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Title: A Novel Approach to Process-based River Restoration in Oregon: Practitioners' Perspectives, and Effects on In-stream Wood

Abstract approved:

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The widespread fragmentation, channelization, and simplification of river ecosystems has had acute environmental impacts, including degradation of water quality and habitat and biodiversity loss (Vörösmarty et al., 2010). These concerns have incited an increased focus on reestablishing ecological and hydrogeomorphological functions and improving habitat that has been lost in riverine ecosystems. The broad set of activities aimed at improving the environmental health of rivers, referred to collectively as river restoration, has become a multi-billion dollar industry (Bernhardt

et al., 2005), and one of the most active areas of applied, contemporary water resources research (Wohl, Lane, & Wilcox, 2015).

An innovative approach to process-based river restoration has recently emerged in Oregon, and is being implemented across the state by a small group of U.S. Forest Service (USFS) fisheries biologists and hydrologists. The development and dissemination of this practice – termed *Stage 0* restoration – may mark an important shift in the approach to river restoration in the Pacific Northwest, yet the phenomenon remains undocumented in the literature. This research presents Stage 0 practitioners' perspectives and a case study of the impacts of this restoration on large in-stream wood.

Qualitative semi-structured interviews and participant observations were conducted with seven USFS fisheries biologists and hydrologists to characterize what inhibits and enables the implementation of Stage 0 restoration. Interviewees cited stakeholders' fears about fish, sedimentation, and an unfamiliar morphology as serious challenges; they also noted that scientists have been crucial enablers by "bridging the gap" through advocacy and participation in stakeholder meetings. The most salient catalyst for the Stage 0 practice, however, is the interviewees' commitment to building relationships through peer-review, mentorship and outreach. The findings from this study point to the importance of Stage 0 stakeholders engaging in transparent dialogues about values, and exploring perspectives of other groups to identify opportunities for building stronger collaborations.

Continued monitoring to assess the impact of Stage 0 restoration on biophysical processes is also critical. Given the broad effects of in-stream wood on important riverine processes, a case study on this important ecosystem constituent was conducted on Deer Creek in the Western Cascades of Oregon. This research explores the effects of the experimental placement of unknown quantities of large in-stream wood in the floodplain, and the response of that wood to one year of flows after restoration. The abundance, size and spatial distribution of large in-stream wood were estimated from repeat unmanned aerial vehicle (UAV)-captured, high resolution

aerial imagery of a 500-m transect of Deer Creek before (April 2016), after (September 2016), and one year following completion (September 2017). Data were compared with a 2002 field inventory from a 500-m transect of Lookout Creek in the H.J. Andrews Experimental Forest (HJA).

The abundance of wood in Deer Creek more than tripled as a result of the restoration activities (from 428 to 1,560 pieces), but decreased by 25% over the year following restoration. Most of this change involved wood in small size classes (<30 cm diameter, <10 m length), which apparently was rearranged by 2016-17 winter peak flows (~1.5-year recurrence interval). The restoration efforts sharply increased wood of a particular larger size class (>60 cm diameter, 10 to 20 m length), though after restoration, Deer Creek only had about 40% as many large diameter class (>60 cm) pieces per unit stream channel length as Lookout Creek. More wood was contained in accumulations in Lookout Creek, and the accumulations were larger and more widely spaced, due to fluvial rearrangement during high flow events. Uncertainty in wood diameter and length and location of logs in repeat drone-based imagery was high. Thus, if wood monitoring using drone-mounted cameras continues in Deer Creek, it should include field verifications of sizes and establishment of a ground control network. The response seen at Deer Creek points to the importance of promoting long-term wood recruitment processes at Deer Creek, and continuing to study the stability of wood. There are opportunities for research partnerships between Stage 0 practitioners and HJA scientists, who have collectively conducted decades of research on large in-stream wood.

A Novel Approach to Process-based River Restoration in Oregon:
Practitioners' Perspectives, and Effects on In-stream Wood

by

Stephanie Rae Bianco

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Stephanie Rae Bianco, Author

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1 General Introduction

This thesis presents an investigation into a new approach to river restoration being implemented across Oregon by a group of U.S. Forest Service (USFS) fisheries biologists and hydrologists (referred to in this research as practitioners), called Stage 0 restoration. Several Stage 0 projects were completed between 2012 and 2018, involving, in total, hundreds of hectares of cut-and-fill earthwork and placement of thousands of pieces of large wood in floodplains. The practice is undocumented in the literature, and little is known about the methodology, motivations for the approach, or its potential impacts on riverine biophysical processes.

This document consists of two manuscripts, contained under Chapters 2 and 3. Chapter 2 presents the results of my qualitative semi-structured interviews with seven Stage 0 practitioners. This research explores their perspectives on the approach by characterizing how science is informing their work and identifying challenges and enablers to implementation. The findings from this qualitative study provided important context for the second half of the study. Chapter 3 presents a case study of a Stage 0 restoration project completed in 2016 on Deer Creek in the Western Cascades of Oregon. This research examines one of the most conspicuous aspects of the Stage 0 approach – addition of high amounts of large in-stream wood to the floodplain. Repeat unmanned aerial vehicle (UAV)-captured high resolution aerial imagery of a 500-m transect of Deer Creek before, after and one year following project completion was used in combination with supplementary ground-based imagery to assess the impact of the restoration and a year of fluvial forces on the abundance, size and spatial distribution of large in-stream wood. Data were compared with a 2002 study on Lookout Creek in the H.J. Andrews Experimental Forest (HJA) to provide historical context to the short-term Deer Creek study.

By considering both the practitioners’ perspectives and the impact of a Stage 0 project on in-stream wood, an important driver of ecosystem functions, this thesis acknowledges the importance of both social and biophysical processes in river restoration.

2 Practitioners' perspectives on a novel approach to process-based river restoration in Oregon

2.1 Introduction

The widespread fragmentation, channelization, and simplification of river ecosystems has had acute environmental impacts, including degradation of water quality and habitat and biodiversity loss (Vörösmarty et al., 2010). These concerns have incited an increased focus on reestablishing ecological and hydrogeomorphological functions and improving habitat that has been lost in riverine ecosystems. The broad set of activities aimed at improving the environmental health of rivers, referred to collectively as river restoration, has become a multi-billion dollar industry (Bernhardt et al., 2005), and one of the most active areas of applied, contemporary water resources research (Wohl et al., 2015).

An innovative approach to process-based river restoration has recently emerged in Oregon, and is being implemented on federal lands across the state. Several of these river restoration projects were completed between 2012 and 2018, involving, in total, hundreds of hectares of cut-and-fill earthwork and placement of thousands of pieces of large wood in stream channels and floodplains. Momentum appears to be growing for this new approach, with more projects slated to begin in the coming years.

A small group of U.S. Forest Service (USFS) fisheries biologists and hydrologists, referred to herein as practitioners, are designing and implementing these river restoration projects with the apparent support of several scientists. The connection between science and practice is embodied in the very name of the approach; the USFS practitioners who developed it are calling their projects *Stage 0* restoration – a direct reference to Cluer and Thorne's (2013) Stream Evolution Model. For the purposes of this research, the term scientist is used to describe someone who researches geomorphological and biological riverine processes and publishes peer-reviewed articles relevant to river restoration, whom the practitioners at times call on to provide expert input.

The emergence and growing popularity of Stage 0 projects may mark an important shift in our approach to river restoration in the Pacific Northwest, but to date the phenomenon remains undocumented in the literature. This study seeks to provide a better understanding of the relationship between science and practice in Stage 0 restoration, as well as insights into what might inhibit or enable this practice from being implemented elsewhere. I conducted qualitative interviews with USFS fisheries biologists and hydrologists from three National Forests in Oregon who have experience implementing Stage 0 restoration projects to address the following research questions:

1) How is science informing the practice of Stage 0 restoration?
2) What are some potential enablers and challenges to the implementation of Stage 0 restoration projects elsewhere?

The field of river restoration, like so many other applied sciences, has suffered from a disconnect between theory and practice (Palmer, 2009). Though that gap has seemingly narrowed over the past decades (Wohl et al., 2015), our understanding of the interplay between science and practice is still limited (Dickens & Suding, 2013). The Stage 0 practitioners' engagement of the scientific community and broader public has sparked an important dialogue. Their efforts may help to further narrow the gap between science and practice. With the growing impetus to move towards more process-based restoration projects nationwide (Beechie et al., 2010; Kondolf, 1998; Wohl et al., 2005, 2015), it is important that we reflect on lessons learned from practices like Stage 0 restoration to shed light on what its potential impacts and limitations may be.

This study is intended to be a starting point to document the unfolding of this innovative approach to river restoration in Oregon. I first present some additional background and context for the Stage 0 approach, followed by results and my interpretations of my interviews with practitioners. All accompanying tables and figures are included at the end of this chapter. I conclude with some remarks on how scientists and practitioners might strengthen their connections with each other and the greater community of stakeholders to overcome the challenges they face and continue improving the Stage 0 practice.

2.2 Background

In this section I describe the development of the Stage 0 restoration approach and present some of the motivations for this study. First, I take a look back at the emergence of process-based river restoration approaches to help provide context for the Stage 0 practice. I will then chronicle the development of the Stage 0 practice and describe some salient features of the approach.

2.2.1 Process-based river restoration

We cannot tell the story of the Stage 0 approach without describing the emergence of process-based river restoration. The Stage 0 methodology embodies the same fundamental principles, and is considered by its creators to be a type of process-based approach. The development of process-based restoration parallels the progression of riverine ecosystem science. Our understanding of rivers has shifted substantially from conceptualizing rivers as continuua (Vannote, Marshall, Cummins, Sedell, & Cushing, 1980) to how many river scientists today describe them – as riverscapes, or complex tapestries of connected patches, dynamic in space and time (Carbonneau, Fonstad, Marcus, & Dugdale, 2012; Poole, 2010). Central to this conceptualization is the coupling of complex biological and physical processes over a broad range of scales. This biophysically integrated conceptualization of riverine ecosystems has implications for land management, and is informing contemporary restoration practices.

One manifestation of this biophysical conceptualization of riverine ecosystems is the growing impetus from the scientific community to devote its efforts to process-based river restoration methodologies (Beechie et al., 2010; Kondolf, 1998; Wohl et al., 2005, 2015) instead of the form- or structure-based approaches like Rosgen's Natural Channel Design (NCD) that have dominated the industry over the past few decades (Lave, 2009). Process-based river restoration differs from form-based methods like

NCD in that it “aims to reestablish normative rates and magnitudes of physical, chemical and biological processes that create and sustain river and floodplain ecosystems” (Beechie et al., 2010, p. 209) instead of aiming to create a static form or particular habitat type. As such, process-based restoration projects are highly contextual and rely on a nuanced understanding of how facets of the ecosystem have changed and might be expected to change over a broad range of spatio-temporal scales.

Though project settings and objectives vary widely, some important processes in process-based restoration more broadly include floodplain building, pool or bar formation, primary production, hyporheic exchange, wood recruitment and sediment retention (Roni & Beechie, 2013). Process-based restoration principles emphasize the importance of landscape- and watershed-scale processes, many of which act over long time scales. Although process-based river restoration, as it is described in the scientific literature, does not offer the same formulaic approach as NCD, its principles align more readily with contemporary conceptualizations of rivers as dynamic landscapes, and appears to be more widely accepted in the scientific community.

2.2.2 Emergence of Stage 0 restoration

Since no literature currently exists documenting Stage 0 restoration as a practice, I obtained the information in this section from my qualitative interviews and participant observations with Stage 0 practitioners. A description of both of those methodologies follows, along with more detailed findings in subsequent sections.

Stage 0 restoration has been developed incrementally over the last decade or so, and grew out of the scientific community’s push to move towards more process-based approaches. Instead of conceptualizing a specific structure, shape, or habitat as an end goal, Stage 0 restoration practitioners see resiliency and the creation of a diverse array of habitat types as the expected and desired consequence of restoring complex processes, especially energy dissipation, sediment deposition, hyporheic exchange and floodplain connectivity.

Though a strict definition Stage 0 restoration has not yet been articulated, there are several characteristics that these projects share. According to the practitioners, Stage 0 restoration is only implemented in areas that are thought to be former depositional reaches – wide valleys where sediment accumulated over time – since these areas were shaped by the processes they are aiming to restore. Due to anthropogenic disturbances like road building, timber harvesting and berm construction, these former depositional reaches are currently channelized, incised and functioning as transport reaches conveying sediments downstream. The Stage 0 restoration approach involves removal of berms and human-constructed structures that channelize rivers to re-establish floodplain connectivity (Figure 2.1). Another important aspect of this approach is the placement of substantial amounts (upwards of 300 to 400 pieces per mile) of large wood in the restored river and floodplain to dissipate energy and create hydraulic complexity (Figure 2.2).

The origins of the Stage 0 approach can be traced back to the Karnowsky Creek restoration project on the Siuslaw National Forest, where an unexpected event in 2002 led a group of USFS practitioners to reflect on how they were approaching restoration. The year after the completion of a NCD project in 2001, a landslide was deposited in the site, destroying the channel they had constructed. While the practitioners responsible for the project viewed the landslide as a failure for the project, another practitioner visiting from the Deschutes National Forest expressed a different perspective – he thought the disturbance had actually caused more favorable conditions. The conversations that transpired following that event helped these USFS practitioners start to see disturbance and dynamism as natural and important features of riverine ecosystems in the regions where they were doing restoration. This was the beginning of their decades-long adaptive management approach to restoration.

The lessons learned from the Karnowsky Creek project did more than just change the interviewees’ perspectives on river restoration; these insights informed their technical approach to projects in a very tangible way on subsequent projects. The practitioner from the Deschutes National Forest who saw the presumed failure on Karnowsky

Creek as a success decided to emulate the alluvial fan created by the landslide on the upper reaches of a new project near the Deschutes National Forest – the Camp Polk Meadow Whychus Creek Restoration (Camp Polk), which began in 2009. Interestingly, on that same Camp Polk restoration project, NCD was implemented on the lower project reaches below the alluvial fan, so the practitioners were able to qualitatively compare outcomes. According to the interviewees, the team from the Deschutes National Forest saw more favorable outcomes of the project on the upper reaches compared to the lower reaches where NCD was implemented. They used lessons learned at Camp Polk to inform their efforts on their next projects, since then completing a number of other projects on Whychus Creek.

This process over the past decade on Whychus Creek gave way to what the interviewees today call Stage 0 restoration and inspired application of these projects on National Forests across Oregon (Figure 2.3, Table 2.1). Stage 0 restoration has steadily been growing in scope and scale since then. Between 2014 and 2017, the Stage 0 practice disseminated from the Deschutes National Forest to the Siuslaw, Willamette, Fremont-Winema and Ochoco National Forests, with more slated to begin in following years.

2.2.3 The Stream Evolution Model

Although they had already implemented several projects that are now referred to as Stage 0, the approach only got its name after the practitioners became aware of Cluer and Thorne's (2013) publication of the Stream Evolution Model. This publication was highly influential to the Stage 0 practitioners' work.

Cluer and Thorne's (2013) Stream Evolution Model (SEM) portrays how channels theoretically undergo various phases of morphological changes following disturbances (Figure 2.4). The SEM revisits past conceptual channel evolution models (CEMs) (Schumm, Harvey, & Watson, 1984; Simon & Hupp, 1986), which have been widely used to model channel response to incision and channelization. The SEM incorporates the core elements of past channel evolution models, and builds on those conceptual models in a few key ways. Most notably for the group of USFS river restoration practitioners, the SEM includes a precursor stage that was not incorporated in past models – Stage 0. This phase in the SEM, which marks the start of the cycle, is characterized by an anastomosing morphology, a "dynamically meta-stable network of anabranching channels with vegetated islands" (Cluer & Thorne, 2013, p. 142). Further, they attribute Stage 0 with the most habitat and ecosystem benefits of any phase in the SEM, which has obvious implications for restoration.

Drawing on findings from other studies (Montgomery, 2004; Walter & Merritts, 2008), Cluer and Thorne (2013) argue that some streams likely exhibited an anastomosing morphology prior to European settlement of the U.S., and that Stage 0 therefore represents a pre-disturbance condition in those settings. Cluer and Thorne also suggest that "an unintended consequence of the broad acceptance of CEMs as conceptual models for alluvial stream behaviour has been to help perpetuate the assumption that a single-thread, meandering channel represents the natural configuration of a dynamically stable alluvial stream and that this, consequently, represents a universally appropriate target morphology for restoration" (2013, p. 136). Though controversial (Cluer & Thorne, 2013), this concept is key to understanding the value of the SEM to Stage 0 practitioners.

Stage 0 practitioners have rejected the single-thread channel as a target for restoration in the depositional reaches where they are implementing their projects, and are using anastomosing streams as a new guiding image for river restoration on federal lands in Oregon. This could mark an important shift in the approach to river restoration in the Pacific Northwest, highlighting the value and motivation for this study on Stage 0 restoration. Given the practitioners' connection to the scientific community, the uncertainty about where anastomosing streams are expected to have naturally occurred on the landscape, and the growing momentum towards implementing more of these projects in the future, it is important to understand the social processes at play in implementing Stage 0 that influence its trajectory.

2.3 Methods

2.3.1 Study design

I conducted a qualitative interview study, the core of which consisted of semi-structured interviews with experts in the area of research to address the following research questions:

1) How is science informing the practice of Stage 0 restoration?
2) What are some potential enablers and challenges to the implementation of Stage 0 restoration projects elsewhere?

The Institutional Review Board (IRB) approved my research protocol on July 28, 2017, which included my recruitment letter and study instrument, the interview guide. I used a non-probabilistic, purposive sampling approach to identify and recruit interviewees that met the following criteria at the time of the interview: 1) they were a current employee of the USFS, and 2) they had experience implementing at least one large scale process-based river restoration project in Oregon as a USFS employee. Though my study population was relatively homogenous, I interviewed USFS fisheries biologists and hydrologists from three different National Forests in Oregon and at various levels in the USFS to provide different perspectives. The interviewees also have varying degrees of expertise in the river restoration discipline; three have been with the agency for more than two decades and have worked on dozens of river restoration projects while others have managed only one large scale Stage 0 restoration project to date.

2.3.2 Data collection

<u>Literature review and participant observation</u>

Prior to conducting interviews, I reviewed publicly available resources including watershed and sub-basin assessments, Federal Energy Regulatory Commission (FERC) relicensing reports, and documents required by the National Environmental Policy Act (NEPA). Information obtained from these resources provided important context for my study.

Participant observation was another critical component of my research, and involved informal conversations and meetings with potential interviewees and other experts in the field of river restoration. These exchanges exposed me to terminology and concepts used by restoration practitioners and scientists, further assisting me in developing the substantive frame of the study. Examples of participant observation include guided tours of restoration sites led by the interviewees, meetings with scientists, and attending the River Restoration Northwest symposium in February 2018. I used the results of my participant observations to triangulate the findings from the interviews and to inform my interpretations.

Semi-structured interviews

Qualitative interviews are well suited to explore the research questions of interest because they provide rich, detailed data that allows for a better understanding of the experience, insights and perspectives of a study population (Rubin & Rubin, 2005). Rather than providing generalizable results, this methodology solicited holistic descriptions and narratives that paint a picture of a time and place in the rapidly evolving field of study of river restoration. Semi-structured interviews also provide the flexibility to explore subjects in varying depths depending on the participants' degree of expertise or level of comfort with that subject (Weiss, 1995).

I conducted in-person, semi-structured interviews with seven participants from September 2017 through October 2017 in accordance with the IRB-approved protocol (Table 2.2). Though this sample size is relatively small, this is to be expected with this emerging field. Research also suggests that qualitative interviews with six or more participants is substantial to derive meta-themes (Guest, Bunce, & Johnson, 2006). I obtained informed consent from the interviewees prior to starting each interview, noting the details of consent in a field notebook. All interviewees consented to audio recording the interviews. Each interview lasted between 60 and 90 minutes.

The interview guide gave a loose structure to the interviews, and was intended to serve to prompt me about general lines of inquiry, or domains, rather than to provide verbatim questions (Weiss, 1995). Although I covered the same main domains in all of the interviews, I pursued additional topics at my discretion in order to develop more detailed information related to participants' specific areas of expertise and unique perspectives on issues. I transcribed audio files within seven days of the date of the interview for use in data analysis.

2.3.3 Data analysis

I employed an inductive, in vivo coding approach to categorize data from the transcribed files into meta-themes (Thomas, 2006). In vivo coding relies on careful, repeated reading of the raw text to sort actual words or phrases used by the interviewees into meaningful, representative categories. Those categories were mostly defined by my research questions, but coding allowed additional themes to emerge from the transcribed files. The headers of the results and discussion section indicate the meta-themes that emerged from coding.

2.3.4 Strengths and limitations of methodology

As with any non-probabilistic qualitative interview study, the results of this research are not generalizable, though they may be applicable to similar situations and populations (Rubin & Rubin, 2005). To strengthen the validity of my study, I provided interviewees with the opportunity to perform stakeholder checks during the manuscript-writing phase to comment on their quotes and my interpretations and offer suggestions for edits. Triangulation of the results of my semi-structured interviews with my findings from participant observations also enhanced the validity of my findings.

