A Review and Recommendations for Assessing Floodplain Vegetation Recovery Following Stage 0 and Beaver Dam Analog Restorations in the Pacific Northwest

by

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ABSTRACT OF THE PROJECT OF

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Floodplains are a significant and increasingly threatened ecosystem. As restoration projects are implemented more frequently in degraded floodplains, novel methods are emerging with a focus on restoring critical processes in which vegetation plays a key role. The purpose of this paper is two-fold: 1) to develop expectations for vegetation response, and 2) to provide recommendations for implementation and monitoring of emerging restoration methods that fit within both the ecological and social frameworks of the landscape. First, I conduct a review of vegetation recovery following dam removal and floodplain reconnection to provide an assessment of potential vegetation responses and riparian plant community development for two novel types of stream restoration that are emerging as potentially valuable techniques, but which have limited data on vegetation recovery: Stage 0 restoration and beaver dam analogs (BDAs). Second, I provide recommendations for implementing restoration monitoring of vegetation for these two emerging restoration methods that are derived from this review. Because these restoration methods are new, there is a dearth of empirical data on these specific actions, but a review of the literature from related stream restorations provides insight into what may be expected. Further, restoration is often conducted with a focus on the physical and biological dynamics of the system with little regard for the social dynamics, yet the implementation and evaluation of restoration social frameworks can be as important as ecological frameworks. Therefore, I include social as well as biophysical factors in evaluating and making recommendations for vegetation assessment in these novel types of restoration. Focusing specifically on floodplains in small river systems in the Pacific Northwest (PNW), I address vegetation disturbance responses, natural recruitment of forbs and shrubs, nonnative vegetation, replanting efforts, and sociocultural considerations. In developing expectations for vegetation responses, the objectives of the paper are to explore the questions: 1) What do we expect to see in terms of plant community development following Stage 0 restoration and beaver dam analogs, 2) how does this affect recommendations for how floodplain restorations with these treatments are managed, and 3) how do these recommendations fit within the social context of the landscape? These questions were addressed through a review of the fairly limited literature on Stage 0 restoration and beaver dam analogs and the development of a conceptual framework based on a systematic review of dam removal and floodplain reconnection studies. In doing so, 6 key recommendations were identified. These include: 1) Restoration should be placed in a disturbance framework, 2) Restoration should be placed within the social framework of the system both locally and at a landscape scale, 3) Restoration should include more research in order to understand variability across systems, 4) standardization of metrics and tools for evaluating vegetation response, 5) Restoration should include more vegetation monitoring and consideration of long-term processes, 6) Restoration should include active revegetation and facilitation of natural recruitment.

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CONTENTS

INTRODUCTION

River floodplains support important ecosystems, possessing significant social and economic value, and provide key species-specific habitats. Floodplains disproportionately support biodiversity and ecosystem processes in comparison to other landscapes, providing cool, moist microclimates and offering connectivity to species across elevational and climatic gradients (Kremen & Merenlender, 2018). Critical ecological processes of floodplains include redistributing sediment and organic matter during flood pulses, erosion and deposition of sediment (storage), storage and routing of water, and nutrient retention (Beechie et al., 2010; Bellmore et al., 2014; Hauer et al., 2016; Junk et al., 1989). In the Pacific Northwest (PNW) region of North America, the habitat diversity and complexity of floodplain reaches are particularly important for ESA threatened species such as Chinook salmon (*Oncorhynchus tshawytscha*) (Bellmore et al., 2013; Jeffres et al., 2008). Over the last century, industrial and agricultural development has disproportionately affected floodplain ecosystems resulting in the losses of natural functions. (Bayley, 1995; Tockner & Stanford, 2002). Because floodplain ecosystems are embedded in ecological, socioeconomic, and cultural systems, these losses pose a threat to local, regional, and global communities (Baldassarre, 2013; Hand et al. 2018; Kauffman et al., 1997). As research has drawn attention to the degradation and threats facing floodplains, stream restoration has become an increasingly common approach to mitigate and ideally reverse some of these losses with increasing resources being directed toward floodplain restoration efforts (Bernhardt et al., 2005; Bernhardt et al., 2007; Opperman et al., 2010; Rohde et al., 2006).

Riparian vegetation plays a key role in floodplain ecosystems where it has significant effects on local hydrology, geomorphology, and biota, and can also act as an indicator of other important landscape processes. Vegetation mediates the exchange of materials between the streambank and upland areas, affects the movement of sediments eroded and deposited by the river, and affects the flow of wood and leaf litter in floodplains (Gregory et al., 1991; Lisius et al., 2018). Floodplain plant communities are shaped by and are dependent on dynamic river processes, responding to changes in physical conditions and hydrologic connectivity, and developing across landscape gradients and disturbance history. These communities can be sensitive to local and landscape-scale land use, flow modifications, restoration actions that influence the hydrological regime, and habitat structure in the riparian zone. Therefore, vegetation is an important response metric in evaluating restoration activities like channel widening, channel re-establishment, and floodplain reconnection (Gothe et al., 2016; Gregory et al., 1991; Hauer et al., 2016; Roni et al, 2019).

The purpose of this paper is two-fold: to develop expectations for vegetation response to floodplain restoration, and to provide recommendations for implementation and monitoring within the ecological and social frameworks of the landscape. First, I conducted a literature review of vegetation recovery following dam removal and floodplain reconnection in the PNW to provide an assessment of potential vegetation responses and riparian plant community development for two novel types of stream restoration that are emerging as potentially valuable techniques, but which have limited data on vegetation recovery: Stage 0 restoration and beaver dam analogs (BDA). Second, based on my review, I provide recommendations for implementing restoration monitoring of vegetation for these two emerging restoration methods and discuss how they should be considered within a disturbance framework. Further, as we increasingly recognize that floodplain restoration occurs in a human-dominated landscape, I highlight key social factors that must also be considered in Stage 0 and other restoration efforts and how they fit within a restoration implementation and monitoring framework (Fig 1).

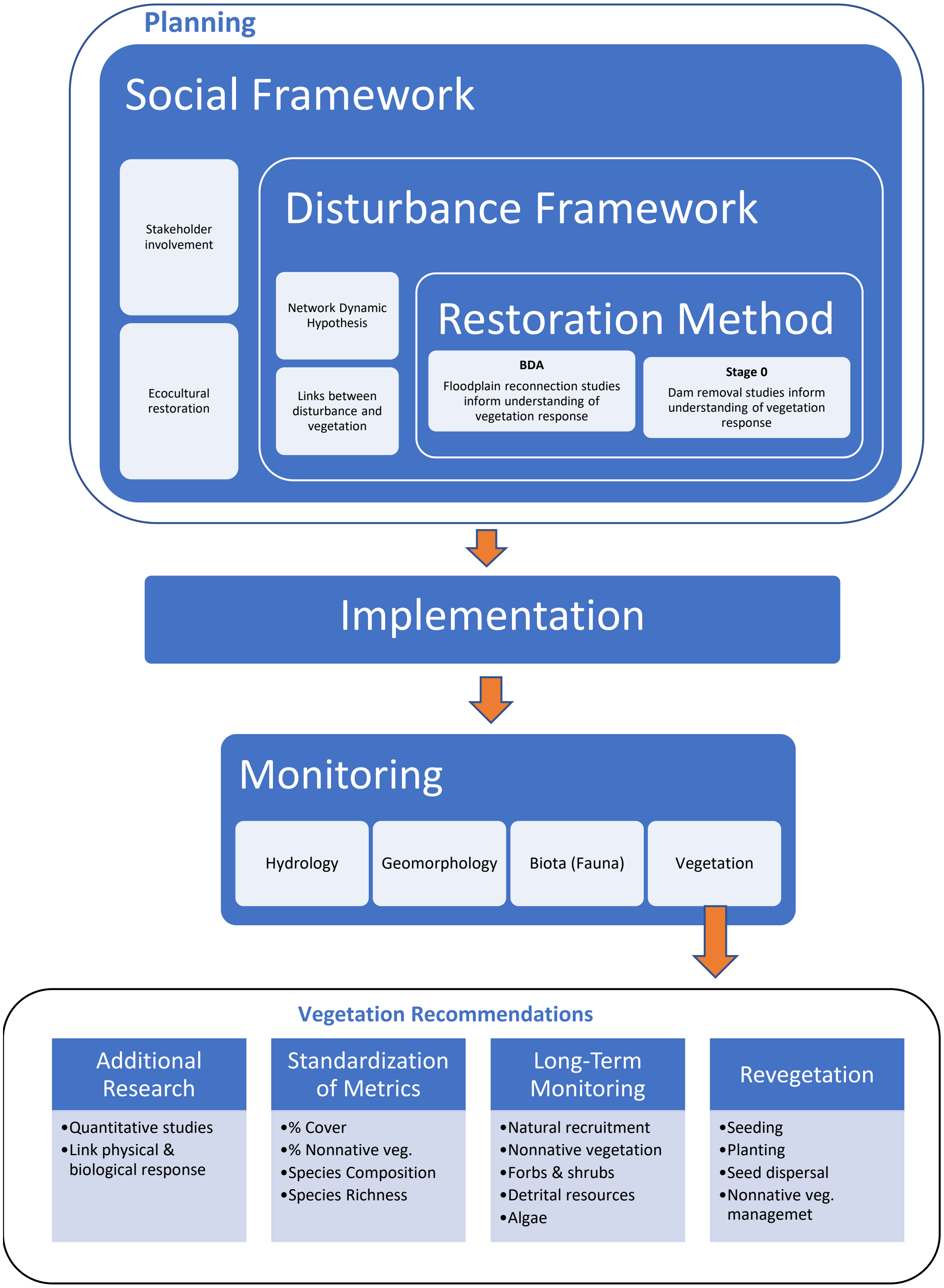

Figure 1. Conceptual diagram illustrating the nested nature of large-scale stream restoration efforts within a larger social framework and providing key considerations for vegetation monitoring in Stage 0 and beaver dam analog restoration efforts in the PNW. Monitoring biota (fauna), geomorphology, and hydrologic process responses are also key but are beyond the scope of the current study, which focuses in particular on vegetation.

BACKGROUND

Despite their ecological value, throughout history, floodplains have been disconnected from the river that formed them, and converted to other land uses (Opperman et al., 2010). Ancient civilizations were established on floodplains through the cultivation of their fertile land, resulting in the restriction of floodplains by more than 50% of their historical distribution and the loss of their natural functions (Eros et al., 2018; Tockner & Stanford, 2002). Anthropogenic modifications to support land uses such as agriculture, forestry, and urbanization include channelization, flood control by levees, and dam construction. These actions have disconnected floodplains from their rivers, resulting in loss of lateral hydrologic connectivity, reducing flows and water availability, degrading instream habitat, and decreasing floodplain biodiversity (Eros et al., 2018; Opperman et al., 2010; Tockner & Stanford, 2002). Coupled with trapping and extirpation of beaver, who are themselves ecosystem engineers, controlling river grade control and maintaining wetlands in unconfined depositional valleys, these anthropogenic manipulations have resulted in the head cutting of river channels, lowering of the shallow groundwater table, and a transition from wetlands to arid terraces (Bouwes et al., 2016; Powers et al., 2018). Through these processes, rivers throughout the world have been reduced from complex wetland systems of floodplains and braided channels to single channels supporting a mere fraction of their historic biodiversity and function (Baird et al, 2005). Alluvial systems that previously were able to store and exchange periodic floods and inputs of sediments and nutrients generated by natural disturbances are now vulnerable to damage from disturbance events and less resilient to impacts of climate change and land use (Cluer & Thorne, 2013).

Climate modeling efforts indicate that the effects of climate change will include altered precipitation events, reduced streamflow, increased flooding, changes in vegetation patterns, and overall changes in floodplain characteristics (Moradkhani et al., 2010). Larger and more severe wildfires in the PNW associated with warm, dry conditions are also expected to increase with a warming climate (Halofsky et al., 2020; Kitzberger et al., 2006; Mote et al., 2003). Snowpack accumulations will decrease with warming temperatures, resulting in the loss of meltwater providing critical water supply for ecosystems, agriculture, and municipalities, particularly in the summer when flows are low and demand is high (Sproles et al., 2013). As climate change causes conditions to become warmer and drier with more extreme and unpredictable precipitation, drought, and wildfire events, functioning floodplains will become even more critical (Kremen & Merenlender, 2018). Increasing lateral and vertical connectivity and raising the water table in floodplains through restoration can lead to increases in mesic vegetation resilience to climate variability (Silverman et al., 2019). Restoring floodplain connectivity and streamflow regimes and aggrading incised channels can also increase habitat diversity and population resilience of keystone species like salmon (Beechie et al., 2013). Restoring floodplain processes may help mitigate the negative impacts of climate change on riparian and aquatic ecosystems, and the human communities that depend on them (Moradkhani et al., 2010)

In addition to anthropogenic impacts and threats from climate change, floodplains in many regions have been impacted by the loss of beaver. A critical component of riparian floodplain ecosystems, beaver cut wood from the riparian zone to build dams which trap and accumulate sediment, reduce stream velocity, and shift the landscape from a fluvial to a complex system of wetlands with open canopies and accumulation of detritus and nutrients (Butler & Malanson, 2005). Beaver enhance floodplain connectivity by building dams that obstruct flow and decrease stream velocities, allowing for aggradation of sediment behind dams. This raises the streambed, reconnects incised channels with the floodplain, and forces a greater magnitude of overbank flow, causing stable multi-threaded channel networks to form (Scamardo & Wohl, 2020). The anthropogenic removal of beaver from the landscape has exacerbated stream channel incision and rapid down-cutting of the stream bed, resulting in the disconnection of channels from their floodplains and the development of single-thread systems with limited floodplain connectivity (Bouwes et al., 2016; Scamardo & Wohl, 2020; Wohl et al., 2021). In the PNW in particular, studies have suggested that the loss of beaver has fundamentally altered stream function and floodplain connectivity at a regional scale (Bouwes et al., 2016; Nash et al., 2021).

