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Publication Date
2022-12-01

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Redwood Creek Restoration at the Banducci Site: Geomorphic Changes on Lower Redwood Creek from 2003 to 2022

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LDARCH 227: River Restoration

Mathias Kondolf

December 18, 2022

Table of Contents

Abstract **1**

1. Introduction **2**

1.1 Site Location 2

1.2 Site History 3

1.3 Banducci Restoration Project 3

1.3.1 Phase I 4

1.3.2 Phase II 4

1.3.3 Habitat Improvement Method: Floodplain Reconnectivity 5

1.3.4 Habitat Improvement Method: Large Woody Debris 6

1.4 Project Objective 7

2. Methods **7**

2.1 Initial Field Trip 7

2.2 Reference Documents 7

2.3 Field Data Collection 8

2.4 Data Analysis 9

4. Discussion **13**

4.1 Overall Trends 13

4.1.1 Cross Section 3 14

4.1.2 Cross Section 5 14

4.1.3 Cross Section 7 15

4.2 Ecological Impacts 15

4.2.1 Channel Impacts 16

4.2.2 Floodplain Impacts 17

4.3 Uncertainty 17

5. Conclusion **18**

References **20**

Appendix **22**

Acknowledgements: Special thank you to our project partner, National Park Service Project Manager Carolyn Shoulders, and to Hannah Hansen and Maria Lopez Vazques for assisting with field surveying work.

Abstract

This project analyzes and evaluates the geomorphic changes of Redwood Creek at the Banducci site since the National Park Service conducted restoration actions in 2003. Floodplain disconnection and reduced channel complexity resulted from land use changes caused by years of farming activity along Redwood Creek, now a part of the Golden Gate National Recreation Area, a unit of the National Park Service. We resurveyed four cross sections previously surveyed after Phase I construction in 2003 to identify topographic changes after 19 years. Our analysis included three of the surveyed cross sections. This comparison between current and as-built data illustrates an increase in channel and floodplain complexity between 2003 and the present. Increased complexity developed from the construction of log jams and grading the right bank, which also increased the habitat health of multiple endangered and threatened aquatic and riparian species. Increased cover, rearing habitat, winter refugia from high flows, and a larger riparian canopy corridor resulted in improved habitat for several salmonid species (coho salmon and steelhead trout) and resident and migratory songbirds.

1. Introduction

1.1 Site Location

The Banducci site is located along lower Redwood Creek within the Golden Gate National Recreation Area (GGNRA), a unit of the National Park Service (NPS) in Marin County, California (Figure 1). It is bounded on the left bank by Muir Woods Road (also known as Frank Valley Road), while on the right bank it opens to a large field dominated by non-native grasses and ruderal vegetation. The creek flows out to the Pacific Ocean at Muir Beach. The area we focused on was part of a 2003 restoration project which included 3,800 linear feet (ft) of the creek channel. Today, the creek is surrounded by a canopy of primarily native red alder (*Alnus rubra*) trees.

Figure 1. *Context map for the Banducci site, downstream of Muir Woods, located in Marin County, California.*

1.2 Site History

When the Redwood Creek watershed was within the boundaries of Mission San Rafael, the Mexican government deeded land to individuals for various land uses. In 1850, the Banducci family moved to this site and began growing flowers for the cut flower trade. To protect their farm from Redwood Creek's flood waters, they built levees along the right bank (when viewing downstream), which had the effect of channelizing Redwood Creek. These man-made levees disconnected high flows from the floodplain, which in turn would have increased the volume and velocities of flows within the channel banks (Junk et al., 1989). By the 1990's, when NPS first evaluated channel conditions for the project, the channel reach had very little complexity or natural sinuosity. It was so straight and flat that NPS nick-named the reach a "bowling alley." In the mid-20th century, Redwood Creek's floodplain woodlands had been cleared, and much of the riparian vegetation and woody debris within the creek was also removed or destroyed (PWA2002-PreliminaryDesignReport.Pdf, 2002). The National Park Service bought the Banducci flower farm property in 1986 to prevent development of the area. The property was then subject to NPS management policies, which entail protecting and restoring natural features and processes, including habitat for listed species (Lower Redwood Creek – Golden Gate National Recreation Area (U.S. National Park Service), 2015).

1.3 Banducci Restoration Project

NPS conducted restoration actions at the Banducci site in two phases. The first phase (Phase I) occurred in 2003, and the second phase (Phase II) occurred in 2007, upstream of the first phase. Phase I is the location studied in this report. However, because Phase II has impacted Phase I downstream, it is important to include context for both project phases when analyzing our surveying results.