2.4 Results and Discussion

Three principal findings emerged from the qualitative interviews and participant observations I conducted with USFS Stage 0 restoration practitioners. Stakeholder fear emerged as the key barrier that interviewees identified to implementing Stage 0 restoration. This challenge has in part been addressed through the role scientists play in "bridging the gap" between the interviewees and stakeholders and between the science and practice of river restoration. Absolutely central to the Stage 0 approach, however, are the relationships the interviewees have built through their peer-review, mentorship and outreach efforts. Each of these three themes is explored in the subsections below.

2.4.1 Stakeholder fears

Stakeholders play a central role throughout the entire process of planning, implementing and monitoring Stage 0 restoration, from partners securing funds and sometimes land for projects to agency personnel issuing permits and overseeing regulatory compliance. Interviewees cited that fear on the part of some stakeholders about harming fish, sedimentation during construction, and an unfamiliar morphology has been a serious challenge to implementing Stage 0 restoration and has halted some projects altogether.

The most acute source of stakeholders' fear, according to the interviewees, is the perceived potential impact of Stage 0 projects on endangered fish species, especially salmon. Since the Stage 0 approach involves flattening the surface of the valley floor to disperse flow, stakeholders have voiced fear that a water depth needed to maintain fish passage might not be sustained, or that fish may become stranded on the floodplain. As a fisheries biologist from the Siuslaw National Forest shared, given the complex life histories of these species and the many variables influencing their populations, Stage 0 practitioners are trying to shift their focus towards restoring process:

> Everybody goes back to fish numbers, but fish numbers are so dependent on other things. [Recently] they did some troll surveys out from Puget Sound down to Northern California, and they had net runs that in some places didn't capture a single salmon. They're predicting much lower numbers over the next few years for returns. So, you finish these [Stage 0 restoration] projects, and if no fish come back or you don't see as many numbers, it's like 'Oh, it didn't work'... so I try to stay away from fish numbers and try to just talk about what process we're restoring. We're restoring the native plant communities. We're restoring the hydrologic connection to the valley, improving wildlife habitat. That's our charge on the Forest – we're not in

> charge of populations; we're in charge of habitat. – Fisheries Biologist, Siuslaw National Forest

The Stage 0 practitioners seem to be grappling with the tradeoffs of focusing too heavily on salmon to the potential detriment other aquatic species that also make up an important part of the ecosystem. While they share a concern for protecting endangered species and are monitoring their sites to track water depths and fish use throughout the year, many expressed that this single-species focus has stifled innovation and has led to ineffective approaches to restoration (i.e. construction of single habitat structures like pools), an idea supported by some scientists (Palmer, 2009; Wheaton, Darby, & Sear, 2008). Stakeholder fear of negative impacts on salmon is understandable, however, and the stakes are arguably especially high for stakeholders whose job responsibilities include permitting and enforcement of the Endangered Species Act (ESA) – a policy with tremendous implications for river restoration in the Pacific Northwest.

Another aspect of Stage 0 projects that has caused fear and concern among project stakeholders is the sedimentation caused during and immediately following implementation. Because Stage 0 projects cause disturbance to riparian areas, some people view this restoration approach as at odds with protection of water quality, as a hydrologist from the Willamette National Forest described:

> As a hydrologist, I'm worried about water quality…With the [USFS] timber folks I'm like, 'Hey guys, make sure there's no sediment going into the streams.' And they're like, 'So you're putting a bulldozer in the stream?' And I'm like, 'Yeah…but it's for restoration!' And by law we can do that because it's for restoration, not putting trees to the mill. And that makes sense to some people and some people it doesn't." – Hydrologist, Willamette National Forest

This account points to an interesting cognitive dissonance – for some stakeholders, even for some within their agency, Stage 0 restoration simply does not look like restoration; it looks like disturbance. Perhaps having to play simultaneous roles as both enforcers of regulations and implementers of projects that cause significant riparian disturbance has put Stage 0 practitioners in a difficult position. Tension might be particularly pronounced given that the USFS has invested significant resources in limiting the delivery of sediment to streams through maintenance of riparian buffers, and has begun to focused more on stewardship in the Pacific Northwest in the wake of the Northwest Forest Plan and the Endangered Species Act (Gillis, 1990). Conceptualizing Stage 0 efforts as restoration can also be a difficult leap given some of the “do no harm” tenets put forth by restoration scientists (Palmer et al., 2005). USFS personnel, other stakeholders and policy makers are continuing to discuss how much disturbance they are willing to tolerate in the short term to potentially achieve ecosystem benefits in the longer term.

In the same manner that stakeholder fears about salmon and sedimentation has impeded Stage 0 projects, differing expectations and visions for restoration have also acted as a roadblock. Interviewees discussed how the Stage 0 anastomosing morphology often does not align with stakeholders’ visions of what a restored river should look like, which has given rise to skepticism and doubt from stakeholders about the Stage 0 approach. A fisheries biologist from the Deschutes National Forest provided his perspective on this challenge:

> The C channel from Rosgen's classification is like everyone’s Nirvana. Everyone's been trained to build to that. That's the perfect stream in most people’s minds. When we deviate from that, that's when we run into hardship. – Fisheries Biologist, Deschutes National Forest

Aesthetics seem to play some role in conceptualizations of what this fisheries biologist describes as the perfect stream. Though the interviewees commented that there are many circumstances where a C stream type from Rosgen’s classification - a single-thread meandering channel – is an appropriate template for restoration, they believe that there has been a disproportionate emphasis placed on maintaining this morphology and that this has resulted from the long legacy of human impacts on river ecosystems. A fisheries biologist from the Willamette National Forest described how he thinks this history has influenced the values people attribute to rivers:

> You see a stream – you see it simplified – and it’s beautiful. First it’s hard to get over that. You go up into the Western Cascades, and a completely degraded river looks beautiful. You don’t know any better. We're devoid of the opportunity to see properly functioning, unaltered stream systems, so

> everything we're familiar with, everything we see, our whole idea of a river, is already a degraded system. – Fisheries Biologist, Willamette National Forest

Seemingly superficial issues of what constitutes a "degraded" or "beautiful" river are in fact rife with complexity and nuance, and speak to how difficult it can be to disentangle subconscious values and worldviews from visions for restoration. Yet the value-laden nature of restoration is a subject that is often avoided, and is a ubiquitous problem in this field (Wheaton et al., 2008). Communication about the motivations and values underpinning restoration therefore remains a central challenge for implementing Stage 0 restoration.

2.4.2 Scientists "bridging the gap"

Despite the challenges they face, the interviewees have been successful in implementing several Stage 0 projects over the recent years. They attribute their success in part to the role scientists have played in supporting Stage 0 restoration through their advocacy of the approach, their participation in stakeholder meetings and their prior publication on relevant geomorphic and biological processes. All of this has helped to "bridge the gap," as interviewees described – to increase understanding between the practitioners and other stakeholders, and also to shift the interviewees' understanding of riverine ecosystem processes.

I observed scientists' advocacy for Stage 0 at the River Restoration Northwest Symposium in February 2018, where researchers whose work has strongly influenced the Stage 0 practice – Brian Cluer and Janine Castro, for example – held joint sessions with some of the interviewees. During one of these sessions titled "Restoring to Stage 0 – Science Base, Historical Perspectives & Natural Functions" (River Restoration Northwest, 2018), scientists presented the research and science behind the Stage 0 concept, and practitioners presented outcomes and lessons learned from projects. This collaboration scientists has helped to build the morale of the Stage 0 practitioners and to affirm that they are not alone in their beliefs, as a hydrologist from the Willamette National Forest describes:

> Bit by bit you see those key players in key positions accepting, seeing, understanding…When you get those scientists that have been concentrating their careers in certain areas, and they understand the implications of how the restoration that we're doing will affect what they've been studying, and they agree with [the Stage 0 approach], that really, really helps bridge that gap. – Hydrologist, Willamette National Forest

The potential for a reciprocal relationship between practitioners and scientists, where science not only informs practice, but practice also informs science, has been held up as an ideal to strive for in this applied field (Palmer, 2009; Rogers, 2006). Though scientists have not conducted formal studies on the impacts of Stage 0 restoration to date, these interactions might represent a foundation for future collaborations.

In addition to advocating for Stage 0 restoration, scientists have also helped to "bridge the gap" between the interviewees and their partners by attending stakeholder meetings to serve as subject matter experts when disagreements arise. A hydrologist from the Deschutes National Forest described how this dynamic played out for one Stage 0 project:

> A big reason we started bringing Janine [Castro] to our stakeholder meetings was because we were so divided. She is very well respected in her field, and also a very good communicator. [We brought] her in as the expert, because you know, [stakeholders] would say 'You're going to capture all the sediment in this first part of the project and it's going to be sediment starved the rest of the way down.' And we'd say, 'No, we don't think that's going to happen.' And they'd be like, 'Well, who are you?' And we'd be like, 'Janine, can you answer that question?' I think it definitely helped. It was nice to have the expert come in. – Hydrologist, Deschutes National Forest

It is possible that scientists are able fill this mediator role effectively because they are seen as credible and impartial by many stakeholder groups. Since several of the scientists collaborating with the interviewees have affiliations with governmental agencies, they may also have credibility with stakeholders from those agencies, who tend to be more skeptical of the Stage 0 approach.

While the role scientists play as subject experts is an important one, on the other hand it might be damaging to hold them up as the "experts who solve environmental problems" (Rogers, 2006, p. 269); this discounts the history of restoration as a social process (Wohl et al., 2015) and minimizes the expertise and knowledge that every stakeholder brings to the table. Many of the interviewees, for example, hold Masters of Science degrees and have several decades of experience observing and studying aquatic ecosystems. This is to say that perhaps the dichotomy alluded to by the interviewees between themselves and scientists is not quite so distinct as some perceive it to be. It would be valuable to explore why certain people are seen as credible experts by stakeholder groups to help inform future collaborations.

Scientists have also helped “bridge the gap” between the science and practice of river restoration through the publication of prior research on geomorphic and biological processes relevant to river restoration. In addition to Cluer and Thorne’s Stream Evolution Model (2013) discussed earlier, the USFS practitioners also cited the work of Janine Castro, Michael Pollock, Philip Roni and Tim Beechie, frequently referencing the book *Stream and Watershed Restoration* (Roni & Beechie, 2013). One interviewee cited the importance of Christine May’s research on landslides in the Oregon Coast Range in helping him understand disturbance dynamics. All of these scientists, and the many who came before them, have been instrumental in helping shape the interviewees’ understanding of riverine ecosystem processes.

But science alone is not enough to affect how river restoration is approached; in this applied field, change transpires when people use science to inform their practice, which seems to be occurring in Stage 0 restoration. When taken in context, it is unusual that the restoration practitioners that I interviewed unanimously stressed the importance of science and peer-reviewed literature. Their relationship to science stands in contrast to findings from a large interview study, in which only 1 out of 317 (0.3%) restoration practitioners in the U.S. identified peer-reviewed scientific literature as an important driver for restoration practices (Bernhardt et al., 2007). I would argue that it is the practitioners’ active engagement of the scientists and their openness to learning that paved the way for the emergence of Stage 0 restoration.

2.4.3 The Restoration Assistance Team: building bridges

Though the advocacy and support from scientists has been an important enabler for Stage 0 restoration, their role in the practice is just one part of a much larger community forged by the interviewees through their peer-review, mentorship and outreach efforts. Through their joint participation as members of the USFS Region 6 Restoration Assistance Team (R.A.T.), the interviewees have built the bridges, or relationships needed for this innovative approach to river restoration to emerge and disseminate across Oregon.

The R.A.T. is unique even within the USFS; nothing quite like it exists in any other branch or region in the agency. The interviewees make up a portion of the team, which consists of employees from the management branch of the USFS from across Region 6 with experience in river restoration. Their mission is to provide consultation and support for projects throughout Oregon and Washington.

As R.A.T. members, the interviewees have established a system whereby they provide periodic peer-review of each other's proposed and completed projects, a process that several interviewees cited as a critical enabler of Stage 0 restoration and the refinement of the practice. A fisheries biologist from the Siuslaw National Forest shared the value he sees in peer-review:

> [The Restoration Assistance Team] is a good mix because we all see things differently. We're all going out on each other's projects and reviewing and getting feedback from each other…In the late '90s, we used to hate people coming in. Everyone was all defensive about what they were doing, everyone had their own way. Now we're talking more about restoring processes and thinking about how the stream should be working...It really is a totally different way of looking at it. – Fisheries Biologist, Siuslaw National Forest

As this fisheries biologist's account suggests, a willingness to be open to potential criticism was a catalyst for change – it allowed the interviewees to start thinking about restoration in a new way. As an example, this peer-review process led to the interaction at Karnowsky Creek described earlier, which resulted in several interviewees from different geographies in Oregon starting to think about landslides and natural disturbances as desired and expected ecosystem processes rather than failures. The ability to have these difficult conversations and learn from each other speaks to the deep level of trust that must exist between the interviewees. Expanding the circle to include more reviewers, including people from outside the USFS, could help strengthen their peer-review process.

Mentorship provided by more senior members of the R.A.T. has also shaped Stage 0 restoration, and has helped build bridges between different generations of USFS restoration practitioners. The four youngest interviewees all provided accounts of insights resulting from mentorship from more senior members of the R.A.T. In many cases, the scope of their proposed bank stabilization or engineered log jam restoration designs grew drastically after meeting with experienced practitioners. A fisheries biologist from the Willamette National Forest, who implemented her first Stage 0 project in 2016 discussed how having mentors who were willing to take risks helped pave the way for her:

> I think it took some practitioners…who were brave enough to implement a project like that to show people. Because I was terrified and skeptical…but now that I've been through it and I've seen the results, I am 100% sold. You have to see it to understand it. – Fisheries Biologist, Willamette National Forest

This statement illuminates an interesting point – fear about Stage 0 restoration is not just a challenge associated with other stakeholder groups, it is also a concern even within this tight knit circle. It is also important to note that less senior members have contributed to the development of the Stage 0 practice as well; according to the interviewees, their skills with new technologies and unique perspectives continue to push the limits of the practice.

Outreach is another important way the interviewees have built partnerships and connections. Within the agency, the R.A.T. hosts an annual training session called NR20, where they share lessons learned and river restoration best practices with USFS employees from across the U.S. The interviewees also host guided tours for the public, including student groups and other citizens and stakeholders. Interviewees emphasized the importance of getting people out in the field to see the outcomes of Stage 0 restoration, and stated that in many cases, people who were skeptical before were "brought on board" through their outreach efforts. The interviewees' outreach efforts have also helped build partnerships with scientists. On three separate occasions over the last year, interviewees invited scientists and researchers from institutions across the state and from the research branch of the USFS to workshops and field trips focused on identifying opportunities for monitoring and research.

Although connections are just beginning to be forged, these partnerships and collaborations will likely become more critical given the political and social challenges the interviewees face. These partnerships may also help to drive new research directions in the restoration community, and to illuminate how the Stage 0 approach can continue to be refined.

2.5 Conclusion

This study revealed that despite stakeholder fears and differing visions for restoration, the relationships forged by the interviewees have allowed them to develop and continue refining their innovative approach to river restoration. This is not to say that the interviewees have completely overcome the challenges they face. On the contrary, the challenges identified in this research will likely endure moving forward, and new issues may arise as the practice expands and more stakeholders become involved. How Stage 0 practitioners choose to address these challenges in the present could be an important determinant for the acceptance and success of future projects.

The barriers posed by differing visions and fear among Stage 0 stakeholders point to an important opportunity – to engage in transparent and explicit dialogues about values, a subject that has too often been neglected from conversations about river restoration. These dialogues may help the Stage 0 stakeholders move past disagreements about guiding images, which can be fraught with ambiguity and veiled subjectivity, towards identifying shared values and common ground.

The interviewees have invested significant effort thus far in engaging in a dialogue about risk and uncertainty, another topic often avoided in this field. During my interviews and interactions with Stage 0 practitioners, I was struck by their openness and humility – they never claimed to have the answers or expressed certainty about their approach. This sort of transparency and modesty gives the space for growth. I hope those conversations expand to include other stakeholders, including groups that have historically been left out of dialogues.

In a similar vein, I also see potential to shift how practitioners communicate about Stage 0 restoration. Perhaps the branding of the practice as Stage 0 is misleading in the sense that it does not readily reveal the underlying objectives of the practice – to restore complex processes, not necessarily to impose form. If these practitioners focus their communication too heavily on the desired morphology of their projects, they may be met with the same criticisms that Rosgen's methodology has faced even though their underlying philosophies are quite distinct.

In cases like Stage 0 restoration, where practitioners are citing scientific literature and engaging the scientific community, it would be mutually beneficial for those scientists to commit more time to collaborating with practitioners to learn about how and why their ideas are being put into practice, and also what the impacts of those efforts are on biophysical processes over time. For example, before-after-control-impact studies could be conducted on Stage 0 restoration projects to test Cluer and Thorne's conceptual model of stream evolution. This would help us to better understand the resilience and dynamics of these systems, a topic poorly understood at present. Not only would this help to close the gap between science and practice, it might also help to foster more of an adaptive management approach to applied river restoration science – where science informs practice and vice versa – rather than the top down approach that currently exists. Monitoring restoration projects is no small task, especially for projects of this scale; it requires the commitment of all stakeholders. It will be important to continue sharing lessons learned and findings from these monitoring efforts to help identify the settings in which Stage 0 restoration is most effective and applicable, a critical question given the concerns that have arisen about the short-term disturbance caused by the projects.

This research synthesized practitioners’ perspectives on this innovative approach to river restoration. Exploring the perspectives of other stakeholder groups is an exciting avenue for future research. How do scientists view the operationalization of their research? What role does fear play in stakeholder decision-making? There are many questions left to explore, and qualitative interviews can provide new insights to paint a more complete picture of this complex network of players.

This is an exciting moment in time for the river restoration community in the U.S., and the emergence of Stage 0 restoration presents an opportune time to reflect on the implicit values that guide our visions for restoration, how we communicate about our science and practice, and how we can continue learning and improving our efforts together.

2.6 Tables and figures for Chapter 2

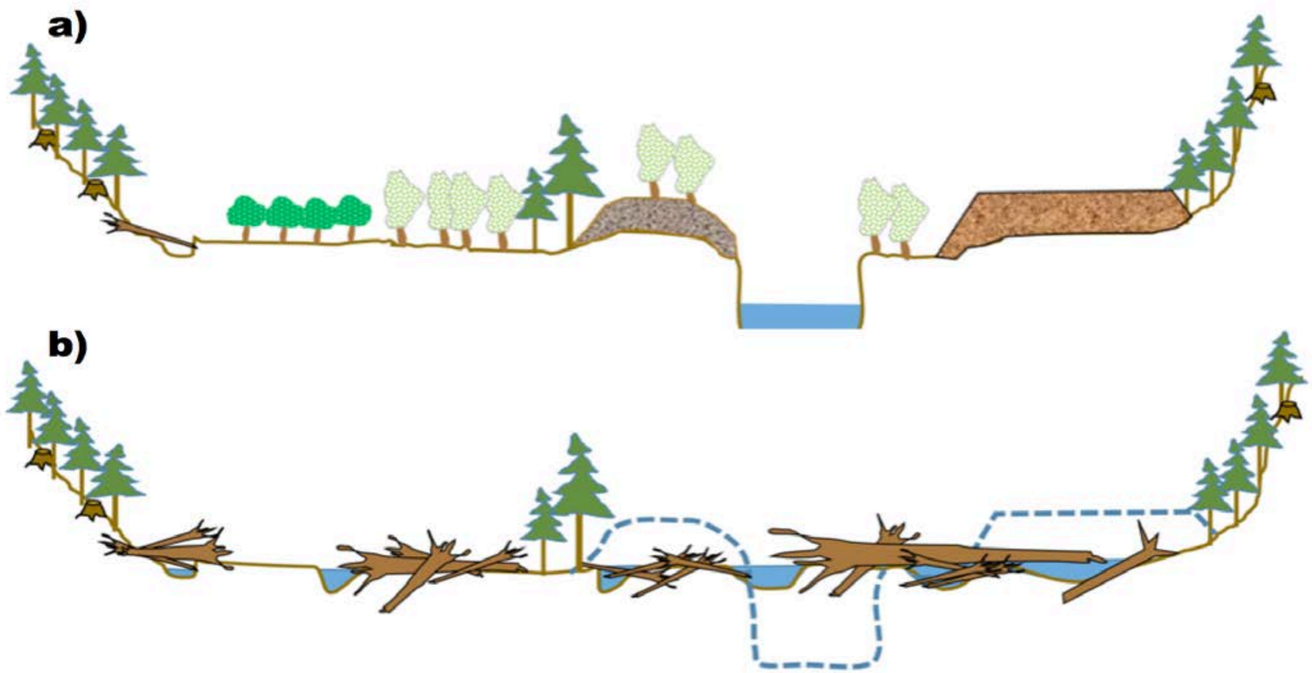


Figure 2.1: Conceptual diagrams of conditions before and after a Stage 0 project.Perspective along a cross section spanning the valley floor. Before restoration (a), the river is channelized, incised and constrained by manmade features that prevent water from interacting with the floodplain. Stage 0 restoration involves (b) redistributing material from those manmade features (represented by the blue dotted line) and addition of large wood to spread flow over the valley bottom. Stumps along the hillslopes indicate land use history of timber harvest. Created by Johan Hogervorst (USFS), used with permission.

