Post-fire vegetation transitions are occurring in the Northwest and the mechanisms behind these transitions are partially understood, however, we lack key information about what areas will be most vulnerable to transitions in the future and how and why the effectiveness of management actions varies across sites and years. The following key findings are organized by questions posed by the Deep Dive Biophysical Dimensions working group.

What is a post-fire vegetation transition?

Many terms have been used to describe vegetation transitions (e.g., state change, regime shift, conversion; Scheffer et al. 2001, Beisner et al. 2003, McKenzie and Tinker 2012, Coop et al. 2020), however, explicitly defining transitions is both difficult and context dependent. These terms all share three important features: 1) the change in vegetation is abrupt, 2) it involves crossing a threshold where recovery to the previous conditions are unlikely, and 3) the change leads to new and persistent ecological properties. There are also common concerns when identifying whether vegetation change qualifies as a transition. Does the change fall within the natural variability of an ecosystem? What timeframe constitutes persistence? Finally, identifying whether a transition has occurred must be based on understanding the ecological history, including the traditional practices and use of fire that helped shape the landscape prior to fire exclusion and suppression of indigenous burning (Lake 2007, Lake et al. 2017, Secaira 2019). What qualifies as a vegetation transition, and whether or not that transition requires management intervention, is contextual and heavily dependent on the values of the people who interact with the ecosystem.

Where are these transitions occurring and where will they occur in the future?

Post-fire vegetation transitions have been observed in forest and sagebrush ecosystems in the Northwest. For example, parts of the sagebrush ecosystems in eastern Oregon and Washington have transitioned to grasslands, often dominated by exotic annual species, following fire (Davies et al. 2012, Bates et al. 2014, Davies and Bates 2017). These transitions are more likely in Wyoming big sage than mountain big sage, in warm-dry than cold-moist sites, in areas with other conditions favorable to annual grasses (e.g., soil disturbance, lack of biological soil crusts; Reisner et al. 2013), or following repeated fires (Condon et al. 2011, Davies et al. 2012, Chambers et al. 2014, Nelson et al. 2014, Davies and Bates 2017, Mahood and Balch 2019). Dominance by annual grass species like cheatgrass (Bromus tectorum) following fire can increase fire frequency (Balch et al. 2013), thus reducing the likelihood that sagebrush species will reestablish over time. Sagebrush ecosystems are also experiencing juniper encroachment due to historical grazing and fire
suppression, which increases fuel accumulation and leads to more severe fires that result in high shrub mortality and post-fire conditions dominated by weedy vegetation (Condon et al. 2011, Bates et al. 2014).

Failures of post-fire tree regeneration in dry conifer forests have also been observed in the Northwest. For example, studies of post-fire regeneration in dry conifer forests in the Eastern Cascades, Blue Mountains and northern Rockies found that roughly 30% of sampled plots contained no conifer regeneration 5-21 years post-fire (Dodson and Root 2013; Kemp et al. 2016, Boag et al. 2020). Although in some forest systems, post-fire regeneration can continue for decades (e.g., for shade tolerant species), there is a window of opportunity in the first 10 or so years post-fire when much of the conifer regeneration naturally occurs. One of the main drivers of limited post-fire conifer regeneration in these studies was a lack of seed source due to large high-severity patches, which will continue to limit the potential for conifer regeneration in these sites for the next couple of decades, at least. Regeneration failure was also more likely at lower elevations and on warmer and drier aspects (Dodson and Root 2013, Kemp et al. 2016, Stevens-Rumann and Morgan 2016, Boag et al. 2020). However, in many sites in the Northwest, abundant post-fire tree regeneration has occurred in the past few decades, especially if a seed source is nearby and in moister forest types (Harvey et al. 2016, Kemp et al. 2016, Stevens-Rumann and Morgan 2016, Urza and Sibold 2017, Downing et al. 2019, Littlefield 2019, Povak et al. 2020). In subalpine forests, regeneration failure was less likely than in drier forest types, although lower tree regeneration densities have been observed when the first few years following fire are particularly hot and dry (Harvey et al. 2016, Urza and Sibold 2017). Repeated fires at short-intervals (e.g., <30 yrs), especially when they burn with high severity, have also led to very limited or a complete lack of post-fire tree regeneration in some locations in the Northwest (Stevens-Rumann and Morgan 2016, Busby et al. 2020).