1.3.1 Phase I

Phase I spanned 3,800 ft of creek channel adjacent to a portion of a 28-acre former flower field and a 5.5-acre ball field (PWA2002-PreliminaryDesignReport.Pdf, 2002). The goal of Phase I was to “restore a naturally functioning creek, riparian and floodplain ecosystem at the site, with the goal of improving habitat for salmonids and native songbirds” (PWA2002-PreliminaryDesignReport.Pdf, 2002). Habitat enhancement for salmonids focused on winter refugia and summer habitat, which included improving in-channel complexity, and increasing the extent of the riparian canopy. Construction involved removing the levees, lowering the floodplain, installation of log jams, regrading a vertical bank, and replanting the area to stabilize the bank as it reconnects and expands the floodplain. Logs consisted of Eucalyptus trees, with rootballs, imported from a different NPS site. Active revegetation of new floodplains was conducted; however, natural recruitment of native species eventually provided most of the cover.

1.3.2 Phase II

In 2007, Phase II commenced upstream of Phase I and spanned 580 ft. This work included installing more woody debris in the channel, and creating a pond for the red-legged frog, *Rana draytonii* (Lower Redwood Creek Floodplain and Salmonid Habitat Restoration, Phase 2, Banducci Site, 2015). The NPS toppled Monterey cypress (*Cupressus macrocarpa*) trees from a nearby windrow on the former farm and repurposed them for log jams. Lastly, they lowered the bank to connect the channel with the floodplain and regraded the right bank. All these actions had the same goal as the Phase I project: to reconnect the floodplain, improve riparian and in-channel habitat, and increase geomorphological complexity. The Phase II project likely impacted the hydrology, hydraulics, and sediment load within the Phase I reach. Impacts from the upstream project should be considered when interpreting changes in elevation data before and after Phase II construction. However, the extent of this impact can not be extrapolated from the data collected by our team.

1.3.3 Habitat Improvement Method: Floodplain Reconnectivity

Floodplain connectivity is key to the health of a riverine ecosystem (Junk et al., 1989) (Opperman et al., 2010)(Serra-Llobet, 2022). Levees set close to river channels harm floodplain ecosystems by separating them from the water, sediment, and fluvial energy they are dependent on (Serra-Llobet, 2022). In the case of the Banducci Restoration Project, levee removal was the first step in reconnecting the floodplain. After removing the Banducci site's levees, the NPS regraded the floodplain to improve topographic heterogeneity so that floods of multiple magnitudes could inundate the floodplain. Additionally, NPS installed large woody debris (LWD) which backed-up water in the channel thereby increasing the water surface elevation and encouraging flows onto the floodplain.

When the floodplain and river systems are connected, the ecosystem can fully benefit from a flood pulse which circulates nutrients throughout the floodplain and creates topographic heterogeneity via scour and deposition (Junk et al., 1989) (Opperman et al., 2010). Both macro and microbiota rely on inundated floodplains for food, shelter, and spawning habitat (Junk et al., 1989) (Opperman et al., 2010). Inundating the floodplain with nutrient-rich stream water increases the floodplain's nutrient pool and improves the riparian vegetation biomass (Junk et al., 1989) (Garssen et al., 2017). Flood water inundation and replanting in the regraded areas reestablished mature riparian vegetation which was "integral to the success of the restoration project" (PWA2002-PreliminaryDesignReport.Pdf, 2002).

Increased floodplain connectivity can also occur through the creation of side channels. Side channels, in the form of low-flow off-channels or backwater channels, serve both as highly important refuge areas during the winter and rearing locations during low flows for juvenile salmonids (PWA2002-PreliminaryDesignReport.Pdf, 2002). During normal base flow conditions, side channels are connected to the main channel, but have very low flow or no flow at all, creating a protected and still location for juvenile salmonids to rear. However, during high flow events, side channels fill with more water which can result in reconnection with the main channel if they were previously disconnected. However, even with more water, water velocities observed in side channels are often typically lower than in the main channel. During high flow events, typically observed in the winter season in northern California, water velocity in the main channel may be too high for juvenile salmonids to withstand, but side channels create winter refugia for the juveniles to take refuge (Schlosser, 1995).

1.3.4 Habitat Improvement Method: Large Woody Debris

In order to minimize intervention, management, and maintenance for the project, the NPS focused on process-based restoration that included large woody debris (LWD). LWD serves multiple functions to improve channel complexity, increase sediment storage, and encourage pool formation, and floodplain connectivity. LWD can trap sediment and other large debris, hydraulically roughen the channel bed, and route flows under or over (to produce pools) and around (to initiate channel migration and floodplain connectivity) the weir (PWA2002-PreliminaryDesignReport.Pdf, 2002).

LWD also improves aquatic habitat by creating pools, lowering water temperatures, and providing cover. Instream log structures that create cover and form pools improve habitat conditions for salmonids such as coho salmon (*Onchorynchus kisutch*) and steelhead trout (*O. mykiss*), two species of interest for the Phase I project. Pools are critical summer habitat during low flow conditions for salmonids (California Department of Fish and Wildlife, 1998). Additionally, covered pools help keep water temperatures low, which is required for the success of salmonid species while providing protective cover from non-aquatic predators (California Department of Fish and Wildlife, 1998).