Figure 2.2: Stage 0 restoration project on Lower Staley Creek (a) before restoration in Summer 2017, and (b) a few months after restoration in Fall 2017. Photos courtesy of Matt Helstab (USFS) and Johan Hogervorst (USFS), used with permission.

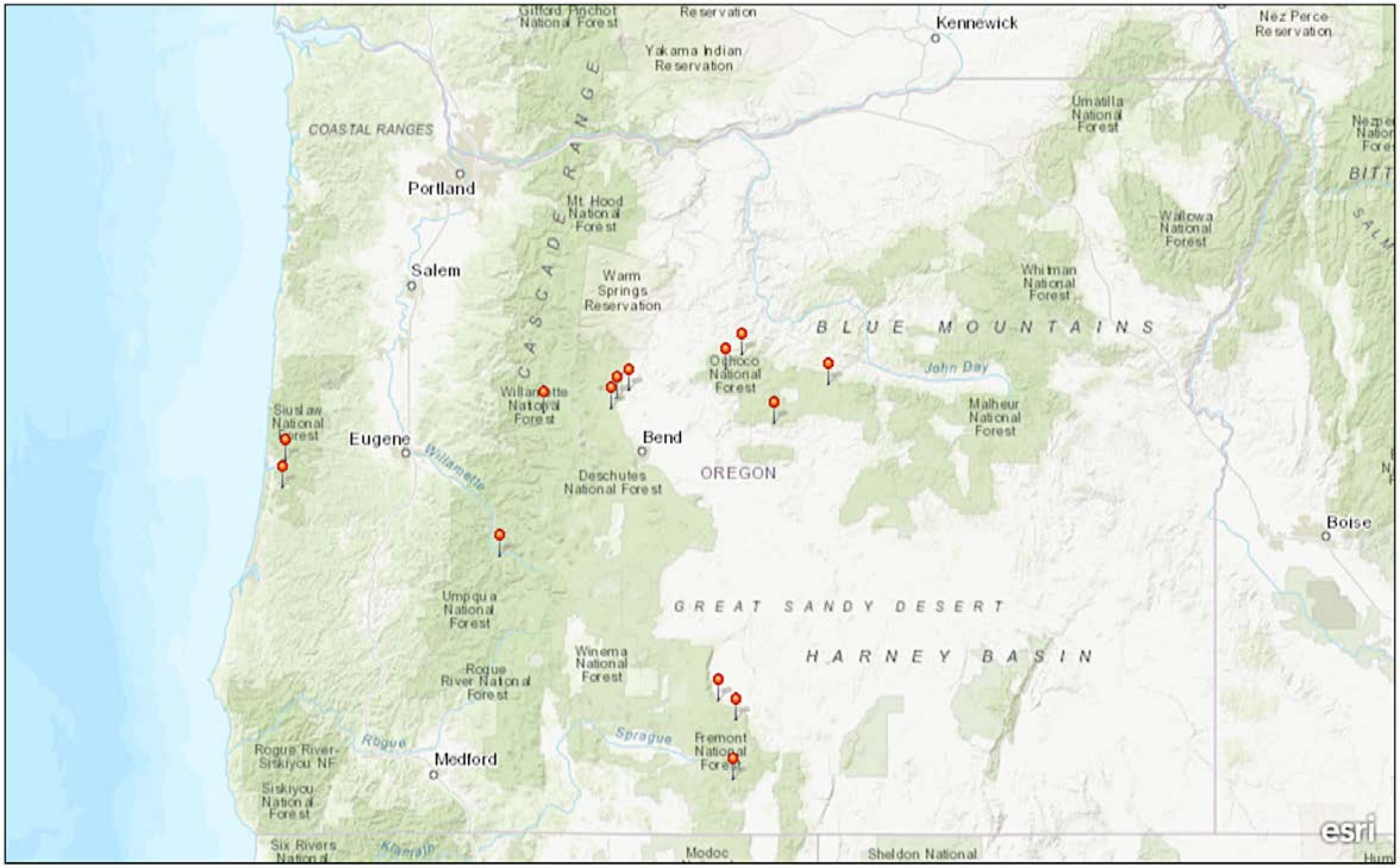


Figure 2.3: Location of Stage 0 river restoration projects in Oregon. Current as of March 2018. Created with input from Stage 0 practitioners.

Table 2.1: Information on Stage 0 restoration projects in Oregon. Current as of March 2018. Created with input from Stage 0 practitioners. Some information was not provided or is unavailable (indicated by -).

Project Name	Project Start Year	National Forest	Approx. Latitude	Approx. Longitude	Approx. Project Area (acres)	Notes
Karnowsky Creek Restoration	2002	Siuslaw	43.995421	-123.98969	-	-
Camp Polk Meadow Whychus Creek Restoration	2009	Deschutes	44.321521	-121.50941	70	-
Fivemile-Bell Landscape Management	2012	Siuslaw	43.850000	-124.01600	7,000	Project ongoing, implementing in several phases
Whychus Floodplain Restoration Project	2014	Deschutes	44.267791	-121.55475	170	-
Whychus Canyon Preserve Creek Restoration	2016	Deschutes	44.364401	-121.42404	-	Project ongoing, implementing in several phases
Deer Creek Floodplain Enhancement	2016	Willamette	44.242700	-122.06013	45	~400 pieces/mile large wood
Lower Staley Creek Floodplain Restoration	2017	Willamette	43.482522	-122.38306	46	~50,000 CY sediment moved, ~600 pieces/mile large wood
Grizzly Creek Channel Headcut Repair	2012	Fremont-Winema	42.278055	-120.64207	-	-
Wooley Creek Headcut Repair and Meadow Restoration Project	2012	Fremont-Winema	42.708934	-120.74914	-	-
Dog Creek Restoration	-	Fremont-Winema	42.600374	-120.61455	-	-
Dick Creek Restoration	-	Ochoco	44.550270	-120.57981	-	-
Toggle Meadow Restoration	-	Ochoco	44.392816	-119.92480	-	-
McKay Creek Restoration	2016	Ochoco	44.472739	-120.69251	-	-
Lost Creek Restoration	2012	Ochoco	44.190826	-120.33489	-	-

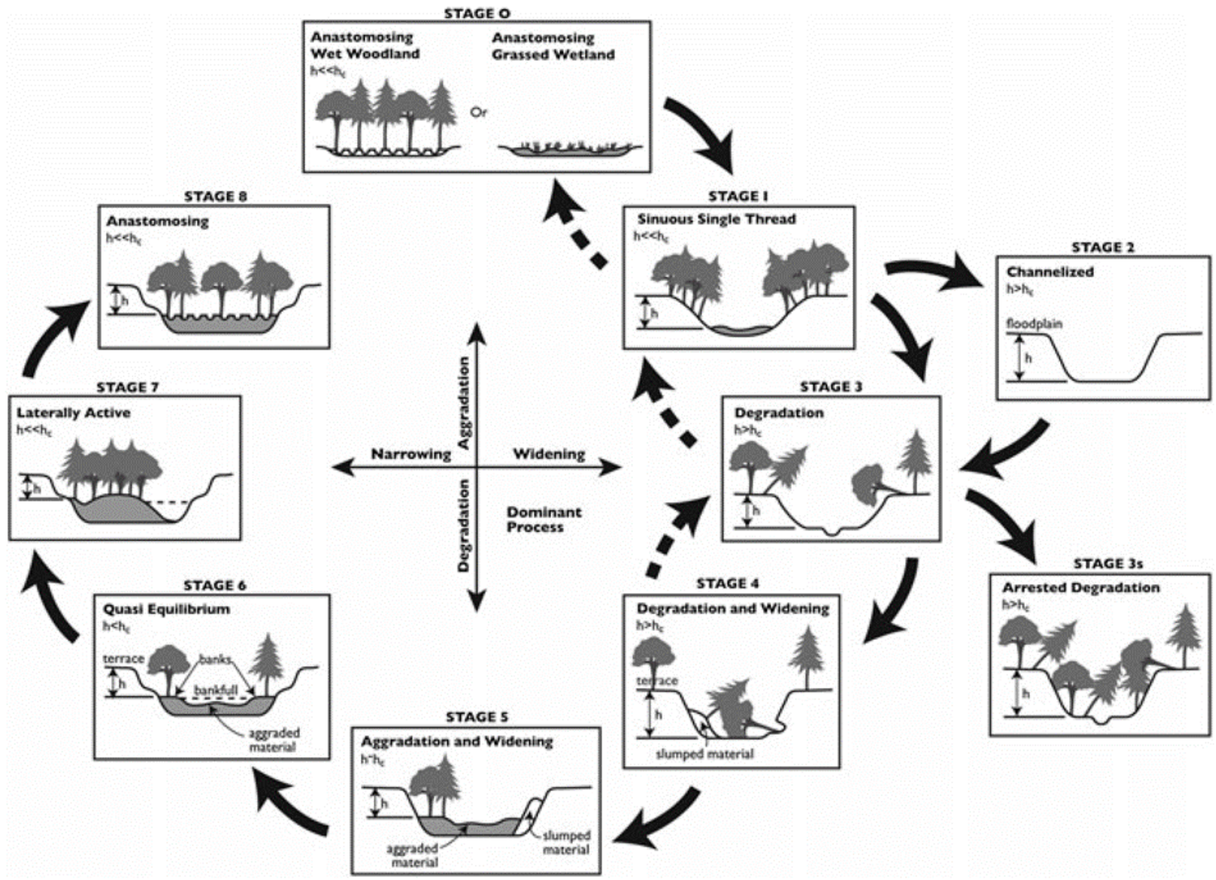


Figure 2.4: The Stream Evolution Model (Cluer & Thorne, 2013), a conceptual framework depicting how rivers undergo morphological changes in response to disturbances. Cycle starts with Stage 0 (represented by an anastomosing morphology), and may go through phases (rectangles labeled ‘Stage’) of evolution as indicated by the arrows. See Cluer and Thorne (2013) for a full description.

Table 2.2: Interviewee information: U.S. Forest Service (USFS) position title, National Forest, and number of years they have worked with the agency.

Interviewee No.	**USFS Position Title**	**National Forest**	**No. Years with USFS**
1	Fisheries Biologist	Siuslaw National Forest	23
2	Fisheries Biologist	Willamette National Forest	4
3	Hydrologist	Willamette National Forest	25
4	Hydrologist	Willamette National Forest	8
5	Fisheries Biologist	Willamette National Forest	11
6	Fisheries Biologist	Deschutes National Forest	23
7	Hydrologist	Deschutes National Forest	15

3 Response of in-stream wood to a novel approach to process-based river restoration in the Western Cascades, Oregon

3.1 Introduction

Centuries of channel engineering, timber harvesting and removal of in-stream wood have left most of the world's rivers severely depleted of this important resource (Wohl, 2013). It was only in the last 50 years that scientists have begun to characterize the complex impacts large in-stream wood has on river biophysical processes; its presence can cause channel widening and migration (Nakamura & Swanson, 1993), formation of plunge and scour pools (Montgomery, Buffington, Smith, Schmidt, & Pess, 1995), increased sediment deposition and morphological variation (Faustini & Jones, 2003), and creation of multithread, anabranching channels (Abbe & Montgomery, 2003; Wohl, 2011). It has also been linked with biological processes, including increased carbon retention (Wohl, 2011), increased nutrient availability (Anderson & Sedell, 1979) and promotion of island establishment and vegetation succession (Fetherston, Naiman, & Bilby, 1995). Large in-stream wood is now considered to play as critical a role in river ecosystems as vegetation or sediment (Roni & Beechie, 2013).

Many studies have also focused on characterizing the recruitment processes, stability and fate of wood in river networks. Early research characterized the main processes by which wood was recruited to streams in forested mountain landscapes, identifying mass movements and windthrow as key delivery mechanisms (Keller & Swanson, 1979). Key pieces that remain in place even at high flows have been found to form stable bar-apex accumulations of wood which encourage channel anabranching and create the refugia needed for long-term riparian forest regeneration (Abbe & Montgomery, 2003). Flume studies revealed that piece diameter and rootwad presence were important factors in stability (Braudrick & Grant, 2000), and tagged wood studies showed that piece length relative to channel width and whether pieces were part of accumulations were also critical factors controlling stability (Gurnell, Piégay, Swanson, & Gregory, 2002).

The characteristics and functions of stable, large, in-stream wood has become a topic of growing concern for river restoration. In recognition of the critical functions of in-stream wood, and to address the historic removal of wood from riverine landscapes (Wohl, 2013), many contemporary restoration practices involve deliberately adding wood to streams (Bernhardt et al., 2005). There has been increasing momentum towards using wood addition practices that emulate more natural delivery processes like windthrow or regeneration of forests to promote longer term wood recruitment (Roni, Beechie, Pess, & Hanson, 2014). Regardless of installation techniques, wood additions to streams remain somewhat controversial, and there is debate about the importance of stability of the added wood as practitioners shift away from constructing large engineered log jams and allow for more movement of pieces (Roni et al., 2014).

This research took advantage of a Stage 0 restoration project implemented in 2016 on lower Deer Creek in the Western Cascades as a case study. The restoration project involved valley-wide leveling of the incised channel and floodplain and experimental placement of an unknown quantity of unsecured pieces of large wood. No studies have documented the impact of a Stage 0 project on in-stream wood, or the fate of the added wood after restoration. Given the experimental nature of the wood addition and the broad effects in-stream wood has on many of the geomorphic and biological processes Stage 0 practitioners hope to re-establish through their restoration efforts (see Chapter 2), it is important to examine this topic to help inform future wood placement efforts.

This study used repeat unmanned aerial vehicle (UAV)-captured, high resolution aerial imagery of the Deer Creek Stage 0 restoration site before, immediately after, and one year following completion of the project to answer the following research questions:

1. What was the impact of the Stage 0 restoration project on the abundance, size and spatial distribution of large in-stream wood in Deer Creek?

2. How has the abundance, size and spatial distribution of large in-stream wood in Deer Creek responded to peak flows in the year following restoration?

Supplementary ground-based images collected at Deer Creek on various days in the year following restoration also gives a sense of the magnitude of events that are capable of causing wood response (i.e. movement) in lower Deer Creek. Through comparison with data from an adjacent watershed, Lookout Creek, where decades of research have been conducted on in-stream wood, this study provides insights on the short-term resilience of wood in this restored system.

3.2 Study Site Description

3.2.1 Deer Creek site description

Deer Creek is a fifth order tributary of the McKenzie River in the Willamette National Forest, in the Western Cascades Mountain Range of Oregon (Figure 3.1). The 6,000-ha basin spans elevations from 570 to 1,630 m, and is underlain almost entirely by Western Cascades geology, comprised of deeply dissected, weathered basalts and tertiary volcanic flows and tuffs (Stillwater Sciences, 2006a). Mass wasting events are common in the upper portion of the watershed, making this basin particularly productive in sediment compared to others in the Upper McKenzie River watershed (Stillwater Sciences, 2006a). The climate is maritime, with an average annual precipitation of approximately 280 cm falling mostly from September through March and as snow at higher elevations. Streamflow regimes are characterized by high winter discharges from November through April, with rain-on-snow events causing peak flows (Grant & Swanson, 1995).

The upper portion of Deer Creek above its confluence with Budworm Creek is confined and incised, whereas the lower portion is a 100 to 150 m wide alluvial valley whose channel migrates laterally within the floodplain (Stillwater Sciences, 2006a). Before the restoration was completed, the lower portions of the creek were cobble and gravel dominated, plane-bed and pool-riffle units with a reach averaged slope of

0.0182, estimated bankfull widths of 18 to 20 m, and large wood loading of about 6 pieces per 100 m (Stillwater Sciences, 2006a). Post-restoration conditions have not been thoroughly documented.

The Eugene Water & Electric Board (EWEB) operates a transmission line that runs within 50 m of the active channel of lower Deer Creek for 1,390 m (450 m of which are in the active channel itself) in the area where the Stage 0 restoration project was completed. The construction of the transmission line in 1960 required the clearcutting of vegetation within and adjacent to the corridor (Figure 3.2), and maintenance of the corridor requires continued tree felling (Stillwater Sciences, 2006b). In the wake of the construction of the transmission line, the 1964 flood denuded the entire valley bottom of nearly all remaining standing vegetation (Figure 3.3). The wood that was delivered to the stream was salvaged by the USFS (USDA Forest Service, 2016). The largest flood of record in 1996 further reduced large wood in Deer Creek (Stillwater Sciences, 2006b). The riparian area of lower Deer Creek is currently comprised of red alder (*Alnus rubra*), bigleaf maple (*Acer macrophyllum*), and immature conifers, predominantly Douglas-fir (*Pseudotsuga menziesii*).

Construction of roads (density is 2.4 km/km^2) and timber harvesting have also impacted large wood loading to Deer Creek. An estimated 70% of the basin has been harvested since the mid-1800s, 14% of which was in the riparian zone in lower Deer Creek between 1964 and 1980 (Figure 3.1) (Stillwater Sciences, 2006b). The last stand-replacing fire occurred in the early 1900s and burned 100 acres in the headwaters. Fires of this size (up to 280 ha) and intensity occur on average every 130 to 190 years (Stillwater Sciences, 2006b).

3.2.2 The H.J. Andrews Experimental Forest

Deer Creek is adjacent to the H.J. Andrews Experimental Forest (HJA) where seminal research on wood in streams has been conducted (e.g., Anderson & Sedell, 1979; Czarnomski, Dreher, Snyder, Jones, & Swanson, 2008; Faustini & Jones, 2003; Gurnell et al., 2002; Keller & Swanson, 1979; Lienkaemper & Swanson, 1987). The HJA is a National Science Foundation-funded Long Term Ecological Research

(LTER) site, managed jointly by the Pacific Northwest Research Station, the Willamette National Forest, and Oregon State University.

The HJA is a 6,400-ha site encompassing the entire Lookout Creek watershed (Figure 3.1), which ranges in elevation from 410 to 1,630 m. The basin is underlain by a mixture of Tertiary volcaniclastic rocks and deeply dissected lava flows, and like Deer Creek, the landscape has been shaped by fluvial, glacial and mass movement processes (Swanson & James, 1975). Given their geographic proximity, similar geologic settings, drainage basin areas and elevation ranges, Lookout Creek and Deer Creek exhibit comparable climatic and streamflow regimes. Lookout Creek is gaged, so can serve as an analog for flow conditions at Deer Creek over the period of record (Figure 3.4).

Perhaps the biggest distinction between Deer Creek and Lookout Creek is the history of land use in the basins (Figure 3.1). Roads were built throughout the Lookout Creek basin (density 2 km/km^2) throughout the 1950s and 1906s (Jones, Swanson, Wemple, & Snyder, 2000), and approximately 25% of the area was harvested from the late 1940s to the mid-1970s (Jones and Grant, 1996). The remainder of the watershed is mature and old-growth forest dominated by Douglas-fir (*Pseudotsuga menziesii)*, Western red cedar (*Thuja plicata*), and western hemlock (*Tsuga heterophylla*). Stream segments adjacent to young forest plantations in the HJA were found to have significantly less wood than segments adjacent to mature or old-growth forests, even 50 years after harvesting (Czarnomski et al., 2008), so a stream segment bordered by old-growth forest on lower Lookout Creek was selected for comparison with Deer Creek. This selected segment is further described in the Methods section.

3.2.3 Deer Creek Stage 0 restoration project

A Stage 0 river restoration project was completed on lower Deer Creek in the summer of 2016 by the USFS and the McKenzie River Watershed Council. The purpose of the project was to “improve ecological function and biological productivity for Endangered Species Act (ESA)-Threatened spring Chinook salmon and bull trout, rainbow trout, cutthroat trout and other native species in the lower 1.6 miles of Deer

Creek" (USDA Forest Service, 2016, p. 1). Deer Creek is designated critical habitat for spawning spring Chinook salmon (*Oncorhynchus tshawytscha*), and foraging bull trout (*Salvelinus confluentus*), both Endangered Species Act (ESA)-Threatened species (USDA Forest Service, 2016). In addition to the project purpose stated above, the goal of Stage 0 restoration more broadly is to restore a multi-thread anastomosing morphology in former depositional reaches that have been channelized and incised. More information on Stage 0 restoration can be found in Chapter 2.

The total restoration project area encompassed approximately 33 ha, including the lower 2.5 km of the Deer Creek floodplain and three small upland stands totaling about 16 ha (Figure 3.5) (USDA Forest Service, 2016). The project was designed using the Geomorphic Gradeline Concept methodology, which was developed by Stage 0 practitioners and involves redistributing sediment across the floodplain, leveling artificial surfaces like berms and using that material to fill in the incised channels.

Perhaps the most conspicuous aspect of the project, however, was the addition of large wood to the floodplain. The largest pieces of wood were sourced from the upland stands (Figure 3.6) where 0.2-ha gaps were cut in even-aged stands of mature (~140 year old) Douglas-fir (Figure 3.7) (USFS, personal comm. October 2017). These even-aged, mature stands may be the legacy of wildfire ignited by escaped campfires from pioneers traveling on the Santiam Wagon Trail (Frederick Swanson, personal comm., 2018). To harvest wood in these upland stands for restoration, the top halves of the mature Douglas-firs were snapped off, and the bottom halves were then pushed over with their rootwads still attached (Figure 3.7).

