lodgepole pine (*P. contorta*), which are serotinous species that release seeds from their cones following fire. These traits are adaptations for surviving in frequent-fire environments, essentially representing in conifers the kinds of adaptive responses shown by many California hardwood and shrub species, which likely would favor an increased prevalence of these conifers in future landscapes with more fire. This is particularly true for knobcone pine, as the Klamath ecoregion is central in the natural range of knobcone pine (Reilly et al. 2019), suggesting that this species may become a more important species in plant associations in the ecoregion under future fire regimes. Forest Service managers may not favor a potential increase in dominance by these 'non-commercial' conifers, but these native species are well-prepared evolutionarily and ecologically to increase in importance in future environments, and they represent plant species that can help maintain ecological services desired from these landscapes.

In summary, the BioA and the Science Synthesis summarize a future with fires in western US forested landscapes that are more frequent, larger in area, and more severe. The BioA and the Synthesis consider strategies to increase the resilience of forested landscapes to those effects by adapting stand composition or structure. A science-based strategy to restore and maintain resilience will involve recreating the 'mixed-severity' fire regimes and stand structures that shaped the evolution of these forests, essentially by reintroducing periodic fire, as managed wildfire or as prescribed fires (Perry et al. 2011, Hessburg et al. 2016, North et al. 2019). Numerous research studies in 'dry' western forests have concluded that restoring fire to these landscapes is a necessary element for their ongoing management, in conjunction with prior reductions in currently accumulated fuels.

V. Management at Landscape Scales

The 2012 Planning Rule [36 CFR § 219.5(a)(1)] explicitly directs Forest Service managers to adopt a "broader landscape" focus in forest planning documents:

> "*Assessment.* Assessments rapidly evaluate existing information about relevant ecological, economic, and social conditions, trends, and sustainability and their relationship to the land

> management plan within the context of the broader landscape. The responsible official shall consider and evaluate existing and possible future conditions and trends of the plan area, and assess the sustainability of social, economic, and ecological systems within the plan area, in the context of the broader landscape (§ 219.6)."

Forest Service scientists have provided numerous guidance documents since the adoption of the 2012 Planning Rule describing approaches that land managers should consider in developing landscape-based approaches to climate change (e.g., Peterson et al. 2011; Hessburg 2015, 2016, 2019, 2020; Swanston et al. 2016; many others). In my experience, Forest Service managers have yet to incorporate the already vast and still-growing scientific framework embracing landscape-scale management into day-by-day decision-making. Some of the relevant science is summarized in this section. All of this science should be addressed in the NWFP and individual forest LMP amendments.

Complex Adaptive Ecosystems in the Klamath Ecoregion. The NWFP resulted from recognizing that landscape processes, which are known scientifically to intrinsically involve land areas larger than forest stands, are essential in the conservation of forested ecosystems (e.g., Pickett & Thompson 1978; Franklin & Forman 1987; Forman 1995; Franklin et al. 2002, 2013, 2018; Franklin & Lindenmayer 2009; Puettmann et al. 2009; Franklin & Johnson 2012; Turner & Gardner 2015; Hessburg et al. 2015, 2016, 2019, 2021; Reilly et al. 2018; Spies et al. 2018a; Taylor et al. 2021; Gaines et al. 2022). Identifying composition, structure, and ecological processes in forest stands distributed throughout northwestern landscapes was a major focus in the NWFP, because local stand conditions were key considerations in the habitat needs of the Northern Spotted Owl. However, an underlying motivation for the sociocultural dynamic that led to the NWFP was the widely recognized impact Forest Service management was having on 'old-growth' forests in Pacific Northwest, and effects on old forests remain a public concern today.

What defines a 'landscape' is scale-dependent. A landscape can be defined practically as the smallest area within which all the elements needed for an entire disturbance/recovery cycle exist (Pickett & Thompson 1978, Pickett & Cadenasso 1995, Forman 1995, Franklin & Forman 1997, Drever et al. 2006, Turner & Gardner 2015). Disturbance events (e.g., large fires) can help to define regions in which the recovery from a disturbance is 'internal' within the region, which may span from 10,000 acres to 50,000 acres or more.

Fundamentally, *managing only at the scale of local stands cannot address landscape-scale processes*. To address and satisfy the requirement in the 2012 Planning Rule, the FS must manage within a landscape-scale framework *in addition to* planning for stand-scale dynamics. Landscape resilience depends on developing and implementing management that links together individual stand-level approaches into landscape-level outcomes (Box 3). Planning for the effects of altered climate involves considering the dynamics of entire landscapes as well as the processes taking place at the level of stands in the component ecosystems (Franklin & Forman 1987, Forman

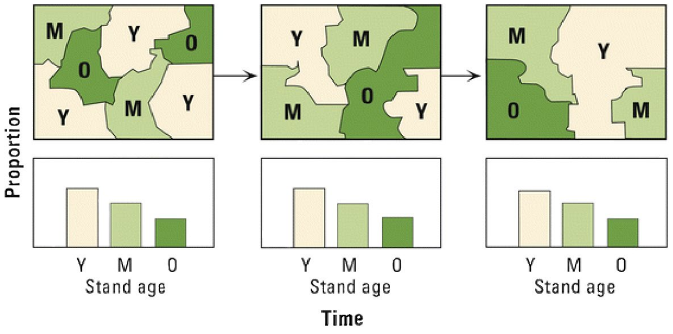

Figure 6. Conceptual dynamic relationships under a 'Shifting-Mosaic Steady State' landscape model. Real landscapes generally exhibit some version of the shifting mosaic (upper panel), but not the "steady state" of the lower panel (see Box 3 for additional information). Excerpted from Turner & Gardner (2015).

1995, Franklin et al. 2002, Franklin & Johnson 2012, Turner & Gardner 2015, Franklin et al. 2018; Figure 6).

Box 3. Perspectives on Landscapes as Dynamic Ecological Systems

Landscape ecology (e.g., Forman 1995) evolved out of discussions in the late 20th Century about the nature and behavior of ecological systems. Prominent ecologists engaged over several decades in studying relationships surrounding concepts like 'succession' and 'climax' as they were understood in the context of ecosystem dynamics. Several long-term research projects were established to investigate forested ecosystem dynamics, including the HJ Andrews Experimental Forest within national forest lands in the western Cascades of central Oregon (where Jerry Franklin was a principal investigator for many years), and the Hubbard Brook Ecosystem Study within national forest lands in the White Mountains of New Hampshire.

Among the prominent ecologists who worked within the Hubbard Brook study were Herbert Borman and Gene Likens. These authors published a highly influential treatment of forest ecosystem biogeochemistry in the mid-1970s, then followed up with *Pattern and Process in a Forested Ecosystem* at the end of the decade (Borman & Likens 1979). Their research led them to formulate a model of ecosystem dynamics on a landscape scale, known as '*the shifting-mosaic steady state*;' the overarching dynamic in the model is represented in general terms in Figure 6.

In this model, landscapes include a variety of local ecosystems, which may be thought of as being in various stages of successional development within the landscape, represented in the figure as 'young,' 'mature,' and 'old.' The shifting-mosaic model posits that the landscape reaches an 'average' or steady-state distribution of stages, but because ecological processes within the landscape (e.g., fire and other disturbances, growth of vegetation according to species traits, and succession from young to old forest) do not stop, the places where each stage occurs shift through time. The result is a landscape in a 'steady-state' condition (as in the lower panel in Figure 6), but with a 'shifting mosaic' of patches/ecosystems of various ages that 'move around the landscape' (the upper panel in Figure 6). In this landscape, disturbances convert 'mature' and 'old' ecosystems back to 'young' ecosystems, which then trend through successional processes back to 'old' ecosystems.

In the decades since *Pattern and Process* was published, it has become clear that landscapes seldom develop a 'steady state' distribution of successional stages. That is, the areas of 'young,' 'mature,' and 'old' stages are not in equilibrium, but occur in a varying combination of areas that add up to the area of the whole landscape. The '*shifting mosaic*' landscape concept is a generally accepted fundamental construct in landscape ecology: landscapes <u>*do*</u> exhibit a shifting mosaic of constituent ecosystems through time, in response to internal ecosystem processes like succession and to disturbances like climate change and fire. See Turner and Gardner (2015) for additional explication and Franklin et al. (2018) for an application of the construct to practical forest management.

Identifying plan options that will produce benefits at differing severities of climate change (Peterson et al. 2011, Swanston et al. 2016) is clearly hindered when expected future conditions are the same as existing conditions in the managed landscapes, a viewpoint termed a 'climate stationarity' perspective (Safford et al. 2012). A 'stationarity' framework, however, is fundamentally embedded in most current Forest Service management plans, where it's likely to be an issue that prevents managers from engaging with real climate-change issues.

For example, Hessburg et al. (2016) recommended a 'comprehensive landscape strategy' that clearly assumed a 'static' environment in which the landscape factors that will be important for future climate regimes are the same factors, in terms of intensities, locations, and rates of change, as those that determined the composition, structure, and processes acting in current landscapes. However, current landscapes developed in climate conditions in the past, and while future landscapes will undoubtedly be affected by the same ecological processes, the details of those processes in the future are unlikely to be the same as those of a century (or even a few decades) ago. Thus, a recent scientific assessment (Hessburg et al. 2019) of climate-change effects, wildfires, and forest resiliency across landscapes in the western US included the following:

> "(A) task for current era managers is to *manage for the changes, with uncertainty clearly in mind*. Promoting forest resilience or resistance to wildfires and other disturbances will require planning on an uncertain amount of unbridled and ongoing disturbance. It will necessitate being mindful and inclusive of species-level traits; characteristic patch-level tree clump and gap distributions, tree sizes, densities, and canopy layers; meso-scale seral stage and fuelbed heterogeneity; and broad-scale forest and non-forest patchworks. … This may require preemptively adapting landscapes in areas with anticipated future water deficit, before abrupt changes occur from disturbance- or drought-related mortality events. Examples of preparing landscapes for the coming wildfire and climatic regime changes include reducing forest area, expanding woodland or grassland area, reducing canopy cover and layering, and increasing the areal extent of large trees of fire-tolerant species. In these ways, managers can also better prepare human communities for future uncertainty by reducing the likelihood of abrupt broadscale changes." (emphasis in original)

Strategies to Incorporate Climate Change into Forest Management. Forest ecologists working in various regions in the United States have identified ecological characteristics and processes that can be incorporated into the NWFP and LMP amendments to guide both landscape and stand-level strategies that address climate-change effects and help guide a transition to forests of the future (Millar et al. 2007, Stephens et al. 2010, Dawson et al. 2011, Peterson et al. 2011, Millar & Stephenson 2015, Swanston et al. 2016, Restaino & Safford 2018, Hessburg et al. 2019, Richter et al. 2019. White & Long 2019, Gaines et al. 2022, Larson et al. 2022, Steel et al. 2022). The expected effects of altered climate on forested landscapes in the future will result from the same ecological processes that shaped current forests, but the extent and range of those processes are almost certain to extend outside the range of historical conditions (Millar 2014). Forested ecosystems will undergo adaptive transitions to accommodate future conditions, even without management intervention; more desirable future outcomes might be obtained through appropriate management.

Millar et al. (2007; refined in Millar & Stephenson 2015) proposed a three-part strategy for responding to climate-change effects:

- Resistance: *Stabilize existing stands through management practices that reduce the effects of shorter-term climate changes*. Examples could include increasing the level of fuels management to reduce potential future fire severity, or reducing stand density to allow existing vegetation to resist the effects of increased vapor pressure deficits/CWD.
- Resilience: *Incorporate management practices to prepare forest stands to respond adaptively to climate changes that can be anticipated in the longer-term future*. Examples could include reducing stand density from current stocking levels to levels that are expected to be compatible with future projected future CWD, or altering stand composition to favor different species (such as hardwoods in the Klamath ecoregion) better adapted to expected future conditions.
- Response (alternatively termed Realignment): *Plan for and implement management actions that address future conditions that may be outside the range of those in existing forests*. Examples could include planting new species that don't occur in the region now, planting existing species in more favorable locations (e.g., uphill or on north-aspect slopes), introducing genetic variation to existing species from other populations better adapted to a warmer and dryer future climate, or intentionally changing stand structure to protect desired ecological locations and functions (e.g., creating denser riparian stands in cooler, moister valley locations to increase stream shading and protect water quality and instream habitat conditions).

This strategy (and others that incorporate similar ranges of action) involves a phased sequence, depending on the degree of climate-driven alteration that has occurred (or will occur) in ecological factors in different parts of a landscape, representing a gradient in responding to changes that occur over time and space. Actions in each phase likely will overlap in (different parts of) most landscapes. The key elements are identifying probable future conditions, then incorporating management elements that address how those future conditions are likely to affect desired ecological functions in future stands, and thus the ecological services that those functions will support. Uncertainty is embedded throughout this process, but Forest Service managers already plan for uncertain future conditions; the difference represented in these climate-adaptation strategies is that climate change is certain to introduce conditions outside the 'historical' range addressed by current management plans.

The NWFP currently identifies management criteria for *composition*, *structure*, and *function* as elements in implementing the plan's conservation strategy.[8] The 2012 Planning Rule emphasizes a requirement that plans address the connections among forest composition, structure, and ecological processes and the ecological services provided by National Forest landscapes; up to the present time, however, the Forest Service has provided only limited guidance to its managers about how to address ecological services in its programs (e.g., Deal et al 2017).[9]

The 2012 Planning Rule mandates that Forest Service planning efforts (for projects as well as forest plans) address the effects of climate change on national forest *landscapes*. In effect, these requirements place Forest Service managers in northwestern California in the position of having to developing responses based on current land management plan policies that are known to be out of step with current science, while amended planning documents that will be based on the current science are still in development. A prudent strategy in such conditions is to base proposed project actions on the updated science, to the extent possible, instead of on currently adopted plans.

Managing National Forest Landscapes as Self-Organizing Complex Adaptive Systems. Both the NWFP and the 2012 Planning Rule address National Forest landscapes from a perspective enriched in ecosystem science (the landscape focus in the 2012 Planning Rule essentially *requires* a focus on ecosystem processes). Ecosystems are classically defined as a collection of interacting biotic organisms and the physicochemical environment in which they occur, although current conceptions of ecosystems are more detailed and nuanced. 'Ecosystem-based management' (or just 'ecosystem management')[10] incorporates many disciplinary subject areas and procedures, but its fundamental principle is that *multiple processes are involved in the managed landscapes and ecosystem-based management must attend to multiple objectives and interactions*, rather than focusing on managing for single resources (such as a listed wildlife species) or for narrow quantitative outputs (such as board feet of logs). The *intent* of the 2012 Planning Rule in adopting an ecosystem-based focus is emphasized in the definitions in 36 CFR § 219.19. Current forested-ecosystem science (i.e., what's taught in the best 'forestry schools') incorporates interpretive

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[8] These terms refer to ecological community traits related to the identities and relative abundances of (primarily plant) species (the *composition*), the ways the species are arrayed in physical space (the *structure*), and the ecological dynamics or *processes* (the *functions*) of forest stands. The original term '*function'* was intended in the NWFP to address ecological processes occurring in forested landscapes, in conjunction with focuses on community composition and structure. Since the publication of the Millennium Assessment (2005), however, the term 'function' has largely been superseded in forest planning discussions by 'ecological *process*,' as the focus on ecological functions has been captured by the broader meaning as the processes that support and deliver ecosystem services.

[9] See URL https://www.fs.fed.us/ecosystemservices/ for USDA Forest Service 'Ecosystem Services' guidance. Additional information is available at URL: https://www.fs.usda.gov/ccrc/topics/ecosystem-services.

[10] See URL: https://www.fs.usda.gov/about-agency/emc for the USDA Forest Service website for Ecosystem Management Coordination.

frameworks for forested ecosystems in which the inherent complexity of ecosystems in embedded (Box 4).

The following 'hypothetical' can help illustrate how interpreting landscapes in ecosystem terms would assist managers in incorporating climate-change and ecosystem-services considerations into managing Forest Service landscapes in northwestern California. As a general property of ecosystems (not documented here but well-supported in ecological science), the level of 'services' provided by a landscape is a function of the complexity of the ecosystems in the landscape (there are exceptions!), and more-complex ecosystems generally provide more services, or a higher quality of services, than less- complex ecosystems. That is, ecosystem complexity (assessed by

Box 4. Ecosystems: Complex, Adaptive, Self-Organizing Systems

The term 'ecosystem,' a concept referring to the union of biotic and physiochemical elements in a given location, was introduced to science in the 1930s. The concept grew throughout the rest of the 20th Century, with trophic dynamics, population growth and regulation, nutrient cycling, and other subfields being combined within an ever-enlarging framework. By the early 1970s the concept had incorporated elements of the post-WWII cybernetic revolution, and the concept of an ecological 'system' was born, in which information within the system influenced the state of the system and its behavior. An influential paper (Odum 1969) popularly fused ecological dynamics with ideas about system 'succession' and the internalization of control. A less widely-read but (eventually) more influential paper (Holling 1973) parsed questions of ecosystem behavior in terms relevant in the 21st Century, including 'resistance' to change, 'resilience' following disturbance, and the meaning of ecosystem 'stability.'

An outgrowth of the critical assessment of 'system' concepts was the development of 'hierarchy theory,' which identified 'nestedness' within biological systems. A highly influential monograph (O'Neill et al 1986) established the concept of differing response rates for different levels of organization, including ecosystems. For example, physiological reactions occur in seconds to hours, annual plants live and die in months, population demographics for larger plants and many animals are years to decades, and 'succession' is a landscape-level process that occurs on the scale of decades to centuries. This structured concept enabled ecologists to focus critically on the processes that affected ecological systems, realizing that levels of biological organization too distant from the ecosystem level of organization were not affecting the system's dynamics.