Floodplain plant communities are distinct from surrounding landscapes because of links among hydrology, geomorphology, and biota. In a floodplain context, riparian ecosystems occur where groundwater is in close proximity to the soil surface or where there is a direct connection between groundwater and surface water. These interfaces support greater biomass and species diversity than the surrounding landscape and even short-term declines in alluvial groundwater tables can alter vegetation composition and cover, changing the distribution and abundance of riparian plant associations and leading to the decline of phreatophytes like willow and cottonwood (Baird et al., 2005). Local groundwater upwelling in floodplains is associated with higher species richness of woody and herbaceous plants, faster growth rates of tree species such as cottonwoods, and a higher standing crop of algae (Tockner & Stanford, 2002). Areas that are perennially inundated support aquatic vegetation while areas that are seasonally inundated support a wide variety of wetland obligate, facultative, and riparian vegetation types including woody species, sedges, rushes, and grasses (Wohl et al., 2021). Therefore, in considering the restoration and conservation of aquatic ecosystems and overall species diversity, floodplains are important focal areas on the landscape.

Floodplain plant communities are not only affected by adjacent fluvial systems, but they also act as physical engineers of river ecosystems. Vegetation in floodplains both affects and responds to fluvial processes with above-ground biomass modifying the flow field and retaining sediment, while below-ground biomass affects the hydraulic and mechanical properties of the substrate. Certain plant species will colonize exposed or inundated alluvial sediment, trapping and stabilizing sediment to build pioneer landforms which trap propagules and facilitate colonization by other plant species. Plants also act as ecosystem engineers, affecting the interface between areas dominated by fluvial processes where plants are unable to survive, and areas dominated by vegetation by influencing the progression and recession of the boundary zone between active river bed and floodplain(Gurnell, 2014). Plant communities and the physical processes that they influence along stream corridors also have feedbacks with wildlife. For example, in the floodplain woody riparian species can provide food and dam-building materials for beaver who increase the size and extent of optimal habitat for riparian vegetation through dam-building activity (Butler & Malanson, 2005; Pollock et al., 2014).

Streamside vegetation is critical to the quality of instream habitat for aquatic ecosystems, affecting factors such as structural complexity, pool formation, water quality, light availability, water temperature, and food availability. In floodplain complexes, downed wood and willow mats create niches for aquatic insects and fish, and organic matter inputs from riparian vegetation are a major food source for aquatic invertebrates, which are in turn a major food source for fish (Apostol & Berg, 2006; Godinho, 2009; Rich et al., 2016; Stephens, 2017). Forbs and shrubs contribute to fish habitat productivity by providing cover, nutrient inputs, and pool-forming root structures (Burton, 2005). Studies have demonstrated strong linkages between vegetation structure (trees, shrubs, or herbaceous vegetation) and bird community composition in floodplains (Stephens, 2017). Overall, extensive and complex riparian vegetation enhances many key ecological functions of streams and riparian zones in and along riparian corridors (Godinho, 2009).

Since floodplains are such highly degraded and threatened ecosystems, they have become the focus of many restoration programs over recent decades with a number of different techniques employed to restore lateral connectivity and reconnect floodplains to their river channels (Roni et al., 2019). Because these ecosystems hold such high value to humans through natural capital, recreational, and aesthetic values, and are a fundamental component of our life-support system, the restoration of degraded floodplain ecosystems is of the utmost importance to local, regional, and global societies and future generations. Floodplain restoration efforts work to re-establish processes, functions, and related biological, chemical, and physical linkages between aquatic and riparian ecosystems, and repair damages caused by human activities (Kauffman et al., 1997; Millennium Ecosystem Assessment, 2005; Tockner & Stanford, 2002). Some of the more common examples of restoration that reconnect floodplains are dam removal, levee removal, levee setbacks, aggradation of incised channels, channel reconstruction, remeandering, and reconnecting or constructing side channels, ponds, and wetlands (Roni et al., 2019). However, these techniques are not an option in many river systems, particularly those that have experienced severe downcutting (Cluer & Thorne, 2013). Two novel stream restoration methods focusing on floodplain reconnection which are becoming increasingly popular in Oregon and around the PNW are Stage 0 restorations and the construction of BDAs (Bianco, 2018; Pollock et al., 2013; Powers et al., 2018). These restoration techniques have great potential but are new and therefore we have limited understanding regarding system response.

TWO NOVEL TYPES OF FLOODPLAIN RESTORATION: STAGE 0 AND BEAVER DAM ANALOGS

Traditional form-based restoration focuses on channel form and follows designs based on equilibrium conditions with equal sediment inputs and outputs, resulting in narrow tolerances for stream habitat form and designs lacking focus on natural, stochastic occurrences like log jams, beaver dams, and dynamic processes that create multithreaded channels, raise water tables and alter sediment dynamics (Ciotti et al., 2021). These traditional restoration efforts typically began with identifying a pre-disturbance channel or reference condition based on a stable, single-threaded panform that was previously altered by anthropogenic manipulation and focused on the geometry of channels, preserving incised forms through stabilization measures resulting in limited regeneration of high-quality habitat (e.g. Rosgen) (Cluer & Thorne, 2013; Powers et al., 2018; Rosgen, 1996; Wohl et al., 2015). Emerging restoration efforts are becoming less prescriptive in their final configuration and instead focus on restoring processes and reconnecting river channels to floodplains. Process-based restoration is an alternative paradigm that recognizes streams are not simply a channel but a complex dynamic and evolving system including all of the area of the valley floor that affects or has been affected by fluvial processes (Ciotti et al., 2021).

Stage 0 Restoration

Restoring to a Stage 0 condition also referred to as Stage 0 restoration, is a novel method of restoration with a process-based approach, emphasizing and relying upon dynamic landscape and river processes that occur over long periods of time. At a series of workshops held by the USFS PNW Research Station in Oregon in 2019 and 2020, practitioners and researchers collaboratively defined Stage 0 as “a valley-scale, process-based (hydrologic, geologic and biological) approach that aims to reestablish depositional environments to maximize longitudinal, lateral and vertical connectivity at base flows and facilitate development of dynamic, self-forming, and selfsustaining wetland-stream complexes" (Flitcroft et al., In Press). Rather than focusing on a single structure or habitat as the outcome, Stage 0 practitioners focus on the creation of diverse habitat types and the restoration of geophysical processes, including floodplain connectivity, hyporheic exchange, energy dissipation, and sediment deposition (Bianco, 2018). Over time, as native flora and fauna interact with water and sediment, initial configurations of habitat are expected to change along non-linear trajectories that are not predetermined by the restoration practitioners (Castro & Thorne, 2019; Wohl, 2019). Since originating in Oregon, over 20 Stage 0 projects were completed between 2012 and 2018, including hundreds of acres of earthwork and thousands of woody debris placements (Bianco, 2018).

The concept of a Stage 0 condition is based on Cluer and Thorne's Stream Evolution Model (Fig 2), which added a precursor stage to existing stream evolution models. Their research suggested that streams historically displayed anastomosing morphology (multi-threaded channels) prior to human disturbance and described the stream evolution model as an evolutionary cycle rather than a linear model (Cluer and Thorne, 2013). The Stage 0 restoration approach was developed in incised streams flowing through degraded meadows where anthropogenic manipulation and the loss of beaver resulted in channel incision and a transition from a wetland stream complex to a single-threaded channel in an arid terrace (Powers et al., 2018).

The expectations are that restoration to a Stage 0 condition will result in river systems that are biologically productive and resilient, and thus better able to support focal species. However, ecological responses to this type of restoration have not yet been documented and there exists some controversy around Stage 0 among stakeholders due to the extensive earth moving disturbance in and around the wetted and dry portion of the floodplain. There are concerns that it could negatively affect organisms during project implementation, delaying or negating ecological benefits (Weybright, 2019). Restoring to a Stage 0 condition is typically implemented in areas that were once depositional reaches prior to human disturbance and involve the use of heavy machinery for the removal of berms, rip rap, and landscape features used to channelize the river, the filling of incised river channels, and placement of large quantities of large wood in the floodplain (Bianco, 2018). By resetting bed elevation, the intent is that natural channel development will be able to occur (Meyer et al., 2016). Because of the cut-and-fill earthwork involved in channel modification, stakeholders are concerned with short-term increases in sediment and turbidity and potential negative impacts on salmon (Bianco, 2018). At this point in time, assessments of Stage 0 are limited and primarily focused on geomorphology and aquatic food webs, with little focus on the dynamics of vegetation recovery, even though the floodplain plant community represents a critical component of the functionality of floodplains and creates important connections between the aquatic and terrestrial environments, as described by Cluer and Thorne (2013).

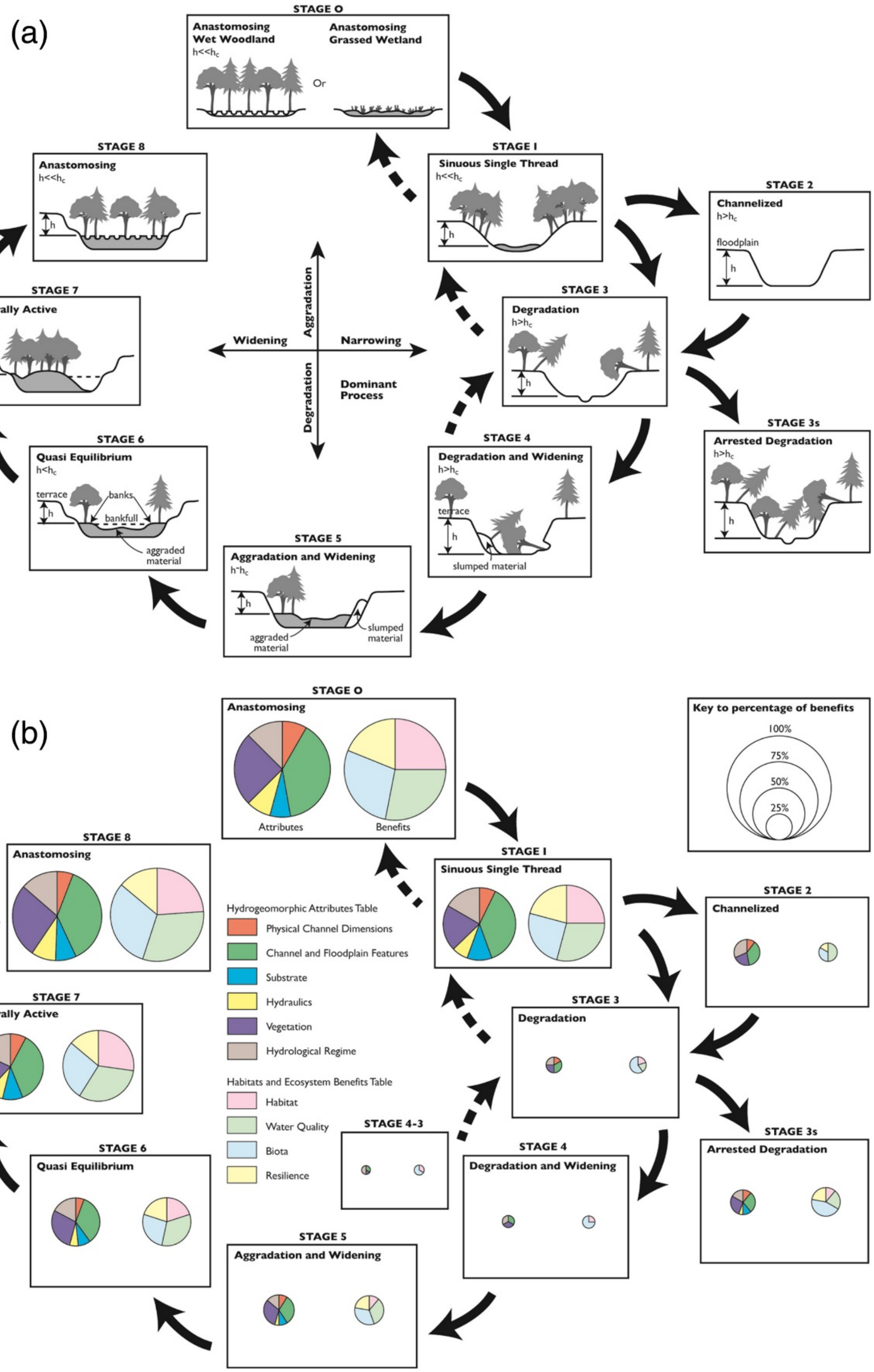

Figure 2: Cluer and Thorne’s stream evolution model Diagram (Cluer and Thorne, 2013)

Beaver Dam Analogs

The loss of beaver has been identified as contributing to landscape-scale declines in river network complexity and function in the western US. While beaver populations are slowly recovering in some areas, they remain limited in others. To try and restore the function of beaver on the landscape, without the animals themselves, restoration scientists are exploring the potential to create artificial beaver dams or beaver dam analogs (BDA). A BDA is a human-constructed, low head, permeable instream structure made of wood, mud, and rock intended to emulate natural beaver dams and their effects by slowing water flow, increasing sediment deposition, and improving stream and riparian habitat (Fig.3) (Lautz et al., 2019; Pollock et al., 2017; Scamardo & Wohl, 2020). BDAs are a low-tech, process-based restoration method that exploits vegetation sequences and ecological and geomorphic feedbacks to accelerate the aggradation and recovery of incised floodplain channels (Pollock et al., 2014). Pollock et al (2014) developed a framework to illustrate how beaver dams and live vegetation can accelerate the recovery of incised streams. Biogenic features such as vegetation influence the bed load and suspended load transport by changing the slope, roughness, and channel width, each tipping Lane’s balance to the left and increasing rates of aggradation (Pollock et al., 2014).

The removal of beaver from the landscape has exacerbated stream channel incision where rapid down-cutting of the stream bed disconnects the channel from the floodplain resulting in a substantial loss of riparian vegetation biomass and diversity. BDAs can accelerate the incision recovery process and alter hydrologic, thermal, geomorphic, and vegetation characteristics of floodplains and improve habitat conditions for fish species (Bouwes et al., 2016). BDAs are used not only to enhance lateral connectivity but also ideally, to establish riparian vegetation and habitat requirements for the reintroduction of beaver and provide foundations for natural dams with the goals of raising water tables and promoting growth of riparian vegetation. Local factors like soil grain size and regional water gradients can also influence restoration outcomes with BDAs and warrant further study (Pollock et al., 2014; Scamardo & Wohl, 2019). Submerged floodplains upstream of beaver dams allow dense emergent vegetation to thrive, which provides flow resistance and reinforces long-term storage of sediments (Beechie et al., 2010; Gurnell et al., 2012, Pollock et al., 2014). Work on BDA's has also focused primarily on physical processes, but vegetation is a key component of the restoration goals and therefore warrants greater consideration in assessing these restorations moving forward.