The USFS took an experimental approach to wood addition to Deer Creek – a large amount was scattered across the floodplain, and only a few of the pieces were buried or otherwise secured. The USFS developed a wood-specific related project objective, which was to increase large wood frequency in channels and across the floodplain to at least 187 pieces per km of all size classes (which they define as "small" = 30 to 60 cm diameter and >7.6 m long; "medium" = 60 to 90 cm diameter and >7.5 m long;

“large” = >90 cm diameter and >15.2 m long), with at least 109 pieces per km in the medium and large size classes upon project completion (USFS, personal comm. October 2017).

3.3 Methods

The following tasks and analyses were performed to assess the response of large in-stream wood in Deer Creek to the restoration treatment and peak flows in the year following restoration (Figure 3.8):

1. Collection and processing of repeat UAV-captured aerial imagery
2. Large wood mapping and comparison with data from Lookout Creek
3. Location error estimation for UAV-collected imagery
4. Collection of supplementary ground-based imagery

A number of other analyses were considered, including stream channel cross-sectional surveys, longitudinal surveys, and sediment size analysis, however, data were not available to conduct these analyses for pre- and post-restoration conditions (Table 3.1).

3.3.1 Collection and processing of repeat UAV-captured aerial imagery

This study used unmanned aerial vehicle (UAV)-captured aerial imagery, a methodology only recently applied to the river restoration field (MacVicar et al., 2009; Marteau, Vericat, Gibbins, Batalla, & Green, 2017). High-resolution UAV-captured imagery of the Deer Creek restoration site was collected in April 2016 (before restoration), September 2016 (after restoration) and September 2017 (one year after restoration) (Figure 3.8). Imagery in 2016 was obtained by a USFS private contractor over a five day period using a 20-megapixel camera mounted on a DJI Phantom 4 Drone. Between 72 and 217 1080 HD NADIR (vertically downward-facing) images were captured at four sites along the restored portion of Deer Creek (Figure 3.9), with 80% overlap between images (front and sides). Each image was saved as a georeferenced JPEG file with a latitude and longitude for the center pixel, estimated with the UAV GPS.

Additional imagery was collected on September 28, 2017 by Jared Ritchey using a 12.3-megapixel camera mounted on a DJI Mavic Pro Drone (Figure 3.10). At sites 2, 3, and 4, 123, 254, and 269 1080HD NADIR images, respectively, were obtained from a 100 m flying height with an 80% overlap (front and side) between images. Each image was saved as a georeferenced JPEG file with a latitude and longitude for the center pixel, estimated with the UAV GPS.

3D models were created with the Structure from Motion algorithm (using Agisoft PhotoScan) provided by Bo Zhao, at Oregon State University. The steps included uploading and alignment of photos, building a dense point could and a Digital Elevation Model (DEM), and construction and export of orthomosaics as TIFF files. Eleven orthomosaics were constructed, covering four sites and on three dates spanning a 1.5-year period. The Site 4 orthomosaics (Figure 3.11, Figure 3.12, Figure 3.13) were used for wood mapping.

3.3.2 Location error estimation for UAV-collected imagery

No ground control point network was established for the UAV images, so positional accuracy was unknown. The accuracy of the UAV's GPS was estimated from rapid static spatial positioning data collected in October 2017 using a survey-grade Leica GS14 GNSS receiver (

Figure 3.14) at thirteen pre-selected photo-identifiable features/points (Figure 3.9, Table 3.2). The rapid static data was processed through the National Geodetic Survey's Online Positioning User Service (OPUS) and compared to estimated locations from georeferenced orthomosaics in ArcMap.

OPUS provided location estimates between ±0.003 m and ±0.138 m accuracy for nine of the thirteen surveyed points; solutions were not found for several points, likely due to limited satellite visibility (Table 3.3). Close visual inspection revealed that only five of the photo-identifiable points (CP006, CP007, CP009, CP010, and CP011) were adequately visible in the orthomosaics on particular image-capture dates.

The average positional error on the drone photographs was 3.8 m (Table 3.4). Residuals for CP006 in the April 2016 orthomosaic differed from the OPUS solution by 13 m and 10 m in the longitudinal and latitudinal direction, respectively. The high errors associated with CP006 and CP007 might be attributed to increased distortion along the edges of the orthomosaics. Alternatively, CP009, which was located in the center of an orthomosaic had much lower residuals (a maximum of approximately -3.8 m) and was the only feature that was clearly visible across all image dates. This error analysis revealed that the value of residuals is not consistent, and that distortion does not occur uniformly across the images.

3.3.3 Mapping large wood in Deer Creek

The georeferenced orthomosaic TIFFs projected with Region 6 Albers NAD83 horizontal projection were used as base maps for wood mapping. Site 4 (Figure 3.9), the most upstream extent of the restoration project, was selected for mapping of large wood because it has the best overall image quality and valley floor coverage for all three dates (April 2016, before restoration; September 2016, immediately after restoration; and September 2017, one year after restoration). Large wood was defined as having a minimum 10 cm diameter and 1 m length, consistent with past studies (Gurnell et al., 2002; Keller & Swanson, 1979).

ArcMap version 10.5.1 (ArcMap) was used to perform mapping. A 500 m longitudinal transect was placed along the center of the valley floor and overlaid with 1 m by 140 m perpendicular belt transects centered on the longitudinal transect and extending across the approximate width of the valley floor (Figure 3.15). Each piece of large wood whose center fell inside the transect was digitized as a polyline with two endpoint vertices and a point midway between the vertices (centroid). Each piece of wood identified was assigned a location, diameter class and length class (based on the scale of the projected orthomosaic). An additional attribute denoted whether the piece was part of an accumulation. Classifications were made following Czarnomski (2003) (Table 3.5, Table 3.6). Diameters for Deer Creek wood were estimated using the measure tool in ArcMap at what appeared to be breast height (~1.4 m above the base of the trunk). Location errors from registration and georeferencing of the orthomosaics used as base maps (Table 3.4) were used as the basis for a smoothing window to account for errors in longitudinal position of wood surveyed from drone photos. Deer Creek wood count data were smoothed with a 10 m window to account for this error (residual).

Data from wood mapping at Deer Creek were compared to a field inventory of large wood conducted along 25 km of stream length in the Blue River watershed (Czarnomski & Dreher, 2002, unpublished data, see also Czarnomski, 2003; Dreher, 2003, and Czarnomski et al., 2008). A 500-m portion of the surveyed area along Lookout Creek was selected to compare to the Deer Creek data. Using 2008 bare earth LiDAR (Spies, 2016), the average valley floor width in this portion of Lookout Creek was estimated to be 120 m, nearly equal to the width of the transect established in Deer Creek. This 500-m section of Lookout Creek is bordered by old-growth forest and has an anastomosing, multi-thread morphology with vegetated islands and channels that have historically avulsed in response to large flood events (Watterson & Jones, 2006). Since one of the goals of the Stage 0 restoration on Deer Creek was to establish an anastomosing morphology, this portion of Lookout Creek is an appropriate comparison for examining the effects of the restoration efforts on Deer Creek.

Lookout Creek wood data were collected in the field (not from drone imagery) and included the same information as was obtained for the Deer Creek wood data, except that the longitudinal location of each piece in an accumulation was reported as the center point of the accumulation, and lengths and diameters (at the midpoint of the piece) were estimated visually. The average longitudinal length of wood accumulations in this portion of Lookout Creek was 21.1 m, thus, the position uncertainty of individual wood pieces is one half of this length; this was used to determine an appropriate smoothing window size of 10 m.

3.3.4 Collection of supplementary ground-based imagery

Two types of ground-based images were used to detect changes in wood over time: repeat photography at georeferenced photopoints and time-lapse photographs using trail cameras.

More than 100 photos of the stream were obtained at various locations before (June) and after (September) the restoration treatment in 2016. I re-photographed 11 of those points in a subset of the study area (Site 4) in August 2017. Repeat photographs were examined visually to detect changes in wood positions as a result of peak flows in the year following restoration in the mapping transect area. Photos were obtained using a handheld camera.

A set of time-lapse photographs from ten trail cameras also were examined visually to detect changes in wood positions as a result of the restoration project and peak flows in the first year after restoration. Time-lapse photographs were collected using ten Bushnell Trophy Cam HD Essential E2 12 MP Trail Cameras secured to trees along the banks of Deer Creek throughout the restoration project area (Figure 3.9, Table 3.7). The USFS purchased and installed five of these cameras (#1 – 5) in Summer 2016, and five additional cameras (#6 – 10) were purchased and installed in late October 2017. Images were periodically downloaded from SD cards installed in the cameras.

3.4 Results

Longitudinal counts of large wood in Deer Creek on three dates over a 1.5-year time period revealed changes in wood abundance, size distribution, and arrangement resulting from both the Stage 0 restoration project and fluvial forces acting over the year following restoration. Longitudinal counts also revealed differences in large wood characteristics and arrangement between Deer Creek and Lookout Creek, a site that has been subject to several decades of fluvial forces with minimal human intervention. Ground-based imagery provided evidence for wood movement, and gave insight into the magnitude of flood events that are capable of moving large wood at the site.

3.4.1 Large wood in Deer Creek and Lookout Creek

Large wood abundance and size

A total of 428, 1,560 and 1,104 pieces of wood were counted along the 500-m study transect in Deer Creek on April 2016 (before restoration), September 2016 (after restoration) and September 2017 (one year after restoration), respectively (Table 3.8). The smallest pieces of wood (size class 1.1) made up 75% of all surveyed wood in Deer Creek on average on all three dates (Figure 3.16). Pieces greater than 20 m in length (size classes 1.4, 2.4 and 3.4) represented only 0.6% of the surveyed wood in Deer Creek on average on all three dates.

The number of pieces of wood in Deer Creek more than tripled as a result of the restoration activities, but decreased by 25% over the year following restoration. Most of this change involved wood in small size classes (1.1, 1.2, 2.1) (Figure 3.17, Table 3.8). Restoration at Deer Creek increased the numbers of pieces of wood in size classes 1.2, 2.3, 2.4 3.2, 3.3 and 3.4 increased by a factor of 3, 3.1, 7, 7, 22 and 6.5, respectively, from April 2016 to September 2016 (Figure 3.17, Table 3.8). The greatest relative increases occurred in the largest size classes (3.2, 3.3 and 3.4), which have diameters >60 cm. The number of pieces of wood in size classes 2.1 and 3.1 (< 5 m in length) decreased over this time period.

From September 2016 to September 2017, the numbers of pieces of wood of most size classes decreased (Figure 3.18, Table 3.8). The smallest size classes (1.1, 1.2) (diameter <30 cm, length <5 m) experienced losses of 25 to 50% of pieces over this time period. There was a 13% increase in the number of pieces in size class 3.3, and a loss of 30% of pieces in size class 3.4 (Table 3.8).

Despite declines in wood from September 2016 to September 2017, the number of wood pieces remaining in September 2017 was higher than before restoration in April 2016 (Figure 3.19, Table 3.8). Compared to April 2016, the number of pieces of wood in September 2017 increased for size classes 2.3, 2.4, 3.2, 3.3 and 3.4 (diameter >30 cm, length >5 m). However, the number of pieces of wood in size classes 1.3 (diameter <30 cm, length >10 m), 2.1 and 3.1 (length < 5 m) declined by 62%, 89% and 100%, respectively, from April 2016 to September 2017.

The numbers and sizes of wood in Deer Creek before restoration (April 2016) were low compared to Lookout Creek in July 2002 (Figure 3.20). There were almost no pieces of wood >60 cm in diameter (size classes 3.1, 3.2, 3.3, and 3.4) in Deer Creek prior to restoration. Before restoration, Deer Creek also had only 28%, 15%, 38%, 36% and 8% of the numbersof wood pieces in Lookout Creek for smaller-diameter size classes 1.2, 2,1. 2.2, 2.3 and 2.4 respectively.

Although Deer Creek in September 2017 had a similar number of pieces of wood compared to Lookout Creek in 2002 (Table 3.8), the size class distributions of the wood were different between the two sites (Figure 3.21). The smallest size class (1.1, diameter < 30 cm and length <5 m) accounted for 80% of the total number of pieces of wood at Deer Creek in September 2017, but only 40% for Lookout Creek. Lookout Creek had more pieces of wood for all size classes except 1.1 and 3.3. Deer Creek had more wood pieces than Lookout Creek in the 3.3 size class (60 cm diameter, >10 m length). The most drastic differences occur for size class 2.1, 3.1 (<5 m length), of which Deer Creek contained almost none. Deer Creek had only 40% as many pieces of wood in size classes 3.1, 3.2, 3.3 and 3.4 as Lookout Creek (64 versus 155 pieces) (Table 3.8).

The USFS met its objective for wood loading as a result of their restoration efforts. Extrapolating from the 500 m study area, one year after restoration in September 2017 there were 289 total pieces of wood per km, 125 of which were in the USFS-designated “medium” to “large” size category.

Large wood arrangement

The proportion of all large wood pieces that were part of an accumulation decreased from 74 to 63% as a result of the restoration project, and increased slightly (from 64%

to 69%) between September 2016 and September 2017 (Table 3.8). In contrast, 97% of wood pieces in Lookout Creek in 2002 were part of a wood accumulation.

Before restoration at Deer Creek, only one region in the study transect had a substantial wood accumulation (about 300 m along the transect, Figure 3.22). The restoration produced additional wood accumulations spread over the transect length, with up to eight wood pieces in these accumulations (Figure 3.22). Orthomosaic georeferencing error may explain the apparent upstream shift of peaks from 2016 to 2017.

Wood accumulations in Lookout Creek were significantly larger and more widely spaced than in Deer Creek for all dates of analysis (Figure 3.22). Wood accumulations in Lookout Creek contained more than twice the amount of wood, and were spaced further apart (~ 100 m), compared to the accumulations at Deer Creek after restoration (~50 m).

Pieces of larger wood (size classes 2.3, 2.4, 3.3 and 3.4) whose length spans the majority of the pre-restoration bankfull width of Deer Creek, which was estimated at 18 to 20 m (Stillwater Sciences, 2006a), were considered separately; these larger pieces are likely to be more stable and retain sediments (Czarnomski, 2003; Lienkaemper & Swanson, 1987). The proportion of pieces of larger wood in accumulations was much higher and increased more sharply after restoration in Deer Creek (from 76% to 95%) (Table 3.9). This fraction did not change over the year following restoration. Moreover, the proportions of these large wood pieces in accumulations are very similar in Deer Creek (95%) and Lookout Creek (97%). When considering the number of larger pieces (2.3, 2.4, 3.3 and 3.4) of wood along the longitudinal transect, the differences in the size and spacing of accumulations was more pronounced (Figure 3.23). Accumulations of larger wood at Lookout Creek contained six times more pieces than those at Deer Creek.

3.4.2 Changes in wood from ground-based repeat photography

Select repeat photography images from photopoints in the transect study area show evidence of wood movement over the year period following restoration in Deer Creek (Figure 3.24, Figure 3.25, Figure 3.26). Timelapse photographs captured with stationary trail cameras showed wood movement on an event-by-event timescale. During an event on February 9, 2017 (848 cfs at the Lookout Creek gage [Figure 3.8]), forces were sufficient to rotate a large piece of wood with a rootwad near the upstream limit of the study transect at Camera 1 (Figure 3.27). An event on March 9, 2017 (the second largest event over the Deer Creek study period, 1,489 cfs at the Lookout Creek gage [Figure 3.8]) deposited two pieces of large wood just upstream of the log that rotated in the February storm (Figure 3.28). Several hundred meters downstream, Camera 6 captured how forces from a storm on November 23, 2017 started to undermine a standing tree near a large wood accumulation (Figure 3.29).

3.5 Discussion

The effect of the Stage 0 restoration approach on long-term stream processes is not yet known, and will play out over the decades to come. This study showed that the addition of large amounts of in-stream wood produced a wood inventory in Deer Creek that was comparable in terms of numbers of pieces to an old-growth reach in Lookout Creek in the neighboring H.J. Andrews Experimental Forest. However, even after restoration, the wood inventory in the study reach in Deer Creek has fewer large pieces than the comparable reach in Lookout Creek and smaller wood accumulations, making wood in Deer Creek more likely to be mobilized, and perhaps removed, by high flows in the future. Thus, it will be important to take a watershed-scale perspective, to promote long-term wood recruitment processes at Deer Creek, and to study the stability of wood to inform future stream restoration.

3.5.1 Deer Creek wood restoration

The addition and maintenance of high abundances of large in-stream wood in Deer Creek may help meet some of the other broad objectives set forth by the USFS, which include increasing secondary channel habitat, increasing pool frequency, promoting deposition of gravels, increasing habitat patch complexity and restoring and/or increasing redd abundance of spring Chinook and cutthroat trout (USFS, personal comm., October 2017). Large in-stream wood may be a good surrogate for these other ecosystem components and processes; its presence has been linked with formation of multi-thread channels (Wohl, 2011), a higher frequency of occurrence of pools (Montgomery et al., 1995), and increased deposition of sediments and geomorphic variability (Faustini & Jones, 2003). The presence of large wood in streams also produces complex hydraulics which create and sustain spawning habitat on larger main channels (Sedell, Bisson, June, & Speaker, 1979) and increases retention time of sediments which promotes nutrient cycling (Anderson & Sedell, 1979). Indeed, evidence from the supplementary ground-based imagery at Deer Creek revealed sediment fining and sorting in proximity to pieces of large wood added during restoration. Activated relic side channels were also observed at higher flows during Deer Creek site visits throughout the summer and fall of 2017. Several spring Chinook redds were also documented in the Stage 0 project area in September 2017 for the first time in over a decade (Meyer, personal comm., October 2017). The addition of large wood to the floodplain may have played a role in these processes.

In further exploring to what extent Deer Creek met its goals for large in-stream wood addition, Lookout Creek can be used as an analog for what wood loading conditions may have been at Deer Creek prior to construction of the transmission line and relatively intense timber harvest. Significantly less of the Lookout Creek basin has been harvested than in Deer Creek (Figure 3.1). Moreover, the 500-m portion of Lookout Creek chosen for comparison with Deer Creek was not adjacent to any timber harvests and was more than a mature tree-height away from roads. These factors have been correlated with higher in-stream wood volume and abundance (Czarnomski et al., 2008; Jones et al., 2000). Though no perfect analog exists, their geographic proximity, similar geologic settings, morphologies, drainage basin areas and elevation ranges make for a compelling comparison.

The Stage 0 restoration resulted in an overall abundance of wood that is comparable to Lookout Creek. As earlier described, the larger pieces (size class 3.3) that were added to Deer Creek were retrieved from mature (~140-year-old) Douglas-fir stands by breaking the trees in half and tipping over the bottoms to preserve the rootwads (Figure 3.7). Whereas whole trees were broken in half for addition to Deer Creek, large-diameter pieces in Lookout Creek were likely recruited to the stream by windthrow (Lienkaemper & Swanson, 1987). These different delivery mechanisms might explain why Lookout Creek had a higher abundance of longer pieces (3.4, >20 m) and Deer Creek had more of the shorter pieces (3.3, >10 m). Though the restoration increased the number and size of wood accumulations, accumulation size and spacing was much smaller in Deer Creek versus Lookout Creek. The process of grubbing and spreading material likely led to this more dispersed pattern of large wood in Deer Creek following restoration.

3.5.2 Future of wood in Deer Creek

Given the significant resources invested into wood addition at Deer Creek, the important role that in-stream wood plays in ecosystem functions, and the lasting legacy that land use practices can have on its abundance, the predicted longevity of the added wood is a pressing concern. A large-scale mobilization of wood to the McKenzie River would also raise serious safety and property damage concerns, highlighting the need to continue studying its stability. The changes observed in the year following restoration in combination with comparisons to Lookout Creek can be used to better understand how wood might respond to future disturbances.

This study revealed minor responses in wood abundance and spatial distribution to flows from September 2016 to September 2017, which is expected given the small relative magnitude of these floods compared to some of the rain-on-snow events seen in the last 50 years at the Lookout Creek gage (Figure 3.4). Ground-based imagery revealed slight wood movement (i.e. rotation of larger pieces and transport of smaller pieces) but no notable rearrangement of larger pieces (size classes 2.3, 2.4, 3.3 and 3.4) of wood in Deer Creek with peak flows up to 1,489 cfs at the Lookout Creek gage (~1.5-year recurrence interval) (Figure 3.8). These findings are consistent with a wood movement study conducted on Mack Creek, a third-order tributary to Lookout Creek, where less than 1% of wood pieces moved in an average year over a 12-year study period (Gurnell et al., 2002).