1.4 Project Objective

The purpose of this report was to analyze the changes in the geomorphology of the Phase I reach by resurveying several cross sections and comparing the survey results to earlier data from these same cross sections. Conclusions from the topographic data, coupled with observations from the site visits, will help determine the Phase I project's impact on the habitat health of the reach with respect to salmonids and songbirds, the project's species of interest.

2. Methods

2.1 Initial Field Trip

During a LDARCH 227 field trip to Redwood Creek at the Banducci site on September 24, 2022, Natural Resource Specialist and Redwood Creek Project Manager Carolyn Shoulders introduced us to the project site, history, and restoration efforts. Shoulders showed us the Phase I project reach, noting the various changes in the creek complexity and floodplain connectivity since restoration.

2.2 Reference Documents

Following the initial field trip to the Banducci site, Shoulders provided several reference documents that allowed us to further understand Phase I and II and how it related to our work. We obtained the Preliminary Design Report from Philip Williams Associates (PWA), which detailed the Phase I project goals, objectives, and design (PWA2002-PreliminaryDesignReport.Pdf, 2002).

Additionally, we received a Microsoft Excel file with survey cross section data collected in 2003 post-construction (Banducci Creek Fieldwork raw Data Retrieved from Ms. Shoulders, 2006). We compared these values from previous survey data with data we collected during our survey to analyze geomorphic changes since project completion. In preparation for surveying, we also referenced the LDARCH 227 Field Survey Guide to ensure proper surveying techniques and processes (Kondolf, n.d.). Lastly, we applied for and obtained a research permit through the NPS to conduct these studies within Muir Woods National Monument.

2.3 Field Data Collection

We conducted topographic surveys of the cross sections over two days of field work. On Saturday, October 22, 2022, we met Shoulders at the Banducci site to locate the monumented post-construction (PC) cross sections (XS) of interest and benchmarks at their endpoints with known horizontal and vertical coordinates. We only found survey hubs for XS 1 and XS 3, which allowed us to confirm the exact starting elevation for those surveys (Figure 2). For XS 5 and XS 7, we found T-stakes indicating the location of the cross section's starting point, but we couldn't locate the exact hub. Locations of these four cross sections within the reach are illustrated in Figure 2.

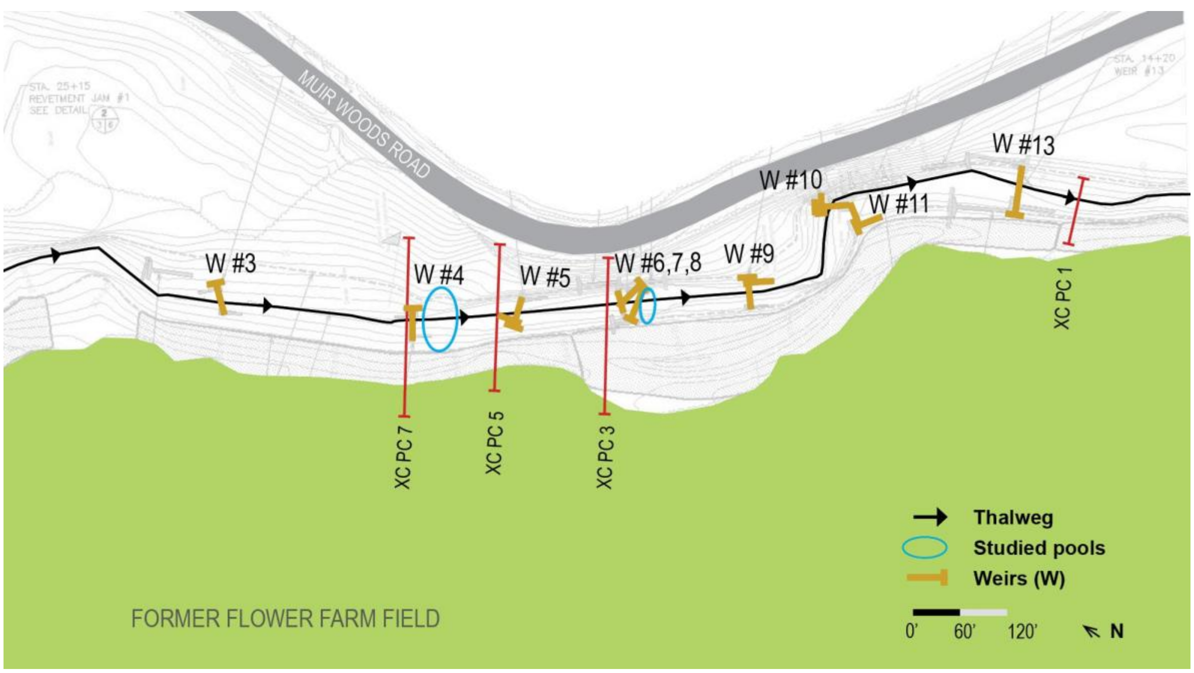

Figure 2. *Cross section map of Phase I reach made with a basemap provided by the NPS and from Environmental Data Solutions 2010. The road located to the north of Redwood Creek is Muir Woods Road, also referred to as Frank Valley Road.*