Figure 3. Examples of Beaver Dam Analogs in the PNW (Pollock et al., 2018)

THE IMPORTANCE OF SOCIOCULTURAL CONSIDERATIONS IN STREAM RESTORATION

While ecological restoration has traditionally focused on physical interventions to re-establish processes and functions of rivers, there is an increasing awareness of the need to also focus on the cultural, political, and economic processes that drive and are affected by these restoration activities (Fox et al., 2017, Wohl et al., 2005 & 2015). Riverine landscapes and their floodplain habitats are not only embedded in diverse ecological settings but in diverse socioeconomic and cultural settings as well (Hand et al., 2018). Floodplains provide an array of critical ecosystem services to local and downstream communities including the provisioning of food and water, regulation of floodwaters, nutrient cycling, and sediment retention (Hopkins et al., 2018). There is an increasing trend in studies emphasizing the benefits and services provided by aquatic and terrestrial ecosystems and government agencies responsible for stream restoration are promoting projects evaluating ecosystem services (Thorp et al., 2010). Empirical findings from research by ecological and social scientists demonstrates the need for more communication and collaboration between ecologists, social scientists, land managers, and stakeholders to find sustainable solutions for natural resource management (Hand et al., 2018). By bringing together diverse stakeholder groups to address resource management, restoration practitioners can transform governance systems, facilitate transboundary management, and enhance community resilience and adaptive capacity while creating a more resilient landscape (Inman et al., 2018).

Socioeconomic considerations may include building social capital with stakeholders near a floodplain restoration project site through outreach efforts and collaboration. The concept of social capital refers to the structure of relationships between and among members in a group that encourages productive activities and plays an important role in restoration partnerships (Floress et al., 2011; Pretty & Ward, 2001). A growing body of scholarship also focuses on social-ecological resilience in rural, resource-dependent communities and managing these systems in ways that promote adaptability and absorb disturbances (Inman et al., 2018; Ostrom, 2009). Floodplain restoration not only provides opportunities to build social capital and increase resilience, but also benefits local fishing and recreation economies, creates jobs, and bolsters regional economies (Kellon & Hesselgrave, 2014). Effects of restoration on the local economy include direct, indirect, and induced cycles of spending and can be measured in terms of jobs, labor income, value added, and output. This is enhanced if local contractors are hired for project construction, as well as engineers, hydrologists, biologists, surveyors, and other skilled labor. Workers involved in the project support jobs in local businesses like restaurants and lodging and can stimulate demand for more employees. Long-term economic activity generated by restoration results enhances fishing and recreational opportunities, that benefit tourism and local businesses (Nielsen-Pincus and Moseley, 2012; NOAA, 2017).

Broad stakeholder engagement and participation are key sociocultural components of restoration and should include rural, resource-dependent communities, marginalized communities downstream who disproportionately bear the costs and benefits of restoration, and partnership with Indigenous peoples and sovereign Tribal Nations for whom these rivers are sacred and central to identity and culture (Egan et al., 2011; Fox et al., 2017; Hikuroa et al., 2021; Inman et al., 2018). Indigenous restoration partnerships have the potential to repair and transform human relationships with rivers and decolonize river governance (Fox et al., 2017). Indigenous people have inhabited and managed riverine landscapes for cultural resources in the PNW since time immemorial including food, fiber, basketry materials, and regalia (Sarna-Wojcicki et al., 2020; Salter, 2003). Plants were collected as cultural resources and tended through controlled burning, digging, planting, weeding, harvesting, and seed dispersal (Zedler &

Stevens 2018). Restored floodplains can serve as areas where people are able to harvest traditional wild foods and medicines. Sarna-Wojcicki et al. (2020) argue that community mobilization around food sovereignty has inspired decolonial socio-spatial formations attempting to reconnect people to place through indigenous foodways and reorient resource management towards stewardship of traditional cultural foods. The idea of cultural foodscapes offers a way to conceptualize the spatiality and seasonality of local food resources and the ways they are managed and accessed. (Sarna-Wojcicki et al., 2020). Kimmerer (2011) discusses the practice of reciprocal restoration in which the repair of ecosystem services contributes to cultural revitalization and renewal of culture promotes restoration of ecological integrity, including restoration of subsistence-use activities and traditional indigenous diets, a focus on cultural keystone species, and traditional land management for biodiversity (Kimmerer, 2011).

QUANTIFYING VEGETATION RESPONSE TO FLOODPLAIN RESTORATION: A SYSTEMATIC REVIEW

Objectives

Monitoring is an important aspect of restoration projects that is often overlooked, and the need for more rigorous monitoring has been discussed in the scientific literature for decades as well as the need for more studies and standardization of data collection. In addition, there is ample literature available on the social context of restoration, but literature is limited on the social context of vegetation in restoration. In spite of its ecological and sociocultural significance, surprisingly few studies on river floodplain restoration explore vegetation response and it is almost entirely absent in many restoration monitoring plans in the PNW. This is an important issue to address as emerging novel types of restoration such as Stage 0 restoration and

BDAs are increasingly applied but are done in the absence of data or understanding of effects on vegetation. Many types of restoration, especially methods like Stage 0, involve a great deal of disturbance which interrupts successional pathways for vegetation and opens the door for nonnative vegetation to establish. This raises the following questions: What do we expect to see in terms of plant community development following Stage 0 restoration and BDAs, how does this affect recommendations for managing floodplain restorations with these treatments, and how do these recommendations fit within the social context of the landscape?

In order to develop a conceptual model or trajectory of what might happen with vegetation succession in a Stage 0 or BDA restoration project, I performed a systematic literature review of studies on relatively well-understood methods of floodplain restoration: dam removal as a surrogate for Stage 0 restoration, and floodplain reconnection as a surrogate for BDAs. Focusing on plant community succession following dam removal projects in small floodplains throughout the PNW, the systematic review method was used to develop a theoretical/conceptual understanding of what we expect to occur in novel methods of restoration. In this review, I looked closely at how each study quantified vegetation recovery and what metrics were used (if any). Using dam removal to better understand Stage 0 and floodplain reconnection to better understand BDAs may be imperfect comparisons, but these methods are so novel we cannot predict what will happen and we must seek answers from other methods where we have data.

The systematic literature review of dam removal and floodplain reconnection studies focused on plant community succession following dam removal projects in small floodplains to inform a theoretical/conceptual understanding of what we expect to occur with vegetation and plant community recovery in the novel types of small floodplain restoration. Aspects of vegetation and plant community recovery encompassed in this literature review included: (1)

disturbance responses, (2) natural recruitment (forbs and shrubs), (3) active revegetation, (4) nonnative vegetation, and (5) social context. Based on the review, I developed recommendations for further studies and monitoring of vegetation in these types of projects and implications for management.

Methods of the Systematic Literature Review

In order to address the study questions: 1) What do we expect to see in terms of plant community development following Stage 0 restoration and BDAs, 2) how does this affect recommendations for managing floodplain restorations with these treatments, and 3) how do these recommendations fit within the social context of the landscape? I reviewed studies on vegetation community response to these four focal restoration methods. I searched Web of Science (https://www.webofscience.com) for the categories: “Stage 0 restoration”, “beaver dam analogs”, “dam removal”, and “floodplain reconnection”, and the subcategory “vegetation”. I searched the USGS Dam Removal Information Portal (https://data.usgs.gov/drip-dashboard/) selecting the “biological” science category and the “riparian vegetation” science type. This yielded 297 studies. I searched Google Scholar (https://scholar.google.com/) for the categories: “Stage 0 restoration”, “beaver dam analogs”, “dam removal”, and “floodplain reconnection”, and the subcategory “vegetation”. I then reviewed each study and determined if they reported data that could be synthesized (see details below). I also searched the text in each study for the terms “social”, “sociocultural”, “stakeholder”, and “tribe” to determine whether the paper included social considerations. I focused explicitly on the PNW region because vegetation communities are variable in this region where most Stage 0 and BDA restorations are currently being implemented. After reviewing papers and reports from these three data sources, I identified a total of 19 studies to include in the conceptual framework (Fig 4) (Table 4).

Table 1. Stage 0 Restoration Studies

Study	PNW	River System	Vegetation	Veg Metrics	Time	Data Reported	Social Context
Bianco (2018)	Yes	Deer Creek, OR	No	NA	NA	NA	Yes
Hinshaw et al. (2022)	Yes	S. Fork McKenzie River, OR	Yes	Canopy cover	2 yrs	Yes	No
Jennings (2021)	Yes	S. Fork McKenzie River, OR	No	NA	NA	NA	No
Powers et al. (2019)	Yes	OR	No	NA	NA	NA	No
Schneider (2020)	Yes	CA, WA, OR	No	NA	NA	NA	No
Scagliotti (2018)	Yes	Whychus Creek, OR	Yes	% cover (as a substrate)	2 wks	Yes	Yes – lists stakeholders

Table 2. Beaver Dam Analog Studies

Study	PNW	River System	Vegetation	Veg Metrics	Time	Data Reported	Social Context
Bouwes et al. (2016)	Yes	Bridge Creek, Murderers Creek, OR	No	NA	NA	NA	No
Butler and Malanson (2005)	No	Glacier NP, MT	No	NA	NA	NA	No
Charnley (2018)	Yes	Scott River, CA	No	NA	NA	NA	Yes
Lautz et al. (2019)	No		No	NA	NA	NA	Yes
Munir and Westbrook (2020)	No	Alberta, Canada	No	NA	NA	NA	No
Nash et al. (2021)	Yes	OR, CA, NV, NM	No	NA	NA	NA	Yes
Orr et al. (2020)	Yes	Crooked River, OR	Yes	Planting depth, cutting width at ground level, length of new growth, distance from stream, distance from BDA	1 yr	Yes	No
Paces (2016)	No	Deer Creek, CO	Yes	% cover, species richness, native species abundance	1 yr	Yes	No
Pilliod et al.(2017)	Yes	Western US	No	NA	NA	NA	Yes
Pollock et al. (2014)	No		No	NA	NA	NA	No
Scarmardo & Wohl (2019)	No	Fish Creek & Campbell Creek, CO	No	NA	NA	NA	No
Silverman et al. (2019)	Yes	Bridge Creek, OR, CO, NV	Yes	NDVI as proximity for productivity and vigor	7 yrs	Yes	No
Vanderhoof & Burt (2018)	No	Missouri River, MT	Yes	Riparian greenness	3 yrs	Yes	No

Table 3. Floodplain Reconnection vegetation Studies

Study	**PNW**	**River System**	**Vegetation**	**Veg Metrics**	**Variables**	**Time**	**Data Reported**	**Social Context**
Baart et al. (2009)	No	Danube River, Germany	Yes	Species richness		10 yrs	Yes	No
Bannach et al. (2009)	No	Vistula River, Poland	Yes	Survival, height of shoot, length of longest leaf	Flooded vs. drained conditions	8 wks	Yes	No
Martinez-Fernandez et al. (2017)	No	Orbigo River, Spain	Yes	Cover (by cover type)		3 yrs	Yes	Yes
Meyer et al. (2013)	No	Rhine River, France	Yes	% cover, species richness, diversity		5 yrs	Yes	No
Schwab et al. (2018)	No	Danube River, Austria	Yes	% cover of macrophytes, species composition, species richness, nonnative species		9 mos	Yes	No

Table 4. PNW Dam Removal Vegetation Studies

Study	**River System**	**Metrics**	**Variables**	**Time**	**Data Reported**	**Social Context**
Acker et al. (2008)	Elwha River, WA	Species composition, cover class, tree mortality	Geomorphic surfaces	61 yrs	R	No
Brown et al. (2022)	Elwha River, WA	% cover, species richness, % nonnative species	Landform, soil characteristics, sediment size, ground cover	12 yrs	R	No
Calimpong (2013)	Elwha River, WA	Plant mortality, plant condition	Site conditions, soil texture, substrate, LWD presence	2 yrs	R	Yes
Chenoweth et al. (2021)	Elwha River, WA	% cover, species composition, species richness, relative frequency of nonnative plants, density of woody plants	Soil texture (coarse, fine), seeding treatment (seeded, not seeded)	5 yrs	R	No
Cook et al. (2011)	Elwha River, WA	% cover, % nonnative species, species richness, seedling biomass, seedling length	Planting treatment, mycorrhizal treatments	1 yr, 8 mos	R	No
Cortese & Bunn (2016)	Elwha River, WA	Shoot & root biomass, fungal colonization	Inoculum treatments	1 yr, 8 mos	R	No
Cubley & Brown (2016)	Elwha River, WA	Seed abundance, species richness	Sampling time, river reach (above & below dam)	2 mos	R	No
East et al. (2015)	Elwha River, WA	None – sediment study, discussed riparian vegetation dynamics	River reach (above & below dam)	2 yrs	NR	No
McCaffery et al. (2018)	Elwha River, WA	None – review on wildlife including vegetation response			NR	No
McCaffery et al. (2020)	Elwha River, WA	% cover, species richness, % cover of grasses/forbs/shrubs, plant height	Browsing level, herbivory measurement, small mammal habitat associations	4 yrs	NR	No
McLaughlin (2013)	Elwha River, WA	Woody plant density, woody plant height, # of native woody plant species with bird-dispersed seeds	Distance to forest, distance to river, LWD volume & height	3 yrs	NR	No
Michel et al. (2011)	Elwha River, WA	% cover germinating seeds, % germination, % viability, seed rain density	Substrate type	1 yr	R	No
Polster (2017)	Heber River, BC Canada	% cover, % cover alder, Species abundance		5 yrs	R	Yes
Prach et al. (2019)	Elwha River, WA	% cover, species composition, number of nonnative species	Sediment type, distance from lakeshore	4 yrs	R	No
Ramsey (2014)	Trout Creek (Wind River), OR	% canopy cover by cover classes, species composition, species richness, % nonnative species, % volunteer, % planted		2 yrs	R	No
Rohdy (2013)	N Fork Feather River, CA	% cover, species richness		1 yr	R	No
Simons et al. (2011)	Clear Creek, CA	Cover (aerial photography)		11 yrs	NR	No
Stephens (2017)	Rogue River, OR	% cover by stratum (tree, shrub, ground vegetation)	habitat type (mainstem, slough, wetland)	3 yrs	R	No
Thomas (2018)	Elwha River, WA	% cover, species composition, species richness, % nonnative species	River reach, year, landform	5 yrs	R	No

*R: Data reported, NR: Data not reported

The Web of Science search for Stage 0 restoration yielded 49 studies, but only one was relevant to the current review. Powers et al. (2019) is based in the PNW and mentions vegetation response, but no data was collected. Three additional grey-literature studies and one additional peer-reviewed study from the PNW were found through Google Scholar (Table 1). The Web of Science search yielded 30 studies in the search for BDAs, 8 of which mentioned vegetation. Three of the 8 studies were based in the PNW. Seven additional studies were found through Google Scholar, 2 of which were based in the PNW. Scamardo & Wohl (2019) mentioned vegetation, but no data was collected; Orr et al. (2020) measured the growth of willow cuttings planted in proximity to BDAs; Pollock et al. (2014) discusses vegetation interactions with physical fluvial processes in stream restoration, but no data was collected; Charnley (2018) discussed vegetation in relation to landowners reasons for participating in BDA projects, but no quantitative data was collected; Vanderhoof & Burt (2018) used remote sensing to evaluate changes in riparian vegetation looking at land cover (herbaceous vegetation, shrub/scrub, emergent vegetation) using vegetation indices and collected data on variables of vegetation composition and cover; and Silverman et al. (2019) used remote sensing to measure changes in productivity of riparian vegetation (Table 2).