Spatial predictions of where post-fire vegetation transitions are most likely have been produced for a few areas in the Northwest. For example, there are publicly available spatial predictions of areas that are most likely to be resilient to fire (recover to conditions similar to pre-fire) in rangeland systems based on soil temperature and moisture (Chambers et al. 2019), however, these predictions are not available for future climate scenarios. While there are no explicit predictions of resilience to fire under future climate conditions in Northwest rangelands, predictions of species’ ranges under future climate suggest that cheatgrass could expand and big sagebrush could decline (Schlaepfer et al. 2012, Still and Richardson 2015, Bradley et al. 2016). In forest systems, spatial predictions of areas that may be vulnerable to post-fire vegetation transitions under current and future climate are limited to drier forests in the Rockies and Blue Mountains (Campbell and Shinneman 2017, Parks et al. 2019, Davis et al. 2020). Overall, there is a need for more spatially explicit predictions of areas vulnerable to climate-driven, fire-catalyzed vegetation transitions at scales relevant to management. Improved projections of future fire properties and post-fire regeneration of different species would aid in assessing the vulnerability to post-fire transitions.
What are the options for managing climate-driven, post-fire vegetation transitions?

There are many ways to think about management decisions surrounding climate-driven, post-fire vegetation change. Based on working group discussions, we frame our discussion of the biophysical knowledge surrounding managing these transitions around the resist, accept, direct framework (Aplet and Cole 2010). Common concepts such as resilience and restoration fit within this framework, but this framework can help provide more specificity in terms of management actions. Decisions about where to resist, accept or direct change are complex and will depend on the social-ecological context. Below we discuss mainly the biophysical context, and thus when making these decisions, it is important to consider other sources of knowledge as well.

**Resist - Managers choose to resist post-fire vegetation transitions.**

In a biophysical context, areas that provide important ecological functions but are slow to regrow could be prioritized for resisting vegetation transitions. For example, critical wildlife habitat, old growth forests, microclimate and fire refugia, areas with high sagebrush cover, and areas that help maintain landscape connectivity may be a priority (Frey et al. 2016, Hessburg et al. 2016, Halofsky et al. 2018b, Chambers et al. 2019, Coop et al. 2019, Krawchuk et al. 2020). Areas at risk of post-fire exotic species invasion, important for ecosystem services (municipal watersheds, timberlands, carbon mitigation projects), or important for cultural reasons may also be prioritized (Halofsky et al. 2018b, Chambers et al. 2019, Wynecoop et al. 2019). There are four overarching strategies that may help to resist post-fire vegetation transitions:

1. **Reduce fire severity** - Fuel reduction treatments have been found to be effective at reducing fire severity in forest and sagebrush systems (Prichard and Kennedy 2014, Moriarty et al. 2016, Prichard et al. 2020). In forests, treatments that combine thinning and prescribed fire are more effective than those that use thinning alone (Prichard and Kennedy 2014, Prichard et al. 2020). In sagebrush systems, the effect of treatments may be short-lived or have other unintended ecological impacts, such as facilitating transition to grassland during prescribed burning to control juniper encroachment (Bates et al. 2014, Pyke et al. 2014). Another option to reduce severity is managing wildfires for resource benefit when they burn under moderate fire weather conditions (Parks et al. 2015, Halofsky et al. 2018b, Parks et al. 2018).

2. **Reduce fire extent** - Fuel breaks can be implemented around high-value resources, especially where fuel treatments may be less effective (e.g. wetter forests; Moriarty et al. 2016, Halofsky et al. 2020). In sagebrush, fuel breaks may reduce fire spread, however, it is still unknown how effectiveness varies with conditions and what their
ecological impacts are (Shinneman et al. 2019). In some ecosystems, such as sagebrush or forests with stand-replacing fire regimes, fire suppression may be a useful management strategy (Halofsky et al. 2018b, Chambers et al. 2019). Pre-positioning fire-fighting resources where fuel and weather conditions increase fire risk may increase efficacy (Chambers et al. 2019).

