Assessing Environmental Changes Following Restoration Along Strawberry Creek

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ABSTRACT

Ecological restoration is the process of reversing environmental degradation by restoring natural ecosystem structure and function, including the reintroduction of native plants and rehabilitation of ecosystem services. Stream ecosystems are common restoration targets due to their widespread degradation and ecological significance. Riparian and stream systems are known to respond well to restoration, however studies on the success of restoration over time are limited. Strawberry Creek in Berkeley, CA offers a unique opportunity to study the impacts of restoration on stream health over time due to its forty-year history of urban stream restoration. This study used modified methods from monitoring surveys conducted at two restoration sites managed by the Creeks of UC Berkeley along Strawberry Creek to better understand changes in stream structure and vegetative communities following restoration. I found the restored channels had "good" stability, and demonstrated insignificant change following restoration. The vegetation survey results included significant decreases in species richness and diversity, and increases in total cover with significant increases in invasive cover. The channel stability analysis indicated that restoration was successful in creating physically stable systems, although previous studies disagree about the extent to which physical stability is an important metric in stream restoration, indicating the need for further research. The vegetative community results indicated pressure from human traffic and competition from invasive species, informing a need for more active management following restoration. Although limited, the results of this study can be used to inform current restoration management practices in urban areas, specifically highlighting needs for active weeding and protection from trampling.

KEYWORDS

urban streams, channel stability, native plant diversity, vegetation cover, invasive species

INTRODUCTION

Ecological restoration centers around the goal of returning native diversity, structure, and function to disturbed ecosystems (Harris et al. 2006). Ecological restoration can encompass a number of different strategies, namely the reintroduction of native plant species and natural habitat characteristics, and the rehabilitation of failed ecosystem functions (Aronson 1993). Restoration efforts are commonly planned to mirror the structure and function of natural ecosystems, and are often modeled after natural and historic reference sites. Riparian and stream ecosystems are common targets for restoration efforts because they deliver disproportionately high levels of ecosystem services as a result of their ecotone characteristics and ecological structure, making them key to healthy freshwater systems (Riis et al. 2020, Seavy et al. 2009). However, due to changes in land use and development, habitat has been reduced by up to 95% in parts of California, resulting in major ecological disruptions (Council et al. 2002). These disruptions affect water quality and flow, erosion, pollination, and numerous other ecological processes (Riis et al. 2020). Given the well-documented positive effects of riparian and stream systems, and the negative impacts of their absences, these ecosystems have become focuses of ecological restoration as a means to absolve environmental degradation in relatively short time spans (Seavy et al. 2009). With the goal of generating a resilient ecosystem through restoration it is integral to consider the success of restoration beyond metrics such as community composition and structure (Hobbs et al. 2009). Quantifying the success of restoration projects in terms of structure and diversity is simple, while consistent monitoring of resilience over time is much more difficult (Kondolf 1995).

The San Francisco East Bay offers a unique opportunity to assess urban stream restoration and the resilience of restored systems. The San Francisco Bay Area was once a prolific and healthy watershed, but after decades of intensive land development has become significantly degraded (McCreary et al. 1992). Up to 90% of wetlands and watersheds in the Bay Area have been lost due to human activity in the last 200 years (Ball 2019). Many streams in the East Bay now find themselves trickling through neighborhoods or flowing under urban centers, far removed from a natural setting. These urban streams are under constant degradative pressure from further land development and urban runoff, resulting in poor ecosystem health and low stability (Riley 2016). Urban streams are documented to have faster flow, higher levels of erosion, and dramatically reduced biodiversity when compared to natural counterparts, resulting in great need for restoration (Riley 2016). In the 1980's the East Bay became the birthplace of urban stream restoration, with daylighting first occurring along Strawberry Creek in Berkeley, CA (Meadows 2019). For nearly four decades urban stream systems of varying scales have been restored in the region, creating opportunities for restored systems to be monitored and assessed over time. Strawberry Creek has been home to many such projects in this time, with several unique restorations of varying age implemented across the three square mile watershed (Creeks 2024). Streams are dynamic systems, naturally stabilizing and "self restoring" (Riley 2016). As such, it is crucial to evaluate restored streams for changes over time to understand if restoration successfully mimics natural systems that self-maintain and improve over time.

This study assessed the success and relative stability of urban stream restoration along Strawberry Creek. The primary goal of this study was to compare monitoring data collected at urban stream restoration sites in the time following restoration to better understand how restoration sites age and change over time, and if stream restoration has been successful. For the purposes of this study, we defined success as significant positive variation in channel stability and plant community structure with increasing restoration age. To assess general changes in system structure over time this study uses modified procedures previously used to collect channel stability and vegetation data at the studied restoration sites. I synthesized the data collected in this study with previously collected monitoring surveys and analyzed for changes over time. This study evaluated restoration sites with two focuses: (1) how physical characteristics of channel stability vary over time and (2) how diversity and cover of plant communities change with restoration age. By evaluating these metrics we can better understand how urban stream restorations mature and change over time and develop improved restoration methods to achieve these results. Based on the claims made by Riley 2016 regarding urban stream restoration and the conditions under which restoration occurs, I expect channel stability to slightly improve as restoration sites age, and for plant coverage and total diversity to increase over time.