In the Web of Science search on dam removal, 166 out of 2,338 studies came up for vegetation, 22 of which were relevant to the current review, 5 of which were syntheses of studies, and 8 of which provided direct empirical data relevant to my study question and were based in the PNW. These 8 studies on dam removal in the PNW that studied vegetation were used to develop a conceptual understanding for Stage 0 and BDAs. The papers included Chenoweth et al. (2021), Cubley & Brown (2016), Cook et al. (2011), Stephens (2017), Michel et al. (2011), Cortese & Bunn (2016), Prach et al. (2019), and Acker et al. (2008).

In the DRIP search on dam removal, 43 studies came up for vegetation but only 21 of the studies actually quantified vegetation response. 6 of the studies were based in the PNW, and 4 of these were repeats from the Web of Science. The studies included Cortese & Bunn (2016) (Repeat from WOS), Calimpong (2014), Cubley & Brown (Repeat from WOS), Thomas (2018), Stephens (2017) (Repeat from WOS), McCaffery et al. (2020), Prach et al. (2019) (Repeat from WOS), Polster (2017), Rohdy (2018), Simons et al. (2011).

One additional article and two additional grey literature sources based in the PNW were included from a search in Google Scholar, Brown et al. (2022), Mclaughlin (2013), and Ramsey (2014). The total number of studies from the systematic review included in the conceptual framework was 19. 14 of these studies were on the Elwha, one was on the Heber River BC, one was on the Rogue, one was in the Wind River system in WA, and the other two were in Northern California (Figure 5) (Table 2).

In the Web of Science search on floodplain reconnection, I tried entering “floodplain reconnection”, “levee removal”, “berm removal”, and “dike removal”. The search results included 89 papers, 19 of which mentioned vegetation. Only 5 were relevant to the current review but all of these were studies of European rivers (Baart et al., 2009; Bannach et al., 2009; Martinez-Fernandez et al., 2017; Meyer et al., 2013; and Schwab et al., 2018), and therefore were not included in the conceptual framework for the PNW. In these five floodplain reconnection studies, metrics and data included cover, species richness, and species composition (Table 3).

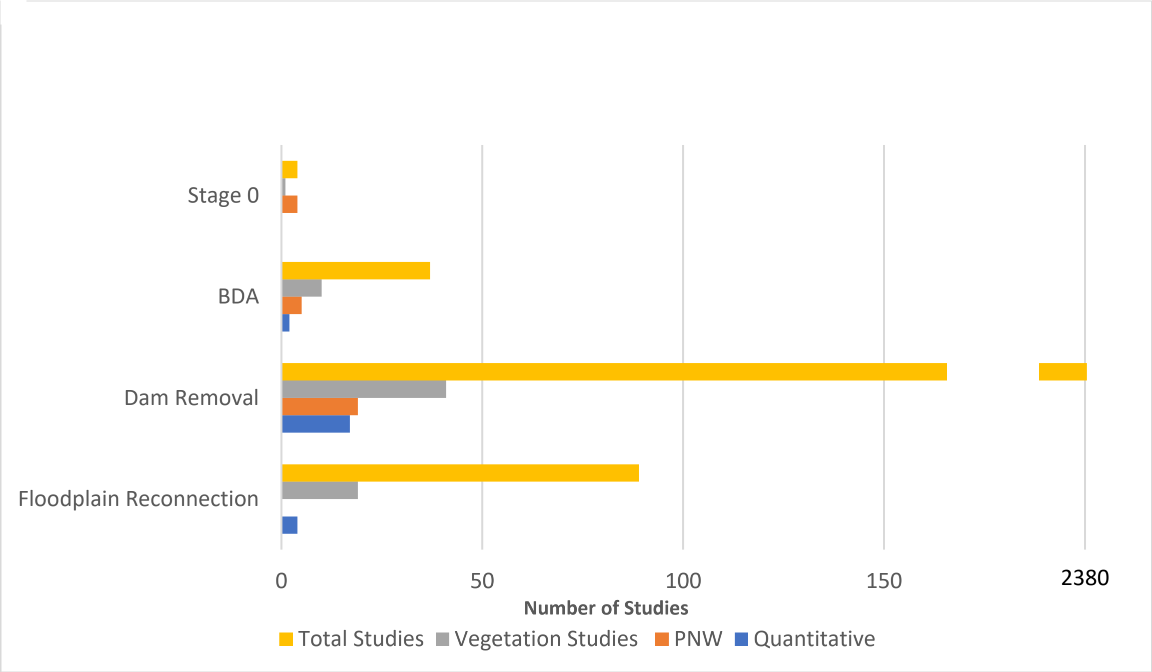

Figure 4. Quantitative vegetation studies in the PNW listed by restoration method

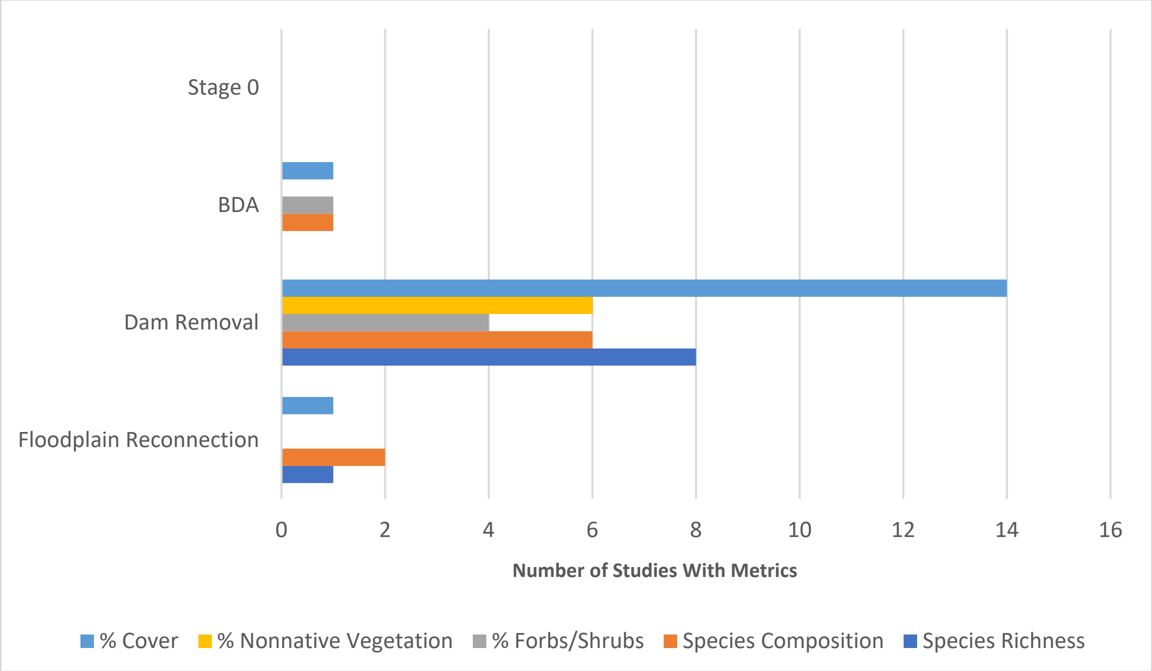

Figure 5. Metrics used in quantitative vegetation studies in the PNW listed by restoration method

Literature Review Results and Discussion

A key finding of this review is that despite the large number of river restoration projects being implemented in the PNW, there is a lack of data on vegetation responses. Although quantitative data to create an aggregate summary of vegetation responses is limited, each of the 19 studies included in the final literature review provide valuable insights into revegetation responses and I discuss and synthesize these below. The five floodplain reconnection studies were not included in the final 19 studies of the systematic review because they were not located in the PNW, however, they offer some understanding of what we expect to happen in BDAs and are included in the discussion section following the findings on dam removal studies. The social context was limited in the 19 dam removal vegetation studies, with only one of the five floodplain reconnection vegetation studies, four of the 11 BDA studies, and two of the six Stage 0 studies mentioning social components, which I discuss following the ecological findings.

Dam Removal in the Pacific Northwest

The 19 vegetation studies on dam removals in the PNW identified in the systematic review from Web of Science, DRIP, and Google Scholar included 14 studies on the Elwha, one on the Heber River BC, one on the Rogue, one on Trout Creek in the Wind River system in WA, one on the N Fork Feather River in CA, and one on Clear Creek in CA. Seventeen of the papers included metrics and of those, 14 papers measured % cover, 6 measured species composition, 8 measured species richness, 6 measured nonnative species (% or frequency), and 4 measured % herbaceous vegetation (forbs/shrubs) (Figure 5). The metrics were associated with a wide range of variables, making cross-study comparison difficult. Only 14 of the studies that collected data on vegetation included that data in their report (Table 1).

Although overall vegetation community responses were a key part of many of the dam removal studies, in the literature review I found that many of the studies were focused on specific aspects of vegetation with associated variables limiting their comparability with other studies for comparison in a broader context. Areas of focus in these studies included seed dispersal (Cubley & Brown, 2016; Michel et al., 2011), wildlife (McCaffery et al., 2018; McCaffery et al., 2020), birds (McLaughlin, 2013), mycorrhizae (Cook et al., 2011; Cortese & Bunn, 2016), plant performance and mortality (Calimpong, 2013), geomorphology (East et al., 2016), and substrate (Chenoweth et al., 2021). Particularly relevant to Stage 0 and the large volume of wood placement, one study highlighted the relationship between plant performance and large wood, finding that higher groundwater content and the presence of large wood in proximity to plants in exposed areas of sediment provided shelter from high winds and improved plant survivorship (Calimpong, 2013). Although many of these narrowly focused vegetation studies didn’t lend themselves to comparative data analysis, they were relevant to Stage 0 and therefore useful in creating a conceptual framework.

One of the most comprehensive and relevant studies from a data review standpoint was by Chenowith et al. (2021) describing the revegetation efforts in a former impoundment following the Elwha Dam removal. The study quantified herbaceous vs. woody vegetation and measured six response variables, including the percentage of bare ground, species composition and species richness of plants, relative frequency of nonnative plants, and the species composition and density of woody plants. They found that the mean frequency of nonnative species was lower on fine sediments than on coarse sediments and this was reduced by seeding. Planting affected vegetation development by increasing species richness and seeding reduced the percentage of bare ground and abundance of nonnative species. Prach et al. (2019) included similar metrics in their study on early seral vegetation in the former impoundment on the Elwha River and looked at categories of herbaceous vegetation, shrubs, and trees. Brown et al. (2022) offered the most comprehensive vegetation dataset assessing the downstream effects of dam removal, comparing plant species richness and community composition in reaches above, below, and between the two Elwha dams over long time periods and highlighting the importance of long-term, multi-year, pre-and post-project monitoring for understanding the effects of dam removal on plant communities and the natural dynamics of riparian vegetation (Brown et al., 2022).

One of the best potential references for Stage 0 vegetation dynamics is a study by Acker et al. (2008). They studied a landslide-dam-break flood on the Elwha River in 1967 that filled a former channel and diverted the river in a reach that was then used as a reference site for the removal of the Elwha dams in 2011. Indeed, the geomorphic conditions created by the landslide-dam-break flood event in this study echoes the origins of the Stage 0 restoration approach when the Karnowsky Creek restoration project on the Siuslaw National Forest had a newly constructed channel filled in by a landslide in 2002. A practitioner visiting from the Deschutes National Forest recognized that the disturbance had created more favorable conditions with an alluvial fan deposited by the landslide and began to develop a new approach to restoration featuring disturbance and dynamism as key features of river ecosystems. By emulating the alluvial fan created by the landslide in Whychus Creek on the Deschutes National Forest, the processes and methods of Stage 0 restoration were developed (Bianco, 2018).

In the Acker et al. (2008) study, 5 distinct surfaces were identified with different substrates and heights above the river channel. Aerial photography was used to determine cover class over time and look at variables of tree mortality and tree species composition. Prior to the dam-break flood, the river flowed in a straight channel bordered by mature forest, which the aerial photograph time series of the study site shows filling in with the flood deposit, shifting the main channel to the east, and creating a series of anastomosing channels across the valley bottom over the next 33 years. Vegetation response included tree mortality due to burial by fine sediments, tree establishment on new surfaces 1-4 years after their creation, high heterogeneity in forest structure and composition, and high variation in species composition between surfaces. Based on these findings, it seems that recreating the natural diversity of riparian forests and vegetation may require mimicking the variety of physical and biotic habitats created by a single, complex disturbance event (Acker et al., 2008).