In the 1980s and 1990s, ecologists (e.g., Pickett & Cadenasso 1995, Forman 1995, many others) expanded the compass of the ecosystem concept, identifying landscapes as a distinct level of organization that included multiple ecosystems. By the early 2000s conceptual papers (e.g., Levin 2005) solidified an understanding (motivated in part by the 'Gaia Hypothesis' of James Lovelock and other 'deep ecologists' and in part by mathematical modelers who had identified criteria for 'domains of stability' in ecological systems) that ecosystems were 'self-organizing' systems. Ecosystems were 'adaptive,' and not 'determinative;' they became complex only if the dynamic interactions of their component populations were interactively stable and if the environment itself were stable enough to allow the system's component populations and the environment to stabilize. Significant, uncontrolled population fluctuations or significant environmental disturbances could prevent development of complex ecosystems. The systems were 'adaptive' in the sense that component species could evolve traits less disruptive, or well-adapted new species could colonize, leading to greater ecosystem 'stability'.

These concepts of ecosystems as complex, adaptive, and self-organizing 'systems' were also applied to forests (e.g., Drever et al. 2006), in the sense of asking whether viewing a forest in system terms provided insights into the dynamics of real forested landscapes. As the awareness of the effects of climate change (and other human-driven disturbances) has become central in resource management, forest ecologists have adopted the conceptualization of forest ecosystems as complex, adaptive systems to help adapt our management of forested landscapes to these changes (e.g., Puettmann et al. 2009, Messier et al. 2014).

monitoring, through time, such characteristics as tree species composition and structural layering in designated stands, or the ratio of exotic to native species in a meadow) can be a proxy for ecosystem services such as wildlife habitat, carbon sequestration, erosion protection, and recreation/aesthetic value. The trends in such monitoring data are indicators of ecosystem functions that are altered by climate change, providing managers with evidence that adaptive actions may be necessary (as well as their likely success).

Consider the example portrayed in Figure 7. In the trajectory in the upper panel, managers observe, but do not respond to, increasing tree mortality (determined to be related to long-term CWD, beetle attack, and/or root disease, say). The reduced stand conditions indicate decreased ecosystem complexity, which in turn is a valid indicator of decreased ecosystem functions and the related ecosystem services (which are the indicators on which the 2012 Planning Rule directs that managers focus). In the trajectory in the upper panel, a new (and different) ecosystem will be gradually assembled as the prior species are reduced and new species arrive by natural colonization (some of which are likely to be 'non-native' and or invasive, as these species are favored by changing climate). Provision of ecological services will recover, although perhaps to a reduced degree, and the range of services may differ from those provided by the prior landscape.

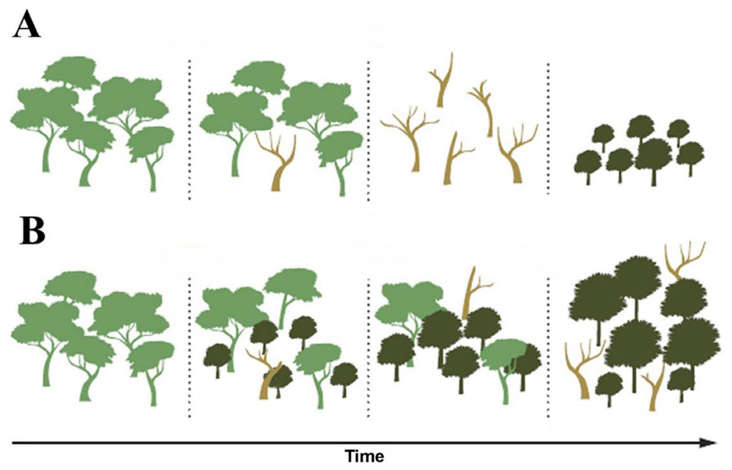

Figure 7.(A) A failure to anticipate climate-change may result in a significant reduction in ecological functions and a loss of ecosystem services. Ecosystem services may rebound following a system collapse, although altered structure, composition, and processes may not replace all services that were lost. (B) Anticipating (and potentially assisting) transformational changes in managed ecosystems can prevent system collapse and help to maintain ecosystem services, although the altered structure, composition, and processes may result in different levels (or kinds) of services provided. (Modified from Millar & Stephenson 2015.)

A contrasting strategy (in the lower panel) includes responding to the observed initiation of increased mortality (interpreted to indicate climate-related ecosystem stress) at an earlier stage, before the ecosystem is altered to the degree in the upper panel. In this example the response could include the intentional introduction over time of one or more species better adapted to anticipated future climate conditions (an example of the '*realignment*' phase of the adaptation sequence described above). As changing climate removes less-adapted species from existing ecosystems, the introduced (better climate-adapted) species will maintain some of the ecosystem complexity present in the original stands, and these ecosystems would continue to provide desired ecological functions and services. Although the degree of services provided could be less than from the original stands, the decline would be less than in the upper panel (although ecosystem complexity could actually be enhanced by the transition, and the overall output of services, or the mix of services provided, could increase).

The contrast between the panels in Figure 7 illustrates that climate-change adaptation requires a mind-set attuned to changing landscape conditions. In the Figure 7 example, the management response to the change in complexity needs to begin by the second step in the sequence, when actions to increase the '*resistance*' of the existing stands could help, or potentially when management approaches such as stand density reduction could increase the '*resilience*' of the ecosystem to further complexity loss. In the Figure 7 lower panel, managers will have opted to implement a '*realignment*' to a 'new' ecosystem better adapted to altered conditions, a response that would clearly require an expectation about what those landscapes should (or must) be like in the future to deliver the ecological functions resulting in the desired services. This mind-set is the key to climate-change adaptation. What will future landscapes need in order to provide ecosystem services (say, clean water, recreation opportunities, or particular wildlife habitat conditions), given that the future may not sustain the same plant alliances in the same places, and certainly not in the same mixtures, that occur now?

The dynamic in the lower panel in Figure 7 may apply to many forest areas the Klamath ecoregion, in which oaks and other hardwood species that are well-adapted to increased moisture stress and fire already occur. A potential adaptation strategy for responding to changing climate could emphasize recovery with fire-adapted hardwoods like black oak, canyon live oak, madrone, and Garry oak, species that are already important members in the region's mixed-conifer forests, improving the functional importance of these landscape elements (White & Long 2019). This strategy could include introductions of oak species currently more common at lower elevations (such as blue oak and valley oak). Appropriate stand-level recovery-project decisions likely would need to incorporate factors like aspect, soil characteristics, and site-specific moisture conditions.

If the amended NWFP and LMPs continue (as expected) to focus on the composition, structure, and processes in public landscapes, the practical effects of climate change on forest ecosystems must be considered. Maintaining the *structure* of forest stands may remain a viable planning focus; selecting species for stand enhancement that maintain stand structure could be preferable to selecting species that result in significantly altered structure. However, maintaining the current *composition* of forest stands in response to changing climate could prove to be counterproductive if existing species composition is not well-adapted to altered future conditions. A primary adaptive strategy should be to alter the composition strategically to address future (rather than previous) ecological conditions affecting the stands (i.e., the 'historical range of variability' may not be a suitable guide to the future). Given altered stand composition, the greatest effect of altered climate may be in elevating the importance of maintaining desired ecological *processes*, and a management focus on maintaining ecosystem processes should be the overriding goal.

Novel ('No-Analog') Communities are Likely to Develop in Northwestern California Because of Climate Change. Based on scientific studies of past climate-change effects on plant and animal distributions, recently observed changes in historical communities, and expectations from climate-science projections, the effect of climate change on local plant and wildlife communities will include both geographic range shifts within landscapes and a dissociation of existing communities (Overpeck et al. 1992, Whitlock 1992, Graham et al. 1996, Graham 1998, Jackson & Overpeck 2000, Davis & Shaw 2001, Whitlock et al. 2003, Skinner 2007, Williams & Jackson 2007, Briles et al. 2008, Millar 2014). Simulations of future landscape patterns in the inner northern Coast Ranges and Sierra Nevada, based on climate change, fire regime change, or both, have projected decreased conifer-dominated forest area in both regions and increased 'mixed woodlands' dominated or co-dominated by one or more oak species and other hardwoods (Lenihan et al. 2008; McIntyre et al. 2015; Shafer et al. 2001, 2015; Liang et al. 2017).

Historically, the post-disturbance recovery of forested landscapes has focused on 'restoring' the same or closely similar ecological communities that were present prior to disturbance. However, re-establishing predisturbance conditions following fire and other major disturbances raises substantive scientific concerns, particularly with respect to the continued provision of ecological services (Dawson et al. 2011, Hurteau et al. 2014). Ecosystem recovery under climate change requires anticipating the future and incorporating elements that address it (Hobbs et al. 2009, 2014; Jackson & Hobbs 2009). Ecological recovery with 'traditional' restoration as a primary focus is appropriate only if ecosystem dynamics remain within the range of historical variation. When ecosystem processes no longer remain within their historical ranges, then recovery projects must focus on creating 'hybrid' or 'novel' ecosystems adapted to the altered conditions (Hobbs et al. 2014, Millar & Stephenson 2015).

Novel (or 'no-analog') ecological communities may be combinations of 'old' species from different existing communities. However, a widely expected effect of climate change is a shift toward communities including 'new' species, sometimes termed 'hybrid' communities. Some 'new' species favored by climate change may be *invasive species*, which can alter ecosystem properties or functions [see Poland et al. (2021) for a recent review]. It seems clear that climate-change adaptation in National Forest landscapes in northwestern California must consider the potential effects of invasive species, although what constitutes an 'invasive' species is unclear, given that species assemblages that provide desired future ecological services may depend on the characteristics of some of the 'new' species. The compositions of future communities needed in the Klamath ecoregion to maintain desired ecosystem functions likely does not have just one answer; numerous alternative communities might be 'assembled,' and no guidebook exists to identify the 'best' composition or structure of future communities.

Plant species respond to altered environmental conditions individualistically, although species with similar niche requirements do respond similarly. While climate-change projections for most individual plant species show shifts toward cooler and/or moister environments (generally expressed as 'poleward and up'), range shifts may be toward more microclimatically favorable locations, such as toward the coast or even toward favorable moisture conditions at lower elevations (Parmesan & Yohe 2003, Loarie et al. 2008, Ackerly et al. 2010, Beier 2012, McLaughlin et al. 2017, Morelli et al. 2020). However, individualistic niche responses by different species mean that future vegetation alliances should be expected to differ from current species groups to varying but unknown degrees, and 'no-analog' communities in the future cannot be unexpected.

The significance of unusual ('extreme') climate-related weather conditions or events for a number of recent disturbances (wildfires, heat domes, and floods) has become clear throughout California (Jin et al. 2014; Keeley & Syphard 2019). Late summer and autumn atmospheric circulation patterns the western US typically involve conditions in which strong 'foehn' winds bring dry air from the northeast over much of California, which have been essential elements in many of the largest wildfires in recent years. However, similar wind events are common each year that are not associated with large wildfires, which depend on ignitions happening during an event. The ignition sources in more densely populated parts of California are nearly always human-caused or human-related (including powerlines; see Keeley & Syphard 2019 for an overview), while ignitions in northwestern California are significantly correlated with natural causes (i.e., lightning).

The degree to which climate change might alter the occurrence of 'foehn winds' is uncertain, as they're a consequence of atmospheric patterns that may be relatively unaffected by climate change, although the increased fuel dryness that results from a warmer atmosphere should result in greater fire intensities throughout the regional landscapes in any event. The NWFP and LMP amendments need to account for the importance of landscape-wide fuels management in restoring resilient ecological conditions in the region as a whole, rather than focusing narrowly on fire-protection in the few WUI areas in the region.

The Critical Zone and Ecohydrology in Ecoregion Management. The 2012 Planning rule requires that the Forest Service incorporate and follow the "best available science" in developing and approving the NWFP amendment (36 CFR § 219.3). However, Forest Service planners and managers may not incorporate the "best available science" in a variety of circumstances, perhaps because some of the "best science" is incompatible with the explicit text in the regulations (e.g., regarding the "historical range of variation"), because Forest Service personnel have not learned the science, or because the Forest Service is improperly wedded to traditional perspectives about managing federal lands that may not incorporate current scientific knowledge.

This concern is most pertinent with respect to relationships among climate, ecohydrology, and landscape processes involving aquatic habitats and species dependent on them in Forest Service-managed landscapes (see Attachment 2 for additional considerations). The Science Synthesis (i.e., Reeves et al. 2018) has identified changes in riparian and aquatic element management that should be considered in an amended NWFP. However, current scientific knowledge about how water in northwestern California landscapes interacts with both biotic and abiotic elements above and below the land's surface to determine aspects of landscape functioning is not included in the current NWFP, and additional ecohydrological relationships have been identified in recent years that need to be considered in the amended NWFP and the individual forest LMPs.

Varying ecohydrological relationships exist among the geosphere, biosphere, and atmosphere, as summarized by the National Research Council (NRC 2001, 2002) and other earth-science publications (e.g., Winter et al. 1998). The dynamics of water across the boundaries among these "spheres" has been highlighted by a recent scientific focus on relationships in the "*Critical Zone*" (CZ; Dawson et al. 2020, McCormick et al. 2021), the elements of the "biological skin" of the Earth's surface. While its specific characteristics vary by location, the CZ represents a structurally unifying concept for ecohydrological analyses that jointly considers the interactions within this "skin" on dynamic processes in the geosphere and biosphere.

Northwestern California CZ studies have identified strong relationships among geological substrate conditions and both surface water and vegetation dynamics. For example, a recent study (Dralle et al. 2023) clearly links ecohydrological conditions in northwestern California to variations in the annual flow regimes in streams in this region that provide critical habitat for sensitive species that must be addressed in the NWFP amendment (see Attachment 2).

An extended understanding of 'riparian' relationships has emerged since the formulation of the existing NWFP, and the NWFP amendment should reframe riparian-related discussions to be more consistent with the current understanding that the "riparian zone" is functionally a varying zone of interactions between aquatic system elements and terrestrial elements (see Attachment 2). This understanding leads to expectations that riparian functions under changing hydrological conditions resulting from climate change may differ from the relationships on which the current NWFP is based. The altered understanding of both Critical Zone dynamics and the nature of riparian systems has important implications for managing fuels and fire within these federal landscapes.

VI. Conservation Management in Northwestern California Forests

Future management plans for northwestern California's National Forests should be based, in part, on current and future conservation values exhibited by these landscapes. The Forest Service is required to address the status of a number of 'sensitive' wildlife and plant species in future planning, a topic specific to those species, not further addressed here. However, conservation science *per se* offers insights for management that need to be reflected in current and future plans.

In general, wildlife species respond (both in terms of preferences for use and in terms of numbers of individuals, reproductive success, and other measures of 'fitness') primarily to habitat structure, which is the underlying basis for standard management guidance.[11] The effects on wildlife of fires

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[11] The most widely accepted framework for California is the California Wildlife Habitat Relationships program (https://wildlife.ca.gov/Data/CWHR).

(or fire suppression and fuels management) and climate change are best understood in terms of alterations in habitat structure. Wildlife species respond individualistically to altered environments; altered habitat conditions (including those resulting from wildfire or forest management activities) usually results in altered mixtures of wildlife species (e.g., Thomas et al. 1979, Kennedy & Fontaine 2009, Fontaine & Kennedy 2012, Stephens et al. 2019). Disturbance-caused habitat alterations increase habitat types preferred by some wildlife species while decreasing the habitats types preferred by other species. Large landscapes typically include many habitat types in a shifting ecosystem mosaic, where each habitat type occurs in different places in the regional mosaic at different times (Pickett & Thompson 1978, Franklin & Lindenmayer 2009, Turner & Gardner 2015). The 2012 Planning Rule explicitly directs Forest Service management plans, including the NWFP and forest LMPs, to be framed in precisely such landscape contexts, which are considered to be a 'coarse filter' approach that will provide habitats for all common wildlife species in the landscape.

Wildlife studies during recent decades have shown that local species groups that were established in North America during the Pleistocene Epoch fragmented over the following millennia because of habitat changes resulting from warming climate (e.g., Graham 1988, Graham et al. 1996), and similar effects have to be expected in the climate-altered future for northwestern California. Recent climate changes altered wildlife associations in the Sierra Nevada just during the past century (e.g., Moritz et al. 2008, Tingley et al. 2012). More generally, projections of future ranges of various wildlife species show that new associations of species are likely to form, consequences of habitat alterations and direct changes in the ecological conditions to which wildlife species are adapted (Stralberg et al. 2009, Langham et al. 2015). The NWFP and LMP amendments must be based on reasonable science-based projections of habitat conditions in these landscapes during the effective life of those plans that reflect the effects of climate change and increased disturbances.

Beyond general habitat-based relationships for biodiversity, ecosystem resilience, and similar indicators of climate-adaptation, conservation science has shown that habitat relationships are more significant for certain important habitat types (riparian areas and hardwood-dominated forests and woodlands), which merit particular planning attention. In addition, the extent of habitat fragmentation (or it's converse, connectivity) in a landscape is well documented to be an essential index of resilience to disturbances among many wildlife and plant species.

Instream and Riparian Habitats have Transcendent Conservation Significance in the Klamath Ecoregion. Streams and their riparian areas are intrinsically already the most 'connected' habitat elements in most landscapes (Beier 2012; Fremier et al. 2015). From biological and physical/hydrological perspectives, *riparian areas* function both in the aquatic ecosystems with which they are associated and in nearby terrestrial zones (National Research Council 2002; in the NRC conception of 'riparian', all waterbodies, rather than just streams and rivers, have riparian ecotones). Riparian habitats are among the most important habitat elements for many wildlife species, including both terrestrial and aquatic vertebrates and invertebrates (RHJV 2004).

In conifer-dominated landscapes (e.g., North et al. 2009, 2019; Stephens et al. 2018a), lower slopes near streams have higher levels of soil moisture, and often support larger trees and denser or more complex (e.g., multi-layered) forests. These locations, intrinsically parts of the riparian zones in regional landscapes, are more likely to maintain 'late successional' habitat conditions in the climate-altered future in most of the Klamath ecoregion; deep river and stream valleys may provide climate 'micro-refugia' as the 21st Century unwinds (Thorne et al. 2020, JH Thorne *in seminar* 2021). Protecting and enhancing these riparian areas would enhance the connectivity of both terrestrial and aquatic features, in addition to advancing the goals of the Aquatic Conservation Strategy (ACS) of the NWFP (Reeves et al. 2018). A well-managed riparian habitat network would also sustain landscape connectivity between lower and higher elevations throughout the Klamath ecoregion, supporting local migrations of mobile species and the potential climate-driven colonization of higher-elevation habitats by slower-migrating plant species.