METHODS

Study site description

The urban creek restoration sites that I surveyed for this study are located along Strawberry Creek in Berkeley, CA (Figure 1). The Strawberry Creek watershed is approximately three square miles, with two forks that flow through the Berkeley Hills before reaching a confluence on the UC

Berkeley campus, flowing westward through the city, and discharging into the San Francisco Bay (Alameda County 2024). Since the 1980's public and private environmental groups have implemented restoration projects along Strawberry Creek primarily focusing on channel reconstruction and the restoration of riparian vegetation. (Riley 2016) For this study, I assessed two restoration sites along Strawberry Creek. I selected sites based on the extent of previously collected data available. The Creeks of UC Berkeley, a local restoration and research group, restored two areas of Strawberry Creek that were chosen as study sites for this project. The Creeks of UC Berkeley completed the Strawberry Creek North Fork Mitigation Project, and the Riparian Enhancement Project at the Women's Faculty Club of Strawberry Creek, in 2015 and 2016 respectively (Figure 2).

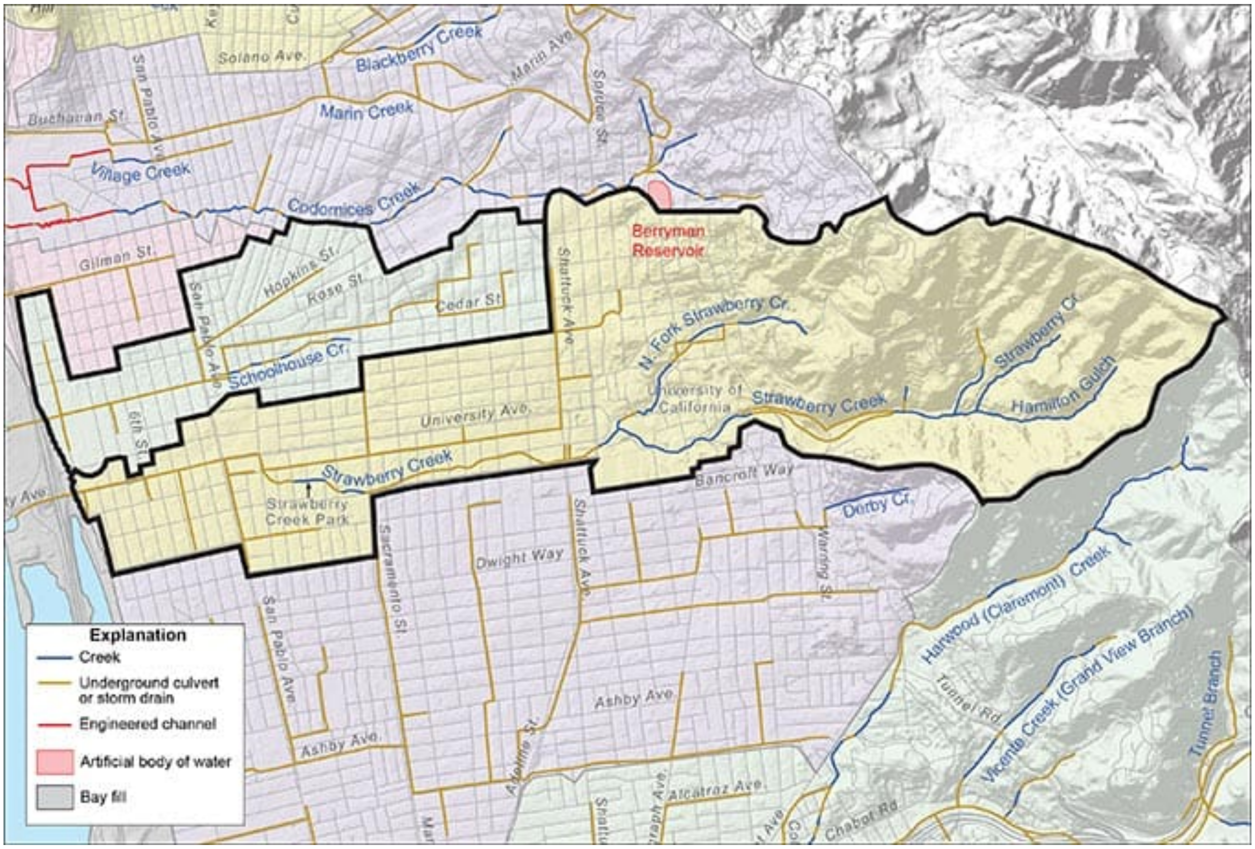

Figure 1. Map of Strawberry Creek Watershed.