During the second day of field work, on Sunday, October 23, 2022, we surveyed four cross sections that were previously surveyed following Phase I: XS PC 1, XS PC 3, XS PC 5, and XS PC 7. We conducted the survey using a stadia rod, tripod, automatic level, and measuring tape, following surveying techniques referenced in the Field Survey Guide. We began by clearing a line of sight from the starting survey marker towards the creek with the bearing provided by referenced data. After extending the measuring tape, we surveyed elevations at multiple points along the tape, starting at the previously conducted survey monuments on the right bank to ground our survey to a known starting elevation (referred to from now on as the common point for each cross section). Within the floodplain, we took elevations at every major change in grade until we reached the bank of the river, where we took elevations more frequently to increase the detail of the geomorphic changes in the stream bed. We used turning points at points of large elevation change and blocked lines of sight. We also noted important descriptors along the cross section, indicating features like the thalweg, right and left river bank, start of riparian canopy, and floodplain terraces or side channels.

2.4 Data Analysis

We compared the new survey data to data previously collected in 2003, 2004, and 2005, provided to the team by Shoulders. We did the comparison by overlaying the historical data collected with the data we collected. We noted and discussed observations of any changes between the cross-sectional surveys in context with what was observed in the field.

Without the use of a GPS to assign coordinates to corresponding survey data points, our team assumed the starting location of each cross-sectional survey would coincide with the surveying monument installed for the original surveys, located on the right bank. This would theoretically ensure we had the same starting coordinates and elevation as previously conducted surveys to ground our survey data to, creating a common point between the surveys.

For XS PC 3, this common point method worked well since we found the hub for the right endpoint and therefore knew the actual elevation from which to start our survey. As previously stated, we found T-stakes for XS PC 5 and XS PC 7's right bank starting locations, but we could not locate their monument pins. For this analysis, we therefore assumed the elevations of endpoints on the right bank for XS PC 5 and XS PC 7 were the same as in the 2003 surveys. For XS 1, the monument pins we found did not correspond to the same monument pins in the dataset provided as evidenced when plotted in Excel, resulting in the exclusion of XS 1 in our analysis.

3. Results

Cross section PC 7 is located most upstream within the reach and directly upstream of Weir 4. Cross section PC 5 is downstream of Weir 4 and the plunge pool created by Weir 4. Cross section PC 3 is the furthest downstream cross section analyzed and is located directly upstream of the three-weir structure. The relative locations of the cross sections, weirs, and pools are illustrated in Figure 2.

In our survey, XS PC 3 extended 126.75 ft (with 21 datapoint observations (n)), XS PC 5 extended 142.72 ft (n = 23), and XS PC 7 extended 196.85 ft (n = 30). We graphed the survey data in Excel and overlaid new data on older data. For XS PC 3, we overlaid the 2022 survey data with data from 2003, 2004, and 2005, shown on Figure 3. For XS PC 5 and XS PC 7, we overlaid our 2022 data with data from 2003 and 2004 (Figures 4 and 5).

The plots are oriented such that the viewer is looking downstream, allowing river-left to be aligned with 0 ft and river-right aligned with the maximum distances displayed in each plot. The figures note the right bank edges of the riparian canopy for 2003 and 2022 surveys, showing the width of the canopy has expanded to the right approximately 42.37 ft, 52.15 ft, and 21.28 ft for XS PC 3, PC 5, and PC 7, respectively, since the November 2003 post-construction survey. We defined the canopy edge by where the line of trees and dense vegetation ended in the floodplain. Before the 2003 construction, the riparian canopy consisted of a single line of trees lining the river's banks (Appendix Photo 1, Figure 3). Today, riparian vegetation on the right bank consists of a dense stand of alders and understory vegetation which have occupied the floodplain areas graded as part of project actions (Appendix Photo 2, Figure 4).