Sediment texture and variation in substrate are one of the most critical environmental factors in plant community development and composition of early successional vegetation, and this was a key finding in many of the vegetation studies (Prach et al., 2019). When establishing similarities between dam removal revegetation and Stage 0, it is important to consider that both result in the transport of sediment. Dam removal releases a pulse of stored sediment from the former impoundment and Stage 0 releases sediments from the valley floor through cut-and-fill earthwork, both of which provide opportunities for dynamic channel changes and create new surfaces on which riparian pioneer species can reproduce (Powers et al., 2018). Sediment pulses following a dam removal may partially or completely fill downstream channels through aggradation, forming numerous bars and braided channels, and forcing flow into side channels. Aggradation of riffle crests can fundamentally change the riverbed from pool-riffle to braided morphology (East et al., 2015). We see similar patterns in Stage 0 restoration when the main channel is filled to the level of the geomorphic gradeline (Powers et al., 2018). Sediment deposition downstream of dams leaves behind deposits and surfaces associated with variable aggradation and degradation of the sediment pulse to be colonized by vegetation. Existing vegetation is often buried, resulting in mortality of vegetation in late-successional seral stages that is less tolerant to burial (Powers et al., 2018; Shafroth et al., 2002). Coarse textured sediments experience slower natural regeneration with rocky substrates dominated by woody plants, while fine sediments regenerate more quickly with fine rooted plants like grasses and forbs and experience higher species richness and plant cover (Chenoweth et al., 2021).

Seed dispersal is another important component of plant community recovery following dam removal, and two common pathways for recolonizing bare substrates are by seed rain (anemochory) or by water downstream (hydrochory). Vegetation colonization in former impoundments is influenced not only by sediment texture and its effects on germination success, but by a range of factors including source population sizes and species-specific differences in seed production, dispersal, and intrinsic germination potential (Michel et al., 2011). Hydrochory is particularly important for riparian species which often produce floating seeds that can be carried long distances downstream, often during high flow events, depositing seeds on new sediment and debris and contributing to plant community composition and diversity. This is especially true for species like cottonwood and willow which require fine-textured sediments deposited during high flow events for germination. Increased seed transport post dam removal plays a significant role in establishing vegetation downstream where large amounts of sediment are deposited and may make it unnecessary to seed areas of exposed sediment (Cubley & Brown, 2016).

Revegetation in floodplains has important interactions and feedbacks with birds and wildlife and the ways in which they disperse seeds and nutrients on areas of bare substrate. Several studies looked at the ways in which revegetation interactions extend beyond plant communities and their connections and feedbacks with soil and hydrologic dynamics, focusing on birds, small mammals, ungulates, and beaver (McCaffery et al., 2018; McCaffery et al., 2020; McLaughlin, 2013; Stephens, 2017). Birds act as an important restoration agent due to their frugivore diet, sufficient abundance, and activity throughout restoration sites. Out of the 39 woody species that are common to early seral stages of plant community development, 59% produce fruits dispersed by birds with a strong relationship between bird species and plant composition (McLaughlin, 2013; Stephens, 2017). Wildlife also act as restoration agents by recolonizing dewatered reservoirs in response to early seral stage vegetation. Changes in terrestrial fauna over time can therefore signal transitions between successional stages for vegetation and changes in composition and structure. Wildlife and macroinvertebrate restoration trajectories are closely linked with restoration goals for aquatic species and riparian plant biodiversity through their reciprocal functional roles (McCaffery et al., 2018). Small mammal colonization compliments revegetation succession and demonstrates restoration and ecological processes (McCaffery et al., 2020). Beaver play a key role in shaping riparian vegetation through dam-building activity. Ungulates affect structure, distribution, composition, and productivity of plant species through browsing activity. As riparian vegetation becomes more established these interactions will continue to shape plant composition and distribution (McCaffery et al., 2018).

Links between large wood and revegetation are facilitated through the interactions and feedbacks of birds and terrestrial wildlife. Large wood provides a refuge for mice and facilitates their movement out onto alluvial terraces, protected some plants from browsing by deer and elk by impeding ungulate movement, and were used as perches by birds acting as seed dispersers. As salmon populations recover in restoration project areas, black bear and other piscivorous mammal and bird species also play an increased role in linking terrestrial and aquatic food webs and providing a seed source for small mammals in scat (McCaffery et al., 2020). Large wood attracts birds to areas of exposed sediment early in the revegetation process before woody plants become established when seed dispersal is most important. Implications for restoration include leveraging limited project resources through supporting seed dispersing birds with large wood distributed throughout the project site where plant establishment is desired (McLaughlin, 2013).

As plant communities develop on newly exposed substrates along a river channel, root system development is of critical importance, and this includes the symbiotic relationship between plants and mycorrhizal fungi. Two of the studies focused explicitly on interactions between vegetation and mycorrhizae. There is concern that freshly exposed sediments in former impoundments may not support rapid reestablishment of native vegetation due to the absence of arbuscular mycorrhizal fungi propagules as rhizosphere activity significantly improves soil aggregate stability over time (Cook et al., 2011; Cortese & Bunn, 2016). Studies on the effects of native vegetation, mycorrhizal inoculum, and mulch on restoring sediment in former reservoirs concluded that mycorrhizal fungi propagules are available to pioneering plants in recently dewatered reservoir soils with availability decreasing with distance from mature plant communities, natural mycorrhizal inoculation through wind or animal spore dispersal can sufficiently colonize native plant species over time, and either commercial inoculum or whole soil inoculum from mature plant communities may be most beneficial at the reservoir-scale key microsites where native seed and spore sources can help regain critical ecosystem function. Other benefits include improved soil texture, water-holding capacity, and nutrient availability to aid revegetation efforts and reduced colonization by nonnative vegetation. In areas of exposed sediment, inoculated mulch sacks may contribute to the rapid establishment of native plants through retention of soil moisture, and reduced runoff and erosion (Cook et al., 2011; Cortese & Bunn, 2016).

Following dam removal, plant community succession and the ways in which management can influence their trajectories is an important consideration. Succession can develop over long time scales, and one study found that a former impoundment was still in its herbaceous stage of succession in the third and fourth year following the disturbance of the dam removal and noted a pervasive high percentage of bare ground lacking vegetation and leaf litter. Forbs may develop the highest canopy cover on a site while shrubs take longer to develop and may maintain the lowest canopy cover for several years. Forbs and grasses should dominate over a long time period with no shade to inhibit their growth and limited organic matter, later giving rise to woody species (Ramsey, 2014). Alders play an important role as an early seral species in PNW systems, fixing nitrogen and creating substrate for conifer establishment. These natural processes rebuild diverse ecosystems and creation of diversity with microsites creating habitat for a diversity of plant species (Polster, 2017). In immediate proximity to the channel, there is a reinforcing pattern of bank stability following dam removal in which vegetation reduces the availability of bank sediment for mobilization and grows larger each season, further increasing bank stability (Simons et al., 2011). Some studies suggested that active restoration may not always be necessary on a site, but if it is, quick-growing grasses, forbs, and herbaceous plants should be planted first as they speed the physical ripening of soils which will prepare them for the successful planting of native trees and shrubs (Rohdy, 2013). Aggressive treatment of nonnative species may be necessary to allow native species to dominate (Ramsey, 2014). These management actions will help ensure development of the desired plant community of species complex and size structured vegetation of a dynamic floodplain ecosystem.

Although standard, comparable vegetation metrics were not included in all of the studies (total vegetation cover, nonnative vegetation cover, herbaceous vegetation cover, forbs and shrubs, vegetation composition, changes in vegetation composition over time) and many that were included were not comparable due to their wide range of variables, a few of the studies included useful metrics and data. Chenoweth et al. (2021) was the most comprehensive including percent bare ground (cover), species composition, species richness, relative frequency of non-native plants, and density of woody plants measured for five years following dam removal. By the end of the study, they found 99% cover on fine sediments and 50% on coarse sediments. They also found 19-27% nonnative vegetation in areas that had been seeded and 16-31% nonnative vegetation in areas that were not seeded. Average species richness was 23.4 species per location on fine sediments and 15.8 species per location on coarse sediments (Chenoweth et al., 2021). Brown et al. (2022) was also quite comprehensive in their data and metrics, including percent cover, total cover of native and nonnative species, and both native and nonnative species richness.

Dam Removal in a Broader Context: National, International, and Synthesis Studies

Although I limited the scope of the systematic review to studies from river systems in the PNW, there are several studies worth noting from other systems that help set the conceptual framework within a broader context. These include studies from Colorado, the Eastern US, Europe, Korea, and both national and international synthesis studies. Dam removal research in Europe in particular offers an example of the ideal type and uniformity of data collection in response to restoration. In a national context, several relevant studies offer potential applications for research in PNW systems. Cannatelli & Curran (2012) created a channel evolution model incorporating local hydrology and vegetative growth following dam removal in West Virginia.

Although applicable to East Coast river systems, this could provide the basis of a similar model for dam removals and Stage 0 in the PNW. Several of these papers offered the type of broader vegetation examination and metrics that would have been useful in comparisons between the PNW studies. Following a dam removal in Colorado, Auble et al. (2007) found that early vegetation recovery consists of colonization on bare, moist substrate typically found in riparian zones and vegetation recovery follows a different trajectory from flooding of the reservoir over very long time scales involving persistent legacy vegetation established during the transition from reservoir to upland (Auble et al., 2007).

A series of Wisconsin dam removal studies focused on natural regeneration found that new sites tended to be dominated by grasses and forbs and riparian trees establish after 30 years post-removal. Plant communities are likely to develop over time and not become arrested in an early successional stage (Orr, 2002). Species diversity and frequency are positively correlated with time since dam removal, and temporal vegetation dynamics are site-specific therefore vegetation restoration should be site specific and focused on techniques to minimize nonnative species (Orr & Stanley, 2006). Short- and long-term vegetation change of the riparian plant community in different parts of the riparian landscape can be characterized by the presence of facultative wetland species both pre and post dam removal. The expansion of the pre-removal herbaceous community on newly exposed sediment is facilitated by stored seeds in the surrounding substrates, and because these communities are adapted to hydrologic and geomorphic variability, they are able to re-establish in a new riparian area with a similar disturbance regime. Wetland areas may transition quickly from bare soil to a heavily vegetated wet meadow and large expanses of unvegetated sediment are unlikely to persist. Mid-channel islands may be initially dominated by persistent nonnative vegetation, but across the landscape, native vegetation should establish rapidly enough to dominate the new community. This suggests that natural revegetation following dam removal can result in the development of a diverse, dynamic vegetation community (Lisius et al., 2018).

In a European context, Lejon (2012) includes a summary of four studies detailing the effects of dam removal on riparian vegetation and succession following a dam removal in Northern Sweden in which the major vegetation response in the former impoundment was colonization by pre-removal species. This research illustrated how dam removal can successfully restore species composition due to an available species pool and sufficient conditions for natural regeneration (Lejon, 2012). In a study on early spontaneous vegetation recruitment in a former impoundment in France, Ravot et al. (2019) used colonization indicators related to vegetation structure, taxonomic richness and diversity, and composition, calculating these indicators at different spatial scales. This type of study using these indicators could be applied to PNW systems to characterize a pool of species naturally recruiting, analyze longitudinal patterns in colonization, and assess temporal change in the vegetation community (Ravot et al., 2019). Another study on temporal development of riparian vegetation relative to river morphology by Kim et al. (2012) observed sand bar formation both in and downstream of the former impoundment on the Gongreung River in Korea being primarily colonized by grasses within a year of dam removal and tree establishment five years after dam removal. Trees were expected to dominate the sandbars within a decade to several decades, and the study emphasized the importance of long-term studies on geomorphologic changes and vegetation (Kim et al., 2012).

Several dam removal synthesis studies were identified in the systematic review, offering a broader perspective and context across regions and systems. Shafroth et al. (2002) evaluated dam removal case studies from North America for potential responses of riparian vegetation on the basis of relationships between riparian plants, stream hydrology, and fluvial processes. Dam removal causes changes to the physical environment that influence the establishment and growth of riparian vegetation and initial vegetation in former impoundments tends to be dominated by weedy plants with rapid growth, high seed production, and effective dispersal mechanisms with colonizing species eventually giving way to successional species over time (Shafroth et al., 2002). In a synthesis of common management concerns with dam removal across the U.S., Tullos et al. (2016) found nonnative contribution to species richness to be similar to values reported for riparian area species richness around the world and no relationship between proportion of nonnative species with time since dam removal. They included studies with vegetation metrics and looked at relationships to variables of dam size, landform, sediment grain size and composition, active revegetation efforts, and nonnative propagule pressure (Tullos et al., 2016). A synthesis of a series of small dam removal studies in Wisconsin by Doyle et al. (2005) examined effects of changes in channel form on riparian vegetation and developed a conceptual framework for full and partial ecosystem recovery including vegetation response over time (Doyle et al., 2005). Foley et al. (2017) synthesized dam removal studies across the US, noting the relationship between vegetation development and substrate in former impoundments and downstream. They cautioned that exposure of large areas of bare sediments may result in the unintended spread of nonnative vegetation with introduced species forming a large component of the plant community, suppressing establishment of native plants (Foley et al., 2017).

Dam Removal and Stage 0 Restoration

The dam removal studies included in this review provided useful analogs to Stage 0 in many respects, but they are also different in key ways. Both dam removal and Stage 0 allow for recovery of lateral connectivity and former impoundments experience similar processes to Stage

0 in terms of exposed area. After dam removal, the exposed areas are revegetating in a way that is similar to new vegetation in the early exposed areas of a Stage 0 restoration. However, channel morphology and development may differ. Ecological disturbance theory offers a framework for understanding the effects of dams and dam removal on downstream riparian plant communities, which we can then apply to Stage 0 restoration (Brown et al., 2022). Although there are many similarities including a reset of the plant community and riparian fluvial floodplain plant communities growing in areas where they have not been for a period of time, dam removal creates a different disturbance from Stage 0, and there are significant differences longitudinally above and below the dam removal site and temporally. Due to a variety of factors, it is possible that both the former reservoir and the downstream reaches may never attain pre-dam ecological conditions (Bellmore et al., 2019). Key differences include sediment size, seed bank, and interaction with the floodplain. Most of the studies included in the literature review focus on vegetation recovery in the former impoundment area. In reality, the best analog may actually be downstream of the dam where sediment flushed from the dam aggraded the main channel and created anastomosing channels across the valley bottom, but the number of studies reporting the downstream vegetation response is extremely limited. To date, Brown et al. (2022) is the only comprehensive vegetation dataset assessing downstream effects of large dam removal.