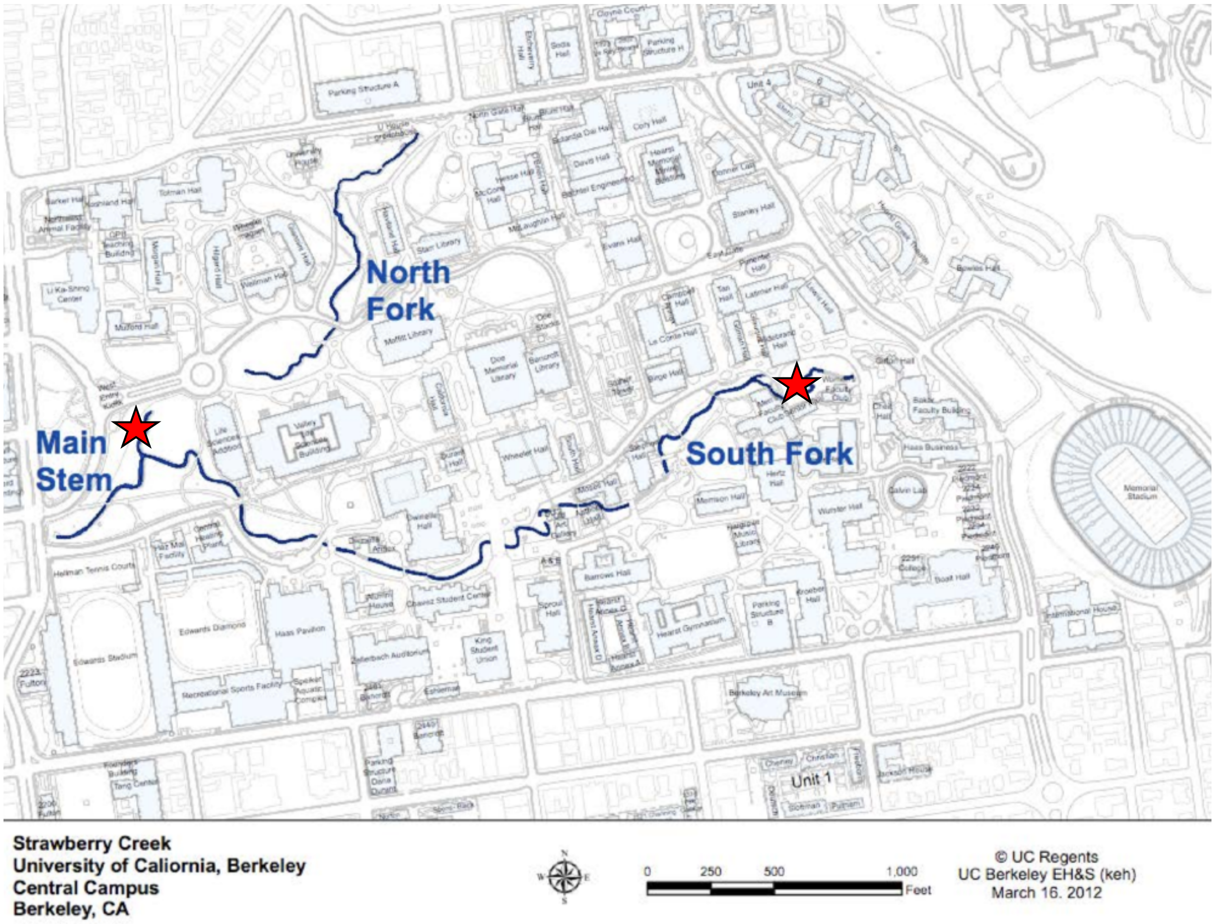

Figure 2. Map of Strawberry Creek on UC Berkeley Campus. Left star: North Mitigation Project (37.87146º N, 122.26450º W). Right star: Riparian Enhancement Project at the Women's Faculty Club of Strawberry Creek (37.87221º N, 122.25533º W).

Restoration monitoring

To assess the restoration study sites along Strawberry Creek, I followed the procedures outlined in previous monitoring surveys conducted by the Creeks of UC Berkeley, an organization centered on research, habitat restoration and stormwater recording in the creeks on the UC Berkeley Campus (Creeks 2024). The Creeks of UC Berkeley chose the monitoring methods used in this survey under guidance from the Environmental Protection staff in the UC Berkeley Office of Environment, Health and Safety (Massell 2017). The staff intended for methods to describe the biological and structural conditions of restoration sites in the years 2015, 2016, and 2017, following completion, with the intent to document ecological and structural changes in stream integrity (Massell 2015).

To evaluate changes in creek restoration over time, I synthesized data collected in monitoring surveys conducted in 2015, 2016, 2017, and 2024. The collected data included channel stability scores, native plant counts, vegetation cover, and native plant survivability. There were discrepancies in the previously collected monitoring data. The Women's Faculty Club restoration site had no previous channel stability data and was also missing a 3-year vegetation monitoring report. The North Fork restoration site had data for all of the following procedures collected in 2014, 2015, and 2017. I compiled the data and computed averages recorded by year and analyzed them using a combination of one-way ANOVAs and regression comparison tests to evaluate significant changes in restoration structure over time.

Channel stability

Stability assessment

To assess creek channel stability at the study sites I conducted a visual assessment employing elements of the rapid assessment techniques outlined by the Department of Transportation (DOT) *Assessing Stream Channel Stability at Bridges in Physiographic Regions* (Henderson 2006). The DOT outlined techniques to quantify channel stability on a scored scale of 1-12 (excellent to poor). I made visual assessments at both sites in late February 2024. To assess channel stability I evaluated the following creek characteristics and scored them respectively: entrenchment/channel confinement, bed material, bank soil texture and coherence, average bank slope, vegetative or engineered bank protection, bank cutting, and mass wasting or bank failure. I weighed each surveyed parameter equally and averaged recorded scores to assess channel stability. To assess different characteristics of the restoration sites I made observations every 10 meters in sections along each creek (Figures 3&4).

Analysis of channel stability

To interpret the channel stability scores observed during monitoring surveys I compiled all channel stability scores and computed averages for each stability metric as well as each monitoring station and the whole restoration site during each monitoring year. I analyzed averages across years and conducted a one-way ANOVA using RStudio (R version 4.1.2 (2021-11-01)) to understand if restoration age resulted in significant differences in channel stability. I also conducted a one-way ANOVA using data collected from individual monitoring stations across the study period to understand if changes over time were uniform throughout the restoration site. Due to a lack of previous data I only analyzed channel stability data at the North Fork restoration site.