The California State Wildlife Action Plan (SWAP; California Department of Fish & Wildlife 2015) identifies habitats needed to protect and sustain 'wildlife species of greatest conservation need' in the state. Conservation priorities identified in the 2015 SWAP for northwestern California ecoregions emphasize riparian areas and oak-containing forests and woodlands. The CDFW Areas of Conservation Emphasis (ACE) project also identifies riparian areas and oak-dominated habitats as conservation priorities for these ecoregions.[12] Both programs emphasize climate-change adaptation as a priority to implement state and federal wildlife programs, and both incorporate a focus on enhancing connectivity as a priority objective in those actions.

Broadleaved Vegetation is an Essential Element in Klamath Ecoregion Habitats. A biologically relevant factor for the NWFP amendment is that mid-elevations in the Klamath ecoregion include great variety in 'land facets' (Brost & Beier 2012) and localized climates, resulting in a complex mosaic of habitats, including native grasslands/prairies, broadleaved woodlands, shrublands, and coniferous forests. Conifers provide specific habitat elements not otherwise present in the ecoregion, but the presence of hardwoods (particularly oaks) provides a different set of habitat benefits. Oak-dominated habitats are widely identified as the most important wildlife habitat types in California (CalPIF 2002).

For example, studies in the Klamath ecoregion (e.g., Fontaine et al. 2009, Stephens et al. 2015) concluded that breeding bird communities in hardwood- and/or shrub-dominated habitats include as many species as breeding bird communities in conifer habitats. Oregon white oak woodlands are well documented as a significant habitat for many wildlife species in the Pacific Northwest (Gucker 2007), and are widely distributed throughout forested parts of the Klamath ecoregion. The frequent inclusion of black oaks in conifer-dominated habitats increases the well-documented value of these habitats for a variety of wildlife species (e.g., Block et al. 1994). The evolutionary and ecological significance of shrublands in the ecoregion is further indicated by the dominance of shrublands in the California Floristic Province as a whole (Keeley 2002; Rundel et al. 2016, 2018; Keeley & Pausas 2022), and the species richness in two dominant woody plant genera in California (*Ceanothus* and *Arctostaphylos*), the majority of which occur in shrubland plant associations (Raven & Axelrod 1978, Ackerly 2009).

Genetic relatedness among California oak species also indicates the significance of shrubland adaptations; many oak species that occur as trees also have well-established shrubby variants. These patterns suggest that oak clades have often developed evolutionarily with 'tree' and 'shrub' branches.[13] Studies in forested landscapes in northwestern California and southwestern Oregon (e.g., Odion et al. 2010, Tepley et al. 2017) support the conclusion that recurring fire has had the evolutionarily effect of creating long-term 'alternative stable states' with woodlands and shrublands as an alternative state to conifer forests (Attachment 1). From a conservation perspective, shrublands and hardwood-dominated landscapes in northwestern California are evolutionarily no less significant than those dominated by conifers.

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[12] See URL: https://www.wildlife.ca.gov/Data/Analysis/Ace for the ACE3 website. The criteria and methodology used in the connectivity assessments (and other elements in the ACE project) are fully described in documents available on this website.

[13] Close relationships between morphologically and taxonomically distinct oak 'species' suggest a trend within California's geographical boundaries to local differentiation driven by previous climate and fire regimes. For example, scrub oak (*Q. berberidifolia*), an oak species of California shrublands and likely the most common oak species in the state, is a sister species to Oregon white oak (*Q. garryana*); large scrub oaks can be mistaken easily for small Garry oaks, and *vice versa*. Current California oak taxonomy is summarized in Hipp et al. (2018).

Habitat values in shrublands can recover rapidly after major disturbances, although recovery periods differ and may occur to lesser extent for differing disturbance types (e.g., Fry 2008, Potts & Stephens 2009, Wilkin et al. 2017, Newman et al. 2018). Effects of fire on wildlife species in oak woodlands and similar hardwood-dominated communities are expected to be mediated largely by changes in habitat composition and structure (Purcell & Stephens 2005), as with wildlife use in other habitat types. Likely effects of climate change on oak woodland and shrubland wildlife include species reassortments and the development of 'no-analog' wildlife communities (Stralberg et al. 2009). The amended NWFP and LMPs should emphasize additional studies of these relationships, which are likely to be essential for understanding long-term climate-related modifications of regional habitat relationships.

Habitat Connectivity is a Fundamental Conservation Element at Landscape Scales. Conserving wildlife and plant species requires maintaining viable populations of each species, and maintaining viable populations requires sufficient suitable habitat. Even where total habitat area might be sufficient, appropriate habitat could be unavailable to a species because it's blocked by unsuitable habitat; that is, the effective habitat area could be substantially lessened by *habitat fragmentation*, a process through which continuous habitat is sequentially reduced in total area and the parts isolated from one another. The significance of fragmentation has led to the identification of habitat *connectivity* as a primary element in maintaining population viability. Connectivity must also exist between currently appropriate habitat and where suitable habitat is expected to exist in the future, because habitat alterations resulting from climate change can also act as fragmenting agents.

The concept of *corridors* or *landscape linkages* that combine multiple habitat patches into a *conservation network* has been an element in conservation science since the 1970s. Two perspectives have evolved regarding the relevant focus of conservation corridor development (Taylor et al. 2006.). One perspective (a 'fine-filter' approach) posits that corridors ought to be designed to satisfy the habitat requirements of individual 'focal species,' such as those listed pursuant to federal or state endangered species laws. An alternative perspective (a 'coarse-filter' approach) is that connectivity should be based on an appropriate representation of habitat types across entire landscapes, or on the generalized habitat needs of species that are adversely affected by habitat fragmentation. The 2012 Planning Rule directs that the NWFP and LMP amendments should adopt the latter approach, and documenting effective landscape connectivity therefore is a principal concern for the adequacy of the amended NWFP and forest LMPs.

Some conservation scientists have opined that course-filter approaches ought to take specific account of physical elements, such as slope position and aspect, occurrences of differing substrates, and rock outcrops [the 'land facets' approach of Beier (2012) and Brost & Beier (2012)]. Alternative connectivity approaches using 'land facets' sometimes provide differing recommendations from assessments based on general habitat typing (e.g., Brost & Beier 2012).

The conservation 'network' approaches summarized in the previous paragraphs are outgrowths of 'island biogeography' theory, wherein elements not included in reserves and linkages functionally provide no habitat value (like ocean waters for terrestrial species). A better perspective is that most landscapes demonstrate varying degrees of suitable habitat value throughout the landscape. In landscape ecology, the most common, widespread, and connected habitat type in a landscape is identified as '*matrix*' (Forman 1995), and characteristics of the matrix are significant factors in the ability of those landscapes to sustain viable populations. The importance of matrix areas has been widely recognized in conservation planning (Franklin & Forman 1987, Noss & Daly 2006, Franklin & Lindenmayer 2009, Evans et al. 2017, Kennedy et al. 2017, Keeley et al. 2022); most particularly, when the matrix itself provides essential habitat elements for species of interest, the entire landscape is more functionally 'connected'.

The 2012 Planning Rule specifies that forest plan amendments (including the NWFP and the forest LMPs) should focus management on a 'coarse-filter' basis to assure that the plans sustain wildlife and plant populations. This direction is fundamentally matrix-based, because matrix-based approaches essentially require that the composition, structure, and ecological processes in these National Forest landscapes be managed to maintain the complexity and sustainability of all ecosystem components. The Planning Rule is rather indefinite about how to do that, however, and the Forest Service therefore needs to present a feasible management framework in the NWFP amendment to assure that the 'coarse-filter' does in fact assure the viability of all 'common species' in these landscapes.

Conservation within California landscapes is a substantive concern for many members of the public, as well as for state conservation agencies such as the California Department of Fish & Wildlife (CDFW). As the state agency responsible for conservation planning for wildlife and habitat conditions in one of the five 'global biodiversity hotspots' constituting Mediterranean-type climate regions, the CDFW has developed an extensive conservation planning framework, which should be incorporated into the NWFP. The basic framework for California, including northwestern California, is the California Essential Habitat Connectivity project (CEHC; Spencer et al. 2010). The CEHC study incorporated minimum patch size requirements (i.e., potential *reserve areas*) that essentially assured that most National Forest lands in Klamath ecoregion were identified as high-value habitat areas, although peripheral areas of most NF patches were excluded because of *edge effects*. That is, since these large areas of federal lands are intrinsically contiguous with other federal lands, the CEHC study identified the National Forest landscapes in northwestern California as exhibiting high existing connectivity.

The CEHC study did not, however, address connectivity at local scales within the larger landscapes (although it provided recommended methodology for developing local connectivity). It remains the responsibility of the Forest Service to address connectivity among and across stands in the managed National Forest landscapes. The Forest Service has developed preliminary matrix-focused connectivity approaches for LMPs for National Forests in the southern Sierra Nevada (e.g., Estes et al. 2021), which may be helpful in planning for connectivity in the NWFP amendment and the forest LMP amendments in the Klamath ecoregion.

Other conservation studies (e.g., McGuire et al. 2016, McRae et al. 2016) in the western US have identified the importance of connectivity for regional conservation. Assessments for NW California that overlapped with the CEHC study [using different criteria as part of the CDFW's 'Areas of Conservation Emphasis' (ACE) project[14]] also identified intrinsic connectivity in northwestern California as 'high.' Because the ACE project incorporates an explicit focus on climate-change adaptation, planning for the NWFP and forest LMP amendments should reflect these current State of California's approaches regarding wildlife habitat management for federal lands in a changing climate.

A 'New' Conservation Focus for Amending the Northwest Forest Plan and Individual Forest Land Management Plans. The amendment process for the Northwest Forest Plan must be built on scientific understanding that has developed since the 1994 NWFP was adopted. It's clear that much of the forested landscape in the Klamath ecoregion was mischaracterized in the original NWFP, and that a management direction that accommodates increased temperatures, greater aridity and moisture stress, and more fire is required for the next planning cycle. Under current Forest Service planning requirements, future management must incorporate a focus on ecosystems and

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[14] See URL: https://wildlife.ca.gov/Data/Analysis/Ace.

landscapes, and on how they interact with climate change and fire to yield ecosystem services important for people as well as for the environment itself.

The Klamath ecoregion has been important in the evolution of California's native flora and fauna since the Jurrassic Period (see Attachment 1 for additional information), representing a separate 'western American' radiation of important lineages of many dominant plant and animal clades in North America today (Raven & Axelrod 1978, Whittaker 1961, Sawyer 2006, Ackerly 2009, Lancaster & Kay 2013, Kauffmann & Garwood 2022). For example, the Klamath ecoregion is particularly significant for clades in the beech family (Fagaceae), including California near-endemic species in all three western Sections of the oak radiation (*Protobalanus*, *Lobatae*, and *Quercus*), with divergence times dating to the late Paleogene Period. The Klamath Mountains *per se* host the only North American species (deer oak, *Q. sadleriana*) in Section *Ponticae*, a white-oak clade with its origin in the late Eocene Epoch, for which the closest surviving genetic relative occurs in the Caucasus Mountains in western Asia. Moreover, the Klamath ecoregion is clearly central in the evolution of golden chinkapins (*Chrysolepis*) and the monotypic tanoak (*Notholithocarpus*), all endemic to the California Floristic Province (Kremer et al. 2012, Zhou et al. 2022). The significance of the Klamath ecoregion in the evolutionary history of California's native flora is a *per se* reason that the NWFP amendment needs to emphasize maintaining ecological dynamics in the ecoregion.

Climate change and its modifications in ecological processes, particularly fire, are likely to cause further alterations in landscape compositions in the ecoregion, as has occurred periodically throughout geological and evolutionary time. The future is never certain, but it's not unreasonable to expect a reduction in the dominance of conifers in many mid-elevation landscapes, with increased importance of hardwood tree species and more (potentially much more) coverage by shrublands (see Attachment 1). Current understanding of landscape dynamics indicates that the 'connectedness' of these landscapes will play a significant role in the ability of species in the ecoregion to adapt to these changes. All of the species currently in the ecoregion may not continue to exist in the region in the future, but maintaining the extraordinary biodiversity in the Klamath ecoregion depends on how well management incorporates appropriate ecological dynamics.

The NWFP amendment should focus on enhancing and maintaining aquatic and riparian areas, which are already considered by many conservation ecologists to be among the most important habitat elements in California landscapes for both aquatic and terrestrial species. Wider watercourse protection areas throughout the region will help protect water quality in a warming climate, as well as providing a core framework for ecoregional connectivity. Stream canyons may provide cooler, moister microrefugia that sustain complex forest structure and the species that respond to it.

In addition, the NWFP amendment should include an increased focus on the presence of hardwoods within the forest matrix, as well as increasing the numbers and areas of hardwood woodland/forest patches. Increased fire will likely result functionally in a restoration of landscape dynamics dominated by broadleaved plant species (White & Long 2019). Mixed-conifer stands throughout the ecoregion already include varying degrees of dominance by black oak, canyon live oak, Oregon white oak, and madrone, species resilient to increased fire and already important habitat elements for wildlife, and the ecoregion has numerous disturbance-maintained Garry oak woodlands. Oak-dominated woodlands are also culturally significant resources for California's Indigenous communities, an additional focus for the NWFP amendment.

The remaining 'dry' mixed-conifer forests in northwestern California should be restored to a more natural stand structure (the ICO structure), with lower tree densities and more variability in tree spacing, an outcome that should provide greater resilience to wildfire effects and result in fewer but larger/older conifers (the majority of which are likely to be the regionally favored Douglas-fir). Hardwoods within conifer forests should be enhanced, as individual habitat areas ('islands') for woodland-associated wildlife species and as elements in 'stepping-stone' linkages among woodland patches in a coniferous matrix, forming a distributed network of woodland habitats throughout coniferous landscapes. Connectivity within the region will be functionally enhanced by increasing the representation of hardwoods in areas reforested after major disturbances by (1) decreasing the distances among woodland patches and by (2) increasing the proportion of hardwoods in the forest matrix; both measures enhance the capability of the landscape to sustain wildlife movements among the distributed habitats.

Plans for the Klamath ecoregion, and for projects within it, must reemphasize the originally intended role of 'adaptive management' in the NWFP by increasing the Forest Service commitment to monitoring conditions in FS landscapes. Uncertainty about future conditions must be addressed in management plans by including a commitment to monitoring what's actually occurring in the landscape, then adjusting management approaches accordingly.

VII. References

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ATTACHMENT 1

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SENIOR ECOLOGIST (ESA) (*EMERITUS*)
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MEMORANDUM

TO: Interested Persons

DATE: 20 November 2023

SUBJECT: Importance of Hardwood Trees and Shrubs in the Alternative Stable States of Northern California Landscapes for Planning and Management

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I. Roles of Climate Change, Increased Fire, Moisture, and Evolutionary History in the Ecology of Northern California Landscapes

Post-fire landscape dynamics have emerged as a substantive management and planning concern in this era of climate change, with increased aridity and increasingly large and high-severity wildfires. Numerous studies throughout the western US in the past decade have documented a decreasing likelihood that western landscape will recover to predisturbance conditions; i.e., these landscapes do not exhibit "stationarity", and do not return to previous composition, structure, and functional processes when disturbed by drought, fire, and other stressors (e.g., Anderegg et al. 2013, Serra-Diaz et al. 2018, Meyer et al. 2021, Safford et al. 2022, Wang et al. 2022). While recent studies (e.g., Meyer et al. 2021) have identified broad conditions under which disturbed landscapes may recover to predisturbance conditions, managers have begun to seek additional guidance about post-disturbance restoration projects that can be implemented to help landscapes adapt to altered conditions, particularly for the kinds of severe disturbances covering extensive landscapes that have occurred since the 1980s.

Two principal, overlapping dynamics have increased disturbance size and severity in western landscapes dominated by forests. First, increasing atmospheric temperatures resulting from climate change result in increased aridity and reduced subsurface moisture, a direct stressor for vegetation and a cause of reduced fuel moisture and increased fire (Allen et al. 2010, Abatzoglou et al. 2017, Crockett & Westerling 2018). Increased moisture stress also exacerbates competition among individual plants in all landscapes, which indirectly reduces their resistance to insect attacks and a variety of pathogens (Fettig et al. 2019, 2021). A warming atmosphere may be associated with increased likelihood of more severe and/or longer-term drought, exacerbating the effects of moisture stress at the stand level. These effects are entrained in current climate dynamics, although their severity could be moderated during this century by programs that reduce the planetary human production of greenhouse gases.

The second dynamic affecting forested landscapes is the management approach for most federally owned lands during the last century that emphasized fire suppression and a management focus on an extraction of resources with economic value, particularly large trees. This emphasis resulted in altered forest structures, with increased amounts of fuels (including live and dead vegetation, with abundant litter and duff on the ground surface) and a scarcity of large trees that could have survived lower-severity fires in prior landscapes. The result of this failed management paradigm has been a substantial increase in fire dynamics on recent decades, with both larger and more-severe fires in western forested landscapes (Parks et al. 2016, Keeley & Syphard 2018, Hessburg et al. 2021, Wayman & Safford 2021, Airey-Lauvaux et al. 2022).

The consequences of fire and other forest disturbances have led to an increasing concern that climate change will drive forest ecosystems beyond the range of known historical conditions, and more specifically that this combination of stressors is leading to "type-conversions" among forest types, or even to conversion from forests to non-forested ecosystem types, with resulting adverse changes in the ecosystem services that these landscapes provide (Shatford et al. 2007, McIntyre et al. 2015, Coppoletta et al. 2016, Liang et al. 2017, Bost et al. 2019, Young et al. 2019, Stevens-Rumann & Morgan 2021, Taylor et al. 2021, Vanderhoof et al. 2021, Guiterman et al. 2022, Safford et al. 2022, Steel et al. 2022).