3. **Replant following fire** - In forest systems, following fire, planting at lower densities and with variable spatial patterns can increase resilience to future fire and drier conditions (Hessburg et al. 2016, Halofsky et al. 2018a, North et al. 2019). Microsite planting, fall planting and seedling drought conditioning may increase seedling survival (Halofsky et al. 2018a, Halofsky et al. 2020, Hill and Ex 2020, Sloan et al. 2020). In rangelands, seeding with a variety of seed sources, multiple seeding methods, and over several years, can increase perennial establishment, and seeding sagebrush soon after fire can minimize the risk of herbaceous competition preventing establishment (Pyke 2011, Brabec et al. 2015, Davies and Bates 2017, Davies et al. 2018). Seed enhancement technologies may also increase native perennial establishment success (Madsen et al. 2016, Davies et al. 2018).

4. **Reduce exotic annual grass cover** - Reducing exotic annual grass cover may both promote establishment of natives and reduce future fire risk (Chambers et al. 2007, Balch et al. 2013).

**Accept** - Managers choose to accept post-fire vegetation transitions.

In a biophysical context, it may make sense to accept post-fire vegetation transitions on south-facing and/or steep slopes, sites with poor soil or sites that already have marginal climate or environmental conditions for the pre-fire dominant species (Hessburg et al. 2016, Halofsky et al. 2020). In forest ecosystems, many of these areas may not have been forested historically and allowing the development of non-forest patches can help reduce the likelihood of large high severity fires in the future (Hessburg et al. 2015, Hessburg et al. 2016, Hessburg et al. 2019). In sagebrush systems, it may be necessary to accept transitions where restoration of sagebrush is unlikely to be successful due to climate or edaphic conditions and cover of exotic annual grasses is already very high (Chambers et al. 2019). In both systems, managers may also choose to accept transitions where resisting would require significant resources and/or repeated intervention (e.g. remote areas, challenging terrain, marginal climate). Post-fire vegetation transitions may also be accepted in landscapes where allowing ecological disturbances to operate is the primary objective (e.g. wilderness; Halofsky et al. 2018b). Although accepting transitions sounds passive, it can be an active decision and long-term monitoring will be key for understanding what these landscapes will transition to and if any changes in management need to be made in the future.
**Direct** - Managers choose to direct post-fire vegetation transitions to more desirable state.

Directing vegetation transitions is surrounded with substantial uncertainty and decisions about directing change will depend both on what is biophysically possible and on management goals, ethics, risk assessments and policies guiding management. Areas where directing change following fire may be considered include areas that will transition to exotic plants without intervention or where the climate is no longer suitable for the dominant pre-fire species. Prior to wildfire, vegetation change may be directed on important cultural landscapes where fire suppression has led to a loss of food sources, ceremonial sites or other important cultural features (Hasan 2018, Karuk Media 2019, Wynecoop et al. 2019). Although the effectiveness of different strategies at directing vegetation change is a key knowledge gap, the literature suggests the following may be potential management options:

1. **Promote partnerships between tribes and federal agencies** - Traditionally, Indigenous people have directed vegetation change through burning and other management practices, creating a depth of understanding about how and when to manage specific landscapes to achieve specific outcomes (Lake 2007, Hirtle 2019, Karuk Media 2019, Secaira 2019). Thus, working to incorporate tribes and Traditional Knowledge into management of non-tribal lands may improve management outcomes (Lake et al. 2017, Hasan 2018, Wynecoop et al. 2019, Oberman 2020).

2. **Assisted migration/gene flow** - Planting species or genotypes from warmer/drier sites in cooler/moister sites may improve planted seedling survival and adaptation to future climate conditions (Schreiber et al. 2013, Butterfield et al. 2017, Richardson and Chaney 2018, Crotteau et al. 2019, Halofsky et al. 2020, Young et al. 2020). However, cold temperatures may be more limiting to big sagebrush establishment in some cases than water deficit (Brabec et al. 2017) and can also limit survival of conifer seedlings moved from warmer climate zones (St Clair et al. 2020). Additionally, in some cases, local seed sources fare better due to non-climate-related traits (e.g., pathogen resistance; Wilhelmi et al. 2017). Overall, there is limited research testing the effectiveness of this practice (Young et al. 2020), although workshop participants highlighted that some regions (e.g., in California) are starting to adjust seed transfer zones to better match changing climate conditions.