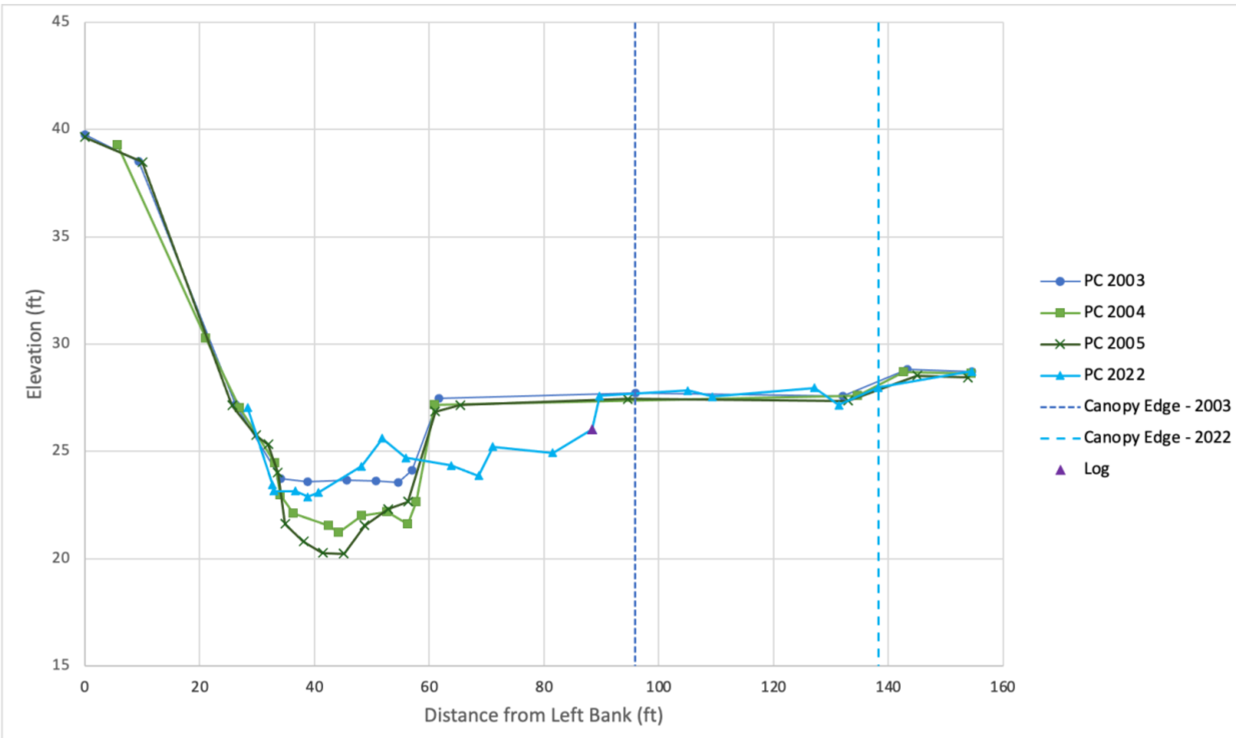

Figure 3. *Cross section PC 3, shown facing downstream, illustrates channel conditions just upstream of the complex three-weir structure in 2003, 2004, 2005, and 2022. This shows the width of the right bank riparian canopy has expanded 42 ft since 2003. The location of a log in the 2022 survey is marked with a purple triangle. The log was from a naturally fallen tree and seemed to be contributing to some bank stability.*