Box 1. Many Northern California Landscapes Have 'Dry', 'Frequent-Fire' Forests

During the Holocene Epoch fire recurrence in most mixed-conifer landscapes in California and the inland Pacific Northwest was sufficiently frequent to maintain open-forest conditions. Mid-elevation forested landscapes in the Klamath Mountains, the northern California Coast Range, the southern Cascades, and northern Sierra Nevada (as well as in much of eastern Oregon and Washington) are dominated by ecological communities identified in the preceding quarter-century as 'dry forests' (Spies et al. 2018). Dry mixed-conifer forests in northern California are generally understood to have exhibited a *frequent-fire, mixed-severity regime* prior to the 20th Century (Halofsky et al. 2011, Perry et al. 2011, Hessburg et al. 2019, Safford and Stevens 2017; Skinner et al. 2018; Stephens et al. 2018; Spies et al. 2018).

Mixed-conifer forests in the eastern Klamath and northern Coast Range ecoregions, including those in the four NW California national forests, evolved with a fire return interval typically less than 25 years (often significantly less, particularly in areas influenced for millennia by Indigenous management); this has been characterized as a *very-frequent fire, low-severity regime* (Halofsky et al. 2011, Spies et al. 2018). The frequent fires tended to maintain low levels of accumulated fuel in these forested landscapes by removing shrubs and smaller trees, and a relative lack of accumulated fuels historically supported low-severity or mixed-severity fires in these 'dry' forests (Halofsky et al. 2011, Perry et al. 2011, Hessburg et al. 2019, Spies et al. 2018, Taylor et al. 2021). Less well-documented (but see Sawyer 2006, 2007; Stephens et al. 2018) frequent-fire regimes support the Douglas-fir and tanoak-dominated mixed-evergreen forests at lower elevations in the western parts of the Klamath and northern Coast Range ecoregions.

Frequent fires, which kill most shrubs and small trees, are stressors that favor plant species that sprout from root collars or burls (i.e., most western hardwoods, including oaks) or germinate from buried seedbanks. Current ecological interpretations of evolutionary dynamics in frequent-fire landscapes emphasize that periodic fires in these landscapes in pre-EuroAmerican times removed most accumulated fuels, and an absence of abundant fuels meant that most fires shaping the evolution of those landscapes were low- or mixed-severity fires. Mid-elevation 'dry' forests in these landscapes developed a general structure in which stands were dominated by large individual trees, clumps of trees of various sizes, and intervening 'open' areas lacking trees (an 'ICO' structure as described by Franklin et al. 2013). Most forest ecologists in the western US have concluded that reducing fuels, reintroducing fire, and reducing conifer stand densities are necessary in establishing climate resilience in 'dry' western mixed-conifer forests (Hessburg et al. 2019, 2021; North et al. 2019, 2021, 2022; Larson et al. 2022; Gaines et al. 2022).

Type-conversions are specifically a concern for California's forested landscapes in the Klamath and northern Coast Ranges ecoregions (described by Griffith et al. 2016), as these landscapes are already known to exist in alternative "stable" ecosystem states, either forest-dominated or shrubland- and hardwood-dominated, in dynamic successional processes mediated by periodic fire (Taylor & Skinner 1998, 2003; Sawyer 2006, 2007; Odion et al. 2010; Halofsky et al. 2011; Estes et al. 2017; Tepley et al. 2017; Miller et al. 2019; Schriver et al. 2018; McCord et al. 2020; Taylor et al. 2021; Jules et al. 2022). Hardwood and shrub dominance is a characteristic component in these low- and mid-elevation landscapes (Box 1).

Plant diversity in California reflects adaptation to climatic, biogeographic, and geological conditions in western North America, most significantly the development of a Mediterranean-type (summer dry) climate since the mid-Miocene Epoch. As with the four other geographic regions on the planet with Mediterranean-type climates, fire has been a significant evolutionary factor for most California plant species. Many forest-associated California plant lineages, including conifers and broadleaved deciduous hardwoods, are derived from ancestors that differentiated in temperate northern North America in the late Cretaceous and early Paleogene Periods; these lineages diversified in western North America with significant exposure to summer drought and periodic fire through the early Neogene Period (Ackerly 2009, Keeley et al. 2011, Pausas & Schwilk 2012, Rundel et al. 2018). These evolutionary histories have important implications for responding to the effects of climate change, increased aridity, longer and/or deeper drought, and increased fire.

A fundamental, long-known ecological pattern for California is a decline in ambient moisture availability from north to south, with a secondary pattern of declining moisture availability as distance increases inland from the coast. Ecological studies of various plant and animal clades have documented decreased biodiversity trends in parallel with those gradients, particularly in clades with a northern temperate origin (Hawkins et al 2003, Ackerly 2009, Lancaster & Kay 2013). California's native oak species, for example, demonstrate species-richness patterns correlated with ambient moisture availability, and the patterns are interwoven with sets of traits the species developed to adapt to moisture stress (Skelton et al. 2018, 2021). The pattern in oaks is related evolutionarily to the sequence of differentiation within each clade: earlier-evolving species are typically less-adapted to moisture stress than are later-evolving species. Notably, many earlier-evolving California oak species commonly occur today as trees in moist-forest landscapes that also support numerous northern-affinity conifer species, while most of the later-evolving oak species occur as dominant shrubby species in warmer and drier inland and/or southerly landscapes.

Such patterns are clearly relevant for adapting communities to landscapes being altered by climate change. Physiological studies of drought tolerance often focus on the ability of plant hydraulic systems (xylem tissues in root, stem, and leaf) to withstand decreases in atmospheric and soil moisture, which can lead to xylem "cavitation" and loss of hydraulic function, loss of photosynthetic capability, or hydraulic failure and death. Water transport in plants is fundamentally a physical process mediated by a cell-turgor gradient from roots to leaves, which is ultimately driven by transpiration through leaf stomata. In consequence, plant evolution is deeply affected in multiple ways by the tradeoff between potential hydraulic failure and maintenance of photosynthesis (McDowell et al. 2008, Brodribb & Cochard 2009, Choat et al. 2018, Brodribb et al. 2020).

Climate-change studies addressing increased moisture stress on vegetation have indicated that low- and mid-elevation conifer forests in California are likely to undergo changes in structure and composition to include more drought-tolerant species, typically hardwoods, and specifically are likely to be dominated by the oak species that already occur in those landscapes (e.g., Lenihan et al. 2008, McIntyre et al. 2015, Liang et al. 2017). Oaks exhibit a variety of adaptations in response to increasing moisture stress (Baldocchi & Xu 2007), including physical modifications in xylem characteristics to resist cavitation; changes in root architecture to access available groundwater; changes in leaf size, specific area, and deciduousness; and even plant size at maturity. Less drought-tolerant California oak species (i.e., those typically associated with moist landscapes dominated by forests) generally reach reproductive maturity as trees, while the shrubbiness typical of oak species that occur in shrublands represents an adaptation among California's oak clades to an increasing summer moisture deficit (Skelton et al. 2018, 2021; Roberts *in review*).

Interactions among groundwater depth and plant hydraulic adaptations can affect both local survival and competition among plant species. In the Klamath and northern Coast Ranges ecoregions, for example, individuals of relatively drought-tolerant Douglas-fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*) are widely involved in competition with Oregon white oak (*Q. garryana*, aka Garry oak) and California black oak (*Q. kelloggii*) for light and for substrate moisture. Landscapes in which this evolutionary dynamic is played out include lower-elevation vegetation types like Mixed Evergreen Forest and Northern Oak Woodland, as well as mid-elevation types like Mixed Conifer Forest. The dynamics of this long-term evolutionary dance involving Garry oak and Douglas-fir have been well-described (e.g., by Schriver et al. 2018, among other northwestern California studies), in which oak-dominated woodlands can be invaded by shade-tolerant Douglas-fir seedlings, which eventually overtop and shade out the oaks unless low-intensity surface fires remove the young conifers (Hunter & Barbour 2001).

Douglas-fir, ponderosa pine, black oak, and Garry oak are all well-adapted to the climatic and ecological dynamics in lower and mid-elevations in these California ecoregions. Recent studies (e.g., Hahm et al. 2018, 2019, 2022), however, have shown that competition among these species is intensely mediated by subsurface moisture, which is related to the structure and geophysical composition of the underlying substrate [i.e., to the subsurface part of the *Critical Zone* (Fan 2015, Dawson et al. 2020)]. Focused studies of stem hydraulics in these species indicate that all are relatively intolerant of intense moisture deprivation (not surprisingly, as all are modern representatives of clades that first appeared in the Oligocene Epoch in western North America, in the temperate northern forests of the late Paleogene Period).

Garry oaks exhibit a characteristic trait shared with other California oak species, varying the development of subsurface root systems according to the encountered presence of subsurface water (Garry oak is also somewhat more tolerant of stem hydraulic stress than is Douglas-fir). Garry oak sprouts abundantly from root-crowns of trees killed in higher-intensity fires, which typically remove most non-sprouting Douglas-fir trees, reducing competition for light for the sprouting oaks. Black oak is somewhat more tolerant of stem hydraulic stress than Garry oak, and ponderosa pine is somewhat more tolerant than Douglas-fir. In addition, black oaks killed in higher-intensity fires also sprout abundantly from root-crowns, a trait that gives this species a competitive advantage in landscapes that experience larger, more common, or higher-intensity fires. Black oak seedlings are moderately shade-tolerant, and can frequently be detected widely in second-growth mixed-conifer stands when there are parent trees in the vicinity [partly because "scatter-hoarding" Steller's jays (*Cyanocitta stelleri*) commonly disperse and cache acorns far outside the seedfall perimeter of parent oaks]. Similar dynamics likely exist for canyon live oaks (*Q. chrysolepis*) in northwestern California, where oaks are often widely dispersed in low- and mid-elevation forested landscapes that span a wide range of substrate and geohydraulic conditions, but that relationship is not currently well-documented.

Assessing plant hydraulic functional capability is not common practice, although it likely would provide important insight for climate-change adaptation in California landscapes. Hydraulic functions vary widely among (and within) plant families in California, and are important variables with respect to changing ecological conditions, but characterizing moisture stress tolerance among plant clades remains to be achieved for most lineages. The relationships of most plant species to locally available groundwater in the Critical Zone are unclear, although recent studies indicates that this may be a significant factor in plant species resilience in a changing climate (e.g., McCormick et al. 2021). For example, perceptive recent syntheses of hydraulic considerations indicate that subsurface moisture availability (the "weather underground") is an essential element in assessing climate-change resilience among oak species (McLaughlin et al. 2017, 2020).

II. Geological Dynamics and Geography: Important Factors in the Evolution of Northern California's Landscapes

Paleoecological vegetation patterns in western landscapes show broad responses to climatic shifts, including increased evidence of fire during warmer climate periods (e.g., Whitlock 1992, Whitlock et al. 2003, Briles et al. 2008). Limited evidence is available about rates of shorter-term vegetation change resulting from climate variation, although a study of pollen from Clear Lake sediments showed that since the last Interglacial (from ca. 130,000 years ago), previous periods of warmer and drier climate favored oaks (and likely other hardwoods) in northern California landscapes (Adam & Robinson 1988). Plant hydraulic adaptations generally favor angiosperms (i.e., hardwoods, and particularly the evolutionarily more-recently differentiated oak species) over conifers in times of warming atmosphere and increased aridity, although additional scientific studies are needed (Choat et al. 2018, Brodribb et al. 2020). The importance of developmental 'plasticity' in plants is another factor with uncertain but probably high importance in climate-change adaptation, another topic for which additional research is needed. Local geohydrology in the Critical Zone (i.e., the dynamics of subsurface water; see McCormick et al. 2021, Dralle et al. 2023) and plant hydraulic functioning indicate a need for greater consideration of subsurface moisture in climate-change (and fire) adaptation programs.

The history of California's landscapes has itself helped shape the diversity of its vegetation patterns. The antiquity of the Klamath Mountains Province as a geographic feature in northern California is generally regarded as a principal factor supporting high biodiversity in the state (Raven & Axelrod 1978, Ackerly 2009, Lancaster & Kay 2013). The Klamath Mountains geological province has existed as a subaerial feature in western North America since the middle Mesozoic Era, representing a long-available "stage" on which the evolution of numerous native plant clades has been enacted. However, much of what's now California south of the Klamath Mountains had yet to be formed prior to the late Neogene Period, and the early differentiation of many clades occurred when much of the state's current landscape was below sea level.

Recent geological syntheses addressing paleotopography in the southwestern US (e.g., Bahadori et al. 2018; Figure 1) have identified evidence of high-elevation landscapes immediately east of the coastal basin that occupied what's now the Central Valley prior to the early Pliocene (ca. 4 million years ago (Ma)). The general evolutionary pattern for the "Arcto-Tertiary Flora" has long been acknowledged to include a southwards colonization of western North America from higher northern latitudes (e.g., Axelrod 1959, Cavender-Bares 2019). A number of these western plant lineages, including most conifers and many "Arcto-Tertiary" angiosperm families, colonized a different 'California' landscape during the Paleogene Period. The northern part of this ancient landscape included the Klamath Province and contiguous uplands to the east, and the "Arcto-Tertiary" lineages colonized the landscapes from the north, moving south through the Klamath Mountains and down the axis of the upland ranges east of the forearc embayment (which were not the "ancestral Sierra"). For tens of millions of years, the landscapes of northwestern California formed the stable "stage" for the continued evolution of these colonizing clades, separating them from the remainder of western ‘California’; i.e., these clades could not migrate south along the nonexistent southern Coast Ranges, and a significant portion of the early radiation of the “Arcto-Tertiary” conifer and angiosperm families in California today occurred in the northwestern part of the state (see following section; Roberts *in review*).

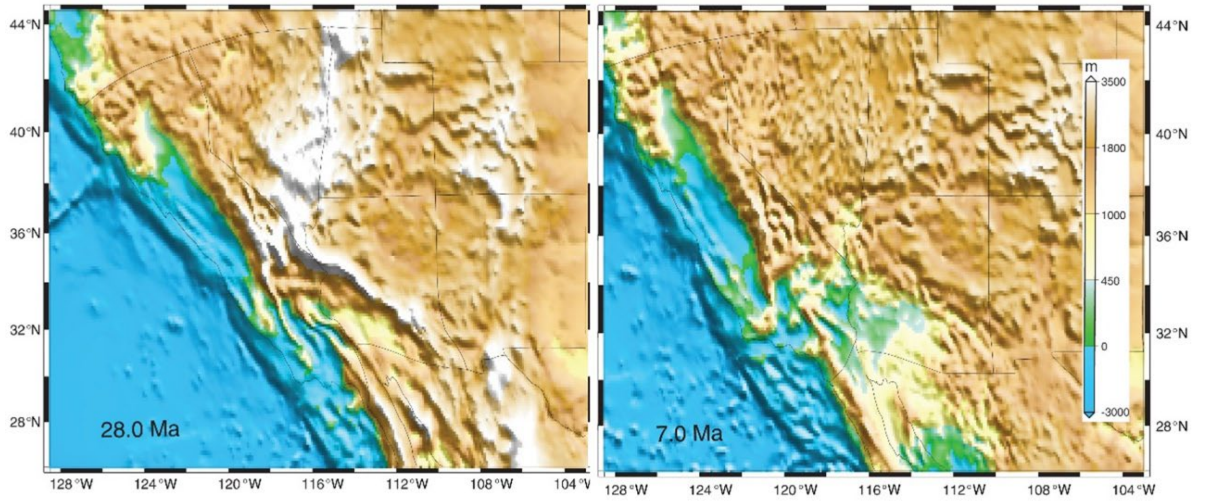

Figure 1. Palinspastic reconstructions of southwestern North America paleotopography in mid-Oligocene (28 Ma) and late Miocene (7 Ma). Los Angeles is now located 30ºN 118ºW. Note the approximate state boundaries (light gray lines), demonstrating a significantly wider east-west extent of mountainous northern California during the period of rapid California oak evolution. Adapted from Bahadori et al. (2018).

The prolonged co-evolutionary history of the colonizing clades in northwestern California shaped the plant communities dominating the region today. Because of this history, plant communities in the Klamath and northern Coast Ranges ecoregions are already adapted to shift to alternative states as conditions change. Even if future “novel communities” assemble themselves as a consequence of climate change, they’re likely to be composed primarily of species combinations that have occurred sometime in the past (although they’re also likely to differ from the “Historical Range of Variation”), emphasizing the significance of genetic and developmental plasticity in native species.

The genomes of many native plant species possess substantial developmental or phenotypic *plasticity* that can support their roles in shifted future conditions (Aitken & Whitlock 2012, Barbour et al. 2019, Cavender-Bares 2019, Venturas et al. 2021). A relevant example is found in the Oregon white oaks at study sites in the Willamette Valley and southwestern Oregon (stands identified in other studies as composed of genetically closely related individuals), which display alternative sets of physical traits in clines from valley bottoms to hilltops (Thilenius 1968, Riegel et al. 1992, Gilligan & Muir 2011), indicating substantial developmental flexibility without significant genetic differentiation. Similar results have been documented for other California oak species; i.e., most native oak species appear to respond well to altered climate conditions (Roberts *in review*), although research focused on such relationships is only at its beginning.

In northwestern California the propensity toward, and stability of, alternative biological community states is a consequence of multiple interacting factors, including the geological age of the physical landscape, existing gradients of moisture availability resulting from geographical location in the state’s northwestern (moistest) corner, and the length of the evolutionary history of the species that occur in these landscapes (Whittaker 1960, Stebbins & Major 1965, Raven & Axelrod 1978, Sawyer 2006, Ackerly 2009, Odion et al. 2010, Halofsky et al. 2011, Lancaster & Kay 2013, Estes et al. 2017, Tepley et al. 2017, Miller et al. 2019, Schriver et al. 2018, McCord et al. 2020, Jules et al. 2022). Our perception of the evolutionary histories of the clades of both conifers and angiosperms that yielded the species present today is a relatively recent outcome of the development of genomic technology and the ability of scientists to apply it to evolutionary issues, and further insights into these relationships are likely as such studies increase.