Dams inundate large areas, submersing soils, and biological legacies for long periods of time, and recovery of the ecosystem including vegetation is related to the size and intensity of the disturbance of the dam removal with revegetation more closely resembling primary succession than secondary succession (Chenoweth et al., 2021). As the water behind a dam is drawn down, the sediment gradually progrades toward the dam, where it eventually overtops the remaining portions of the dam, releasing the bedload into downstream reaches (East et al., 2015).

The remnant channel below the reservoir is often exposed and becomes an incised main channel. This disturbance in the former impoundment differs from Stage 0 where the main channel is filled in to the geomorphic gradeline and water spreads out across the valley bottom creating a network of braided channels but is more similar to the downstream reaches where aggradation occurs. In a former impoundment on the Elwha, bed incision formed high terraces as delta sediments were eroded and redeposited in the lower portion of the former impoundment. These persisted for years after the dam removal, remaining high above the water table. In addition, the vegetation established during impoundment is left stranded (Chenoweth et al., 2021). This differs from Stage 0 where the water table is raised across the valley floor, supporting greater natural recruitment of vegetation.

Below the former impoundment, similarly to Stage 0, new sediment is deposited as impounded sediments are released during and after dam removal. Changes in bed elevation occur downstream as sediment fills interstitial spaces between cobble and large, low-velocity pools are filled in. This is followed by incision, increased braiding, and bed sediment fining (East et al., 2015). Although this is similar to Stage 0 as aggradation occurs, the main channel is never fully filled in to distribute water across the entire valley floor. The vegetation response should be more similar in the beginning, developing along different trajectories over time with hydrology as a key driver. In light of these differences, we should be cautious in extrapolating too far from this review for understanding Stage 0 restoration and how we apply data from longer timeframes after dam removal.

Based on the examples from the literature review, natural revegetation following Stage 0 should progress similarly to what is observed following dam removal. Both are a full reset of the system with high levels of disturbance resetting succession of plant communities. Vegetation succession following dam removal could be compared to succession on river floodplains of unregulated rivers (Prach et al., 2019). The timeline of plant community development is an important factor in both dam removal and Stage 0 restoration where short-term effects of restoration on plant communities is dependent upon dynamic flooding events that move large volumes of sediment over time. Aggradation and sediment deposition in reaches downstream of dam removals and Stage 0 restoration can have both positive effects on colonizing species through the creation of new areas of bare sediment, and negative effects on existing vegetation through burial and/or inundation. Some floodplain species like willow (*Salix sp*.) and cottonwood (*Populus sp*.) are adapted to burial and flood disturbance and will continue to thrive in these conditions. In the short-term, this makes it more difficult to determine effects on species richness, but in the long-ter,m as sediment reaches quasi-equilibrium, the combination of increased surfaces for colonization, a viable seedbank, and hydrochory from upstream should result in an increase in species richness (Brown et al., 2022). Recovery of wetland characteristics including rapid recolonization of riparian dependent vegetation has been observed in less than two years in the initial Stage 0 projects (Powers et al., 2018)

Vegetation attributes for Stage 0 in Cluer & Thorne's (2013) Stream Evolution Model include frequent, small channel adjustments and high water table creating proliferation and succession of aquatic plants, wet woodlands on islands and floodplain supplying and retaining wood, and widespread vegetation in proximity to channels producing abundant leaf litter (Cluer & Thorne, 2013; Powers et al., 2018). Vegetation islands are a key design feature of Stage 0 projects and vegetation islands are often created in dam removals during channel reconfiguration. Large wood is another important component of Stage 0 projects, acting as an analog for forming jams which initiate island formation and become vegetated over time

(Hinshaw et al., 2022). Large wood distributed throughout former impoundments and Stage 0 restoration sites encourages revegetation through seed dispersal by birds and small mammals and practitioners can leverage limited resources for revegetation efforts through ensuring large wood is placed in areas of exposed sediment (McCaffery et al., 2020; McLaughlin, 2013). Replanting efforts can also be concentrated around large wood in the project area to shelter the plants from wind and scouring during high flows, and to protect them from browsing by ungulates (Calimpong, 2013; McCaffery et al., 2020).

Nonnative vegetation is an issue in revegetation of former impoundments and poses a similar issue in Stage 0 restoration. Undesirable nonnative species are less likely to interrupt riparian forest succession on fine sediments and will require minimal control but are more likely on coarse sediments where substantial bare ground remains open to colonization by nonnative species and resources for management should be focused here (Prach et al., 2019). Reed canary grass (*Phalaris arundinacea*) is one of the most common nonnative plant species colonizing former impoundments in the U.S. and hindering recovery of native vegetation (Foley et al., 2017; Orr & Stanley, 2006; Tullos et al., 2016). The combined effects of establishment of nonnative species like reed canary grass (*Phalaris arundinacea*) change in historic water table height, and accumulation of sediment during dam removal could slow or stop vegetation succession (Lenhart, 2000). Ramsey (2014) suggests that aggressive treatment of nonnative species such as reed canary grass (*Phalaris arundinacea*) and bull thistle (*Cirsium arvense*) in project sites allows native species to occupy and dominate the site. Nonnative species may be more dominant around the edges of the restoration project site due to preexisting populations in those locations and treatment should be targeted there (Ramsey, 2014).

Floodplain Reconnection and Beaver Dam Analogs

As with Stage 0, there are very few studies on BDA vegetation responses so we must look to other studies to develop some expectations about how systems will respond. Floodplain reconnection through removal of levees, berms, and dikes reconnects rivers with their floodplains and raises the water table causing plant communities to shift to wet-tolerant species. Similarly, BDAs restore connectivity, submerge areas of the floodplain upstream, and raise the water table, promoting the growth of riparian vegetation (Pollock et al., 2014; Scamardo & Wohl, 2019). The recovery of plant communities surrounding floodplain reconnection and BDAs differs from the vegetation recovery after dam removal or Stage 0 restoration. Floodplain reconnection and BDAs both cause a shift in existing community rather than resetting a community from nothing as is the situation with dam removals. Dam removals are not a good comparison for BDAs in former impoundments because they are dealing with an area with no vegetation for years vs. an area with BDAs added where the plant community stays in place and becomes inundated. River reaches downstream from dams may be a better comparison. The links between dam removal and BDAs are still relevant because we are fundamentally looking at a change in floodplain communities as a result of changing hydrology, however, floodplain reconnection is a better analog to BDAs.

Floodplain reconnection studies from European river systems include vegetation studies focusing on effects of submergence, hydro-geomorphological characteristics, and macrophyte development that offer valuable insight into plant community development following installations of BDAs. Reconnection of former floodplain wetlands to the main river system strongly influences plant species composition and abundance and landscape-scale changes in vegetation can be observed by comparing species tolerance to complete submergence in low-dynamic wetlands to those in frequently submerged grasslands (Bannach et al., 2009). Using a macrophyte regression model for different wetland management options in floodplain reconnection on the Danube River, Baart et al. (2009) modeled species richness and abundance, revealing a strong relationship between water area and depth, macrophyte abundance, and species richness, and identifying hydrology as the primary driver for macrophyte development in riverine wetlands (Baart et al., 2009). Meyer et al. (2013) studied changes in species richness, cover, and composition in macrophyte communities on reconnected side channels of the Rhine River in France and found that vegetation community composition is initially influenced by hydro-geomorphological characteristics (Meyer et al., 2013). In a study on hydrochorous seed dispersal on the Danube River, Schwab et al. (2018) found that seed dispersal from upstream habitats along the new channels was important for establishing target species and recommended that managers reduce sources of nonnative species upstream to prevent colonization in reconnected floodplains (Schwab et al., 2018). Another study on morphological and vegetation response to floodplain reconnection via levee and revetment removal on the Orbigo River in Spain used aerial photography to determine cover type combined with field surveys to determine cover of each species, suggesting that assessments using aerial photography and field surveys in pioneer habitats can illustrate trajectories in river restoration projects like BDAs shortly after completion (Martinez-Fernandez et al., 2017).

Stage 0 Restoration and Beaver Dam Analogs

As two novel methods of process-based stream restoration implemented in incised channels, BDAs and Stage 0 share significant similarities and also have key differences. Like Stage 0 restoration projects, BDAs decrease stream power and velocity, allow for the aggradation of sediment in the incised channel behind the BDA structure, raise the streambed, and reconnect the incised channels with their floodplains. The rate of aggradation of the incised channel is one key difference where Stage 0 accomplishes this immediately by filling in the incised channel, and BDAs rely on slow aggradation as sediments build up. Another key difference is intensity of disturbance. BDAs create very low levels of disturbance with structures created in the channel from natural material with no associated earthwork while Stage 0 restoration projects create a significant level of disturbance with heavy equipment constructing diversion channels to temporarily re-route flows and cut and fill in the stream channel (Bianco, 2018).

In both Stage 0 and BDAs, more frequent overbank flooding increases the lateral extent of groundwater recharge and hyporheic exchange, raising the water table (Powers et al., 2018; Scamardo & Wohl, 2019). BDAs and the large channel-spanning logjams placed in Stage 0 restoration increase roughness and channel width, increasing aggradation by reducing flow velocity enough to allow for the deposit of suspended sediments on the streambed and floodplain. Vegetation and large wood also create flow obstructions and increase the rate of aggradation with roots from live vegetation establishing on the aggrading surfaces and binding substrate while stabilizing streambanks. Areas with low stream power and elevated water tables created by both BDAs and Stage 0 projects allow riparian vegetation to establish (Pollock et al., 2014). BDAs implemented on streams that are lacking woody riparian vegetation may expose impounded water to higher levels of solar insolation, thus increasing stream temperatures. Planting, therefore, is an important component of these restorations (Orr et al., 2020). Similarly in Stage 0 woody riparian vegetation and canopy cover decrease initially as vegetation is submerged and trees die and fall due to raised water tables, but over time in a Stage 0 system, it is likely that the growth of dense, diverse floodplain vegetation and trees provide shade and ameliorate stream temperatures (Hinshaw et al., 2022; Powers et al., 2019). Once restoration is complete, beavers play an important role in maintaining both Stage 0 restoration and BDA projects. Stage 0 restoration encourages growth of vegetation that attracts beaver such as willow (*Salix sp*.). Beavers are part of the succession of a system and later stages of Stage 0 restoration in which riparian vegetation is established and beavers begin to influence flow-field patterns, sediment routing, and channel development (Powers et al., 2018).

Social Context of Dam Removal, Floodplain Reconnection, Stage 0, and Beaver Dam Analogs

While this was not expressly addressed in most of the 19 dam removal vegetation studies included in this literature review, there is an inherent social context of the landscape within which these restorations are embedded. Out of all of the dam removal vegetation studies on the Elwha, surprisingly only one addressed the social context of the landscape and acknowledged the Lower Elwha Klallam Tribe as the stewards of the land and their key involvement in dam removal and restoration. In that study, the social impact of dams on watersheds is acknowledged, including effects on indigenous cultural resources and foods (Calimpong, 2014). The only other dam removal vegetation study including social context, Polster et al. (2017) argues that the incorporation of the social aspects of ecological restoration is important and discusses how hiring a local first nations crew to transplant sword ferns from adjacent forest provided a social benefit from the restoration work. Bianco (2018) acknowledges the importance of both social and biophysical processes in river restoration and conducts social science research on practitioners' perspectives, the importance of partnerships between scientists and practitioners, and the social processes involved in Stage 0 implementation that influence its trajectory (Bianco, 2018). Scagliotti (2019) includes a table of primary Whychus Creek stakeholders and their interest in the creek and Stage 0 restoration occurring there.

Both social and biophysical considerations are necessary when selecting sites for BDA projects and this was mentioned in several of the BDA studies. A key finding included in one inventory of beaver restoration projects by was that restoration assessments will benefit from including social as well as ecological components including identifying and addressing conflict around private property, infrastructure, water rights, and water availability for agricultural land use (Piliod et al., 2017). In the only floodplain reconnection vegetation study that included social context, Martinez-Fernadiza et al. (2017) explains the links between social context and the lack of vegetation monitoring, discussing the opposition from landowners and fear of flood risk from neighboring communities resulting in this type of restoration action being employed much less frequently than needed and points to this social context as the reason why the effectiveness of floodplain reconnection in restoring riparian vegetation has not been frequently assessed (Martinez-Fernandiza et al., 2017). Collectively, these studies demonstrate the importance of sociocultural considerations in restoration through site selection, inclusion of stakeholders and indigenous communities, collaboration between practitioners and scientists, and ultimately whether or not restoration is implemented on the landscape.

RECOMMENDATIONS

I provide below a list of six key recommendations for future Stage 0 and BDA restorations based on this literature review. Details are then included in each subheading of specific recommendations about implementation of restoration and restoration monitoring of Stage 0 and BDAs.

1) Restoration should be placed within a disturbance framework

2) Restoration should be placed within the social framework of the system both locally and at a landscape scale
3) Restoration should include more research in order to understand variability in responses across systems
4) Restoration should include standardization of metrics and tools for evaluating vegetation response
5) Restoration should include more vegetation monitoring and consideration of long-term processes
6) Restoration should include active revegetation and facilitation of natural regeneration

1) Restoration Should be Placed Within a Disturbance Framework

When we consider restoration, we must first place it within a larger ecological framework. In river and floodplain restorations, a larger review of stream ecology literature suggests that a disturbance framework is most appropriate. Indeed, in order to project what may happen with plant community development following restoration disturbance, we must first identify what plant community recovery looks like in response to natural disturbance in small floodplains in the PNW. Riparian plant communities in unconstrained reaches are complex, heterogeneous patches of different successional stages, including herbs and grasses, deciduous trees, and multi-aged stands of conifers (Naiman et al., 2005). In floodplains farther from the active river channel, older plant communities made up of riparian species like willow, cottonwood, and alder are often found along with upland species extending down to the floodplain. Lateral meandering stream channels create depositional surfaces where younger stands establish (Gregory et al., 1991). Riparian succession is one which is dependent upon channel migration and evolution that topples climax communities and creates opportunities for pioneer species and developing assemblages to create new habitats contributing new ecological benefits (Cluer & Thorne, 2013).