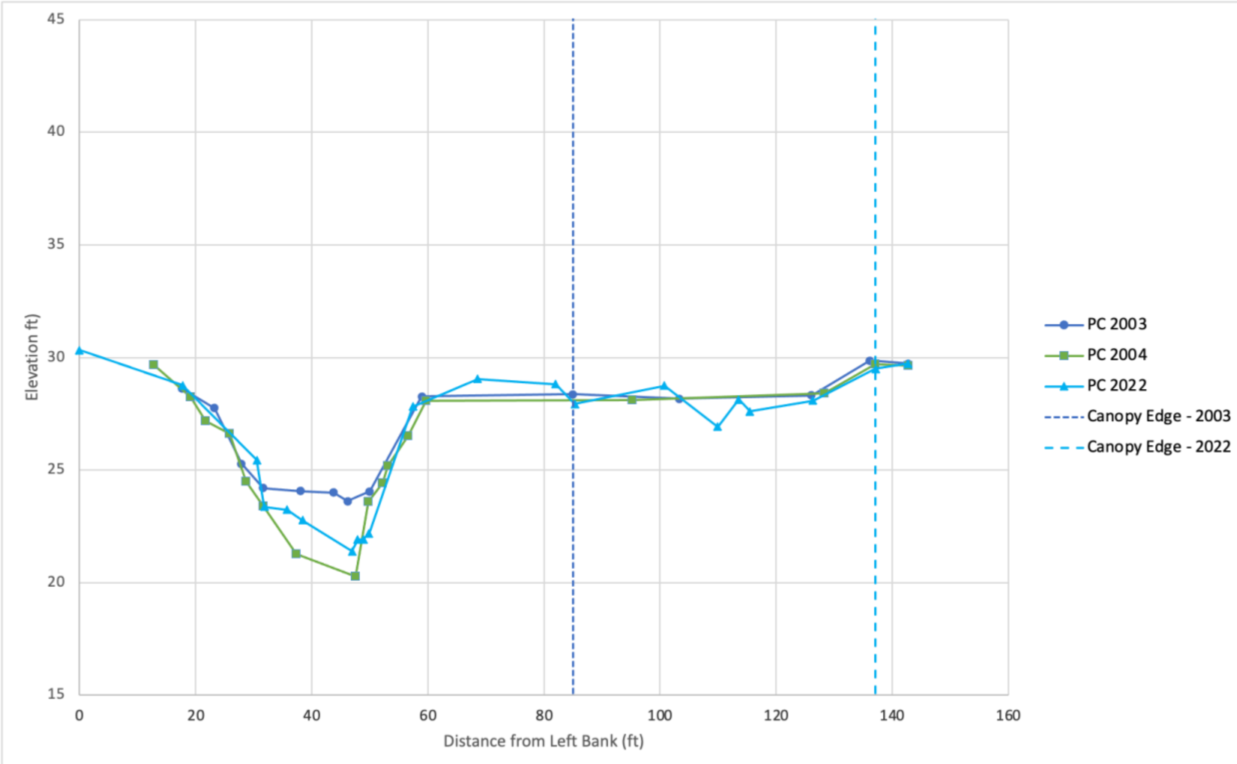

Figure 4. *Cross section PC 5, shown facing downstream, illustrates channel conditions just upstream of Weir 5 in 2003, 2004, and 2022. Width of the riparian canopy on the right bank expanded 52 ft from 2003 to 2022.*

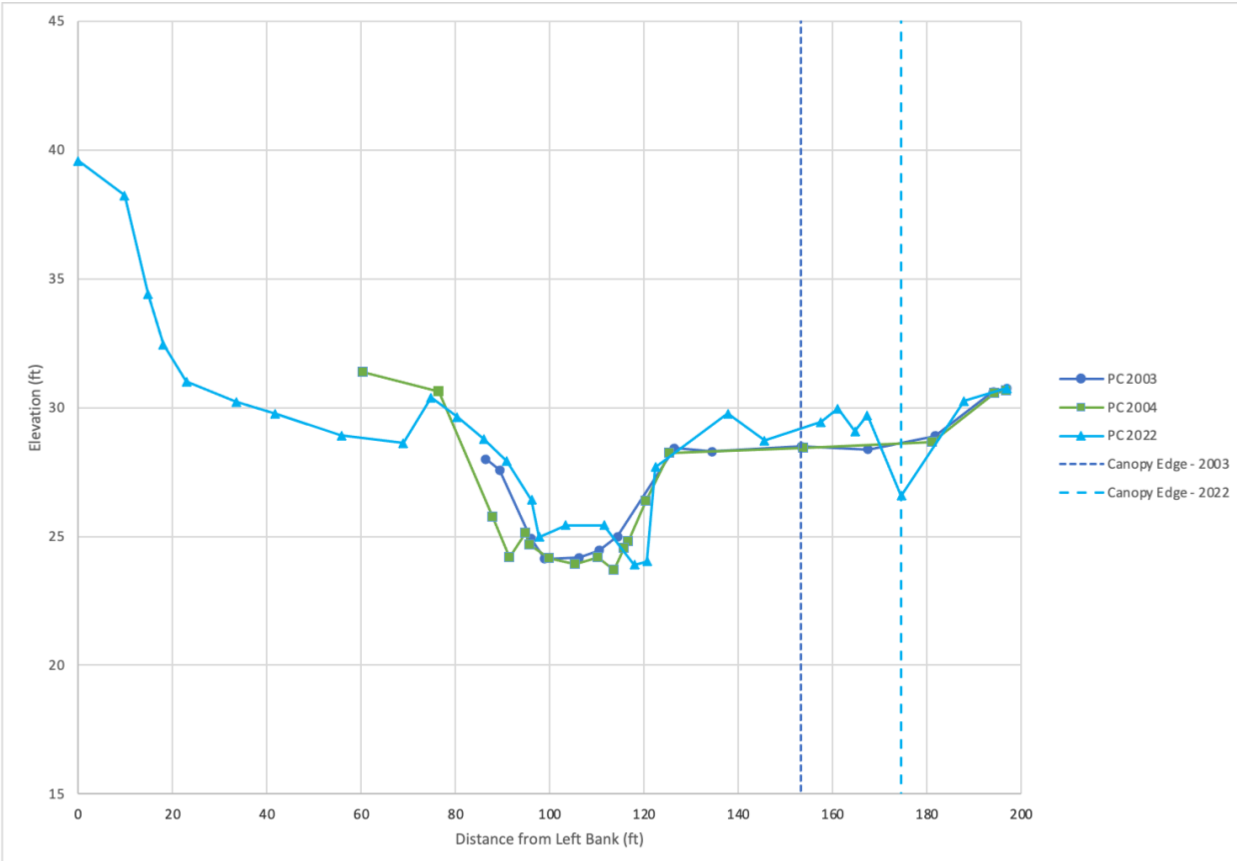

Figure 5. *Cross section PC 7, shown facing downstream, illustrates channel conditions just upstream of Weir 4 from 2003, 2004, and 2022. The width of the riparian canopy on the right bank has expanded by 21 ft from 2003 to 2022.*

4. Discussion

4.1 Overall Trends

Overlaying our 2022 field survey data with field surveys from 2003, 2004, and 2005 has provided insights into how this reach of lower Redwood Creek has changed over the past two decades, specifically post-Phase I construction. It is also possible that Phase II construction, which included six additional log jams upstream, contributed to this reach's increased channel complexity and sediment accumulation by altering the flow and sediment loading. The 2022 survey provides additional evidence of the effects of large wood and constructed features on the geomorphological fabric of this reach.