III. California's Native Oaks: Preadapted for Climate-Change Resilience

Evolutionary patterns in California's vegetation are complex, as illustrated by California's oak species and their close relatives in the family Fagaceae. The family originated in subtropical Asia in the Cretaceous Period of the Mesozoic Era, but the oak genus *Quercus* appears to have evolved no later than about 55 Ma (in the Paleogene Period of the Cenozoic Era) as part of the "Arcto-Tertiary" flora in what's now northern North America. Oaks subsequently migrated throughout the northern hemisphere across land bridges that formerly joined the North American and Eurasian continents (Hipp et al. 2018, Cavender-Bares 2019, Zhou et al. 2022). Oaks have adapted to a wide range of climatic conditions, and constitute important plant community elements in temperate, arid, and subtropical biomes; oaks are widespread throughout northern temperate latitudes in both North America and Eurasia. Physiological and genomic studies have shown that California's *Quercus* clades exhibit traits that have been shaped by their evolution in western North America. California's oak species [and those of their western American relatives, tanoak (*Notholithocarpus*) and the golden chinkapins (*Chrysolepis*)] have differentially developed adaptations that are important for climate-change response (Baldocchi & Xu 2007, Hipp et al. 2018. Cavender-Bares 2019, Kremer & Hipp 2020, Manos & Hipp 2021, Zhou et al. 2022).[1]

Details of oak evolutionary history exceed the focus of this memo, but a significant part of that history is that three dominant western North America oak subclades differentiated from those elsewhere in North America by the late Eocene Epoch, no later than 40 Ma, with a minor (and later) representation of a fourth, and with a relictual representation of an ancient fifth (Hipp et al. 2018, Manos & Hipp 2021, Zhou et al. 2022).[2] The three primary subclades are those generally known as the 'white' oaks (Section *Quercus*), the 'black/red' oaks (Section *Lobatae*), and the 'intermediate' oaks (Section *Protobalanus*). The fourth 'Mexican white oak' subclade (Section *Leucomexicanae*) includes two species which are restricted to southern California (while being more abundant in Arizona, and Mexico). The fifth subclade includes a single species of the ancient

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[1] It should be noted that California members of the oak/beech clade are largely adapted to uplands, although individuals of some oak species also thrive in riparian areas with high groundwater. Pacific madrone (*Arbutus menziesii*), typically an evergreen tree species closely related to manzanitas, is also largely an upland species and appears to be ecologically convergent with evergreen oaks. Most deciduous California hardwood tree species, such big-leaf maple (*Acer macrophyllum*), sycamores (*Platanus* spp.), alders (*Alnus* spp.), willows (*Salix* spp.), and cottonwoods (*Populus* spp.) are associated with riparian and other habitats having abundant near-surface groundwater (Raven & Axelrod 1978). From a Critical Zone perspective, oaks as a group show a different ecological and evolutionary pattern shaped by upland ecohydrological characteristics (Fan 2015).

[2] The closely related tanoak (*Notholithocarpus densiflorus*) behaves ecologically (and is used by Indigenous people) as if it were in *Quercus*. Tanoak is a surviving ancient North American species in its own subclade in the beech family, a member of a sister subclade to *Quercus*; the *Quercus*/*Notholithocarpus* clade is a sister to other crown clades in Fagaceae that include the chinkapins (*Chrysolepis*) of western North America, the 'stone oaks' (*Lithocarpus*) and 'ring-cupped oaks' (*Cyclobalanopsis*) of eastern Asia, and the chestnuts (*Castanea*) of Eurasia and North America. See Manos et al. (2008) and Zhou et al. (2022) for clarifying information.

Section *Ponticae*, the shrubby deer oak (*Q. sadleriana*) of higher elevations in the Klamath and northern Coast Ranges ecoregions, the only western hemisphere representative of this subclade.[3]

Box 2. California's Paleoecological Evolutionary 'Stage'

Much of what's now California had yet to be formed by the beginning of the Miocene Epoch. The Farallon Plate was still subducting beneath North America, the San Andreas Fault System had not developed, and the western margin of North America was a region of active terrane accretion. Although much of 'California' was still a coastal marine basin, the accretion wedge along the Farallon subduction zone was in the process of forming what would become the Franciscan Formation and the ancestral northern Coast Ranges. The ongoing collision of the Pacific Plate with North America began in the early Miocene, leading to the onset of landscape translocation west of the San Andreas Fault toward the northwest, and including the northwestward rotation of the southern end of the ancestral 'Sierra Nevada' to form the current Transverse Ranges.

The mid-Miocene is considered to be the approximate timeframe in which a summer-dry Mediterranean-type climate began developing in the West. The mid-Miocene is also the timeframe during which the southward-flowing California Current system developed, owing to the development of a persistent atmospheric high-pressure region in the northeastern Pacific, an outcome related to a change in circulation in the North Pacific. These changes were associated with cold water, upwelling, and fogginess along the western North American margin. Ambient global temperatures (based on deep-ocean isotope records) declined significantly in the late Paleogene Period, and continued to do so through the entire Miocene Epoch. Global temperatures in the early Miocene were ca. 2^{o} C warmer than today, and by the end of the Miocene they were ca. 2^{o} C cooler than those of the (pre-Anthropocene) Holocene.

In essence, the major period of diversification for California's oak clades was a period when regional landscapes were more discontinuous and varied than those today, and the region's climate was undergoing both overall cooling and summer drying. The evolutionary milieu created in the California Floristic Province by these interacting elements is the 'stage' on which the evolutionary 'play' featuring California's vegetation, including oaks, was enacted. Western oak species are adapted to this regional climatic pattern, a significantly different history than oak (and other clades) elsewhere in North America.

Oaks are well-known for sharing genetic material among related species within each subclade (and to a minor extent between subclades), forming a *syngameon*, a group of closely related species that possess significant amounts of common genetic material but which are maintained as phenotypically distinct species, primarily by the ecological conditions to which individuals are exposed (Cavender-Bares 2019, Cannon & Petit 2020, Zhou et al. 2022). The shared genes (largely resulting from 'cross-pollination' in these wind-pollinated species) increase the genetic variation within each species; this 'extra' genetic variability appears capable of 'preadapting' individuals in each oak population to changing environmental conditions (Hipp et al. 2020, Kremer & Hipp 2020). In addition, numerous studies of California oak species in recent decades have demonstrated that individual oaks exhibit substantial developmental and physiological 'plasticity', such that

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[3] The deer oak (*Q. sadleriana*) is the sole surviving North American species from a subclade in the pre-Miocene 'white oak' radiation in North America. The only other species in the subclade (*Q. pontica*) occurs in the Caucasus Mountains of western Asia. The clade undoubtedly included other species elsewhere in the Northern Hemisphere that were extirpated between the late Eocene Epoch and the present. The shrubby, rhizomatous *Quercus pontica* has hybridized to some extent with a later-colonizing white oak subclade from North America (the '*roburoids'*), but genomically it consistently groups with *Q. sadleriana*, and these two widely disjunct species constitute Section *Ponticae*. See the cited references for more information.

even closely related individuals located near one another can develop different phenological patterns, including differences in root and leaf characteristics and drought tolerance.

The species in each of the three important western oak subclades appear to have diversified in parallel with species in the other subclades with overlapping geographic ranges, such that many California locations host one or more species from each subclade. However, oaks do not show indications of significant interclade competition (Cavender-Bares 2019, Kremer & Hipp 2020), increasing local oak species richness in a range of different environments and allowing oaks to be a highly successful plant genus in this bioregion. These factors made California's oak species highly capable of adapting to the cooling and drying environments in the bioregion since the late Paleogene (Hipp et al 2018, 2020; Kremer & Hipp 2020; Manos & Hipp 2021). California's native oaks can therefore be expected to show substantial adaptability to altered environmental conditions resulting from climate change and other current stressors.

The mid-to-late Miocene Epoch (the geological timeframe the early Neogene Period between approximately 15 and 5 Ma) is associated with significant radiations of California *Quercus* subclades (and with numerous other western lineages of native fire-adapted herb, shrub, and tree species; see, e.g., Raven & Axelrod 1978, Ackerly 2009, Lancaster & Kay 2013). Geological and oceanographic data indicate that the onset of California's Mediterranean-type climate also began in the middle-Miocene (e.g., Rundel et al. 2018; see Box 2), which is virtually universally acknowledged to be an important element in the radiation and survival of numerous endemic California plant lineages.

Fossils of species in the California oak subclades have been identified at various sites in the western US (see summary in Mensing 2005), in an age sequence that's consistent with the evolutionary scenario described by Hipp et al. (2018). Fossils of species in each subclade are oldest in the north and become younger farther south, reflecting oak colonization in the western part of the continent. Fossils have been attributed to several modern species (or their direct ancestors) at localities much farther east than any of the California species occurs today, suggesting colonizing waves of individuals moving south into suitable habitats in the western US from the temperate northern Tertiary forests as climate in the west cooled and dried, apparently followed by later restrictions of these lineages to landscapes in the far west as a Mediterranean-type climate came to dominate the region as a whole. This adaptive pattern is common in other lineages in Fagaceae, and has been identified as a significant factor in the relative dominance of this family in northern temperate landscapes generally (e.g., Zhou et al. 2022).

A universally projected effect of future climate change is increased evapotranspiration resulting from a warmer atmosphere, which is associated with increased evaporative moisture stress for long-lived plant species; i.e., to emphasizing the need for woody species to survive increased drought stress. Climate change may increase the likelihood of intensified multi-year dry cycles (long-term drought), but drought stress occurs every year in California's Mediterranean-type climate, a *seasonal drought* that has shaped the evolution of oak (and other) lineages in the California Floristic Province (Baldocchi & Xu 2007). For example, oaks can respond to increased seasonal drought stress by closing their stomata, but stomatal closure also prevents photosynthesis. Oaks also respond to seasonal drought with physiological traits that allow plants to tolerate drought stress in stems, branches, and leaves without stomatal closure, which allows photosynthesis to continue but increases the risk of xylem cavitation (air embolism; Choat et al. 2018).

Phylogenetically older species of California oaks tend to be less drought-tolerant than more recently evolved species (Figure 2), and generally are associated with habitat types (e.g., temperate forest) with greater ambient moisture; these forested habitats are often dominated by conifer species descended from ancestors that co-evolved with the early oaks. More recently evolved oak species (e.g., the shrub white oaks; Sork et al. 2016) are generally more drought-adapted than are those that differentiated earlier, and are generally associated with more xeric habitat types, including Mediterranean woodlands and chaparral. Drought-tolerant species generally exhibit adaptations like smaller, denser leaves (lower specific leaf area) and/or to be evergreen (Ackerly 2009, Skelton et al. 2021).

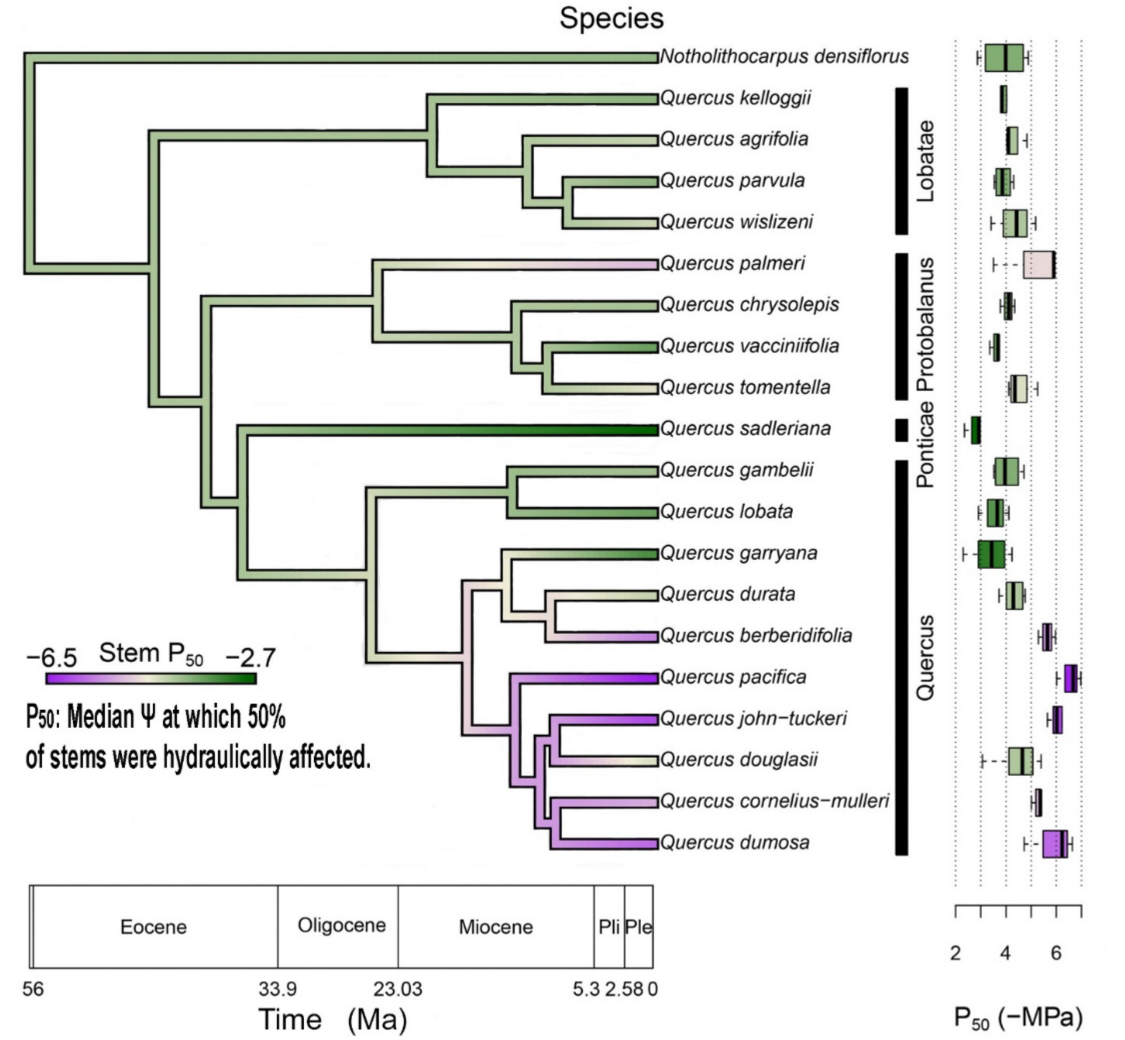

Figure 2. Variation in P_{50} across the time-calibrated phylogeny of 19 Quercus and one sister species from western North America. Branch colors reflect changes in stem xylem vulnerability to embolism (stem P_{50}) in negative megapascals (MPa); larger (that is, more negative) values indicate greater drought tolerance. The boxplots to the right of the phylogeny diagram depict P_{50} for each species: boxes indicate interquartile range, thick vertical black line indicates median, and whiskers indicate full range of values. (Adapted from Skelton et al. 2021).

The cladogram in Figure 2 incorporates current western oak phylogeny (as described in Hipp et al. 2018), and the figure portrays the evolution of drought tolerance among species in California's oak subclades during the Cenozoic Era, clearly showing lower drought tolerance by earlier-evolved species and the adaptation of later-evolved species to California's Mediterranean-type climate after the mid-Miocene.[4] The relative tolerance of each species to drought is an overridingly significant environmental factor in its evolution, and a significant characteristic of each species in terms of climate-change adaptation.

The "preadaptation" of California's oak species to climate change arose over many generations as the subclades evolved under ambient ecological community dynamics, temperatures, fire regimes, and moisture conditions during the last 40+ million years. The development of a Mediterranean-type climate yielded two significant outcomes: (i) California's oaks have been as much subject to natural selection for drought/moisture stress as they have been to respond to periodic fire; and (ii) under conditions of both long-term and local drought stress, California's oak species exhibit adaptations that will favor their increased presence in a fire-, drought- and/or climate-stressed future. More, larger, and/or more severe future fires are generally expected to favor oaks and other hardwood tree and shrub species over conifers (Lenihan et al. 2008, Liang et al. 2017, McIntyre et al. 2015).

Projected future climate scenarios for northern California indicate that the region likely will continue to receive sufficient moisture to maintain (and likely increase) the importance of mid-elevation oak species already present in the region's 'dry'/'frequent-fire' forests (Box 1). For example, Hahm et al. (2018) demonstrated that Garry oak competes effectively with Douglas-fir, the dominant mid-elevation conifer in the region, because of its tolerance for increased moisture stress when subsurface moisture is limited. Management and restoration plans for mid-elevation ecoregions in northern California should direct careful attention to subsurface moisture and the ecohydrology of the Critical Zone within the region (Hahm et al. 2022). Fire-mediated changes in conifer-dominated landscapes in this region include likely increased abundances (as well as possible range shifts) for other oak species in conifer-dominated mid-elevation landscapes, particularly black oak and canyon live oak (McIntyre et al. 2015, Safford et al. 2022).

IV. Habitat Composition and Management Considerations for Northwestern California

Current management directions in northwestern California's forested landscapes were influenced by nominal relationships among vegetation communities and wildlife, particularly "listed" or protected species such as the Northern Spotted Owl (NSO; *Strix occidentalis caurina*) and the Pacific fisher (*Pekania pennanti*).[5] That focus has strong historical roots for national forest landscapes in northwestern California, based on requirement in the National Forest Management

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[4] Gambel oak (*Q. gambelii*) has been identified as an introgressive (hybrid) species involving valley oak (*Q. lobata*) and a species in the mid-American subsection *Prinoideae* (Crowl et al. 2020); i.e., *Q. gambelii* is not a direct descendent of ancestral valley oaks. However, the Figure 2 branch including *Q. lobata* functionally represents the time frame for the ancient divergence of valley oak from all other California white oaks. The even more ancient (in the Eocene Epoch) divergence of *Q. sadleriana* from other California white oaks is also noteworthy.

[5] Habitat relationships for NSO may differ slightly from those of the closely related California Spotted Owl (CSO; *S. o. occidentalis*) of the Sierra Nevada and for fisher populations in the southern part of the Sierra Nevada, but both species are clearly adapted ecologically for older, denser forests throughout their California ranges. However, forested landscapes in NW California are not occupied by a third wildlife species of concern in the Sierra, the Black-backed Woodpecker (BBWO; *Picoides arcticus*), and concerns for "early-successional habitat" conditions are related more directly to habitat relationships with other wildlife species. The BBWO occurs at low densities in unburned landscapes the southern Cascades of northeastern California, exhibiting a strong numerical population response to early-successional habitat conditions following fires (Verschuyl et al. 2021, Stillman et al. 2023).