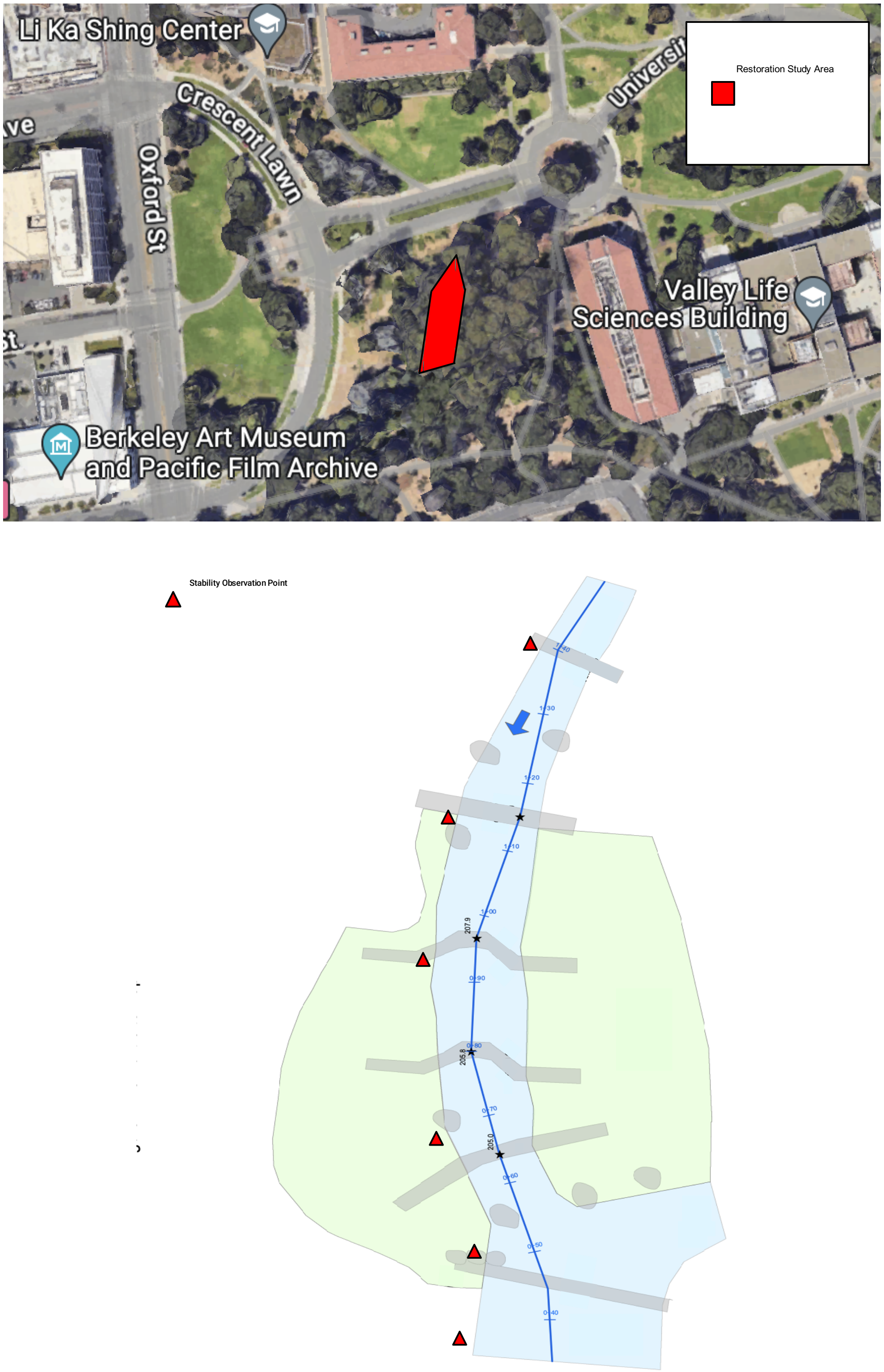

Figure 3. Maps of North Fork Restoration Site. Above: Restoration site location on western side of the UC Berkeley Campus. Below: Restoration site blueprint including channel stability observation points.