Larger flow events are inevitable in the coming decades at Deer Creek. Therefore, it is important to consider factors that contribute to wood stability. The size of wood, particularly diameter and length have a strong influence on its mobility (Braudrick & Grant, 2000; Gurnell et al., 2002; Keller & Swanson, 1979; Lienkaemper & Swanson, 1987; Wohl, 2011). Following restoration at Deer Creek, the smallest size class (diameter < 30 cm, length < 5m) accounted for 80% of the total number of pieces, likely the result of bulldozing and felling of trees (i.e. "grubbing"), in surrounding riparian areas. These pieces are highly mobile, so are not expected to have long residence times in the restored area. There also were fewer large diameter (>60 cm) pieces in Deer Creek compared to Lookout Creek, which may affect the long-term stability of wood. Many of the larger diameter pieces in Deer Creek were shorter than the pieces in Lookout Creek. Wood in Deer Creek is likely to be mobile at high flows, because piece length is less than valley width (e.g., Gurnell et al., 2002, p. 611).

I used a back of the envelope calculation to get a sense of the event magnitude that could theoretically cause more notable wood movement in Deer Creek. Since the physics of wood transport are extremely complex (Braudrick & Grant, 2000, 2001; Braudrick, Grant, Ishikawa, & Ikeda, 1997), I looked at a simple example of a single piece of the largest size wood class (60 cm diameter) sitting atop a flat valley surface, which is not far from the reality given the significant leveling of the valley bottom in the restoration (Figure 2.1from Chapter 2). As a conservative estimate, I assumed that a piece of wood would float when water reached a stage height equal to the piece diameter, spread over the entire valley bottom (100 m). Assuming a water velocity of 1 m/s, this stage height equates to a discharge of 60 m3/s (2,120 cfs). This is slightly less than the 2-year recurrence interval event at Lookout Creek, not a large event relatively speaking. There are many complicating factors, however. For example, most of the larger pieces of wood at Deer Creek were found in accumulations, and many had rootwads, factors which provide additional stability (Gurnell et al., 2002).

Although future conditions at Deer Creek cannot be known, developing hypothetical response curves may be another useful way to conceptualize how the system is expected to respond to perturbations (Wohl et al., 2015). A study from long term data at Lookout Creek produced response curves for channel-cross section change in response to peak flows; peaks with a 6- to 7-year recurrence interval were sufficient to cause observable scour or deposition in 90% of surveyed cross sections (Faustini, 2000). The conceptual framework from this study was adapted to hypothesize about responses of wood to peak flows at Deer Creek.

General hypothetical response curves were developed for wood movement (response variable, y-axis) over a range of peak flows (driving variable, x-axis) (Table 3.10), taking into account many factors contributing to stability. Four main categories of response curves emerge: low resistance to disturbance, high resistance to disturbance, well defined response ("equal mobility"), and poorly defined response ("selective transport") (Table 3.10). Using the changes observed over the study period and the known characteristics of wood in Deer Creek and Lookout Creek, hypothetical curves were developed for the two sites (Figure 3.30).

Deer Creek after restoration is expected to exhibit a lower resistance, more threshold-like response pattern when compared to Lookout Creek (Figure 3.30), because most pieces of wood are moderately sized and the accumulations they form are relatively small. Lookout Creek is expected to exhibit a poorly defined response pattern, and have the highest resistance to disturbance given its broad range in wood size distributions, larger pieces, and presence of large accumulations of varying sizes. These curves suggest that the responses seen in Deer Creek to the estimated 1.5-year recurrence interval flow are negligible compared to the expected changes over the decades to come (Figure 3.30). Although the USFS objective for wood loading has been met, some of the wood that was added to the stream may be moved in a large peak flow event. Therefore, it is important to promote natural, long-term wood recruitment processes at Deer Creek. The ability of the system to recruit wood without human intervention is critical to its longevity and to ecological functioning.

3.5.3 Errors and uncertainty

Mountainous, forested river valleys are challenging places to use aerial imagery for any analysis, especially when incorporating spatial data. The rugged terrain and dense vegetation makes UAV operation difficult and can cause poor GPS reception and image quality issues (shadow, contrast and blur). Differential distortion of orthomosaics is known to be a concern based on the error estimation analysis, but detailed assessment of this error was outside the scope of this research. The lower resolution camera used to capture 2017 images may also have made detection of small pieces more challenging. Due to the differential distortions, varying resolutions and quality of imagery, and canopy cover, diameter and length classification are subject to error. A field campaign is recommended to confirm size categorizations. Wood in large accumulations can also be difficult to detect with aerial imagery, especially as it stacks vertically. This is one possible explanation for the decline in number of pieces of wood from September 2016 to September 2017.

Canopy cover was another source of error and uncertainty of this study. Vegetation completely obscured side channels and channel margins in the September UAV images, making some wood pieces appear shorter or making them completely undetectable; this is important to consider when comparing data between April (before leaf-out) and September (after leaf-out). Canopy cover will become more of a challenge as vegetation becomes established in the active channel.

The lack of a ground control network for the UAV images also seriously limits the potential for most change detection studies, and complicates the interpretation of longitudinal wood count data. Location errors could be reduced by orders of magnitude with a substantial investment of resources up front for establishment of a ground control network and more intensive image processing (Marteau et al., 2017). Ground-based photopoint images were collected at roughly the same time interval as UAV-captured images (Figure 3.8) so cannot be used to determine the magnitude of storm capable of moving wood, though the peak flow between image capture dates could be presumed to be responsible for most of the change observed. Sporadic operation of trail cameras and their inaccessibility at high flows were limitations of the study.

3.6 Conclusion

This study characterized the impact of a Stage 0 restoration project and one year of fluvial forces on large in-stream wood abundance, size and distribution in a 500-m section of lower Deer Creek, and provided broader historical context by connecting findings to data from Lookout Creek, where research has been conducted on large in-stream wood for decades. Minor changes in large wood abundance and distribution at Deer Creek were caused by fairly low peak flows (~1.5-year recurrence interval). These changes are negligible, however, when compared to the changes expected in the coming decades; ongoing monitoring is therefore critical. Establishment of a tight ground control network for UAV campaigns and collection of imagery at low altitudes and from various angles would allow for better change detection. Alternatively, a more targeted approach to monitoring could be taken with a particular focus on the characteristics of key members of more stable accumulations to help inform future wood addition efforts. More importantly, promoting natural, long-term wood recruitment processes at Deer Creek through protection of riparian areas, decommissioning of roads and reducing timber harvesting should be prioritized wherever feasible.

When thinking about the longevity of added wood in Deer Creek, while some changes are expected and even desired, there might be certain scenarios that require the intervention of the USFS to stabilize or replenish in-stream wood. If not already addressed, developing an action or mitigation plan for various scenarios is recommended, especially for cases where large amounts of wood are transported into the McKenzie River.

The proximity of Deer Creek to the HJA, and the existing partnerships that have already been forged there between the Willamette National Forest, the Pacific Northwest Research Station, and Oregon State University researchers provide a solid foundation for collaborative follow up studies to be conducted on Deer Creek. There is much to be gained by both practitioners and researchers from further studies at Deer Creek, and linkages to research from the HJA. Continuing longer-term studies on in-stream important given the substantial resources invested in this aspect of the restoration and the many important functions large wood plays in stream ecosystems.

3.7 Tables and figures for Chapter 3

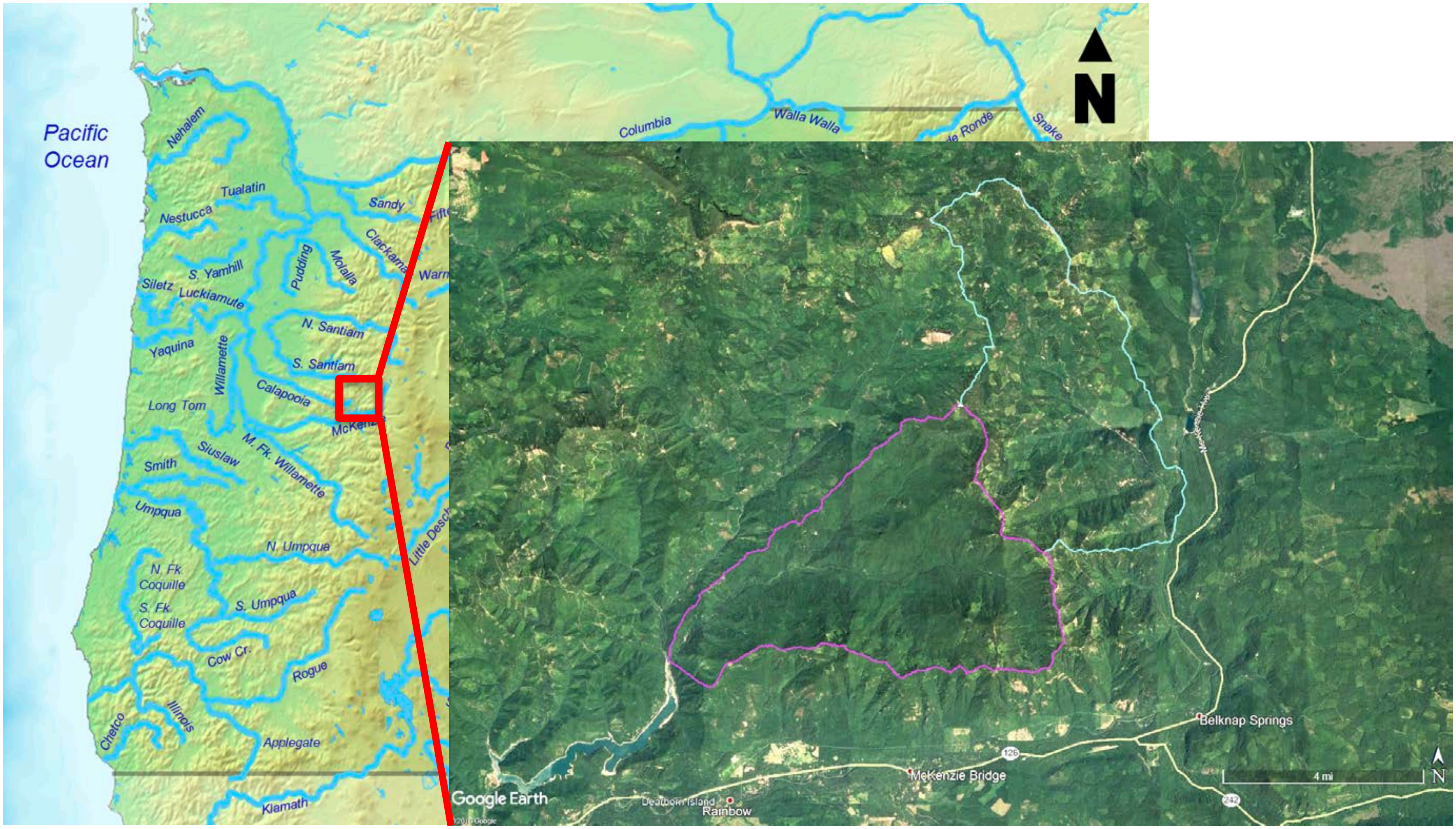


Figure 3.1: General study area in the Western Cascade Mountain Range of Oregon. Deer Creek watershed delineated in teal, and Lookout Creek watershed delineated in magenta. Base map source: Demis Map Server, Creative Commons, Wikimedia.

Figure 3.2: Historic aerial photograph of the Upper McKenzie River, July 1981. McKenzie River runs N-S along Highway 126. Red rectangle shows the approximate area of the Stage 0 restoration project on lower Deer Creek. Note the vegetation cleared along the transmission line extending from the top center to the bottom center of the image. Obtained from the University of Oregon Map Library.

Figure 3.3: Historic photograph of Deer Creek after the 1964 flood. The flows scoured the vegetation from the valley bottom. Much of the in-stream wood was later salvaged. Source: (Stillwater Sciences, 2006).

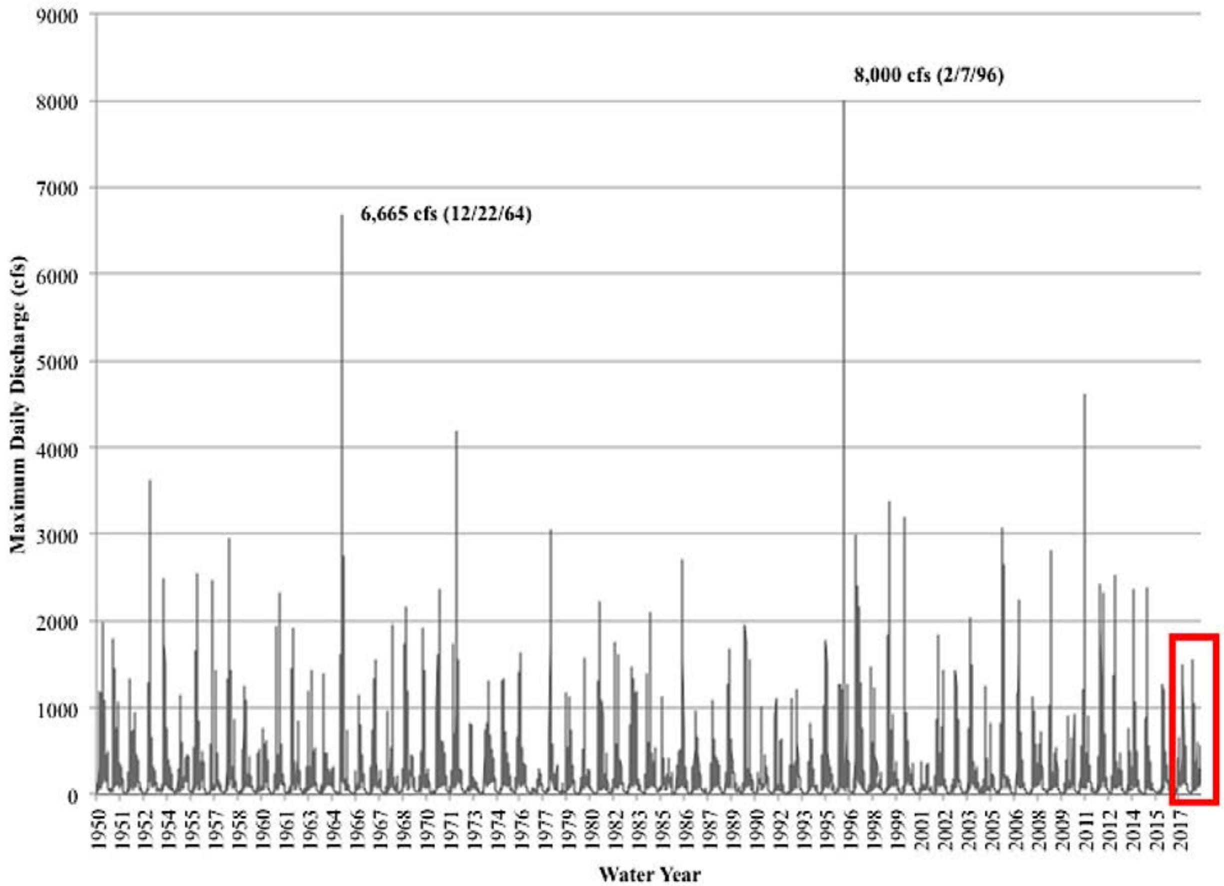


Figure 3.4: Maximum daily discharge (cfs), 1950-2018 for Lookout Creek gage in the H.J. Andrews Experimental Forest (*USGS* Gage No. 14161500). Data from 4 October 2017 onward is provisional. Red rectangle shows the period over which the wood study on Deer Creek was conducted.

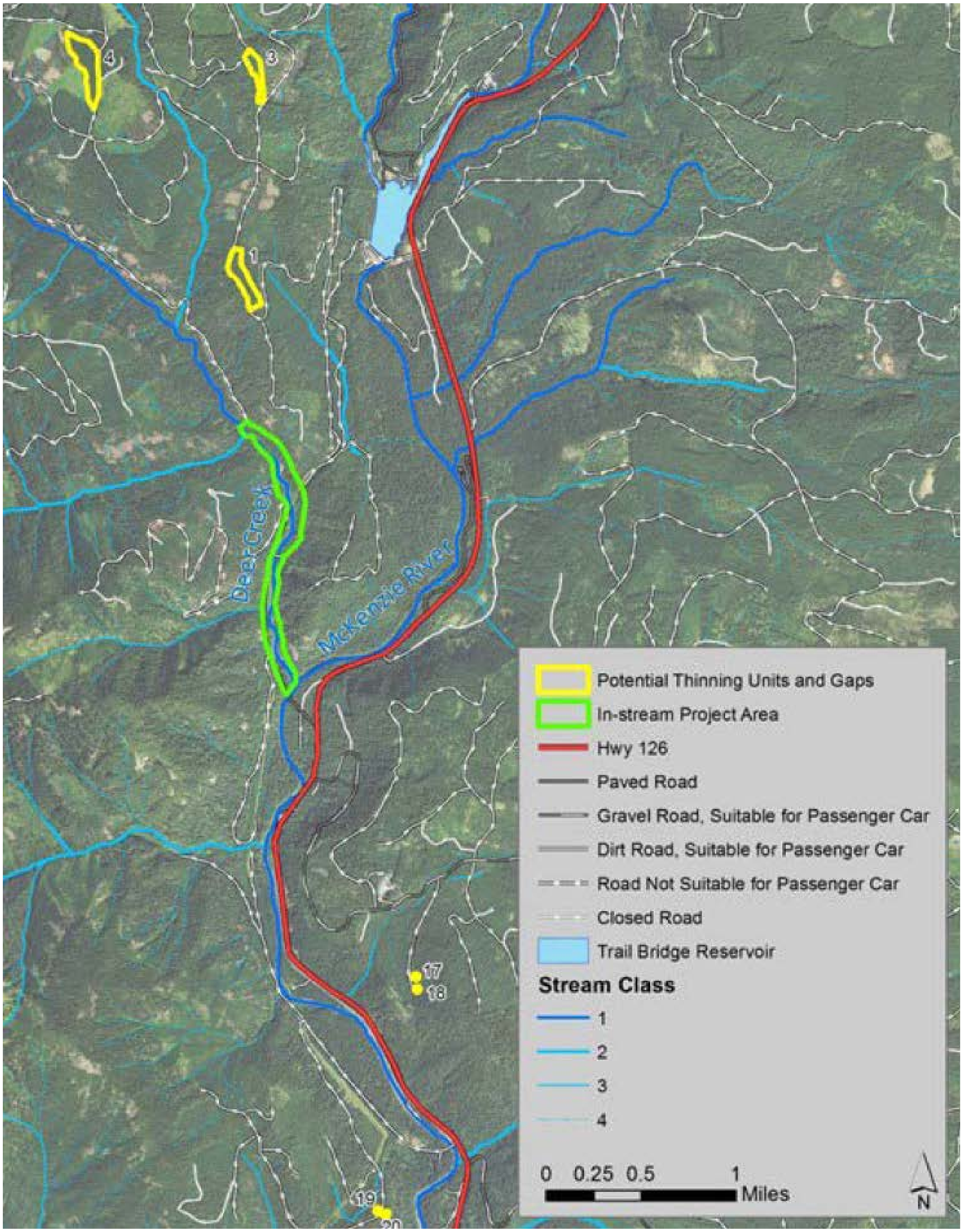


Figure 3.5: Site map of the Stage 0 restoration project on lower Deer Creek. Source: (USDA Forest Service, 2016).

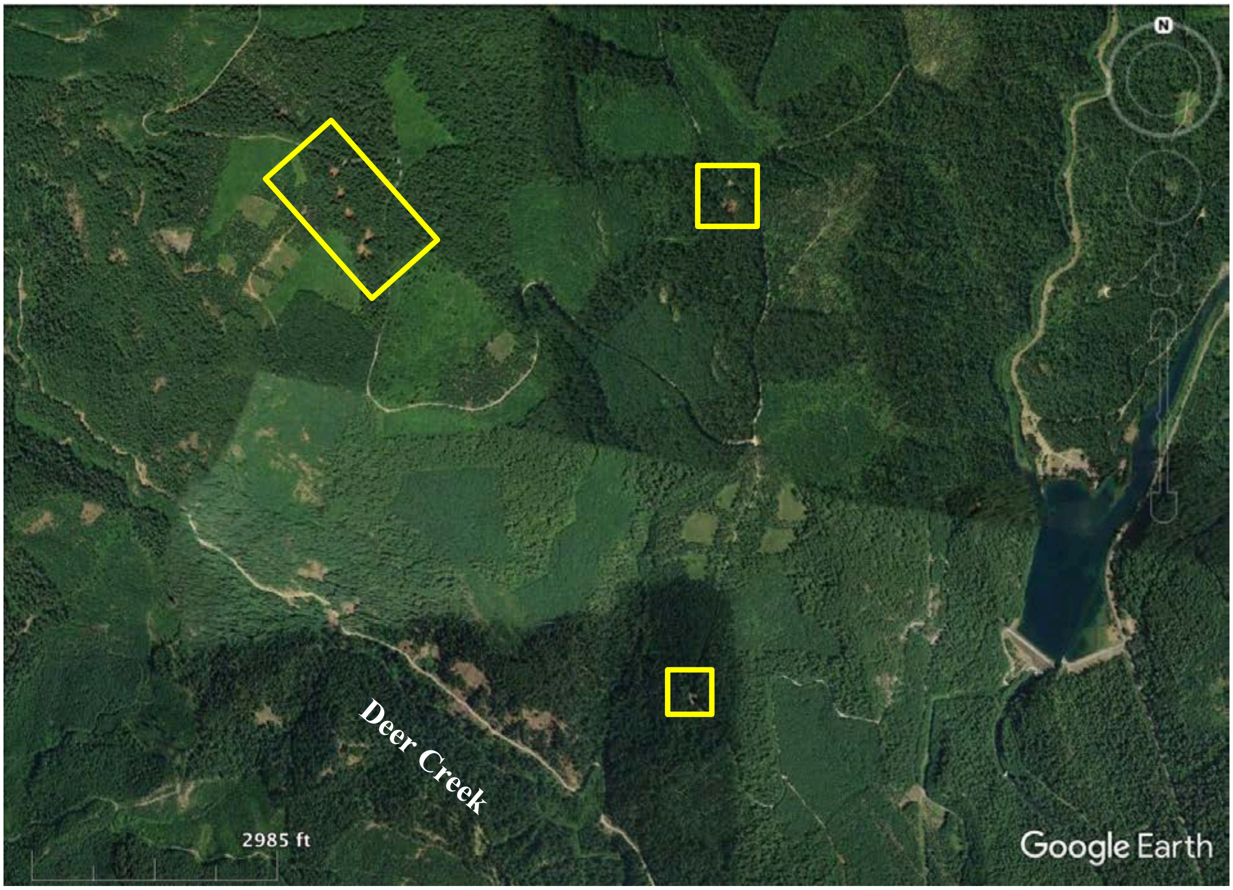


Figure 3.6: Upland stands in Deer Creek watershed with ~0.2-ha gaps cut for Stage 0 restoration large wood procurement.