Act (NFMA; 16 USC §§ 1600-1614) and the Northwest Forest Plan (NWFP), as well as other federal and state laws and regulations.[6]

The dynamics of “frequent-fire”, “dry” forests in northwestern California in the management directions in the NWFP, and in the Land and Resource Management Plans (LRMPs) of the covered national forests, is an issue of current (and significant) scientific and management concern. The NWFP and the northwestern California national forest LRMPs currently focus on achieving and/or maintaining habitat conditions identified in the 1990s for “old-growth” wildlife species (including the NSO and the fisher) that are now understood to prefer conditions that are characteristic of “moist forests”, which occur primarily in western parts of the region, influenced by the ocean’s effects on temperatures and atmospheric moisture. Dense, multi-layered “moist forest” landscapes reflect significantly greater moisture availability than in “dry” forests; even in northwestern California “moist forest” landscapes are dominated by “Pacific rainforest” plant communities (Franklin & Dyrness 1973, Spies et al. 2018), not addressed in detail by this memo. “Moist forest” conditions and dynamics are atypical in northwestern California’s inland, “frequent-fire” forested landscapes (USFS 2020), and the focus in the 1994 NWFP on maintaining “moist forest” conditions throughout these inland landscapes clearly requires reconsideration (USFWS 2011).

A significant (and substantive) difference in ecological and evolutionary patterns between the “moist” and “dry” forest vegetation types is well illustrated in the diversity and importance of hardwood species. In “moist” forests (particularly those north of the Siskiyou region in southwestern Oregon), hardwood richness is dominated by species that are typically “riparian” [Naiman et al. (2010), among others, characterize riparian area composition and dynamics in these forests]. Evidence exists (e.g., Kennedy & Spies 2005) that hardwood “patches” dominated primarily by these species also occurred as consequences of disturbance dynamics in the uplands of the Oregon Coast Ranges.

Aa similar dynamic is reflected in the commonness of much richer hardwood alliances and grasslands in the Klamath and Northern Coast Range ecoregions. Hardwood species richness in those ecoregions reflects the richer diversity of hardwood species in the California Floristic Province as a whole, a product of >40 million years of evolution in the varying geology, climate, physical geography, and ecological contexts of these landscapes. Many plant geographers (e.g. Whittaker 1960; Stebbins & Major 1965; Raven & Axelrod 1978; Sawyer 2006, 2007; Ackerly 2009; Lancaster & Kay 2013) have identified the significance of the Klamath Mountains (AKA the “Klamath/Siskiyou Bioregion”, AKA the Klamath ecoregion) in the evolution of California’s flora for a many clades in the “Arcto-Tertiary” flora, including most coniferous tree clades dominant in the western US today, oaks and their close relatives, and western representatives of the ancestral clades of more widespread plant families elsewhere in North America.

The widely recognized diversity of conifer species in the Klamath ecoregion today is also reflected in the diversity of genomically ‘older’ oak species in the western Klamath and High Northern Coast Range ecoregions (Roberts *in review*). However, the clades making up California’s three dominant oak sections also include numerous “young” oak species, a consequence of continued

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[6] The NWFP was adopted in 1994 to better focus federal agency land management actions in the Pacific Northwest, including northwestern California, on balancing protection for habitat conditions needed by late-successional wildlife species and several anadromous fish species with sustainable commodity outputs and community stability. The NWFP is in the early stages of its first significant revision; for additional information on both the NWFP’s history and its revision, see https://www.fs.usda.gov/detail/r6/landmanagement/planning/?cid=fsbdev2_026990.

evolution in these clades as climate cooled and dried beginning in the mid-Miocene Epoch ca. 15 Ma. Since then, paleoecological and paleogeographic evidence supports a broad conclusion that cooler and wetter climate periods have favored conifers, while warmer and drier climates have favored oaks and other hardwoods, and California's current vegetation is a "dynamic balance" that's adapted to the current phase of a changing climate, particularly to the importance of fire.

Climate-change adaptation reflects interactions involving genes within individuals, individual organisms in a population, and populations within a community; evolutionary history is therefore an important consideration in planning for climate-change adaptation. The biota and ecological communities of the coastal "moist forests" in northwestern California are largely adapted to differing evolutionary trajectories than are those of the "dry, frequent-fire forests" in the interior parts of the region, as described in the Bioregional Assessment (USDA 2020). The planning process for updating the NWFP and the individual forest LMPs needs to be framed consistent with this recognition.

The 2012 revision of USFS planning regulations broadened the Forest Service's management focus toward maintaining biologically diverse, resilient, and functionally connected landscapes (e.g., Estes et al. 2021) and the ecological services they provide. These refocused planning objectives for national forest landscapes ***replaced*** the planning requirements in the 1982 codification of NFMA regulations (which were the basis for the 1994 version of the NWFP), and represent a fundamental shift in objectives (see, e.g., Brown & Nie 2019). With respect to the focus of this memo, two primary objectives of the 2012 rule are significant:

- Ecological (climate-change) *sustainability* (*integrity* and *resilience*): Forest plans must maintain and/or restore ecosystem composition, structure, connectivity, and functional processes in forested landscapes, based on "dominant ecological processes, disturbance regimes, and stressors, such as natural succession, wildland fire, invasive species, and climate change; and the ability of terrestrial and aquatic ecosystems on the plan area to adapt to change" (36 CFR §219.8). Factors that must be considered for this objective include:
  - interdependence of terrestrial and aquatic ecosystems in the plan area,
  - contributions of the plan area to ecological conditions within the broader landscape influenced by the plan area,
  - conditions in the broader landscape that may influence the sustainability of resources and ecosystems within the plan area,
  - system drivers, including dominant ecological processes, disturbance regimes, and stressors, such as natural succession, wildland fire, invasive species, and climate change; and the ability of terrestrial and aquatic ecosystems on the plan area to adapt to change,
  - wildland fire and opportunities to restore fire adapted ecosystems, and
  - opportunities for landscape scale restoration.
- Ecological *diversity* and *integrity*: Forest plans must maintain and/or restore "the diversity of ecosystems and habitat types throughout the plan area" (36 CFR §219.9). This objective is to be met by:
  - maintaining common tree (and other plant) and wildlife species (coarse-filter focus), and
  - maintaining viable populations of federally listed and candidate species and species of local/regional conservation concern (fine-filter focus).

The 2012 planning rule explicitly embodies an ecological tenet that wildlife species are generally associated with subsets of available habitat types, and that by maintaining a diversity of plant associations/habitat types the viability of "common species" that occupy those associations will be sustained in the managed landscapes (i.e., the “coarse filter” approach). The “fine filter” is additionally enacted if the “coarse filter” will not maintain viable populations of listed species and/or species of conservation concern. Basically, managing habitat for protected species like the NSO and the fisher ceases to be the overarching objective of a national forest’s Land Management Plan; species-focused management is meant to be implemented only if managing at landscape scales does not achieve the planned objectives for those species.

Synopsizing the scientific guidance for planning and executing landscape-scale management exceeds the scope of this memo, but both historical and (increasingly) recent examples exist that can assist managers in achieving these objectives (e.g., Pickett & Thompson 1978; Pickett & Cadenasso 1995; Franklin et al. 2007; Franklin & Johnson 2012; Filotas et al 2014; Turner & Gardner 2015; North et al. 2019; Hessburg et al. 2016, 2019; Gaines et al. 2022). A salient factor for achieving those tasks is clearly a need to address the underlying ecological dynamics in the Klamath and northern Coast Range ecoregions as they exist on the ground. An overarching result of these dynamics is that fire, climate change, and other disturbances have led to, and will in the future lead to increased areas of, landscapes that are combinations of alternative community types, which shift their locations through time within these landscapes (Hessburg et al. 2016, 2019; Gaines et al. 2022).

The importance of broadleaved hardwoods for sustaining diverse wildlife within the conifer-dominated montane forests of the western US is not a new perception [see Hagar (2007) and Altman & Stephens (2012) for overall summaries of forested-landscape wildlife-habitat relationships for the Pacific Northwest and northwestern California]. Some wildlife species are clearly associated with conifer-dominated habitat types; other species clearly respond positively to habitat types including broadleaved hardwood species. As described above for coastal Oregon, many hardwood species that are common in riparian hardwood habitats in drier northern California also occur in upland areas, maintained in these landscapes by periodic disturbances. Positive effects have been described independently both for broadleaved trees and for broadleaved shrubs, as many wildlife species (particularly birds) respond differently to variations in vertical habitat structure.

In drier interior northwestern California (and southwestern Oregon) forests, hardwood species are evolutionarily adapted to the effects of the Mediterranean-type climate and its seasonal (i.e., summer) drought conditions (i.e., oaks and their close relatives are often included in riparian areas). Oaks and other hardwoods are also dominant elements in the “alternative state” habitats maintained in geohydrologically suitable upland areas by fire and other disturbances. Post-disturbance succession in low- and mid-elevation conifer forests in northern California virtually always include stages dominated by shrubs and/or sprouting hardwoods, usually including at least one (tree and/or shrub) species of oak, tanoak, and/or chinkapin. Successional processes in northern California’s forested landscapes typically lead to patchy distributions of coniferous, hardwood, and shrub-dominated habitats, and the locations of these patches shift within the landscapes as a dynamic mosaic through time. In consequence, recurring disturbances (typically fires) maintain the alternative states as “dynamically stable” elements in these drier landscapes.

Box 3. Riparian and Non-Riparian Hardwoods in Northwestern California Landscapes

An enormous scientific literature exists addressing the structure, composition, and ecological processes and functions provided by riparian ecosystem elements; summarizing it greatly exceeds the scope of this memo. The word *riparian* is derived from a Latin word meaning "(river) bank", but in modern usage the term includes an ecological transition zone extending from shallow aquatic areas to upland/terrestrial areas that directly interact with the adjacent aquatic components (NRC 2002). Riparian areas encompass the margins of *lotic* (flowing streams and rivers), *lentic* (lakes and ponds), and *estuarine/marine* shores, all of which share some degree of dynamic biological and geochemical interaction among the aquatic and terrestrial components. [The NRC 2002 "riparian" concept functionally incorporates most areas traditionally identified as wetlands (NRC 1995), although wetlands may form in the absence of surface water when near-surface groundwater affects subsurface biogeochemistry; subsurface biogeochemical conditions are a key element for wetland vegetation, which is almost always present where groundwater gradients intersect the surface (Winter et al. 1998, Yu 2015, Dwire et al. 2016, Dralle et al. 2023.] Much scientific effort has been directed to identifying roles that riparian areas play in protecting water quality and in providing organic materials and energy to the aquatic elements in these ecosystems; this memo intentionally does not address this body of science.

A similarly vast scientific effort has been made to identify the significance of riparian areas as habitat for terrestrial wildlife species, largely independent of aquatic ecosystem elements. The definition of what constitutes "riparian habitat" is rather variable, as is the extent or width of the zone considered by various authors to constitute the "riparian habitat" area (Dwire et al. 2016). In general, riparian habitat implicitly (or sometimes explicitly) incorporates only vegetation dominated by deciduous broadleaved hardwood tree and/or shrub species. In addition, an implicit (or explicit) contrast is identified between riparian habitat and the habitat types in the adjacent uplands. In "moist" forests of the Pacific Northwest, upland plant associations are generally dominated by conifers, even though conifers also occur as part of the riparian habitat (often but not always the same species as in the uplands). However, not identifying conifer-dominated streamside areas as "riparian" is fundamentally inconsistent with the identification of riparian areas as "zones of tension" between the aquatic and terrestrial environments (NRC 2002), and with actual conditions in riparian areas described by many federal agency scientists studying riparian areas in the western US (e.g., Dwire et al. 2016).

In the Klamath and North Coast ecoregions (as in other California ecoregions), most low- and mid-elevation forested ecosystems include substantial landscapes in which broadleaved deciduous hardwood trees and shrubs dominate both riparian zones and portions of the uplands (e.g., Halofsky & Hibbs 2008). These landscape patterns exist in northwestern California for reasons described elsewhere in this memo, including the biogeographical and evolutionary histories of the plant and wildlife species that inhabit the region and the importance of adaptation to a Mediterranean-type summer-dry climate (and fire, it's fundamental stressor) since the mid-Miocene Epoch. This combination of conditions is particularly evident in the Klamath Mountains of northwestern California and southwestern Oregon (Atzet et al. 1996, Jimmerson et al. 1996, Sawyer 2007), although upland forests and woodlands elsewhere in most of northwestern California also show overlap among dominant tree and shrub species with riparian areas.

Broadleaved deciduous hardwoods, as well as several important evergreen hardwoods, are essential components in the variable plant associations that make up the shifting mosaic of vegetation types and wildlife habitats in northwestern California. A varying, dynamic combination evolutionary, ecological, climatic, and geohydrological factors maintains biological communities in the region's landscapes in "alternative stable states" that extend from riparian areas into adjacent uplands.

The co-occurrence of broadleaved hardwood species in riparian areas and other disturbed areas reflects adaptations by these species to open-canopy conditions. Riparian zones associated with steeper, lower-order streams (i.e., smaller headwaters streamcourses at higher elevations) generally lack hardwoods (Kampf et al. 2021; Box 3); consequently, the species that constitute "riparian wildlife" for most smaller headwaters streams are largely the same species that respond positively to conifer-forest habitat conditions in the adjacent uplands (McGarigal & McComb 1995). Broadleaved habitat elements increase the diversity of wildlife species both in riparian areas and in upland areas. For birds, broadleaved habitat elements (riparian and upland) result in an enhanced regional avifauna in summertime. Mixed hardwood/conifer forest types (and conifer forests with some hardwoods) in northwestern California and southwestern Oregon harbor a greater bird species richness than the conifer-dominated forests of the Oregon Coast Ranges and the Cascade Mountains. Neotropical migrant bird species, primarily associated with broadleaved vegetation, can compose more than half the total individuals in these habitat types (Ralph et al. 1991, Betts et al. 2010, Stephens et al. 2015).

Hardwoods (including both tree and shrub forms, arrayed in a variety of structural habitat types) sustain biodiversity, ecological processes, and resilience in northern California landscapes, and should explicitly be incorporated in updated management approaches for these landscapes. Increased habitat diversity within forested landscapes will help maintain the richness of native plant associations and wildlife species as well as maintaining or enhancing ecological connectivity, which is a principal management concern in the 2012 planning rules that can be addressed functionally only at landscape scales (Noss & Daly 2006; Brost & Beier 2010, 2012; Fremier et al. 2015; Hilty et al. 2019; Estes et al. 2021). Management that is adaptive to the effects of climate change and increased fire cannot be achieved without establishing landscape-scale approaches that make use of climate change-resilient hardwood species.

V. Conclusion: Northwestern California Landscapes Exist in Shifting Mosaics, a Framework Fostering "Alternative Stable Ecosystem States" and Resilience to the Effects of Changing Climate

Landscapes in northern California incorporate multiply varied vegetation patterns and wildlife communities that have been shaped by the geological and geographic history of the region, climatic variations that include the development of a Mediterranean-type climate with typical summer drought and recurrent fire, and the evolutionary histories of plant and animal lineages that have occupied the region in adapting to that ecological variability. For most of the Holocene, actions of Indigenous people were an additional influence on landscape conditions and dynamics (Kimmerer & Lake 2021). Scientists who have examined northern California landscapes have seen dynamically varying dominance by both conifers and broadleaved vegetation, generally characterized by landscapes having dynamically "alternative stable states" (Taylor & Skinner 1998, 2003; Sawyer 2006, 2007; Odion et al. 2010; Halofsky et al. 2011; Estes et al. 2017; Tepley et al. 2017; Miller et al. 2019; Schriver et al. 2018; McCord et al. 2020; Taylor et al. 2021; Jules et al. 2022).

Achieving landscape resilience in a future rife with drought, fire, and climatic variability is a fundamentally uncertain process, as is indicated in the variety of approaches suggested by various scientists (e.g., Jackson et al. 2009, Pausas & Schwilk 2011, Millar & Stephenson 2015, Parks et al 2016, Rissman et al. 2018, Hessburg et al 2019). There is no well-described "best' course of future management, but it seems to me that following the fundamental recommendation of Millar & Stephenson (2015), to anticipate future ecological and climate conditions and manage appropriately to maintain ecological services provided by forested landscapes, is good advice. In the framework of landscape ecology, northern California landscapes have existed, exist now, and are likely to exist in the future, as "shifting mosaics" of habitat patches of varying sizes, with varying compositions, structures, and functional processes (Pickett & Thompson 1978, Pickett & Cadenasso 1995, Turner & Gardner 2015). Sustainable management adapts to this dynamic by using the natural elements and processes in these landscapes in adapting to the effects of climate change on the region.

Climate change *will* alter California's ecosystems, and managers should anticipate altered composition, structure, and ecological processes in our landscapes, with ecological dynamics that may differ substantially from those today; future ecological communities will likely be composed of species combinations that differ from historical communities (i.e., to be 'novel ecosystems'). Ecosystem *realignment* to adapt to altered climate and landscape dynamics (Millar & Stephenson 2015) will likely be an essential part of planning for a climate-altered future. Realignment may involve 'assisted migration' of some species to new areas, but the adaptability of California's oak and other hardwood species, which are already present and co-dominant in those landscapes, should be a primary restoration consideration that can restore and/or sustain ecosystem resilience in an altered future.

VI. References

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ATTACHMENT 2

CHAD ROBERTS, PH.D.
SENIOR ECOLOGIST (ESA) (*EMERITUS*)
SENIOR PROFESSIONAL WETLAND SCIENTIST (SWS) (*EMERITUS*)

MEMORANDUM

TO: Interested Parties

DATE: 27 December 2023

SUBJECT: The Critical Zone, Riparian Areas, Ecohydrology, and Climate Change in Northern California Land Management Planning

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Federal agency land management in northwestern California has been based for roughly the past three decades on scientific perceptions that emerged in the early 1990s. Altered management circumstances in the past quarter-century include a growing recognition of the importance of stressors like climate change and increased fire, and a greater appreciation of the consequences of less-informed prior management directions. Federal agencies are currently engaged in updating management frameworks for these public landscapes, based on an improved understanding of these landscapes, including the nature of scientific processes that operate within them and the kinds of management policies that should apply to them. Among these recent scientific enhancements is knowledge about how water in these landscapes interacts with both biotic and abiotic elements above and below the land's surface to determine aspects of landscape functioning [e.g., as summarized by the National Research Council (NRC 2001, 2002) and other federal agency earth-science publications (e.g., Winter et al. 1998)].