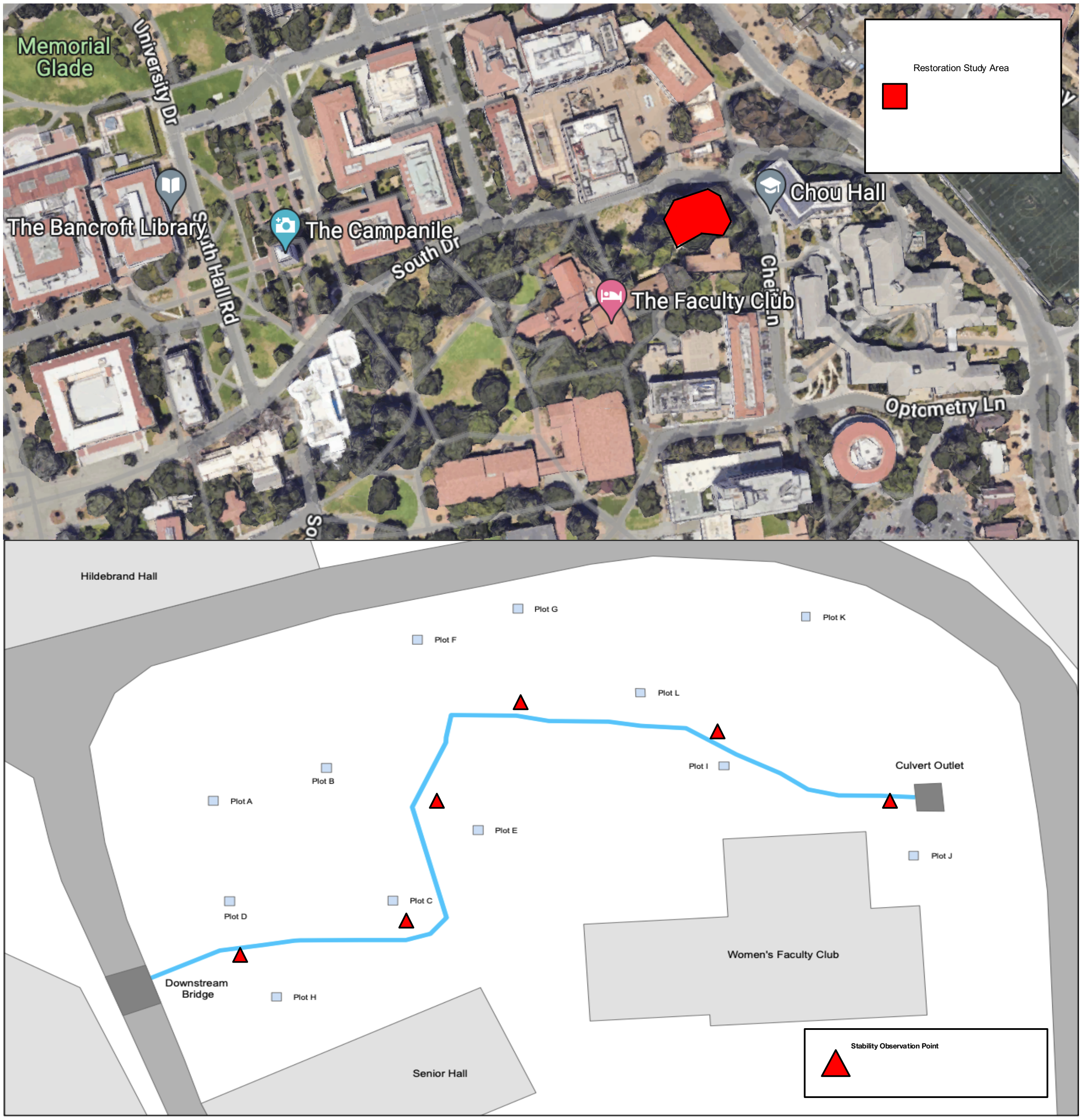

Figure 4. Maps of Women's Faculty Club Restoration Site. Restoration site location on eastern side of the UC Berkeley Campus. Below: Restoration site blueprint including channel stability observation points.

Vegetation assessment

Plant counts and diversity

To assess restoration resilience and success along Strawberry Creek I conducted a vegetation health assessment in the same study period of February 2024. I referenced previously published maps of plant cover at each site and conducted total counts of surviving native plants. I did not include weeds, invasive grasses, or saplings in the plant counts.

To better understand species richness and evenness in the study sites over time I also calculated native species richness and Shannon Diversity Index scores for every monitoring survey in addition to the procedures outlined by the Creeks of UC Berkeley. I calculated species richness by counting the total amount of native species present at each site. Sites with more species are considered more species-rich. The Shannon Diversity index is a measure of the species richness and evenness of a community it can be calculated with the equation:

$$H = \sum_{i=1}^{s} -(Pi * \ln Pi)$$

where H is the Shannon Diversity value for the community. Pi is the proportion of the total population represented by species i. A higher value of H indicates communities with greater species richness and evenness.

Percent cover of vegetation

To assess vegetation cover at the study sites I established 3x3 foot plots at pre-marked locations used in previous monitoring surveys and visually assessed them. I established 10 plots at the North Fork restoration site, and 12 plots at the Women's Faculty Club site. Vegetation cover is an estimated measurement of ground area obstructed or covered by vegetation (LEDDRIS 2024). I recorded the percent cover of native species (planted and volunteered) and invasive species, then I summed the percent cover of each group to estimate total vegetative cover in each plot. Surveyors were unable to locate plots 4, 8, and 9 at the North Fork Restoration site in the years following restoration so no vegetation cover data was collected from those plots in 2017 or 2024.

Plant survival

To monitor the success of the original restoration efforts at each site I inventoried all installed plants included in the "as built conditions" published by the Creeks of UC Berkeley. I recorded each plant as surviving or absent. I assessed the survivability of each species and assessed all plantings to evaluate the standing restoration goal of 70% survival.

Analysis of vegetation data

To interpret changes in vegetative health and plant community structure over time I synthesized data from all previous monitoring studies and computed it alongside the data collected in February 2024. I computed average values for species richness, diversity, vegetation cover, and survivability for each monitoring survey conducted at each restoration site. To analyze vegetative variation over time I conducted a combination of one-way ANOVA and regression correlation tests for each observed metric using RStudio (R version 4.1.2 (2021-11-01)). I used the *ggplot2* package to visualize data. (Wickham 2016) Due to limited sampling, no statistical tests could be conducted on the Women's Faculty Club cover data.

RESULTS

Channel stability

At the North Fork restoration site I found an average channel stability score of 6, the same score given to the As-Built Conditions, and a disimprovement from the Year-3 assessment (5.5). I observed the best channel stability rating between Plot 0+48 and Plot 0+65, with a score of 4.4, indicating very good channel stability. Notable channel characteristics which scored well in this section were entrenchment (3), and bed material (3.5). The worst channel stability rating (8) was observed between Plot 1+40 and Plot 1+85, the section was considered to be rated fair (Table 3). I found on average the channel stability observed in 2024, was not significantly different when compared to previous monitoring studies. After conducting an ANOVA test on the channel stability results I found a p-value of 0.675, indicating no significant variation in channel stability across the 10 years which the North Fork restoration site has been in place.

Table 3. North Fork Restoration Channel Stability Rapid Assessment Ratings. (Ratings: 1-3=excellent; 4-6=good; 7-9=fair; 10-12=poor).