4.1.1 Cross Section 3

Cross section 3, displayed in Figure 3, is upstream from a three-weir log jam complex constructed in 2003 (Figure 2). The post-project survey from 2003 to 2005 for XS 3 showed channel downcutting, where the thalweg dropped approximately 3.5 ft over three years. However, the XS PC 3 2022 survey showed sediment accumulation raising the channel bed elevation almost to the same elevation as in 2003. The channel in 2022 was highly complex, with what looks to be a narrower main channel and additional side channels. Added channel complexity of the right bank is likely a product of high flows accumulating behind the log jam upstream and eventual overflow onto the floodplain on the right bank terrace thereby scouring the right bank (Appendix Photo 4). In the field, we observed a very deep pool that had formed under and downstream of the three-weir log jam, created from flow forced under the weir, that scoured the channel bed, and over weir, creating a plunge pool downstream (Appendix Photo 7).

Lastly, the canopy within this cross section expanded approximately 42 ft on the right floodplain (Appendix Photo 6). This canopy expansion could have been the result of increased floodplain connectivity and water inundation, allowing for greater water availability for shallow-root riparian vegetation and a higher nutrient pool due to the more frequent flooding.

4.1.2 Cross Section 5

Data for XS 5, shown in Figure 4, also shows a similar pattern to that of XS 3, where the channel bed scoured by as much as 3.4 ft between 2003 and 2004, but then aggraded by as much as 1.1 ft by 2022. Cross section 5 is upstream of Weir 5 and is adjacent and partially impacted by the plunge pool downstream of Weir 4. During our site visit, this deep pool was observed in the field (Appendix Photo 5). Scour on the floodplain during overbank floods since 2004 created subtle side channels on the right bank floodplain around 110 ft on the cross section. This area was also graded in the 2003 construction, which allowed for added floodplain connectivity resulting in increased complexity in the decades following.

4.1.3 Cross Section 7

Cross section 7 has the most variety of the three cross sections we surveyed (Figure 5). The cross section is located downstream of Weir 3 and directly upstream of Weir 4 (Appendix Photo 5). In 2003, the cross section appeared more channelized with a trapezoidal shape and a consistent floodplain elevation that lacked variability. In 2004, the channel bottom had more complexity, possibly due to the placement of Weir 3 and 4 upstream and downstream of the cross section causing sediment accumulation in the center of the channel and scouring along the toe of the right and left banks. In 2022, the same scouring and aggradation pattern occurred, with additional sediment accrual in the middle of the channel of approximately 1.5 ft since 2004. The scouring is more extreme on the toe of the right bank which could be a result of Weir 3's orientation. Weir 3 was oriented such that it deflects flow to the right bank (PWA2002-PreliminaryDesignReport.Pdf, 2002). This encourages channel migration and helps protect the left bank from erosion. Additionally, the formation of natural levees occurred at the edges of the main channel. Like XS 3 and XS 5, conditions at XS 7 were influenced by large storm events and likely the effects from Phase II construction upstream.

4.2 Ecological Impacts

Ecological impacts within the reach that were observed include the creation of side channels that create winter refugia, pools that result in rearing habitat and in-channel cover from predators, and riparian canopy expansion.

4.2.1 Channel Impacts

Cross section 3 saw the creation of a side channel near the right bank of the main channel, whereas XS 5 and XS 7 created side channels within their right floodplain. These side channels are beneficial for juvenile salmonids and other aquatic species as they create protected areas that will observe lower velocities than the main channel during high flow events. Juveniles will use these low velocity side channels to seek refuge during high flow events where they would otherwise be swept away in the main channel. Additionally, during low flow conditions, side channels may hold standing water which is excellent rearing habitat for salmonids, which could be observed in the side channel at XS PC 3 due to its elevation relative to the thalweg (approximately one foot greater than the thalweg's elevation). While on-site in October 2022, we did not observe standing water in the side channels on the floodplain at XS PC 5 and 7. This observation and the elevation increase from the thalweg at these cross sections (approximately 4.3 ft higher than the thalweg) suggests it is less likely that the side channels on the floodplain will be used for rearing habitat and more likely that these side channels will be used for winter refugia.