Ecohydrological relationships exist among the geosphere, biosphere, and atmosphere. The nature and extent of these relationships is becoming an ever-more-significant subject of scientific concern because of climate change and its effects on global dynamics. The importance of incorporating the dynamics of water across the boundaries among these "spheres" has been highlighted by a developing focus on functional ecohydrological relationships in the "*Critical Zone*" (CZ; Figure 1). The CZ represents the elements of the "biological skin" of the Earth's surface. While its specific characteristics vary by location, the CZ represents a structurally unifying concept for ecohydrological analyses that jointly consider the interactions within this "skin" on dynamic processes, including the relationships of water with the geosphere and biosphere.

> "The CZ extends from the top of the vegetation canopy to the base of weathered bedrock or actively circulating groundwater. While the relative thicknesses of each layer will vary with tectonic history, lithology, vegetation types and climate, these layers of CZ structure are generally emergent and widespread. The aboveground CZ consists of the microclimate from the soil surface to the top of the canopy and the plants themselves. The belowground CZ is composed of layers that vary in their physical and biogeochemical properties as well as in their water storage capacity and nutrient supply. We highlight the soil, which lacks any bedrock structure, and is often physically detached and highly weathered; underlying saprolite that is also highly weathered but remains in situ, retaining relict bedrock structure; and weathered bedrock, which becomes increasingly less fractured and chemically weathered with depth and can extend many meters deep to the top of fresh bedrock. Groundwater (light blue zone at the base of the figure) fluctuates within the CZ. At some depth, weathered bedrock grades into fresh, chemically unaltered bedrock that is typically perennially saturated with equilibrated pore fluids. Both large, structural roots and fine, absorptive roots permeate soil and

> weathered saprolite and bedrock layers, acquiring essential life-supporting resources from both fracture and matrix-held water. Roots drive weathering deep in the unsaturated vadose zone where dynamic rock moisture is held. Plants cycle water and elements between the subsurface and the land surface and mediate hillslope and Earth system processes such as erosion, evapotranspiration, biogeochemical transformations and runoff. Thus, the vegetation integrates and mediates biogeophysical functions across and within the critical zone, and is in turn shaped by CZ processes, emphasizing the importance of the CZ to plant science as a whole and ecophysiology in particular." *(Source: Dawson et al. 2020).*

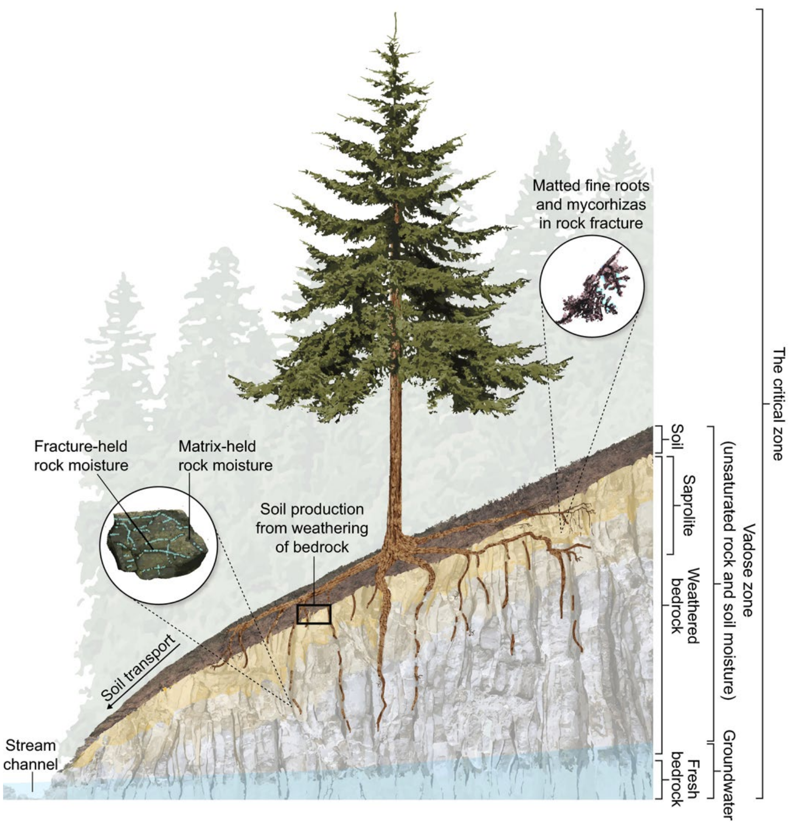

Figure 1. A cross-sectional look into a critical zone (CZ), with commonly observed layers defined along the right margin. Source: Dawson et al. 2020.

The CZ concept explicitly incorporates the dynamics of water within the substrate, (including groundwater) with the biological elements of the CZ (plant species and their roots and mycorrhizae). The concept builds upon long-established geohydrological understanding (see, e.g., Winter et al. 1998; NRC 2001, 2002) that surface water in streams and other aquatic features is functionally continuous with (and readily interchanged with) water below the ground's surface. In the Critical Zone concept, individual plant species (the vegetation that constitutes the upper part of the CZ) typically express various differences in their root system architecture and functions, and Critical Zone ecological dynamics can be shaped to significant degrees by the below-surface hydrology (Figure 2).

In Zone 1 of Figure 2, vegetation roots typically do not reach either the saturated groundwater zone or the capillary fringe above it, and vegetation must adapt to potential moisture deficits during dry periods. In Zone 2, plants with deep root systems (and/or certain mycorrhizal associates) can reach saturated/capillary rise substrate conditions during wet, but not dry, periods. Recent study results (e.g., Hahm et al. 2019, 2022; McCormack et al. 2021; McLaughlin et al. 2020) have shown that native California plant species (particularly native oak species, but likely including many other hardwoods) develop both a dense near-surface root system to capture precipitation as well as deeply penetrating "taproots" that enable perennial use of deeper groundwater (Zones 2 and 3).

Zone 3 and Zone 4 in Figure 2 include species that perennially utilize groundwater, and Zone 4 includes plant species that typically tolerate some degree of oxidatively reduced biogeochemistry;

these zones may encompass various structurally complex "riparian" habitats on floodplain margins and lower hillslopes (NRC 2002). Floodplains also typically include plant species that have evolved to tolerate long-term oxidatively reduced biogeochemistry (Zone 5). Communities at this end of the gradient are often identified as wetlands, and wetland scientists will point out that the continuum is Fig. 1 actually extends further into the aquatic zone, where a zone of interaction (Zone 6?) includes water above a saturated substrate surface. The fundamental relationship between wetlands and the downslope end of the Figure 2 gradient has long been evident to scientists investigating the CZ (e.g., Fan & Miguez-Macho 2011).

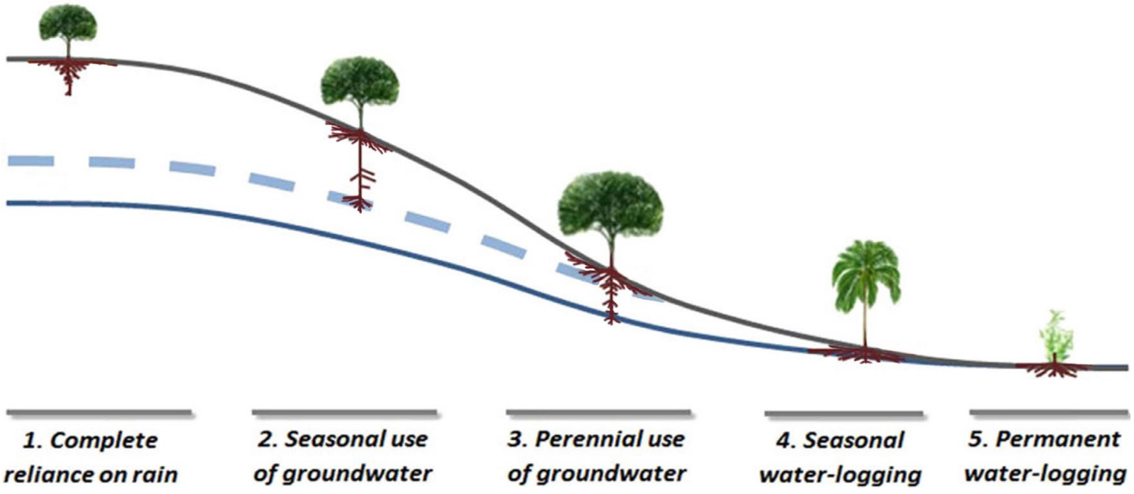

Figure 2. Schematic water table/rooting depth relations along a water table depth gradient. Groundwater surface indicated by solid blue line; seasonally increased groundwater surface indicated by dashed blue line. (Adapted from Figure 4 in Fan 2015.)

Figure 2 is an abstraction of fundamental ecohydrological relationships, a schematic "cartoon" that illustrates certain dynamic processes and evolutionary drivers that occur in the CZ. Real-world gradients are typically more complex, and the proximity of the saturated groundwater and land surfaces that result in wetland development typically also occur in other parts of any landscape (see examples in Winter et al. 1998). This brief summary of "CZ theory" is only a synopsis of current understanding about ecohydrological relationships in real landscapes, as well as a scaffold on which to base additional knowledge as it's learned.

In federally owned landscapes in northwestern California, recent research has demonstrated that dominant vegetation in many upland areas is related to, or even determined by, subsurface characteristics in the CZ. That is, the dominant vegetation in different parts of many northern California landscapes is related to the dynamics of subsurface hydrology, interacting with the annual variation in in precipitation in California's Mediterranean-type climate (Hahm et al. 2019, 2022; Dralle et al. 2023). While a detailed explication of these relationships exceeds the scope of this memo, the application of the CZ framework is particularly applicable to aquatic resources in the Klamath Mountains and Northern Coast Ranges ecoregions. For example, northwestern California's geology is dominated by accretionary processes related to tectonic plates and their interactions, leading to substrate conditions that vary regionally in terms of permeability and groundwater availability. As a direct consequence, CZ-related studies in recent years have documented that different substrates lead to differing ecohydrological dynamics in the region's landscapes. These differing dynamics have consequences for managing these landscapes pursuant to public agency mandates (Figure 3).

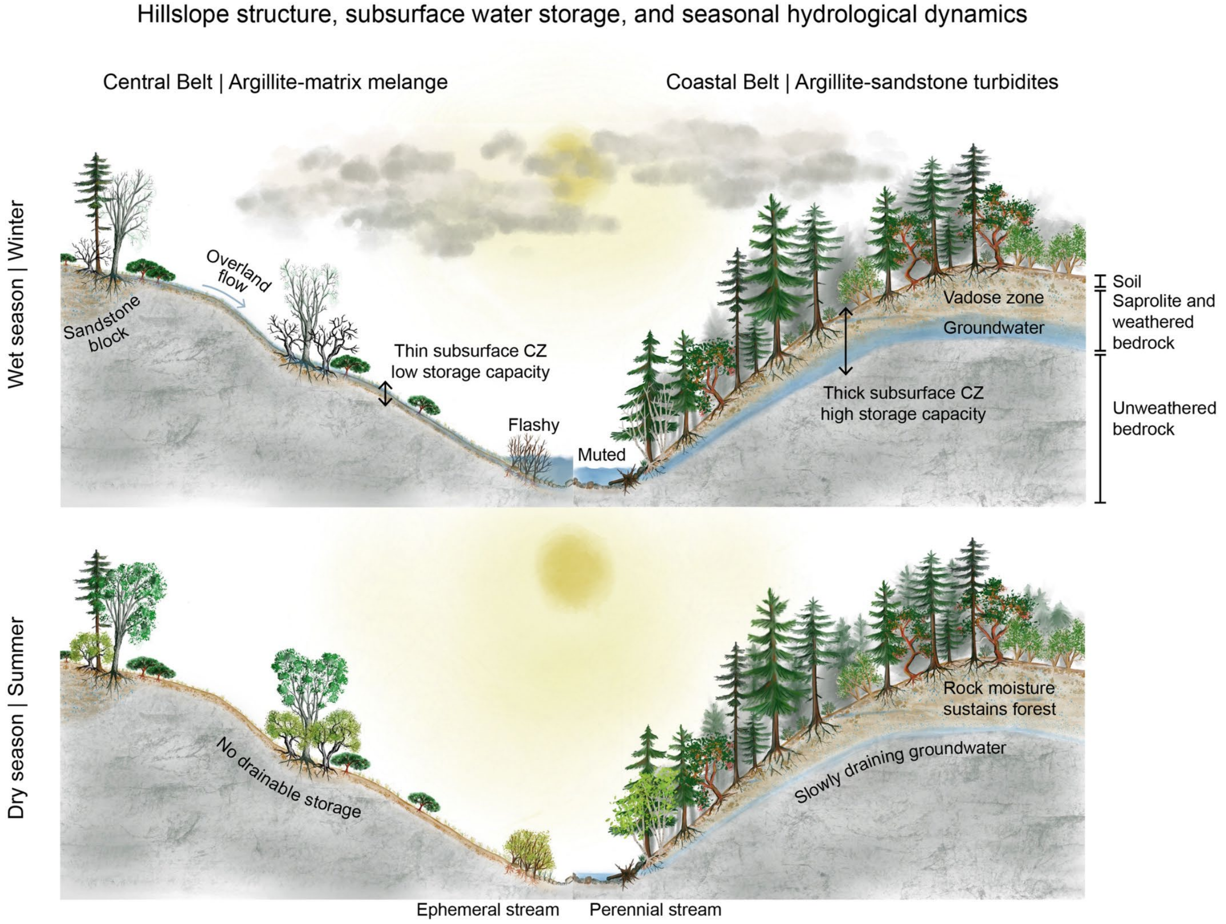

Figure 3. "Seasonal hydrological dynamics between hillslopes representing two dominant geologies in the Eel River watershed leading to contrasting critical zone (CZ) architectures and water storage capacities. A typical wet-season (winter) snapshot is depicted in the top row, while the bottom row illustrates conditions later in the dry season (summer). Stream conditions between the Central Belt mélange (left) and Coastal Belt turbidites (right) diverge following the last significant rainfall event of the wet season. The top row illustrates conditions in the spring/early summer when air temperatures have begun to increase and streamflow is beginning its long seasonal recession. The bottom row depicts late summer low flow conditions when air temperatures are high and water availability in the stream is approaching its annual minimum." Excerpted from Dralle et al. (2023).

Within the Franciscan Formation (a geological unit composed of sedimentary and metamorphic materials that underlie many northwestern California landscapes), the more highly metamorphosed "Central Belt mélange" is less permeable for infiltrating precipitation and storing groundwater than are the turbidite substrates in the "Coastal Belt". This fundamental difference in ecohydrology results in differing patterns in upland vegetation communities between the subregions, and to a substantial difference in streamflow dynamics, because the more-permeable Coastal Belt sustains both more stored groundwater and higher stream baseflows during summer than do the substrates in the less-permeable Central Belt [Figure 3; see the recent papers by Hahm et al. (2019) and Dralle et al. (2023) for additional information]. It should also be noted that CZ studies in more interior northern Coast Ranges sites (Hahm et al. 2022) extend this ecohydrology example to oak-dominated landscapes at lower elevations.

These CZ dynamics portend significant implications for public land management frameworks in northern California as climate-change effects in the region intensify. Regional climate projections universally include increased annual mean temperatures, intensified and longer hot periods in summer, and less nighttime cooling. Changes in precipitation patterns are less clear, but increased heat loading during the summer is functionally equivalent to intensified summer drought and greater vegetation moisture stress independently of precipitation, a general result documented in numerous recent scientific studies throughout the western US (e.g., Anderegg et al. 2013; Crockett & Westerling 2018; Spies et al. 2018; Hessburg et al. 2019, 2021; Gaines et al. 2022). Increased temperatures directly increase vegetation flammability, and climate change will likely increase both the likelihood of burning and the intensity and severity of fires throughout the West, altering post-fire successional patterns, as has occurred throughout the Neogene Period (Whitlock et al. 2003, Abatzoglou & Williams 2016, Tepley et al. 2017).

Projections of these effects on the dominant plant communities in northern California landscapes indicate that vegetation shifts are likely throughout the region, from conifer-dominated low- and mid-elevation landscapes to landscapes that include more broadleaved forests or woodlands and more shrub-dominated patches (Lenihan et al. 2008, Odion et al. 2010, McIntyre et al. 2015, Liang et al. 2017, Coop et al. 2020, McCord et al. 2020, Jules et al. 2022). These changes in vegetation/habitat patterns will likely be accompanied by shifting community compositions and population dynamics in terrestrial wildlife, including potential effects on species with direct implications for agency management.

The CZ dynamics summarized above have implications for aquatic programs to restore salmonid populations in northern California rivers in federally managed landscapes. Near-coast watersheds in these landscapes provide habitat for several listed fish taxa, and are explicitly covered by the Aquatic Conservation Strategy (ACS) in the Northwest Forest Plan (NWFP), which is in the initial stages of being revised/amended for the first time in three decades. Some aspects of the relevant aquatic science underlying potential revisions for the ACS have been identified (e.g., Reeves et al. 2018), but that assessment does not sufficiently incorporate recent knowledge emerging from California CZ science. The ACS assessment also fails to adequately reflect changes in fire dynamics and other aspects of the region's landscapes that must be addressed in updating these planning strategies, described further below.

The NWFP update process is subject to the requirements identified in the "2012 planning rule" (36 CFR § 219), including the requirement spelled out in § 219.3:

> **"219. 3 Role of science in planning.** The responsible official shall use the best available scientific information to inform the planning process required by this subpart. In doing so, the responsible official shall determine what information is the most accurate, reliable, and relevant to the issues being considered. The responsible official shall document how the best available scientific information was used to inform the assessment, the plan decision, and the monitoring program as required in §§ 219.6(a)(3) and 219.14(a)(4). Such documentation must: Identify what information was determined to be the best available scientific information, explain the basis for that determination, and explain how the information was applied to the issues considered."