Stations	As-Built (2014)	2015	2017	2024
0+30 to 0+48	6.8	6.8	6.8	4.7
0+48 to 0+65	5.3	3.7	3.3	4.4
0+65 to 0+96	5.8	5.9	5.2	5.1
0+96 to 1+16	5.6	5.2	4.8	5.8
1+16 to 1+40	7.7	7.6	7.8	7.7
1+40 to 1+85	5.1	5.1	5.1	8
All Stations (Channel Average)	6	5.7	5.5	6

I found an average channel stability score of 5.36 from the observations made during my monitoring study of the Women's Faculty Club restoration site which is considered good using the rating system outlined by the DOT. I observed the best channel stability rating at Plot C with a score of 3.93, indicating good-excellent channel stability. Notable channel characteristics which scored well in this section were mass wasting (2), and slope and bank protection (3). The worst channel stability rating was observed at Plot J, the section was considered to be rated good (7.1) (Table 4).

Table 4. Women's Faculty Club Restoration Channel Stability Rapid Assessment Ratings. (Ratings: 1-3=excellent; 4-6=good; 7-9=fair; 10-12=poor).

Stations	**2024**
Plot J	7.14
Plot L	6.29
Plot F	5.93
Plot E	4.29
Plot C	3.93
Plot H	4.57
All Stations (Channel Average)	5.36

Vegetation assessment

Native plant counts and diversity

I found that total species richness and diversity were lower in 2024 than in previous monitoring years. At the North Fork Restoration site I recorded 10 unique plant species in 2024, which is lower than the 13 unique species observed in previous surveys (Figure 5, Table A1). At the Women's Faculty Club site I recorded 27 unique species, also lower than the previously observed 30 unique species (Figures 6-7 and Table A2). I found the reductions in species richness to be statistically significant at the North Fork site after conducting one-way ANOVAs, which resulted in p-value of 0.039, while reductions at the Women's Faculty site were minimally insignificant (p=0.064) (Table 8).

I calculated the Shannon Diversity Index in 2024 to be 1.028 and 2.36 at the North Fork restoration site and the Women's Faculty site respectively. After conducting a one-way ANOVA of the diversity data at each site I found the North Fork site and the Women's Faculty Club site experienced significant reductions in diversity, resulting in a p-value of 0.0118 and 0.05 respectively (Table 5). I also conducted a linear regression test comparing species diversity at both sites with age, measured as years since restoration. The linear regression found a negative correlation between age and diversity, although the result was not statistically significant (Figure 8).

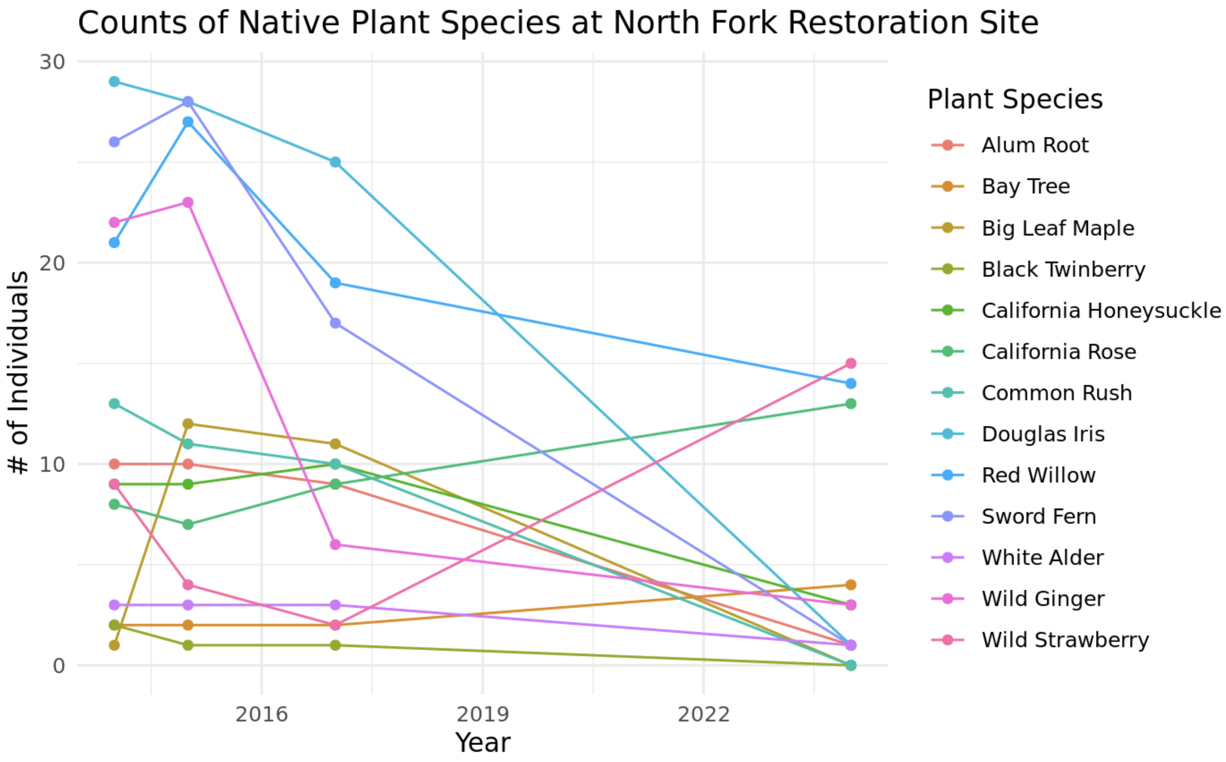

Figure 5. Native plant species counts at North Fork restoration over time.