3. **Change traditional seeding or planting guidelines to better match future predicted conditions** - In sagebrush systems, following fire, this may entail seeding plants that are adapted to a wide range of climatic conditions (Chambers et al. 2017). In forests, this includes planting fire- and drought-resistant tree species at low densities (Hessburg et al. 2015, Hessburg et al. 2016, Halofsky et al. 2018a, Crotteau et al. 2019).
What are remaining uncertainties to consider when evaluating whether to resist, accept or direct change?

There are uncertainties regarding the tradeoffs between deciding where to resist, accept or direct change, partially due to unknowns about how long we can effectively resist change, what landscapes will look like if we accept change, and what management options we have for directing change (Coop et al. 2020). Past studies have assessed the effectiveness of a variety of management strategies relevant to post-fire vegetation transitions, but a key knowledge gap is understanding how and why outcomes may vary across years or sites. For example, the effectiveness of management actions may vary due to differences in climate or weather conditions, vegetation type, soil type, successional stage, land use history, cover of exotic plants, nursery practices, stock type or seed source (e.g., Davies et al. 2009, Bates et al. 2014, Brabec et al. 2015, Dumroese et al. 2016, Davies et al. 2018, Germino et al. 2018, Hardegree et al. 2018, Prichard et al. 2020). Understanding how these factors affect the outcomes of management actions will help managers understand where certain actions may help resist vegetation transitions and where management may be less likely to succeed and transitions could be accepted. In some cases, there are many existing site-specific studies (e.g., post-fire seeding in sagebrush), and a detailed synthesis or meta-analysis of these studies may address this knowledge gap; however, for other potential management actions, new research may be needed to understand how effectiveness varies across sites and years. Additionally, more research is needed on the long-term outcomes and non-target effects of management actions.

Are there existing online tools to help make decisions about managing climate driven post-fire vegetation transitions?

We found over 75 tools that include climate projections, fire predictions, fire observations, landscape data, management planning tools, and seedlot selection tools, among others. There are also websites that collect a subgroup of these tools in one place. However, guidance on which tool to use when and where is largely lacking, and there is very little evaluation of the effectiveness of these tools in achieving or informing desired management outcomes. Deep Dive participants in the fall workshop noted that: 1) existing tools need further evaluation, 2) tool development should be a collaborative process between developers and users, 3) tools should be developed that meet specific needs of managers and stakeholders. Currently, too many of these tools fall into the category of “if you build it, they will come”, and there is a need for co-producing tools that align with associated objectives and that can be easily integrated into on-the-ground decision making.

This database contains links and summaries for the tools found through this synthesis, broken into groups to make finding relevant tools easier. Currently tools are sorted into the following thematic groups: Climate Projections, Planting, Fire Predictions, Fire Observations, Management, Landscape and Biome and Miscellaneous. These tools have not been fully vetted, and further action is required in order to prioritize and assess for recommended use.
The working group identified several research and capacity-building needs to address knowledge gaps, summarized on the following two sections.

### RESEARCH NEEDS

- Spatial projections of plausible ecological futures including future fire properties, post-fire regeneration of specific species and vulnerability to post-fire transitions at scales relevant to management.

- Identification or prediction of novel interactions between/among species and processes.

- Assessment of the adaptability of existing populations to future climate and fire conditions.

- Improved understanding of how and why management outcomes vary between years or sites and what the long-term outcomes and non-target impacts are.

- Improved understanding of the tradeoffs between decisions to resist, accept or direct change.

- Identification of how existing decision-support tools overlap and if key tools are missing.

- More coordinated and widespread monitoring to understand what landscapes look like following transitions, to identify novel interactions as they emerge and to assess long term impacts of management.

### CAPACITY-BUILDING NEEDS

- Improved collaboration between tribes and non-tribal agencies to promote more tribal involvement and use of Traditional Knowledge on non-tribal lands.

- An interactive online platform where managers can share local outcomes and researchers can share results in an informal way to create a community of practice and to promote the transfer of biophysical knowledge between and among practitioners and researchers.

- Organization, evaluation and guidance on how and when to use the many existing online decision-support or data-gathering tools, including the potential to share user experiences with different tools.
REPORT AUTHORS

This summary was written by Kimberley T. Davis, Drew Lyons and Caroline Walls.

REFERENCES CITED

This summary is based on input from working group meetings and a large number of references. Many of the references are listed below, but more references can be found on this map.


Karuk Media. 2019. pananu’thívthaaneen xúus nu’êethtiheesh: We’re caring For Our World.