Figure 3.7: Upland stand gap for large wood procurement (~0.2-ha). Trees were broken in half, with the bottom ends pushed over to preserve rootwads (visible on some pieces). Pieces are stacked and ready for transportation down to the restoration site.

Table 3.1: Data provided by the USFS for Deer Creek before (pre-) and after (post-) restoration. N/A indicates that these data were not available. Bold items show data that is available before and after restoration.

Pre-Restoration Data (before Summer 2016)	Post-Restoration Data (after Summer 2016)
1. LiDAR (2008)	1. N/A
2. UAV imagery of majority of project area	**2. UAV imagery of majority of project area**
3. USFS Level II Stream Inventory Data	3. N/A
4. N/A	4. Transect data (in wetted areas collected: depth, velocity, temperature, substrate categories, geomorphic features)
5. Georeferenced ground photographs (photopoints)	**5. Georeferenced ground photographs (photopoints)**
6. Timelapse photographs from trail cameras installed along banks	**6. Timelapse photographs from trail cameras installed along banks**

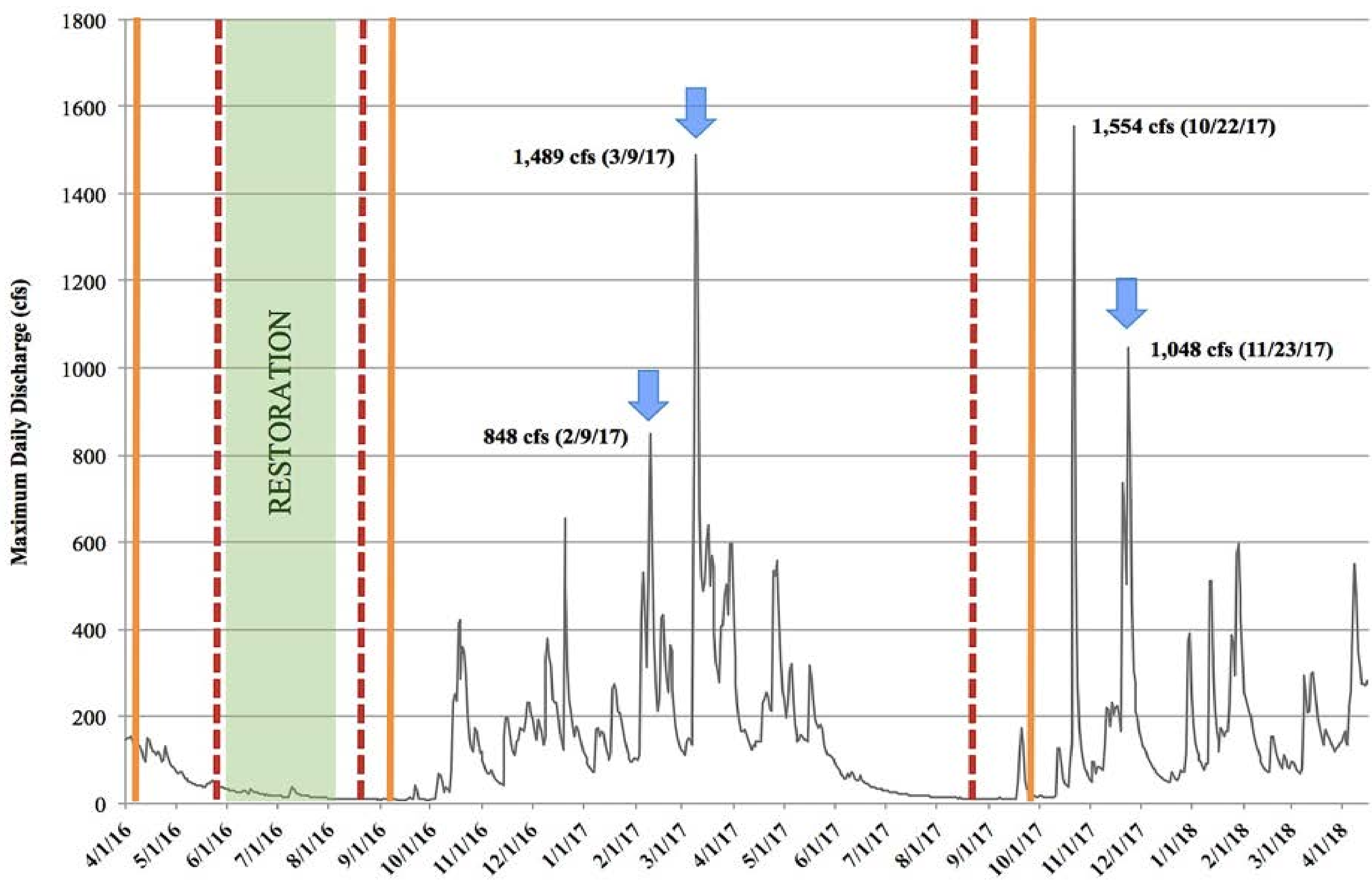


Figure 3.8: Hydrograph from Lookout Creek from April 2016 to April 2018 showing maximum daily discharge (cfs) (*USGS* Gage No. 14161500). Orange solid lines: UAV imagery collection dates; red dotted lines: georeferenced photopoint image collection dates; blue arrows: select trail camera time-lapse imagery of storm events. The green rectangle is the approximate timeframe over which the Stage 0 restoration project occurred

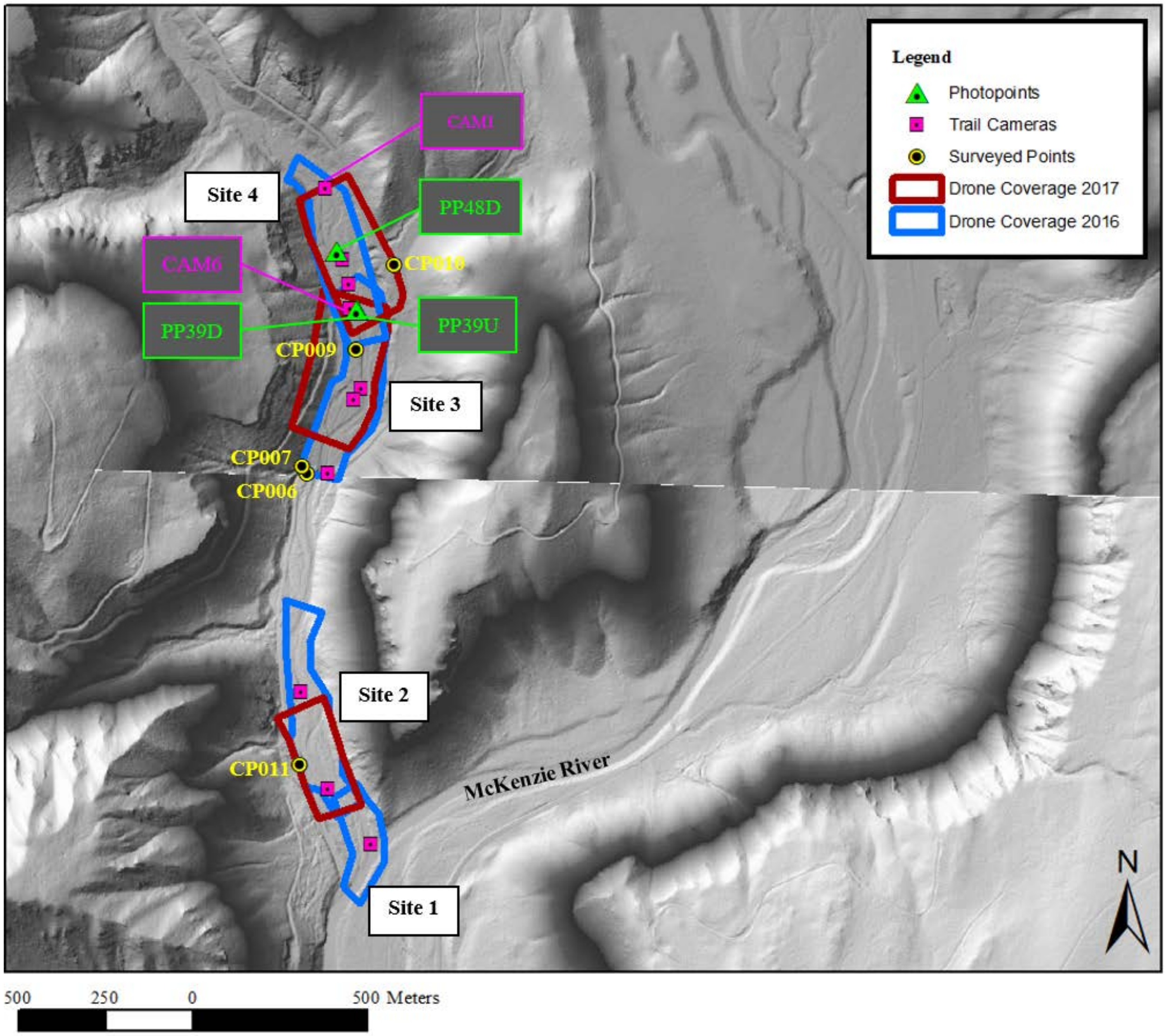


Figure 3.9: UAV-image coverage, and photopoint, trail camera and survey point locations.

Figure 3.10: Jared Ritchey setting up the UAV to collect aerial imagery at Deer Creek on September 28th, 2017.

Figure 3.11: Orthomosaic of Deer Creek at Site 4 in April 2016, before Stage 0 restoration was completed. Created with 217 UAV-captured aerial images.

Figure 3.12: Orthomosaic of Deer Creek at Site 4 in September 2016, immediately after Stage 0 restoration was completed. Created with 237 UAV-captured aerial images.

Figure 3.13: Orthomosaic of Deer Creek at Site 4 in September 2017, one year after Stage 0 restoration was completed. Created with 268 UAV-captured aerial images.

Figure 3.14: Fatima Taha setting up the Leica GS14 GNSS receiver at CP006 for collection of rapid static data on October 24th, 2017.

Table 3.2: Photo-identifiable point identifications, date of rapid static survey, and description of feature.

Photo-Identifiable Point No.	Date of Survey	Description
CP001	10/24/2017	Gate pole
CP002	10/24/2017	Transmission line pole (plaque: EWEB #19035), closest to road
CP003	10/28/2017	Black and yellow road sign just east of concrete bridge
CP004	10/24/2017	“One lane” yellow road sign east of concrete bridge
CP005	10/24/2017	“MP1” sign just west of concrete bridge
CP006	10/31/2017	Intersection of white paint line and crack just west of concrete bridge
CP007	10/24/2017	Transmission line pole (plaque: EWEB #19037), nearest road
CP008	10/24/2017	Transmission line pole (plaque: #28-PL), upstream side of pole
CP009	10/31/2017	Transmission line pole (plaque: EWEB #19033), upstream side
CP010	10/31/2017	Stop sign at road wye near upstream limit of restoration project area
CP011	10/31/2017	Spray painted words on road, far upper-right corner
CP012	10/31/2017	Pothole nearest spray painted words (CP011)
CP013	10/31/2017	Asphalt patch edge just downstream of the first transmission line road crossing

Table 3.3: Location data obtained using the Leica GS14 GNSS receiver. Raw data was processed through OPUS, which provided latitude and longitude (decimal degrees) and associated errors (meters) for the survey. OPUS did not produce a solution for several points (-) likely due to limited satellite visibility. Bold text indicates photo-identifiable point was clearly visible in a georeferenced orthomosaic in ArcMap; OPUS-estimated locations for those points (CP006, CP007, CP009, CP010 and CP011) were subtracted from apparent locations in georeferenced orthomosaics to estimate image georeferencing error (residuals) (Table 3.4).

		OPUS Solutions				**Visible in Images? (Y/N)**		
Photo-Identifiable Point No.	**Date of Survey**	**Latitude (decimal degrees)**	**Latitude Error (m)**	**Longitude (decimal degrees)**	**Longitude Error (m)**	**Apr. 2016**	**Sep. 2016**	**Sep. 2017**
CP006	10/31/2017	44.25007961	0.011	-122.0605825	0.003	**Y**	**Y**	N
CP007	10/24/2017	44.25024687	0.138	-122.0607622	0.048	**Y**	**Y**	N
CP009	10/31/2017	44.25330641	0.008	-122.0589465	0.011	**Y**	**Y**	**Y**
CP010	10/31/2017	44.2554825	0.009	-122.0576749	0.014	N	N	**Y**
CP011	10/31/2017	44.24257279	0.010	-122.0605648	0.008	N	**Y**	**Y**
CP001	10/24/2017	-	-	-	-	N	N	N
CP002	10/24/2017	-	-	-	-	N	N	N
CP003	10/28/2017	44.2500628	0.010	-122.0598612	0.004	N	N	N
CP004	10/24/2017	-	-	-	-	N	N	N
CP005	10/24/2017	44.2501001	0.018	-122.0603531	0.006	N	N	N
CP008	10/24/2017	-	-	-	-	N	N	N
CP012	10/31/2017	44.24253317	0.014	-122.0605705	0.017	N	N	N
CP013	10/31/2017	44.24168119	0.083	-122.0600685	0.087	N	N	N

Table 3.4: Residual location errors in longitudinal and latitudinal directions, calculated by subtracting the OPUS-estimated location (measured location) from the apparent location of the point in the georeferenced orthomosaics (observed location). NA indicates the photo-identifiable point was not visible.

	April 2016 UAV Images		September 2016 UAV Images		September 2017 UAV Images	
Photo-identifiable point no.	**Residual for Latitude (m)**	**Residual for Longitude (m)**	**Residual for Latitude (m)**	**Residual for Longitude (m)**	**Residual for Latitude (m)**	**Residual for Longitude (m)**
CP006	9.84269	13.08026	5.38975	11.93196	NA	NA
CP007	6.26515	-0.80429	2.75258	-1.94623	NA	NA
CP009	-1.73581	-3.79268	0.16920	-2.14167	0.08982	-3.09418
CP010	NA	NA	NA	NA	3.23523	-4.73263
CP011	NA	NA	0.94291	-0.32682	2.91538	0.45370

Figure 3.15: Transect for mapping wood in ArcMap. Total length 500 m, width 140 m, split into 1 m-tall polygons.

Table 3.5: Attributes generated for each single piece of digitized wood. Some variables are categorical. Diameter and length classes, as well as definition of accumulations were adapted from Czarnomski (2003).

Variable	**Descriptions or Categories**
Diameter class	Class 1: 10cm ≤ diameter < 30cm Class 2: 30cm ≤ diameter < 60cm Class 3: diameter ≥ 60cm
Length	Measured distance from one endpoint vertex to the other, in meters
Length class	Class 1: 1m ≤ length < 5m Class 2: 5m ≤ length < 10m Class 3: 10m ≤ length < 20m Class 4: length ≥ 20m
Location in horizontal plane	Latitude and longitude of the center (centroid) of the piece of wood
Accumulation or single	Accumulation: ≥ 3 pieces with > 2 points of contact, Single: not accumulation

Table 3.6: Size classes for pieces of wood, designation from Czarnomski (2003).

Size Class	**Diameter (cm)**	**Length (m)**
1.1	10 to 30	1 to 5
1.2	10 to 30	5 to 10
1.3	10 to 30	10 to 20
1.4	10 to 30	20+
2.1	30 to 60	1 to 5
2.2	30 to 60	5 to 10
2.3	30 to 60	10 to 20
2.4	30 to 60	20+
3.1	60+	1 to 5
3.2	60+	5 to 10
3.3	60+	10 to 20
3.4	60+	20+

Table 3.7: Trail cameras installed for monitoring Deer Creek restoration. Latitudes and longitudes provided in Region 6 Albers NAD83 horizontal projection units.

Camera No.	Latitude	Longitude	Installed	Approximate dates of image coverage	Programmed temporal settings
1	435608.6882	1134412.7230	Summer 2016, USFS	Oct. 2016 – Mar. 2017	2 photos/day (AM and PM)
2	435656.6516	1134207.5697	Summer 2016, USFS	Oct. 2016 – Mar. 2017	2 photos/day (AM and PM)
3	435677.0723	1134139.0717	Summer 2016, USFS	Oct. 2016 – Mar. 2017	2 photos/day (AM and PM)
4	435709.2920	1133838.5402	Summer 2016, USFS	Oct. 2016 – Mar. 2017	2 photos/day (AM and PM)
5	435614.3929	1133596.8810	Summer 2016, USFS	Oct. 2016 – Mar. 2017	2 photos/day (AM and PM)
6	435680.0066	1134067.5317	October 2017, S. Bianco	Nov. 2017 – Dec. 2017	1 photo/15 mins, daylight
7	435739.5159	1132534.9032	October 2017, S. Bianco	Nov. 2017 – Dec. 2017	1 photo/15 mins, daylight
8	435615.7965	1132693.5477	October 2017, S. Bianco	Nov. 2017 – Dec. 2017	1 photo/15 mins, daylight
9	435539.3141	1132970.7257	October 2017, S. Bianco	Nov. 2017 – Dec. 2017	1 photo/15 mins, daylight
10	435690.6428	1133806.9298	October 2017, S. Bianco	Nov. 2017 – Dec. 2017	1 photo/15 mins, daylight

Table 3.8: Summary of wood abundance and size. Number of pieces of wood in Deer Creek (Apr. 2016, Sep. 2016 and Sep. 2017) and Lookout Creek (2002), changes in wood abundance at Deer Creek over time, and difference in number of pieces of wood between Lookout Creek and Deer Creek on different dates. For Deer Creek changes over time, bold numbers indicate a net decrease in abundance from the earlier to the later date; for the Lookout Creek versus Deer Creek comparison, bold numbers indicate that Lookout Creek had a lower abundance of wood.