Rivers in the PNW are disturbance-driven systems with regularly occurring flooding and droughts where habitats are periodically rejuvenated through processes of deposition and erosion. Stream restoration should be nested within a disturbance framework, and the vegetation monitoring recommendations I developed from this review are nested within this framework. Riparian ecosystems have historically experienced natural periodic catastrophic disturbances followed by a series of recovery states over periods of time spanning decades to centuries. As a result of these processes, floodplains offer a dynamic mosaic of habitats in varying successional states (Eros et al., 2018; Reeves et al., 1995; Thorp et al., 2006). In Benda et al.'s (2004) network dynamic hypothesis, a set of predictions relating the degree and spatial distribution of physical heterogeneity in river systems to features of branching river networks offers a physically based framework for understanding how the structure of river networks combined with dynamic watershed disturbances such as floods and fires creates habitat heterogeneity and promotes biological diversity in river ecosystems. They discuss how in riparian plant communities, greater topographic variation in floodplains creates local variation in inundation and soil moisture regimes leading to increased plant diversity and interannual variation in plant recruitment often found upstream of alluvial fans (Benda et al., 2004). Natural, catastrophic disturbances serve as an important source of diversity in riparian plant communities (Acker et al., 2008).

Floodplains are disturbance-dominated ecosystems formed and maintained by fluvial dynamics where changes in the relative contribution of different water sources can dramatically alter species composition and diversity (Tockner & Stanford, 2002). Geomorphic surfaces of floodplains provide a physical template for the development of riparian plant communities and the development of riparian vegetation reflects the disturbance regimes of lateral surfaces outside the active channel. Spatial dimensions of riparian vegetation reflect the heterogeneity of geomorphic surfaces in the floodplain. Mosaics of landforms have a strong influence on spatial patterns of riparian vegetation communities, but riparian vegetation also influences the evolution of geomorphic surfaces through root networks increasing resistance to erosion and aboveground stems increasing channel roughness decreasing the erosive action of floods and retaining material in transport. Additionally, riparian vegetation communities contribute large wood to channels which acts as a major geomorphic feature in rivers (Gregory et al., 1991).

Acker et al. (2008) studied a natural landslide-dam-break flood on the Elwha River that filled the former river channel and diverted the river, resulting in highly heterogeneous forest structure, composition, and productivity due to spatial variability in intensity of a single disturbance event and subsequent smaller events. They noted tree mortality resulting from tree removal and burial by sediment, with the burial process leaving snags and surviving vegetation including Sitka willow (*Salix sitchensis*), red alder (*Alnus rubra*), black cottonwood (*Populus trichocarpa*), and Douglas-fir (*Pseudotsuga menzeisii*). This study can provide a valuable reference for high-disturbance restoration methods and suggests that in order to recreate natural diversity of riparian forests, land managers may need to employ methods that mimic the variety of physical and biotic habitats created by a single disturbance event (Acker et al., 2008).

Wildfires are another key disturbance that is becoming increasingly common in the PNW following a century of suppression (Mote et al., 2003). Fires of high intensity can trigger hydrologic events removing fine sediments from the stream channel and debris flows transporting coarse substrates into stream channels, all processes which provide the materials that maintain productive habitat for fish and other organisms over long time periods. Riparian forest disturbances associated with wildfire contributes large wood from falling dead trees into channels, large rocks carried by debris flows, and regrowth of riparian vegetation can help restore the habitat of several species. Studies have shown rapid stabilization of small order stream channels following debris flows including revegetation of moist bottomland sites (Burton, 2005).

There are also significant links between floodplain vegetation, disturbance, and biota. Wildlife disperses seeds and nutrients, facilitating revegetation of areas disturbed by floods, fires, and landslides, and in restoration projects such as former impoundments in dam removals (McCaffery et al., 2018). Links between disturbance and beaver are discussed in several studies on vegetation community development in former beaver meadows when dams break naturally. Butler and Malanson (2005) discussed the geomorphic influences of beaver dams and beaver dam failures and the critical role of beaver dams and ponds in shaping the riparian environment prior to European contact. In their case study they observed a large volume of sediment removal and downstream transport during dam failure events, followed by decreased sediment evacuation from the former pond and rapid formation of grass and shrub covered beaver meadows on the areas of exposed sediment (Butler & Malanson, 2005).

Disturbance opens the door to nonnative vegetation and interrupts successional pathways. In a study on succession a year after a mud flow from Mt. Saint Helens on the Muddy River, Halpern & Harmon (1983) found that the canopy cover of herbs, shrubs, and trees decreased with distance from forest edges, and weedy species increased in the third and fourth growing season post-disturbance. Riparian zones play an important role in landscapes as corridors for dispersal of plants acting as a primary source of plant colonists throughout the landscape and are thought to be one of the original habitats of weedy vegetation. Riparian zones are especially important sources of plant dispersal during periods of rapid climatic change because of ameliorated climates along river valleys (Gregory et al., 1991).

Understanding natural disturbance regimes and mechanisms is critical to effective vegetative restoration and given the important role played by disturbance in floodplain ecosystems, restoration strategies should be designed and implemented that treat land management activities as disturbance events to be manipulated in ways that retain the necessary ecological processes for creating and maintaining freshwater habitat through time (Acker et al., 2008; Reeves et al., 1995). Applying this disturbance framework to floodplain restoration activities, we can observe a gradient of disturbance level with livestock exclosures and BDAs at the lower end, followed by floodplain reconnection, Stage 0 restoration, and dam removal being at the higher end with the greatest level of disturbance. Exclusion of cattle from the riparian area removes ungulate disturbance and allows vegetation to colonize the inset floodplain, leading to increased channel roughness, reduced flow velocity, trapping of suspended sediments, and aggradation of incised channels (Beechie et al., 2008). BDAs create low levels of disturbance with structures created in the channel from natural material resulting in increased flooding. Similarly, in restoration methods focused on widening stream channels and reconnecting floodplains we expect to see increased flood disturbance creating new, open habitats for colonization by ruderal plant species (short-lived annuals with fast growth rates and early, prolific seed set) that are associated with higher levels of disturbance and more variable and unpredictable habitats over time (Grime, 1979; Gothe et al., 2016). Stage 0 restoration by definition is already imbedded in a disturbance framework creating significant disturbance with heavy equipment work and temporary re-routing of the river channel, causing the river to create new flow paths, sort sediments, and develop new habitat attributes (Powers et al., 2018). Dam removal disrupts and reconfigures the existing physical environment, eliminates an entire ecosystem, and should therefore be considered an intense ecological disturbance resulting in the loss of resident flora and fauna and disrupting ecosystem processes in the short term (Stanley & Doyle, 2003).

2) Restoration Should be Placed Within the Social Framework of the System Both Locally and at a Landscape Scale

We cannot divorce ourselves from the human interactions and human components of restoration on our landscapes. Therefore, in addition to considering the ecological framework, we must consider the social framework for restoration as well. Just as restoration projects aim to restore ecological processes, they should aim to strengthen related social and economic processes. Stream restoration should be nested within a social framework, and the vegetation monitoring recommendations I developed from this review are nested within this social framework as well. The implementation of a large-scale restoration project can improve ecological, economic, and social sustainability in multiple ways. River restoration projects rely upon active stakeholder involvement at every stage, and comprehensive consideration of social aspects is essential for sustainable implementation and success (Heldt et al., 2016). Well-communicated, carefully measured results of restoration are necessary for increasing public participation and improving social perspectives (Smith et al., 1997). Restoration monitoring should be designed in collaboration with stakeholders in order to avoid being tangential to the interests of decision makers through at top-down approach (Lautz et al., 2019). A robust long-term monitoring program that includes the feedback and concerns of stakeholders and makes the results available and transparent will continue to build social capital through trust and improve social sustainability while improving economic sustainability through enhancing ecosystem goods and service and providing income in the local economy (NOAA, 2017).

A study examining public perceptions of large wood revealed ways in which education plays a major role in affecting perceptions, attitudes, and behaviors towards restoration, which is particularly relevant to Stage 0 restoration given the large volumes of wood placed in these projects (Chin et al., 2008). Education programs through organizations and agencies managing restoration projects that engage students with the project site, programs through local schools that help students build work and life skills doing post-restoration planting, community celebrations, site tours, and work parties are all ways that restoration practitioners can continue building social capital in the community and improve social sustainability (Goulden et al., 2013). Inclusion of stakeholders in monitoring through participatory science creates opportunities to engage traditionally underrepresented and underserved individuals and marginalized communities in restoration (National Academies of Sciences, Engineering, and Medicine, 2018). Long-term monitoring of ecological effects will allow for adaptive management of the site as effects are understood over time, which leads to improvement of ecological sustainability through changes in site management as well as social sustainability through community involvement, working with people to understand their concerns, and creating an environment of trust (Grieg et al., 2013; Murray & Marmorek, 2003).

Bianco (2018) notes that the most salient catalyst for Stage 0 practice is the practitioners' commitment to building relationships through peer-review, mentorship, and outreach. The findings from the study points to the importance of Stage 0 stakeholders engaging in transparent dialogues about values and exploring the perspectives of other groups to identify opportunities for building stronger collaborations. The thesis discussed ways in which practitioners are bridging the gap with scientists through collaborations on these Stage 0 projects and how scientists are helping to bridge the gap with community stakeholders by attending meetings and addressing their concerns. Scientists are able to fill a mediator role effectively because they are seen as credible and impartial by many stakeholder groups (Bianco, 2018). This is an example of linking social capital, or links between individuals or groups at one level in society and those who have more power or influence (Goulden et al., 2013). An understanding of power and how power relationships work in relation to environmental justice is a significant part of successful ecological restoration, and because restoration provides such basic resource needs for people, restoration practitioners and scientists can act as conduits between the disenfranchised and those in power (Egan et al., 2011).

When BDA projects are implemented, site selection must consider what is appropriate from a biophysical and a social standpoint. River reaches where BDAs are an appropriate method are typically low-gradient floodplains and these often are located on mixed-use land including privately owned properties and agricultural land that may be affected by changes in water flow and the beavers that are attracted to this type of habitat. Therefore, stakeholder involvement in restoration using BDAs is critical to ensure those impacted are willing to participate and live with the impacts (Charnley, 2018). Similarly, stakeholder involvement in Stage 0 projects is critical in areas with an outdoor recreation and fishing economy where access for boating and fishing may be impacted (Weybright, 2018). In agricultural areas, the ecological landscape may be set within a legal and regulatory framework involving federal and state agencies and a political framework around conflicting interests in water use for fish recovery vs. agriculture that can be volatile. Having a nongovernmental agency like a watershed council implement BDA projects can help serve as an intermediary between private landowners and regulatory agencies and facilitate communication and collaboration between stakeholder groups to ensure successful outcomes (Charnley, 2018).

A potential sociocultural benefit of Stage 0 and BDA projects is that if the entire valley floor can be restored to pre-European contact and pre-manipulation conditions, it may be of significant cultural value to local tribes and communities (Butler & Malanson, 2005; Powers et al., 2018). The concept of ecocultural restoration involves the linked processes of ecosystem repair and cultural revitalization and is described by Kimmerer (2011) as a mutually enforcing restoration of land and culture (Kimmerer, 2011; Sarna-Wojcicki et al., 2019). It is important to partner with sovereign tribal nations on revegetation of restoration sites and replant culturally significant species (Zedler & Stevens, 2018). For example, following removal of the Heber River dam the Mowachaht/Muchalaht First Nation was involved in the restoration work and a crew was hired to transplant sword ferns from the adjacent forest to the disturbed areas (Polster, 2017).

Restoration practitioners can work to decolonize watershed management by bringing the concept of cultural foodscapes to the foreground, supporting indigenous knowledge, and supporting indigenous access to restored floodplains and cultural plant resources (Sarna-Wojcicki et al., 2020). This may be accomplished through a complementary approach of ecocultural restoration using Western Ecological Knowledge (WEK) as the foundation for restoration of species assemblages and ecosystems while using Traditional Ecological Knowledge (TEK) for adding culturally significant species to restoration targets and using traditional management practices to achieve ecological resilience. Due to the different time frames in which they operate, (WEK tends to develop through short-term research while TEK is developed over generations) using both methods would be valuable for vegetation management in restoration given the long timelines of plant succession (Zedler & Stevens, 2018). This approach may also include social considerations around nonnative vegetation management such as manual alternatives to herbicides in areas used by Indigenous communities for subsistence and cultural purposes (Norgaard, 2007).

3) Restoration Should Include More Research in Order to Understand Variability in Responses Across Systems

There is a need for more quantitative studies on the response of vegetation to dam removal including rigorous monitoring of new or recent removals and retrospective analysis of older sites and this is the key actionable recommendation resulting from this review. Long-term studies are necessary in order to better understand complex pathways of vegetative change over time. Botanists and plant ecologists should seek opportunities to collaborate with physical scientists and couple plant response models with models used to estimate water and sediment dynamics (Shafroth et al., 2002). Vegetation is often not included in dam removal monitoring and studies (and other restoration studies), and this illustrates how different non-human actors are represented or not in the debate around dam removal and weighed in the decision-making process (Dufour et al., 2017). When vegetation research is included in a study, it tends to focus on woody species and the role of herbaceous species including the structure they provide during the period of early colonization of bare substrate is underestimated (Ravot et al., 2019). More studies on herbaceous vegetation (forbs) are needed to fill this research gap. Understanding how whole systems respond to a high-disturbance restoration action like dam removal or Stage 0 restoration requires an analysis integrating physical responses with water quality and biological responses, providing better knowledge of mechanistic linkages among physical and biological responses to these types of restoration. A holistic study of this nature could inform the development of standardized metrics to be measured in all Stage 0 restoration studies (Bellmore et al., 2017; Foley et al., 2017).