Another improvement to habitat within the reach was the creation of very deep pools that had formed under and downstream of the weirs constructed within the reach. The pools located immediately downstream of XS PC 3 and 7 are especially beneficial for salmonids due to their locations below the log jams. The log jams will provide shelter from non-aquatic predators and cover the water from sunlight, creating cooler conditions for salmonids and other species. Additionally, pools in the channel help preserve adequate habitat during low flow summer conditions by maintaining enough water in the channel for juvenile salmonids (Lower Redwood Creek Floodplain and Salmonid Habitat Restoration, Phase 2, Banducci Site, 2015).

4.2.2 Floodplain Impacts

The side channels within the floodplains help to reconnect the floodplain with the channel allowing for increased access to nutrients and increased water availability within the floodplain. Higher nutrient and water availability to the riparian zone likely helped lead to the canopy expansion on the right floodplain observed in all three cross sections. Cross section 5 had the largest increase in riparian vegetation, with approximately 50 more feet of width in 2022. In comparison, XS 7 had about 20 ft of increased riparian edge. This riparian canopy expansion allowed for increased habitat availability for local and migratory songbirds and led to increased channel cover, which were two objectives of the Phase I project.

4.3 Uncertainty

In our cross section measurements, multiple sources of error could have impacted the accuracy of our results. For instance, we had trouble locating the starting monuments used for the cross sections in previous surveys without access to a GPS device. In addition, dense vegetation and ambiguous descriptions made these monuments difficult to find. For XS 3, we found two starting monument pins within feet of one another, indicating that the original monument pin may have been completely obscured when the second monument pin was placed.

We assumed that our starting elevation on the right floodplain would have the same starting elevation as the right bank monuments marked that were left from past surveys. Without a GPS device, we could not collect our actual starting elevation in the field to compare to the historical elevation at the same coordinates. Equipment availability and issues finding the starting monument pins for XS 5 and XS 7 may have introduced errors in our results.

Issues around the lines of sight could have also contributed to errors. As mentioned, the dense riparian vegetation obstructed a clear line of sight (Appendix Photo 6). Maneuvering the measuring tape around trees and other obstacles likely added distance to our stations. Without established ending points along the left bank, we decided to mark our cross section path using the established bearing for each cross section from past surveys. While we attempted to follow the bearing, it was difficult to stay true to course using the compass on our cell phones, while also maneuvering the measuring tape around the vegetation. This technique may have resulted in a different cross section alignment from previous cross sections surveyed post-construction.

In addition to challenges with our equipment and overgrown vegetation, there were sources of error with our surveying methods. Instead of closing the survey to assess our accuracy throughout the reach, we ended the survey on the left bank. Time constraints, increasing hazardous wind speeds, and difficult terrain prevented us from surveying back to the starting location. This could have created an accumulation of small measurement gaps that resulted in an unknown amount of overall measurement error.

5. Conclusion

Resurveying cross sections in the lower Redwood Creek reach has illustrated several geomorphic changes since the completion of Phase I. We evaluated geomorphic changes over the past 19 years by overlaying our 2022 survey results with historical survey data from 2003, 2004, and 2005. The survey results reveal an increase in channel and floodplain complexity and improved aquatic and riparian habitat within the reach. Increased floodplain connectivity was the result of the removal of the right bank levee, regrading of the right bank, and the construction of log jams within the channel. The survey results indicate the creation of side channels, which act as rearing habitat and winter refugia for juvenile salmonids, and the expansion of the riparian canopy which increases habitat for resident and migratory songbirds, a species of interest for the Phase I project. Additionally, increased woody debris in the channel creates more cover, deeper pools, and cooler water temperatures for endangered fish such as coho and steelhead, both species of interest in the Phase I project.

Several complications in the methods and execution of the surveying process resulted in errors that may have impacted the accuracy of our results. Dense vegetation created difficult conditions for finding survey monuments and inhibited a direct line of sight while preparing and conducting the surveys. The lack of a GPS device during the surveying also contributed to difficulties while locating the markers, following the correct bearing to guide the surveys, and comparing the coordinates of our survey data points to the previously conducted survey's coordinates. Additionally, failing to close the survey resulted in unknown measurement error. Despite the uncertainties within our methods and analyses, we can conclude that floodplain connectivity and channel and floodplain complexity has increased since the Phase I restoration effort within the Lower Banducci reach.

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Appendix

Photo 1: *View downstream of XS 7 on December 30, 2003. Source: Photos for UCB Pre_Post_Action April 2004*

Photo 2: *View downstream of XS 7 on the right bank outside of the riparian canopy on October 22, 2022.*

Photo 3: *Deep scour pool observed directly upstream of XS 5 on October 22, 2022.*

Photo 4: *View of the right bank of XS 3 during a bankfull event in January 2004. Source: Photos for UCB Pre_Post_Action April 2004*

Photo 5: *View log structure upstream of XS 7 in April 2004. Source: Photos for UCB Pre_Post_Action April 2004*

Photo 6: *View of dense canopy from right bank towards creek on XS 3 on October 23, 2022.*

Photo 7: *View from right bank of three-weir log jam upstream of XS 3 on October 23, 2022.*