Because the NWFP applies to management by both the USFS and the BLM, this federal regulatory standard explicitly affects other plan updates that must be consistent with the updated NWFP; i.e., revised plans for individual National Forests and BLM Field Offices must "use the best available scientific information to inform the planning process". In short, all management plans for northern

California federal lands managed by the USFS and BLM must incorporate the knowledge developed in the recent CZ science, in addition to information presented in both the *Science Synthesis for the Northwest Forest Plan* (Spies et al. 2018) and the *Bioregional Assessment of Northwest Forests* ("BioA"; USFS 2020) These expressions of broad scientific and management consensus reflect the Forest Service's current understanding of how climate change, and increased stressors interacting with climate change, affect federal land management in northern California. Agency management plans should also address the climate-change and fire-related interventions described in two recent General Technical Reports from the Pacific Southwest Research Station, PSW-GTR-270 (Meyer et al. 2021) and PSW-GTR-278 (Long et al. 2023).

In my opinion the plan amendments should include an updated perspective specifically for "riparian" concerns, including how riparian areas are affected by the CZ science, as well as a broader understanding that riparian areas are essentially transitional zones between aquatic and terrestrial ecosystems, including properties related to both. Current ecohydrological understanding of "riparian ecosystems" incorporates the following definition (NRC 2002; Figure 4):

> "Riparian areas are transitional between terrestrial and aquatic ecosystems and are distinguished by gradients in biophysical conditions, ecological processes, and biota. They are areas through which surface and subsurface hydrology connect waterbodies with their adjacent uplands. They include those portions of terrestrial ecosystems that significantly influence exchanges of energy and matter with aquatic ecosystems (i.e., a zone of influence). Riparian areas are adjacent to perennial, intermittent, and ephemeral streams, lakes, and estuarine-marine shorelines."

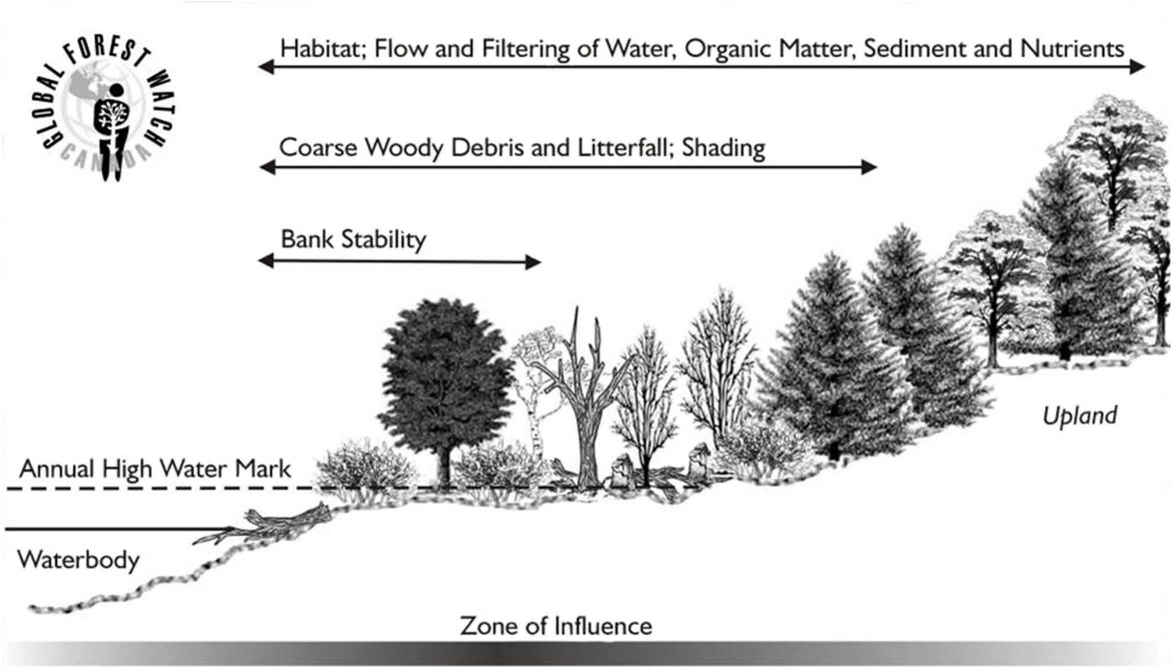

Figure 4. The "riparian area" for a given aquatic feature is functionally a "zone of influence" in which different riparian functions are provided, which extend variably into both the aquatic environment and the upland environment on floodplain, terraces, or slopes, depending on the function. Source: Global Forest Watch Canada, based on National Research Council (2002).

Riparian zones are not defined by or dependent on the presence of specific vegetation types (e.g., broadleaved angiosperms like willows or alders), although some plant species (both angiosperms and conifers) are more abundant and/or are more typically found in riparian areas and/or floodplains than are most plant species in a given landscape. As Figure 4 indicates, riparian zones affect the dynamics of several ecological processes in both the terrestrial and aquatic environments. Riparian resources may be ecologically significant in fairly narrow zones of influence (e.g., in low-order, steep watersheds with minimal floodplains) or quite wide zones of interaction (e.g., low-gradient river sections with wide floodplains). The relevant extent of a "riparian zone" is dependent on details of the riparian functions (or, often, on characteristics of a particular fish or wildlife species) on which a given discussion is focused.

Summarizing decades of river, floodplain, and riparian science vastly exceeds the scope of this memo, but all of that body of knowledge is relevant for appropriate management of riparian areas on federal lands, particularly because most climate science is consistent with a conclusion that warmer ocean and atmospheric dynamics are likely to result in more intense (if less frequent) storms, with resulting intensified hydrological dynamics in northern California watersheds. The expected conjunction of more intense hydrological events, an increased summertime drought/water deficit, and a likelihood of more frequent and intense wildfires in northern California landscapes represents dynamics that are not reflected in current agency land management frameworks.

The Forest Service's *BioA* reflects a recognition that landscapes in northern California (and in Oregon and Washington) that are addressed in the NWFP do not conform to expectations embedded in the current NWFP, such as that all of the forested landscapes in the region are fundamentally the same ecologically. Landscapes near the Pacific Ocean typically receive more precipitation and are wetter throughout a typical year than are landscapes farther inland, but the current NWFP does not reflect this recognition, and the plan essentially presumes that all forests covered by the NWFP are ecologically elements of the coastal "moist forest" types. However, current ecological understanding is that forests in inland landscapes covered by the NWFP are fundamentally different because they're associated with more-frequent fires than occur in the "moist forests".

"Frequent-fire" landscapes differ from "moist" coastal forest landscapes in several key aspects, most particularly in the reduced presence of abundant standing and down dead wood (i.e., "fuels") in dry forests and associated effects on fire occurrence and intensity. The distinctions among "moist" and "dry" (or frequent-fire) forest dynamics in the NWFP zone of coverage are a significant concern for the NWFP amendment; see Spies et al. (2018) and USFS (2020) for background, and Franklin et al. (2013) for a discussion of potential silvicultural practices that may better address "dry forest" dynamics in northern California forest landscapes.

The ACS included in the current NWFP is structured to assure that riparian areas (which may be designated in one or more of several different but overlapping protection zones) are able to accumulate coarse woody debris, which is understood to be a significant element in "moist forest" streamcourses [e.g., Naiman et al. 2000, 2010; Pettit & Naiman 2007; Reeves et al. 2018 (and other chapters in Spies et al. 2018); USFS 2020]. In addition, the ACS includes elements to assure that woody fuels are incorporated into management of nearby non-riparian areas to reduce potential erosion. Current evidence (e.g. Van de Water & North 2010, 2011; Dwire et al. 2010, 2016) indicates that riparian zones in most landscapes are (somewhat) resistant to high-intensity fire when water is present, but in inland regions of the Pacific Northwest where many streams are ephemeral or intermittent, riparian areas dry out during the Mediterranean-type climate's summer drought and may burn with greater intensity and severity because they're more productive and can accumulate greater fuels than adjacent upland areas. The *Science Synthesis* (e.g., Reeves et al. 2018) has identified this apparent dichotomy in management focuses as an important concern for the NWFP update, and riparian management in forested landscapes elsewhere in the region has also been identified as a management concern for Forest Service managers (Van de Water & North 2010, 2011; Dwire et al. 2010, 2016, and additional papers by Dwire and her colleagues).

Additional fuels loading in frequent-fire interior landscapes, either in riparian areas *per se* or in adjacent uplands, is unlikely to be consistent with protecting riparian areas and riparian resources in a future with increased summer drought and greater potential for high-severity fire. For example, some existing management approaches based on existing ACS elements in the NWFP likely should *not* be continued in frequent-fire forested riparian areas:

- Amended plans should likely *not* identify enhancing down woody material in riparian areas or in lower-order stream channels in upper basins in frequent-fire forested landscapes. Evidence indicates that this approach leads to increased energy release and higher-severity burns when riparian areas dry out under late-summer conditions. This is likely to be a concern more in the northern California interior than in "moist forest" landscapes closer to the Pacific Ocean, where a restoration of coarse woody material in larger stream and river channels likely does enhance habitat conditions for sensitive aquatic species.
- Amended plans should likely *not* identify retaining excessive amounts of down woody material at any elevation in frequent-fire forests as a wildlife habitat management approach. Large volumes of down woody material are not compatible with fuels management practices that include prescribed fire or managed wildfire, or the development of fire-resilient plant communities in frequent-fire forests. This is more likely to be a concern in interior California landscapes than in "moist forests" closer to the Pacific Ocean, where retaining large down material to enhance habitat conditions for selected sensitive wildlife species (e.g., large, rotting logs for Plethodontid salamanders) may be appropriate.
- Amended plans should likely *not* identify a widespread retention of slash or woody residue that may result from project activities as an erosion-prevention measure in frequent-fire forests, as there's clear evidence that such fuels can exacerbate the severity of follow-on fires in these areas. Many (perhaps most) treated stands in frequent-fire forests will develop sufficient shrub cover from existing seedbanks or living root systems within about two years to prevent excessive erosion within the project area; natural shrub regeneration may itself lead to high fuels loadings that require management intervention to reduce future fire severity.

The planning framework embedded in the 2012 planning rules identifies sustaining riparian zones as a specific focus in amending and updating national forest land management plans. That focus is also germane for addressing another overriding planning focus in the 2012 planning guidance, the maintenance of landscape connectivity. Recent Forest Service management plan updates for southern Sierra Nevada national forests provide an example of how landscape connectivity can be a focus in these planning contexts (e.g., Estes et al. 2021). Stream and river systems, and the riparian habitat elements that shade and protect them, are fundamentally an interconnected system of habitat elements, often constituting the most intrinsically connected habitat network in a landscape (e.g., Fremier et al. 2015). The stream and riparian area "lattice" within managed landscapes likely should be considered as a starting point for establishing and maintaining landscape connectivity in those landscapes, as the availability of moisture during the annual summer drought is likely to be greater in these locations than in other parts of the landscapes under an altered climate.

The 2012 planning rule recognizes the significance of interacting ecological elements in managed lands. A similar recognition forms the basis of an ecological/evolutionary framework known as *complex adaptive systems* (CAS), which is a perspective that *ecological systems* (that is, complexes of interacting elements in the natural world) mutually adapt to altered environmental conditions (e.g., Levin 2005). For example, a given landscape will include a complex of interacting species (the elements in the system) and their physical environment. When environmental conditions (e.g., ambient temperature or available moisture) affecting that landscape are altered (for example, by climate change or more frequent fires), the elements (species) will mutually adjust their dynamic interactions to adapt to the altered conditions. Some forest ecologists have advocated the CAS framework as a unification of traditional forest silvicultural management with ecosystem theory (e.g., Filotas et al. 2014, Messier et al. 2019). Notably, the Critical Zone concept explicitly includes all the elements recognized to be parts of the CAS framework for landscapes, but with an increased emphasis on subsurface ecohydrological elements that have not been well-studied previously.

The CAS framework emphasizes that the interacting systems will/must adapt to altered conditions. Such adaptation is to be expected evolutionarily and ecologically, but an expectation that landscapes subject to agency management are likely to be altered by changing climate and other dynamics is not a "traditional" perspective in many land management agencies; the general expectation is that managed landscapes exhibit a "*stationarity*" in conditions over time: i.e., "the future will pretty much look (and act) like the past". This expectation of stationarity in landscape conditions is embedded in the concept of an "historical range of variation", which is explicitly identified in the Forest Service's 2012 planning rules as a reference concept. The expectation of stationarity creates a significant barrier to informed climate-change adaptation, and alternative perspectives are needed within agency decision-making processes (Figure 6).

Recent CZ studies in northwestern California have demonstrated that vegetation dynamics in this region result, in part, from intrinsic ecological difference among plant competitors (e.g., conifers vs. hardwoods; Hahm et al. 2019, 2022). Hardwood trees, and oaks (*Quercus* spp.) in particular, are well documented to exhibit adaptations to fluctuating moisture availability, including root systems that allow use of groundwater at both shallow and deep levels (i.e., zones 2 and 3 shown in Figure 2, and for some species typically adapted to riparian habitats, even zone 4). Climate-based projections of vegetation changes in northern California frequently project an increased landscape coverage by hardwood and mixed conifer-hardwood forests and woodlands at low and mid-elevations. Scientists have identified angiosperm-dominated community types as ecologically stable, disturbance-maintained alternatives to conifers at these elevations, and results from studies over longer periods have confirmed that shifting vegetation dominance in the region is already detectable [e.g., Odion et al. 2010, McIntyre et al. 2015, Coop et al. 2020, McCord et al. 2020, Jules et al. 2022, Roberts (in review)].

Updated management plans for public lands in northern California need to incorporate the interrelated threads of enhanced knowledge briefly summarized in this memo. Some of this "new science" is an extension of what was known when prior plans were developed, and some represents interrelationships that were poorly understood or largely unknown in the past. In my opinion, the improved overall framework for the ecohydrology of the Critical Zone in northern California landscapes represents a significant, even fundamental, enhancement of relevant science, but it seems likely that federal land management agencies are not currently well-prepared to incorporate it into management plans, largely because there's no existing compilation of the relevant subsurface data for groundwater storage and dynamics[1], and generating additional site-specific data is expensive in terms of personnel time and operational expense.

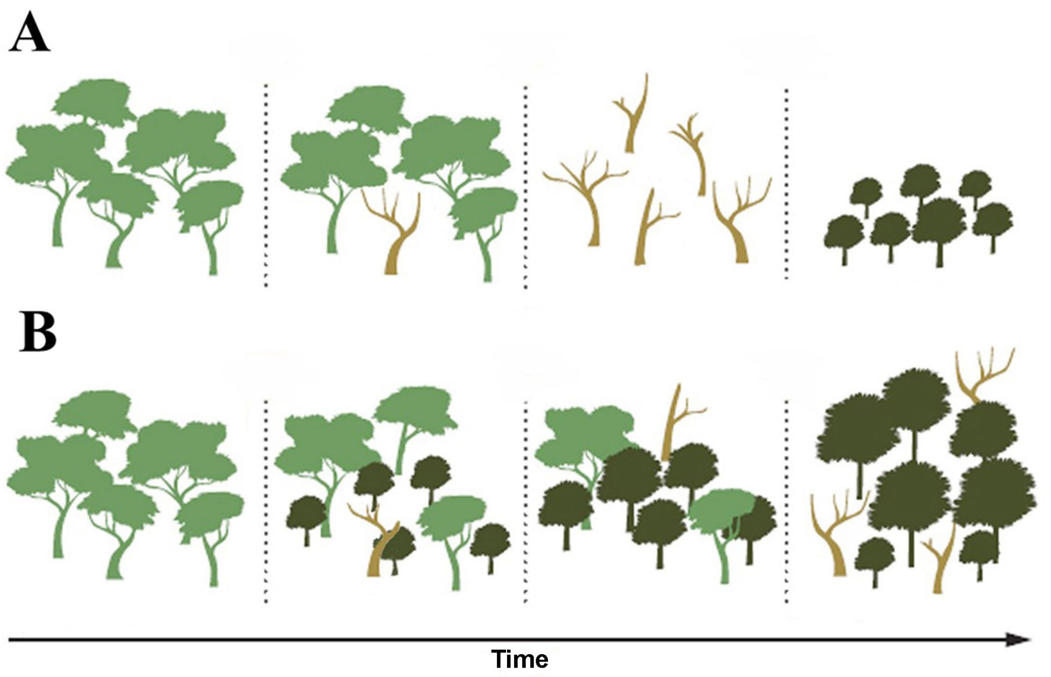

Figure 6.(A) A failure to anticipate climate-change may result in a significant reduction in ecological functions and a loss of ecosystem services. Ecosystem services may rebound following a system collapse, although altered structure, composition, and processes may not replace all services that were lost. (B) Anticipating (and potentially assisting) transformational changes in managed ecosystems can prevent system collapse and help to maintain ecosystem services, although the altered structure, composition, and processes may result in different levels (or kinds) of services provided. (Modified from Millar & Stephenson 2015.)

Scientifically, water is involved in an integrated dynamic process that includes the atmosphere, flowing and ponded surface water bodies like rivers and streams, both shallow and deep groundwater within floodplains as well as in uplands, and the vegetation which forms the outer skin of the Critical Zone (Dawson et al. 2020). The boundaries among these physical states and locations reflect continuous interchanges and transitions, driven by a number of biological, physical, and environmental processes. Management plans for these ecohydrological resources need to reflect the variability of northern California's geological and geographical conditions, the variations in climate-related forcing across the region, and an understanding of how climate change (and changes in stressors like fire, insects, and pathogens) will affect the future dynamics of these resources.

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[1] It should be noted that data regarding groundwater availability in surface soil layers for most of the United States are compiled by the NRCS as part of the SSURGO dataset, and management agencies likely would benefit from incorporating these existing data into plan amendments and updates (also see the paper by McCormick et al. 2021). The data developed by the site-specific Critical Zone studies identified in this memo address water in deeper rock layers, and such data have generally not been compiled for most of the US.

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