			Wood abundance (no. pieces)				Deer Creek change over time			Lookout Creek vs. Deer Creek	
			Deer Creek			Lookout Creek	Change in no. logs			Difference in no. logs	
Diameter (cm)	**Length (m)**	**Size Class**	**Apr. 2016**	**Sep. 2016**	**Sep. 2017**	**Jul. 2002**	**Apr. 2016 to Sep. 2016**	**Sep. 2016 to Sep. 2017**	**Apr. 2016 to Sep. 2017**	**Lookout vs. Apr. 2016**	**Lookout vs. Sep. 2017**
10 to 30	1 to 5	1.1	295	1252	894	460	957	**-358**	599	165	**-434**
10 to 30	5 to 10	1.2	43	132	63	149	89	**-69**	20	106	86
10 to 30	10 to 20	1.3	8	9	3	63	1	**-6**	**-5**	55	60
10 to 30	20+	1.4	0	0	0	15	0	0	0	15	15
30 to 60	1 to 5	2.1	28	11	3	183	**-17**	**-8**	**-25**	155	180
30 to 60	5 to 10	2.2	28	35	30	72	7	**-5**	2	44	42
30 to 60	10 to 20	2.3	16	50	37	44	34	**-13**	21	28	7
30 to 60	20+	2.4	1	7	10	12	6	3	9	11	2
60+	1 to 5	3.1	4	0	0	72	**-4**	0	**-4**	68	72
60+	5 to 10	3.2	1	7	5	33	6	**-2**	4	32	28
60+	10 to 20	3.3	2	44	50	19	42	6	48	17	**-31**
60+	20+	3.4	2	13	9	31	11	**-4**	7	29	22
		Total	428	1,560	1,104	1,153	1132	-456	676	725	49

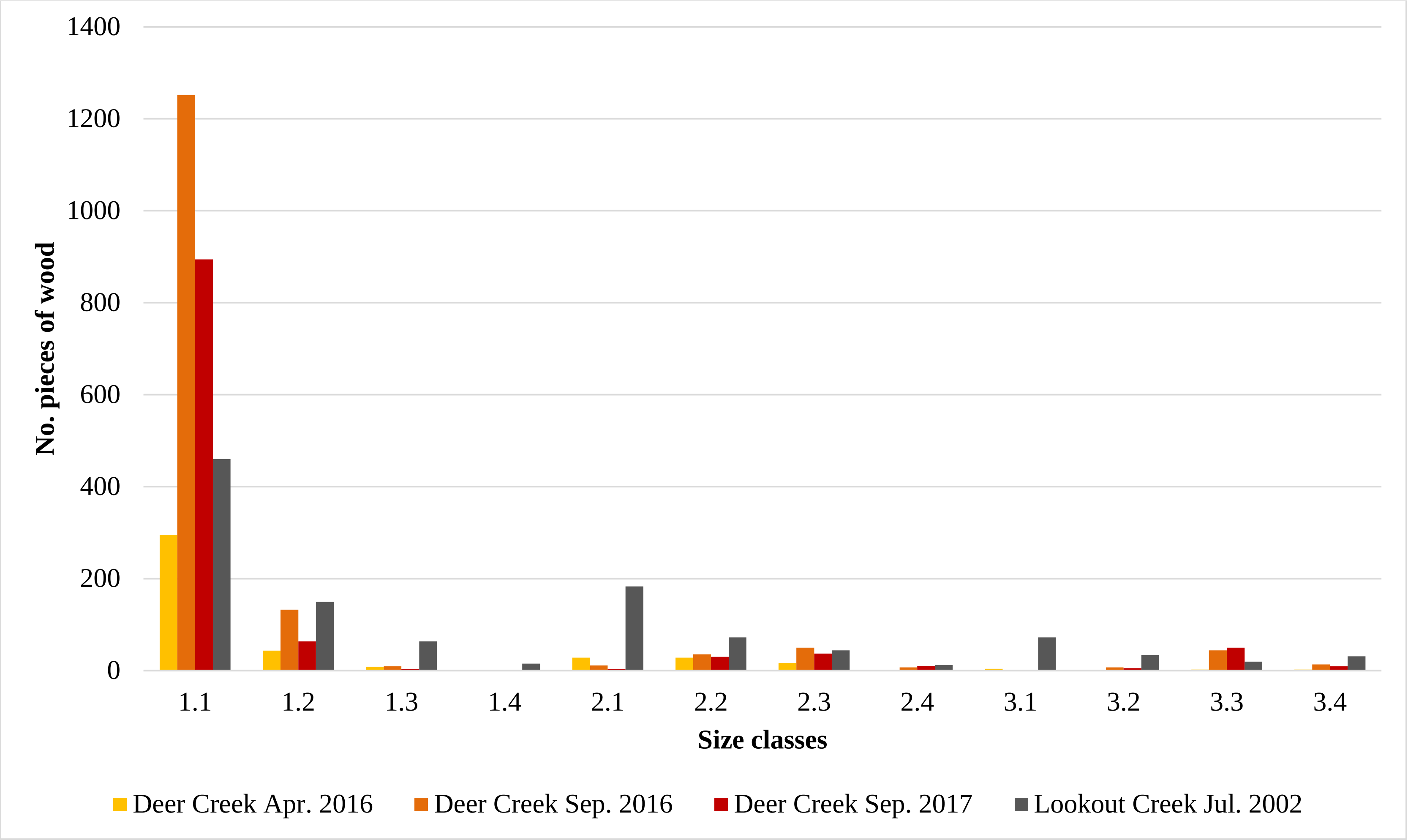


Figure 3.16: Number of pieces of large wood per size class in Deer Creek and Lookout Creek. Apr. 2016, before restoration; Sep. 2016, after restoration; and Sep. 2017, one year after restoration.

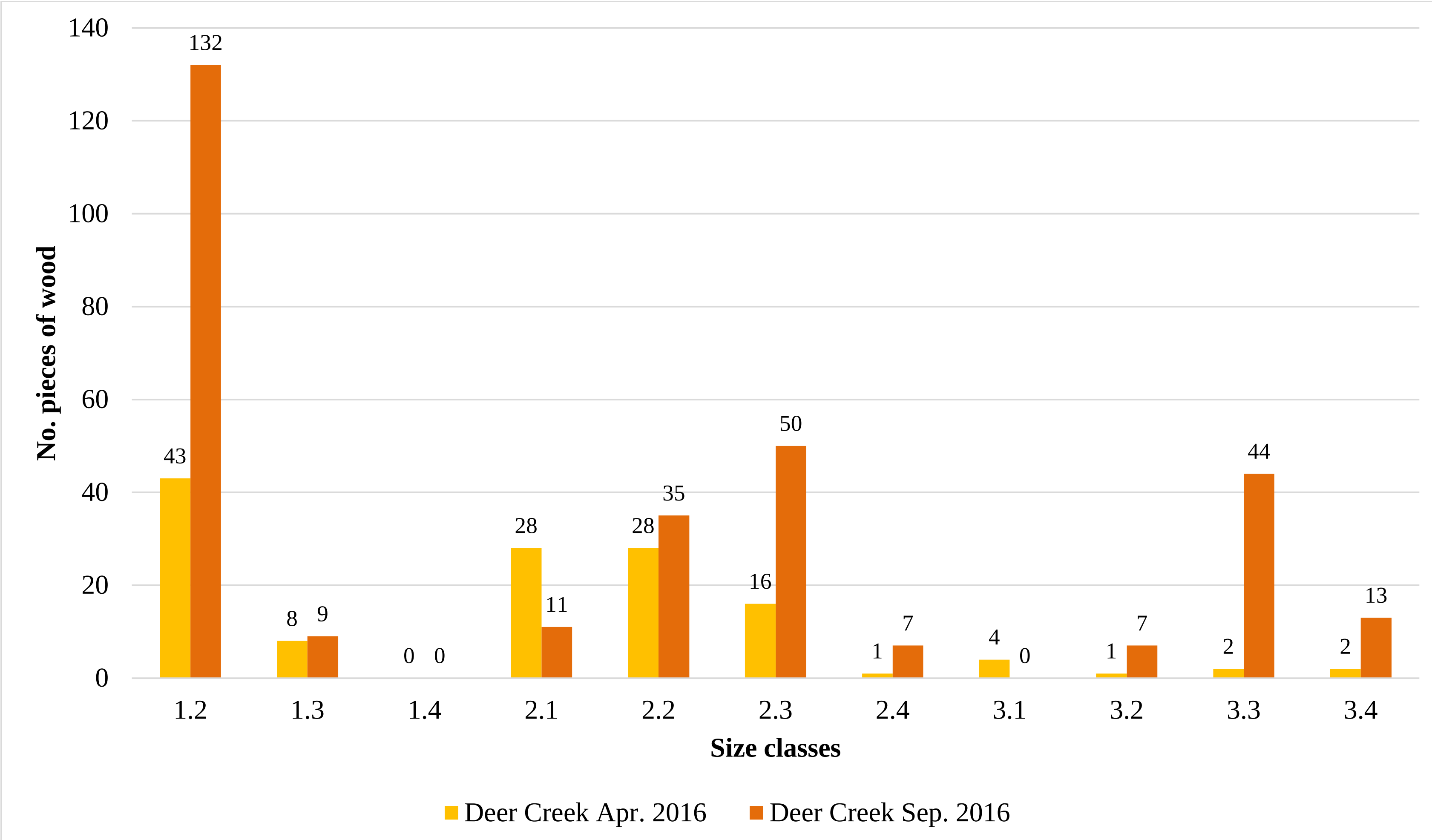


Figure 3.17: Number of pieces of large wood in Deer Creek before and after restoration. Apr. 2016, before restoration; Sep. 2016, immediately after restoration. All size classes except 1.1 shown.

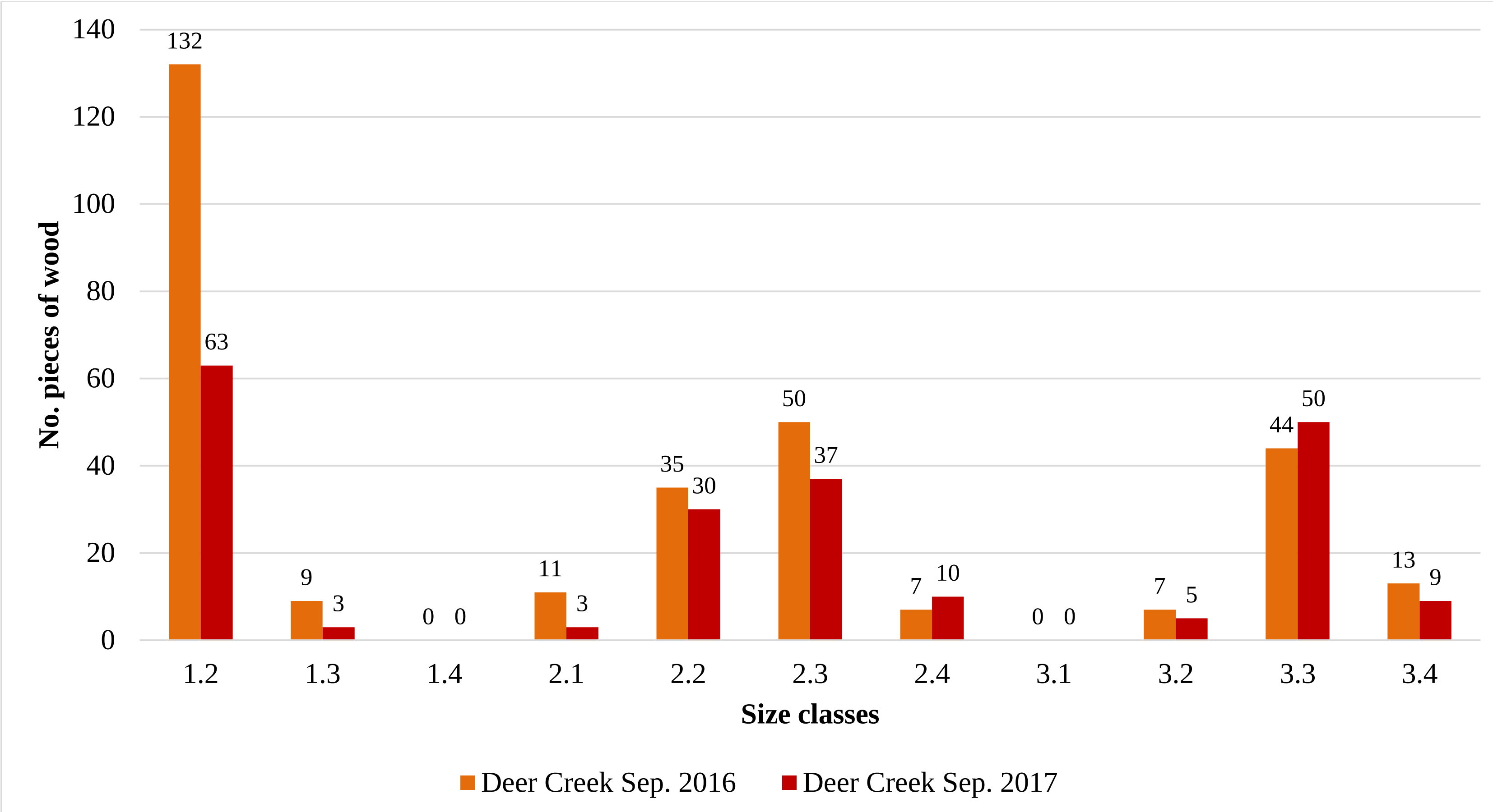


Figure 3.18: Number of pieces of large wood in Deer Creek after restoration. Sep. 2016, immediately after restoration; Sep. 2017, one year following restoration. All size classes except 1.1 shown.

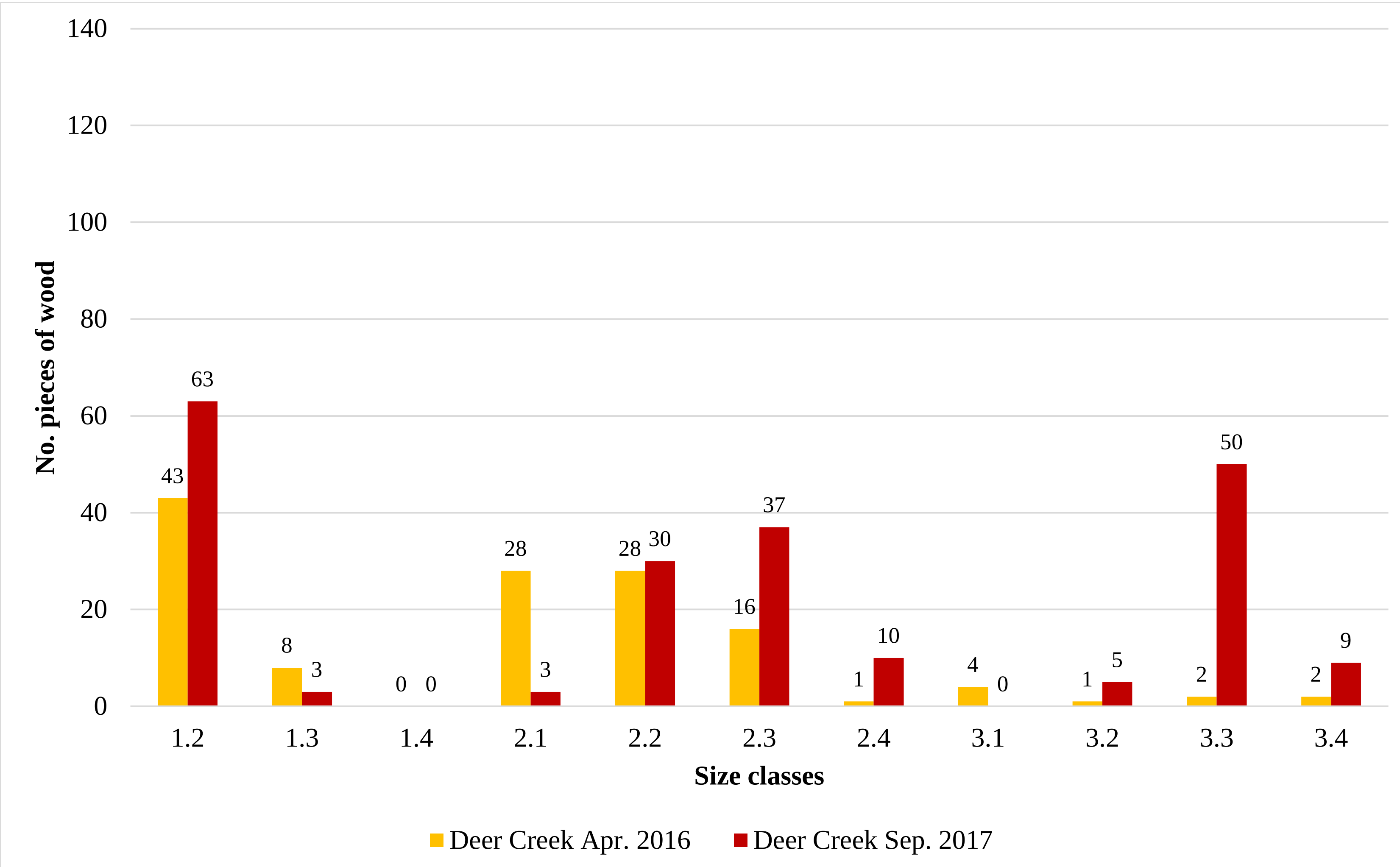


Figure 3.19: Number of pieces of large wood in Deer Creek before and one year after restoration. Apr. 2016, before restoration; Sep. 2017, one year following restoration. All size classes except 1.1 shown.

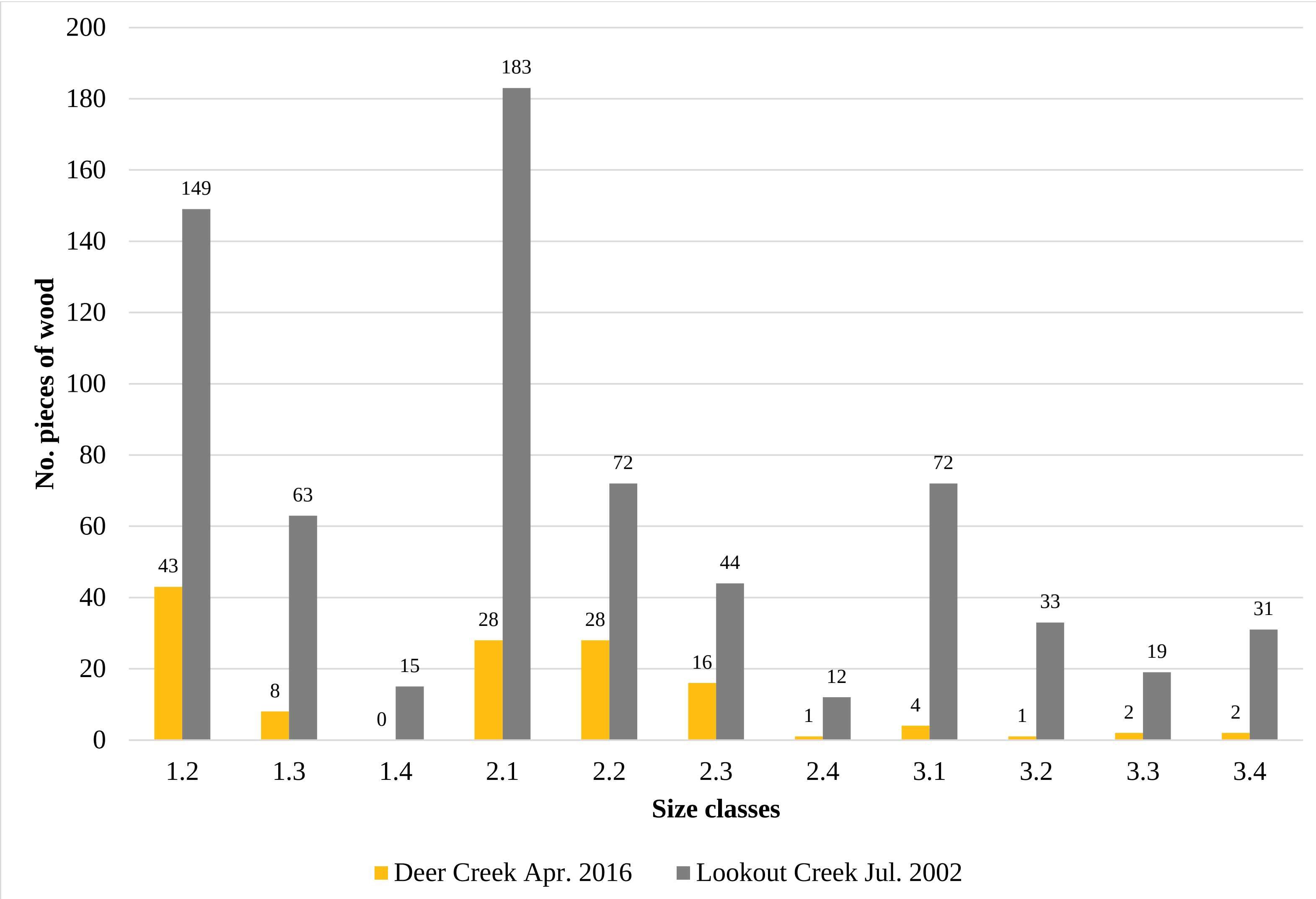


Figure 3.20: Number of pieces of large wood in Lookout Creek and Deer Creek before restoration. All size classes except 1.1 shown.