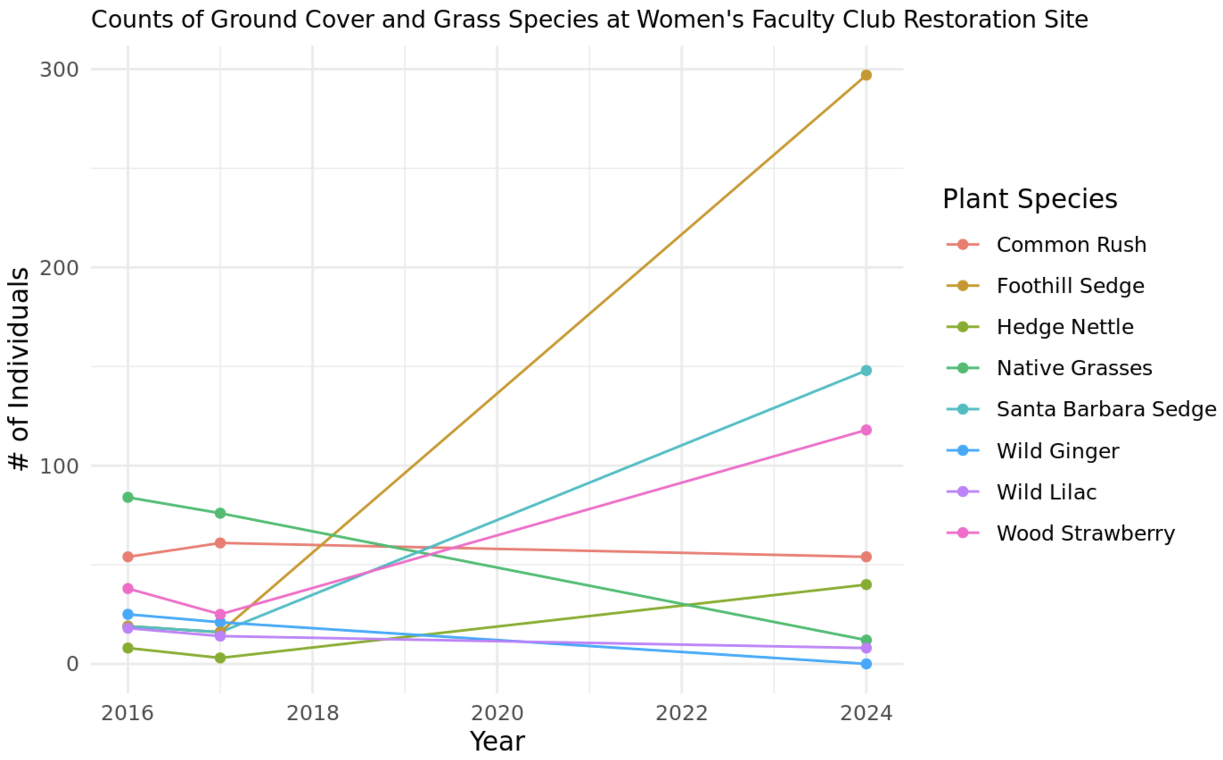

Figure 6. Native ground cover and grass species counts at Women's Faculty Club Site over time.

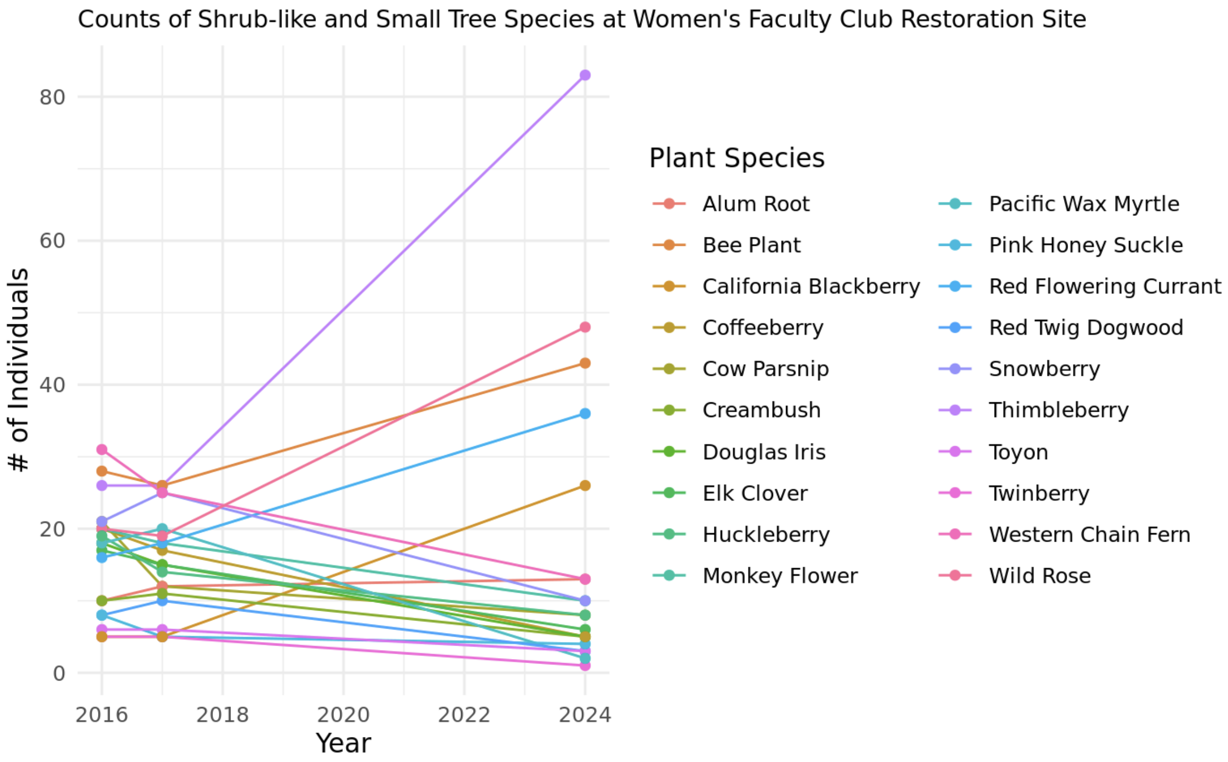

Figure 7. Native shrub-like and small tree counts at Women's Faculty Club Restoration Site.