4) Restoration Should Include Standardization of Metrics and Tools for Evaluating Vegetation Response

Consistency in assessment is critical for comparing responses to restoration across systems and standardization of metrics and tools in studies is, therefore, another important actionable recommendation developed from this review. For some aspects, restoration consistency remains an issue while for other stream restoration efforts, assessments have increasingly moved towards including a suite of consistent metrics. Bernhardt et al. (2007), Hauser et al. (2018), Kail & Wolter (2011), and Roni et al. (2008) all highlight the lack of consistency in restoration monitoring and vegetation assessments in their papers. In their comprehensive review of restoration literature, Roni et al. (2019) identified major categories of physical and biological metrics, common methodologies, and metrics used to evaluate floodplain restoration effectiveness (updated from Pess et al. (2005) and they did find some core consistency in assessment of vegetation for floodplain restoration. They found 59 studies examining the response of riparian vegetation to floodplain restoration, 40% of which used biological metrics using field methodologies (quadrats, cross-sections plots or transects light meters or densiometers, and bore samples) and remote sensing (aerial photography, LiDAR, satellite imagery, and UAV multispectral imaging and structure from motion). The most common metrics calculated were vegetation composition, spatial patterns, canopy cover, species composition, age structure, shade, organic matter, vertical structure, and nonnative species distribution (Roni et al., 2019).

In contrast to the review by Roni et al (2019) of floodplain restoration, my review found little to no consistency in the vegetation assessment of dam removal studies. For monitoring Stage 0, Cluer and Thorne (2013) suggest that metrics used to represent the contribution of vegetation to habitat and ecosystem benefits include the presence of plants (including aquatic, emergent, riparian, and floodplain), leaf litter production, and recruitment of large wood. Leaf litter production supports primary production and trophic status while wood recruitment contributes indirectly through nutrient and carbon cycling, generating hydraulic and morphological diversity, promoting channel stability and sediment storage capacity, enhancing substrate sorting and patchiness, and driving shallow hyporheic flow (Cluer & Thorne, 2013). Beyond vegetation alone there are other valuable metrics to integrate ecosystem responses to restoration. Bellmore et al (2017 and 2019) suggested using dynamic food web models to understand the direct and indirect pathways by which stream restoration affects target species and explore responses. Due to their diverse habitat requirements and sensitivity to changes in habitat, birds are useful indicators of wetland and riparian ecosystem conditions and studies on birds and zoochory (seed dispersal by birds) can help measure vegetative restoration success and inform management actions (McLaughlin, 2013; Stephens, 2017).

Overall, the incompatibility of quantitative data collected in the dam removal studies I reviewed points toward the need for standardization of metrics and tools in studies on vegetation response to restoration. In the limited number of cases where studies included the same metrics, they were measured for different variables, making the data incompatible for creating an aggregate summary. Basic metrics that would be valuable for cross-study comparison include % total cover, % nonnative vegetation, species composition, and species richness. These metrics should be included as a baseline in addition to any variables. Standardization of the timescale of studies would help as well, given my review included such a broad range. Colonization indicators related to vegetation structure, taxonomic richness, diversity, and composition could provide valuable information if applied across studies of Stage 0 and BDA projects (Ravot et al., 2019). Lastly, it is important that these research efforts are closely coupled with practitioners’ goals for Stage 0 and BDA projects including improved riparian and instream habitat, reduction in channel incision, increasing lateral and vertical connectivity, raising groundwater levels, and encouraging beaver to reoccupy a site. This can be accomplished through researchers working in close collaboration with practitioners and coupling research assessments to project goals (Bouwes et al., 2016; Hinshaw et al., 2022; Lautz et al., 2019; Munir & Westbrook, 2020; Powers et al., 2018).

5) Restoration Should Include More Vegetation Monitoring and Consideration of Long-Term Vegetation Processes

Monitoring is an important aspect of restoration projects that is often overlooked, and the need for more rigorous monitoring has been discussed in scientific literature for decades. Particularly, monitoring and evaluation should be watershed-scale, carried out over the long-term, and include a consistent set of metrics for evaluation of project success (Roni et al., 2008). Most policy and research are focused on fish species and driven by aquatic scientists, but it is equally important to look at other aspects of biodiversity. There is a need for increased biodiversity and systems data collection in monitoring and research of floodplain restoration (Bellmore et al., 2013). Traditional methods for monitoring based on wadable streams and suitable for short stream reaches may not be the most efficient methods for monitoring larger-scale projects in floodplains (Roni et al., 2019). Process-based restoration in floodplains is most likely to be successful when paired with process-based management informed by spatially representative monitoring for at least several years following implementation (Hinshaw et al., 2022).

Monitoring is often too short-term to see results that give an accurate picture of plant community development. While it is important to see how ecosystems respond to stream restorations in the short term, we also need to see how they will respond in the long term.

Vegetation response is inherently long-term, with a lag time between restoration and recolonization, but most dam removal studies conclude 1-2 years following removal. To capture the vegetation response trajectory of vegetation communities requires multiple surveys over multiple years (Bellmore et al., 2017; Elzinga, 1998; Gothe et al., 2016; Lisius et al., 2018). Ramsey (2014) suggests collecting long-term data on dam removal vegetation response modeled after the studies at the Muddy River near Mt. St. Helens spanning several decades. A vegetation study downstream of the Elwha dam removal suggested that riparian vegetation changes can be documented as early as 6 years following the removal and further changes develop over decades as forest succession develops on newly exposed surfaces. When downstream landforms are altered by abruptly released sediments from a dam removal or other high-disturbance restoration method like Stage 0, plant communities could assume novel conditions over the long-term that are not revealed through monitoring of short-term responses (Brown et al., 2022). Based on the findings of these dam removal vegetation studies and more general restoration monitoring recommendations, scientists and restoration practitioners should be asking themselves what we need to look for over a time period of several decades when conducting studies or monitoring projects.

In novel restoration methods, it is important to include a long-term vegetation monitoring plan assessing plant community development through quantitative and qualitative methods. These should include quantitative assessments collecting data on natural recruitment, colonization by nonnative species, forbs and shrubs, detrital resources, and algae. By examining how much natural recruitment is occurring on a project site, restoration practitioners can determine how much replanting is needed. Quantifying colonization by nonnative vegetation helps determine how much management is needed on a project and also determines how much replanting is needed to outcompete nonnative species. Forbs and shrubs play a critical role in early succession of plant communities and their cover should be quantified as well. Monitoring plans should examine detrital resources, including catchment and retention of leaves in the project area. Ash, for example, is high in nitrogen and adds nutrients to the system. Monitoring plans should also examine algae which isn't being studied extensively but is an important component of the ecosystem. Remote sensing research is commonly used for restoration and often looks at spatial arrangement of vegetation but doesn't look at composition of what species are there. It can be difficult to determine native vs. nonnative vegetation from aerial photography or satellite imagery and these methods may need to be coupled with plot-based monitoring on the ground (Silverman et al., 2019). Important metrics to include in a monitoring program are total cover, cover of nonnative vegetation, species richness, and species composition. Ravot et al. (2019) offers a helpful table of indicators and metrics that could be used to develop monitoring plans.

Traditional restoration monitoring methods may not capture the complexity of a Stage 0 restoration project, which requires new monitoring methods that can be applied to examine sediment storage, channel migration and avulsion, diversity , and frequency of geomorphic features, abundance and retention of large wood and organic matter, water table height, wetted area, substrate size class diversity and patchiness, diversity of water velocities, area of cold water refugia, and other biological processes (Powers et al., 2018; Meyer, 2018). As practitioners seek to understand ecological effects of Stage 0 restoration, new monitoring designs to capture and quantify change are needed (Flitcroft et al., 2019). Monitoring should consider spatial dynamics across the heterogeneous habitat types created in a Stage 0 project and should include vegetation islands which are a big component of the project, providing habitat patches and sources of organic material. In addition, due to the large scale and strenuous nature of ground-based access of many Stage 0 projects, traditional transect-based monitoring can be difficult or dangerous at high flows. Using field plots in combination with data collection by unmanned aerial vehicles for geomorphic monitoring, in combination with biotic sampling and water quality monitoring can be used to assess the success of Stage 0 restoration projects (Hinshaw et al., 2022).

Beaver-based stream restoration and BDAs are so novel that they have outpaced monitoring, particularly in rangeland systems in the PNW (Orr et al., 2020; Pilliod et al., 2018). Similarly to Stage 0, restoration monitoring methods for BDAs should consider spatial dynamics across heterogeneous habitat types at the reach scale and the watershed scale. BDAs are often installed as a complex of multiple structures requiring research and monitoring extending beyond a single structure assessment to reach and watershed-scale studies of their aggregate effects and cumulative impact across stream gradients (Bouwes et al., 2016; Lautz et al., 2019). Since common goals of these projects are sustaining late season low flows and improving habitat for threatened species, it is necessary to increase the scale of monitoring. Additionally, changes in hydrology may have unanticipated effects on vegetation and plant communities, particularly in late summer, and monitoring species composition and shifts in native vs. nonnative vegetation and the spatial extent of these changes will be important (Lautz et al., 2019).

6) Restoration Should Include Active Revegetation and Facilitation of Natural Regeneration

Active revegetation including broadcasting seed and planting native tree and shrub species in the floodplain is important for creating habitat diversity, preventing the establishment of undesirable nonnative species, stabilizing sediments in the restoration project area, and supporting recreational and cultural use (Shafroth et al., 2002). Revegetation helps prevent sediment erosion and promotes bank stability through root anchorage and provides roughness promoting dissipation during flooding (Ravot et al., 2019). Banks will be more stable if vegetation communities develop into riparian forest than if vegetation communities dominated by grasses persist for a long period of time. Vegetation is one of the ecosystem components that takes the longest to recover and may take many decades to develop tree assemblages and active replanting helps by increasing the rate of vegetation establishment (Doyle et al., 2005). Replanting helps increase species richness which should be an important revegetation project goal because sites with high species richness are more resistant to disturbance and increase resilience to climate change (Chenoweth et al., 2021). Planting dense stands of native cottonwood and willow species can be an effective method to shade out and exclude nonnative herbaceous species in both Stage 0 and beaver dam analog restoration projects (Shafroth et al., 2002). Creating facilitation patches of densely planted vegetation prior to seeding or planting less densely can increase plant survival, minimize the establishment of nonnative vegetation, decrease effects of herbivory, provide more organic matter to soils, decrease erosion, and attract birds and mammals to encourage zoochorous seed dispersal (Chenoweth et al., 2011).

In Stage 0 restorations that create large areas of exposed substrate, seeding can be an important management tool for revegetation. Areas with fine sediments can be left to regenerate naturally unless the surrounding area is dominated by undesirable nonnative species, in which case seeding areas of bare soil with fine sediments decreases the abundance of nonnative species and can help reduce erosion. Seeding herbaceous species accelerates vegetation cover and hinders nonnative species and planting woody species sets the successional trajectory for the site and accelerates succession. This is more critical in areas with coarse sediments and should occur soon after restoration work is complete while residual soil moisture is high across the project area. Lupinus species seeded on both fine and coarse sediments have been shown to have significant impacts on vegetation community development by increasing cover, facilitating the establishment of other plants through structural protection from wind and sun exposure on terraces or leave islands, fixing nitrogen, and reducing fluvial erosion rates by increasing plant diversity and root growth through nitrogen fixation (Chenoweth et al., 2021). Native species that can effectively compete with aggressive weeds can be seeded as cover crops which are able to quickly occupy sites, stabilize the soil surface, and fill in spaces that otherwise may have been occupied by an undesirable species (Shafroth et al., 2002).

On areas of bare substrate, revegetation in combination with mulch sacks can increase soil moisture retention to help with the re-establishment of vegetation and can reduce runoff and erosion 10-fold compared to plots with no replanting or mulch. Active establishment of mycorrhizal vegetation through utilizing mulch and mycorrhizal inoculation on key exposed sediment areas in Stage 0 projects may help reduce the initial establishment of nonnative vegetation (Cook et al., 2011). Large wood can be strategically placed and distributed across the project site on areas of exposed substrate with seed dispersal by birds and small mammals in mind (McCaffery et al., 2020; McLaughlin, 2013). Replanting efforts can also be concentrated around large wood in the project area to shelter the plants from wind and scouring during high flows, and to protect them from browsing by ungulates (Calimpong, 2013; McCaffery et al., 2020).

Vegetation is a key component of BDAs with significant effects on implementation and project outcomes. BDA protocols typically emphasize planting copses of willow cuttings in proximity to each BDA to have the greatest effects on plant growth. Studies have also demonstrated accelerated growth of pre-existing woody riparian vegetation in proximity to

BDAs. If BDAs are implemented on streams lacking woody riparian vegetation cover, planting willow and other woody shrubs will help reduce solar insolation on impounded areas and help mitigate increases in stream temperature (Castro et al., 2017; Orr et al., 2020).

Nonnative vegetation management can play an important role in revegetation efforts. Stephens (2017) observed decreased shrub and ground cover in the wetland complex as a result of noxious weed removal and a reduction and fragmentation of shrub thickets and ground cover as a result of both removal of the weeds themselves and the trail created for off-road vehicles to access the area (Stephens, 2017). In restoration areas where riparian plant communities remain relatively intact, passive restoration processes tied to changes in geomorphology and hydrology without any active seeding or planting may be a successful approach if coupled with nonnative vegetation management to prevent colonization of unwanted species on newly exposed surfaces (Brown et al., 2022).

CONCLUSION

In spite of their ecological, social, and economic importance, floodplains are a degraded ecosystem in need of restoration and conservation to ensure their provisioning of services for current and future generations. As a community, researchers and practitioners working in restoration need to acknowledge that we can no longer consider ecological processes in the absence of people. Every stream restoration is nested within a greater social framework and ecological disturbance framework, and we have to consider these contexts more broadly. As floodplain restoration projects are being implemented more frequently in small floodplains in the PNW, emerging methods like Stage 0 and BDAs can help restore critical ecological and ecocultural processes in which vegetation plays a key role. Dam removal and floodplain reconnection studies can offer some valuable insights into what we might expect to happen with plant community recovery in these novel restoration methods. However, additional studies are needed to evaluate ecosystem responses to these restoration actions over the long term, and standardization of these studies will help ensure we can review the available data and respond with adaptive management. While the function of this paper was developing specific recommendations and a path forward for evaluating vegetation in a new era of restoration with novel methods like Stage 0 and BDAs, it ultimately raised broader questions of how we need to think about stream restoration.

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