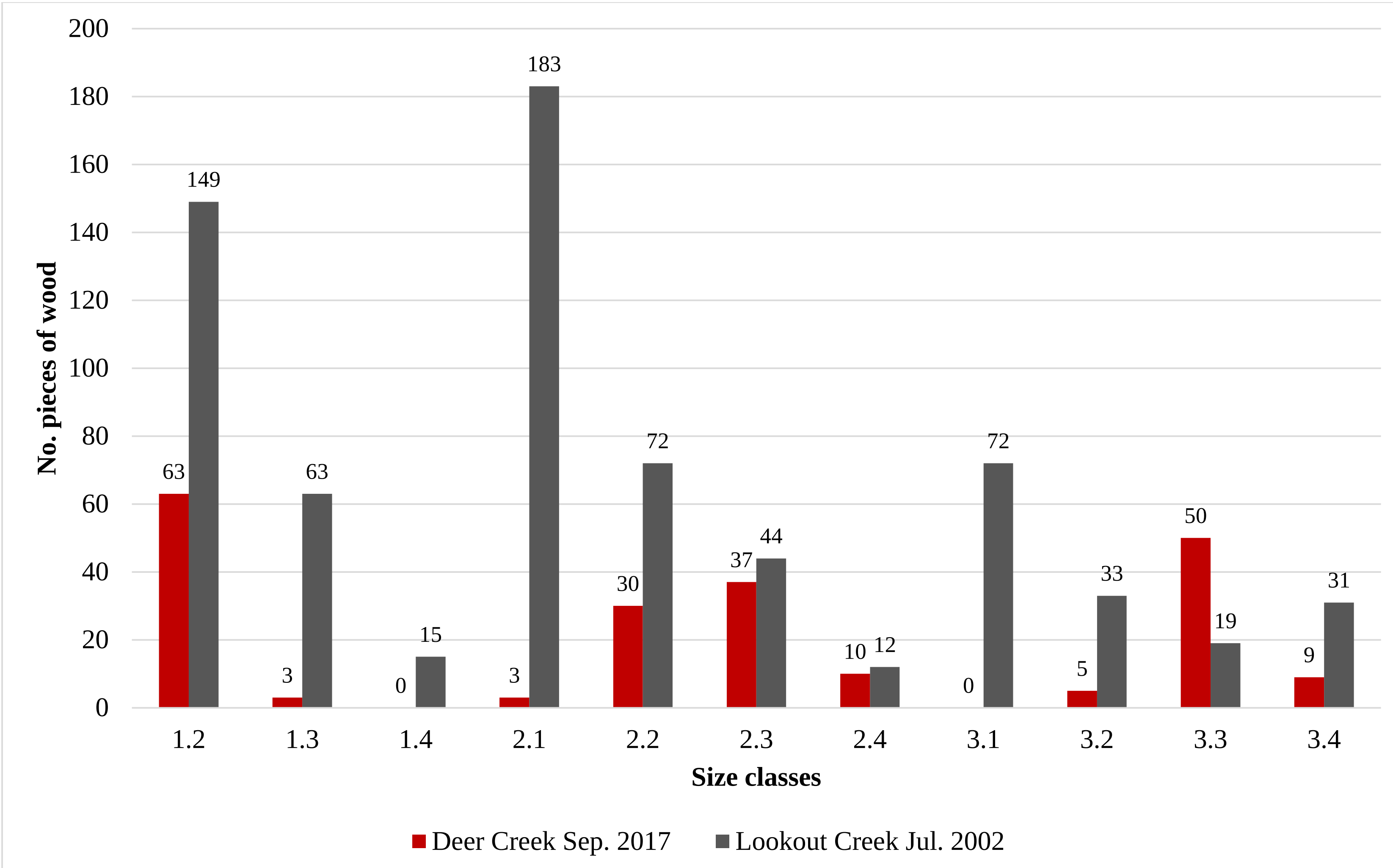


Figure 3.21: Number of pieces of large wood in Lookout Creek and Deer Creek one year after restoration. All size classes except 1.1 shown.

Table 3.9: Arrangement of wood in Deer Creek and Lookout Creek, categorized as part of accumulation (three or more pieces with more than two points of contact) or single pieces by abundance (number of pieces) and percentages for all size classes, and for only larger size classes (2.3, 2.4, 3.3 and 3.4).

			Wood abundance (no. pieces)		**Percentage (%)**	
			In accumulations	**Single**	**In accumulations**	**Single**
All size classes	**Deer Creek**	Apr. 2016	311	117	73	27
		Sep. 2016	999	561	64	36
		Sep. 2017	759	345	69	31
	Lookout Creek	Jul. 2002	1123	30	97	3
Larger size classes (2.3, 2.4, 3.3 & 3.4)	**Deer Creek**	Apr. 2016	16	5	76	24
		Sep. 2016	108	6	95	5
		Sep. 2017	101	5	95	5
	Lookout Creek	Jul. 2002	103	3	97	3

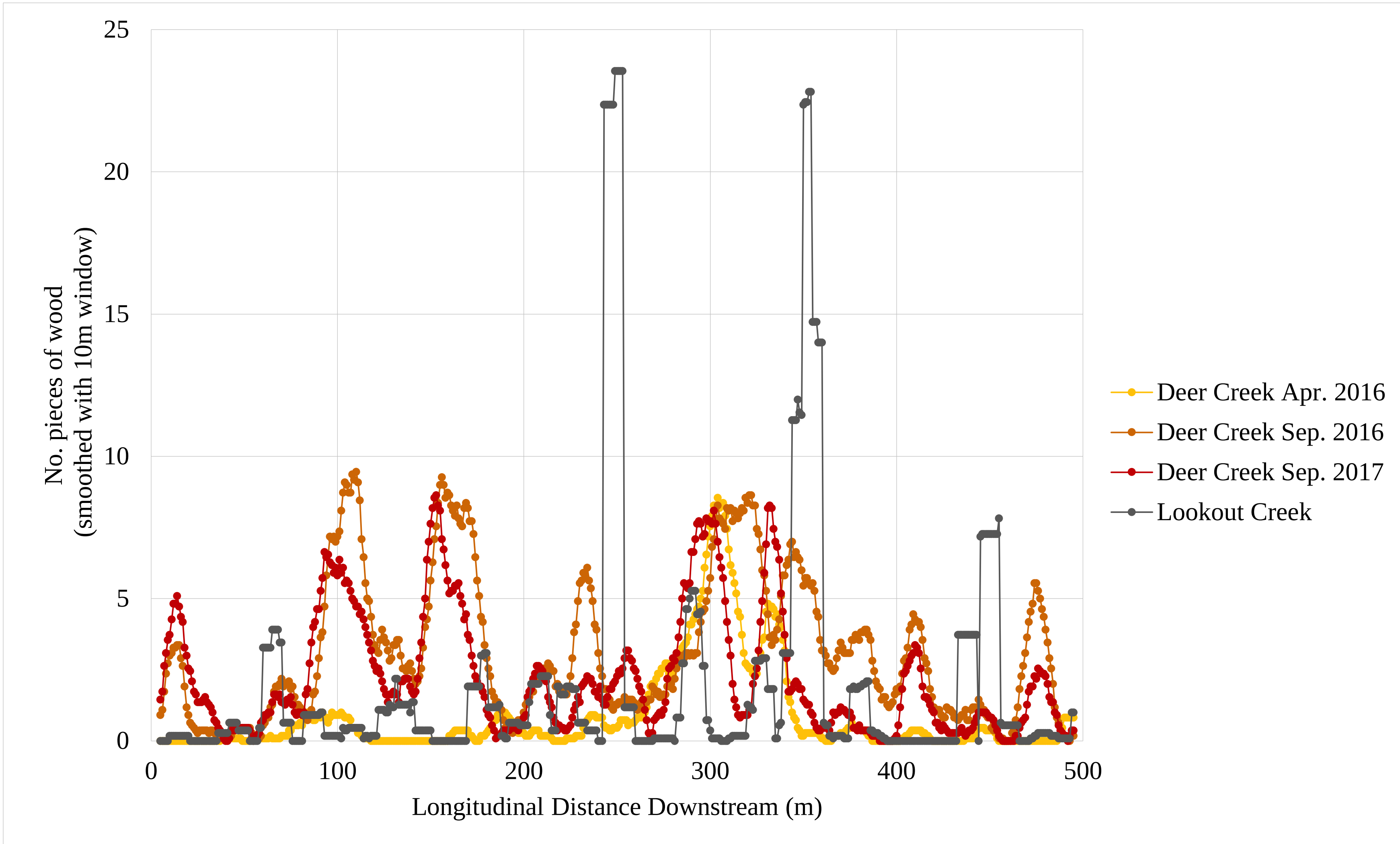


Figure 3.22: Longitudinal wood counts. Number of pieces of wood at each 1 m distance along 500 m longitudinal transect. Values for number of pieces of wood were smoothed with a 10 m window for Deer Creek data to account for image location error and 10 m for Lookout Creek data to account for the differences in reporting location of pieces of wood in accumulations.

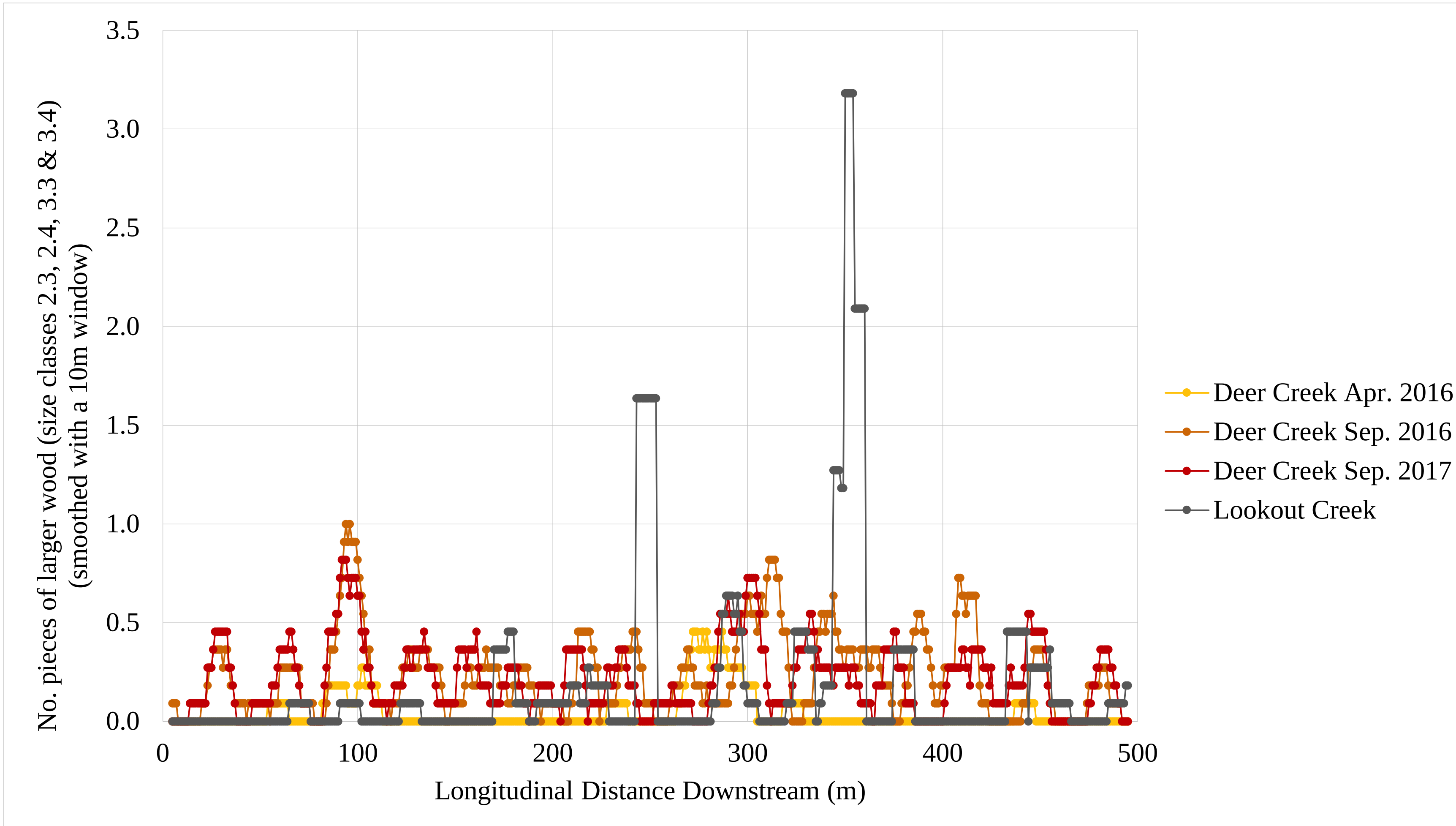


Figure 3.23: Longitudinal wood counts for larger wood, (size classes 2.3, 2.4, 3.3 and 3.4)Number of pieces of larger wood at each 1 m distance along 500 m longitudinal transect. Values for number of pieces of wood were smoothed with a 10m window for Deer Creek data to account for image location error and 10 m for Lookout Creek data to account for the differences in reporting location of pieces of wood in accumulations.

Figure 3.24: Georeferenced photopoint PP38D (facing downstream) on Sep. 2016 (top), and Aug. 2017 (bottom). Red arrow shows stationary clump of alders on shore. Wood accumulated in foreground.

Figure 3.25: Georeferenced photopoint PP39U (facing upstream) on Sep. 2016 (immediately after restoration), and Aug. 2017 (one year after restoration). Red arrow shows stationary clump of alders on shore. Wood visible in foreground in Sep. 2016 is no longer visible in Aug. 2017.

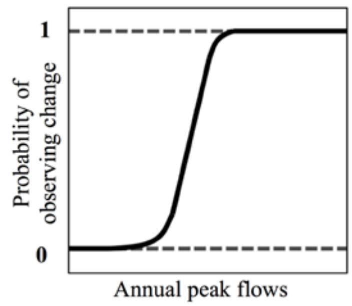
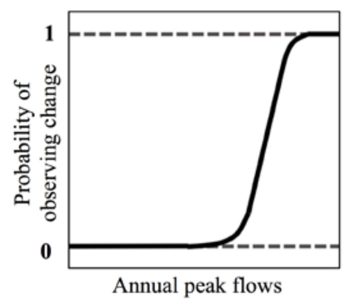
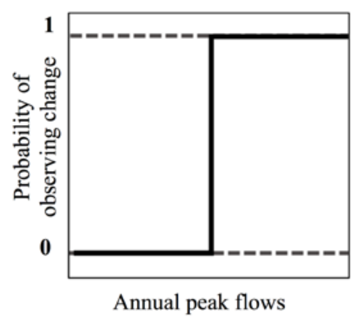
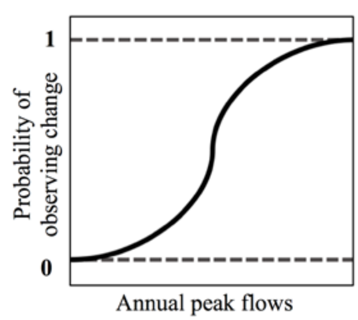
Figure 3.26: Georeferenced photopoint PP48D (facing downstream) on Sep. 2016 (top), and Aug. 2017 (bottom). Red arrow shows stationary clump of alders on shore. Small pieces of wood visible in foreground in Sep. 2016 are no longer visible in Aug. 2017.

Figure 3.27: Timelapse images from Camera 1 on 2/8/17 and 2/11/17. The red arrow in the bottom panel shows the piece that rotated from high flows on 2/9/17. Note the increased distance between the log and the boulder in the foreground.

Figure 3.28: Timelapse images from Camera 1 on 3/5/17 and 3/11/17. Red arrows show wood that was deposited during the high flows on 3/9/17.

Figure 3.29: Timelapse images from Camera 6 on 11/22/17 and 11/24/17. The red arrow shows a standing tree being rotated due to the high flows on 11/23/17.

Table 3.10: Hypothetical wood response curves with associated wood response characteristics and attributes, adapted from Faustini (2000).

Wood response characteristic	Wood attributes	Hypothetical response curve
Low resistance to disturbance	• Low abundance of wood • Small wood size • Majority not in accumulations • Few key members • Little recruitment potential	
High resistance to disturbance	• High abundance of wood • Large wood size • Majority in accumulations • Many key members • Many pieces have rootwads • High recruitment potential	
Well defined response "equal mobility"	• Narrow range of size distributions • Almost all in accumulations or all single pieces • Accumulations similarly sized	
Poorly defined response "selective transport"	• Broad range of size distributions • Mix of accumulations and single pieces • Variably sized accumulations	

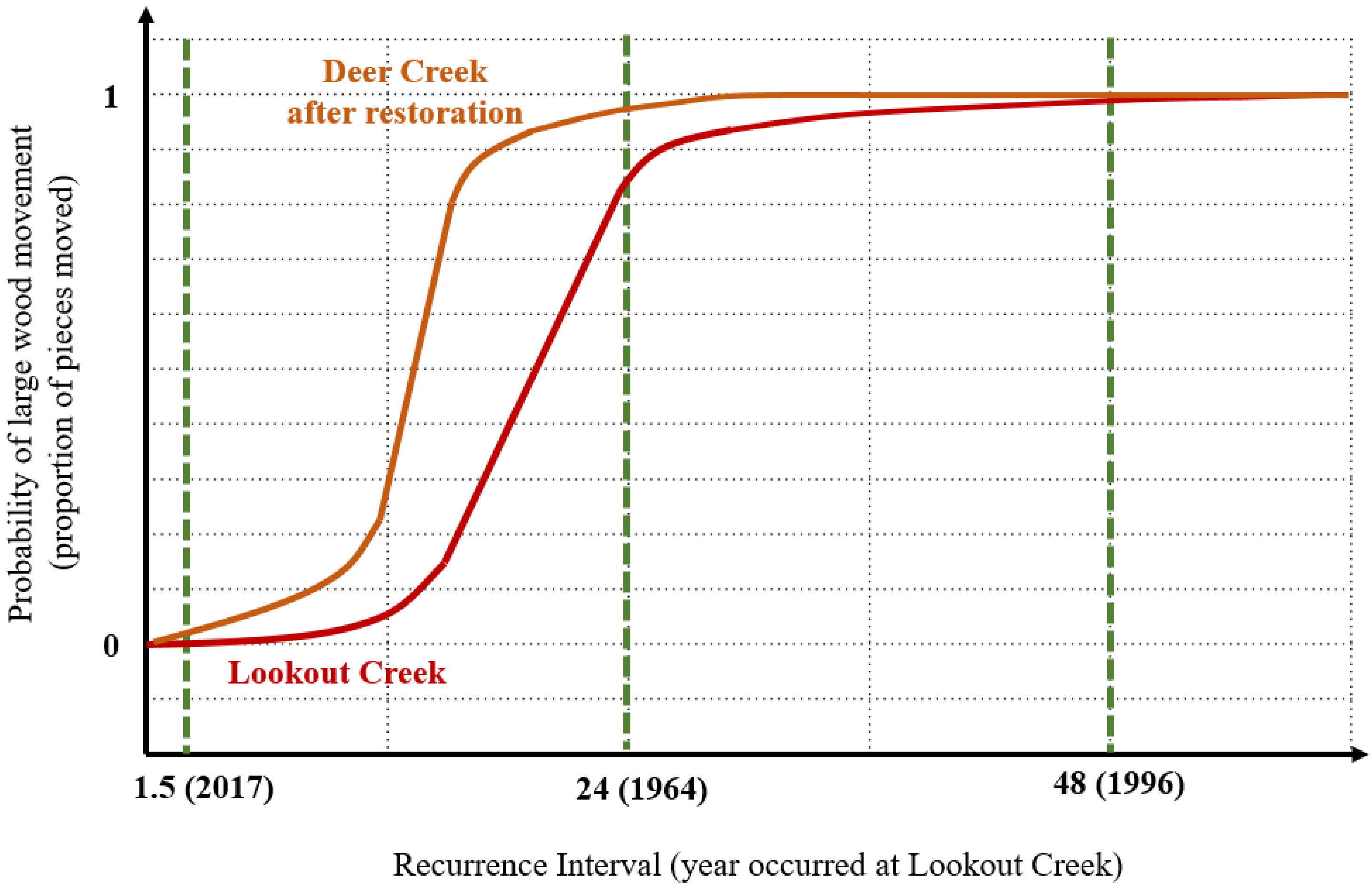


Figure 3.30: Hypothetical response curves for wood movement. Depicts hypothetical response of wood to peak flows in Deer Creek after restoration and Lookout Creek.

4 General Conclusion

This study investigated Stage 0 restoration, a novel approach to process-based river restoration that has recently emerged in Oregon. Through qualitative interviews and participant observation with practitioners and a case study on impacts of a project on large in-stream wood, this research begins to uncover the intricate and complex social and physical realms of this new form of stream restoration.

As this research illuminated, challenges remain to implementing Stage 0 restoration. Personal relationships among practitioners and scientists were important in developing and disseminating the Stage 0 practice, and in overcoming some of the challenges the practitioners face. Therefore, further studies are needed to explore how interpersonal relationships, consensus-building, and connections with scientists help overcome the inherent uncertainty and differences in values underlying any restoration effort.

The effects of the Stage 0 restoration approach on long-term stream processes is not yet known, and will play out over decades to come. This study showed that the addition of large amounts of relatively large wood produced a wood inventory in Deer Creek that was comparable in terms of numbers of pieces to an old-growth reach in Lookout Creek in the neighboring H.J. Andrews Experimental Forest. However, the wood inventory in the study reach in Deer Creek has fewer large pieces than the comparable reach in Lookout Creek and smaller wood accumulations, making the wood in Deer Creek more likely to be mobilized, and perhaps removed, by high flows in the future. Thus, it will be important to take a watershed-scale perspective, to promote long-term wood recruitment processes at Deer Creek, and to study the stability of wood to inform future stream restoration.

Given the contentious social and historical context of forest and stream management in the Pacific Northwest, it is quite remarkable that Stage 0 projects have been feasible. In recent decades, litigation citing the Clean Water Act, the Endangered Species Act, and the Northwest Forest Plan has limited logging of mature trees on hill slopes, and prevented any management activity in riparian areas. Yet it now seems that some key stakeholders in Oregon are willing to accept disturbance in the short term in the name of restoration. Could this be the result of many years of slow, incremental societal progress? Can it be attributed to the Stage 0 practitioners' commitment to education and outreach, or their engagement with scientists? Many questions remain unanswered. Striving to better understand this apparent shift in riverine ecosystem management is fascinating and complex, a topic I hope many after me continue to investigate.

More generally, these findings serve as a reminder of the importance of taking the long view in stream restoration. Although stakeholders may expect to see immediate results, it is critical that we move towards conceptualizing restoration treatments as just the beginning of the process of recovery. The timescales over which we can expect notable changes to occur in riverine ecosystems are still unknown; long-term monitoring of restoration projects should therefore remain a priority moving forward.

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