Table 5. Resulting P-Values of ANOVA tests. Levels of significance for variation of native plant species richness

and diversity at study sites.

	North Fork P-Value	Women's Faculty Club P-Value
Richness	0.039*	0.064
Diversity	0.0118*	0.05*

* indicates statistical significance

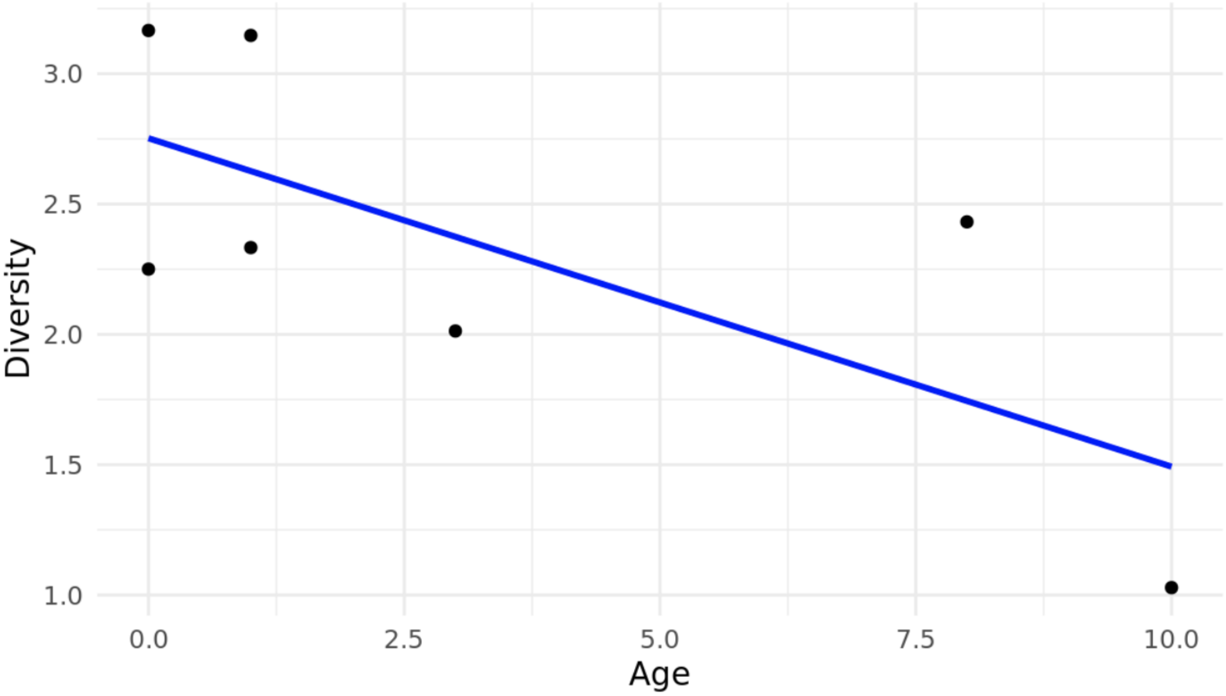

Figure 8. Linear regression model comparing restoration age and Shannon Diversity Index. Age is considered as years since restoration.

Percent cover of vegetation

I found that total vegetation cover increased at both study sites across the monitored time periods. The North Fork site increased from 59% coverage to 72.86% from 2015 to 2024 (Table 6). The Women's Faculty Club site increased from 50.83% to 60.42% from 2016 to 2024 (Table 7). Invasive species cover distinctly increased at both sites as well, increasing from 2% to 12.14% at the North Fork Site, and 0% to 17.92% at the Women's Faculty Club site. I only observed statistically significant variation in invasive species cover at the North Fork Restoration site (Table 8). I also found that invasive species cover increased proportionally to decreases in planted native species cover at the North Fork Restoration Site (Figure 9).

Table 6. Percent plant cover at North Fork Restoration Site.

	2015				2017				2024			
Plot	**Total**	**Planted**	**Volunteer**	**Invasive**	**Total**	**Planted**	**Volunteer**	**Invasive**	**Total**	**Planted**	**Volunteer**	**Invasive**
1	30	30	0	0	60	55	0	5	65	50	0	15
2	60	20	30	10	95	10	85	0	85	5	65	15
3	20	20	0	0	70	60	10	0	55	40	10	5
4	50	50	0	0	na	na	na	na	na	na	na	na
5	30	30	0	0	50	30	20	0	55	25	15	15
6	80	80	0	0	60	60	0	0	65	50	0	15
7	60	60	0	0	90	90	0	0	90	80	5	5
8	90	85	0	5	na	na	na	na	na	na	na	na
9	90	85	0	5	90	85	0	5	95	80	0	15
10	80	80	0	0	na	na	na	na	na	na	na	na
Average	59	54	3	2	73.57	55.71	16.43	1.43	72.86	47.14	13.57	12.14

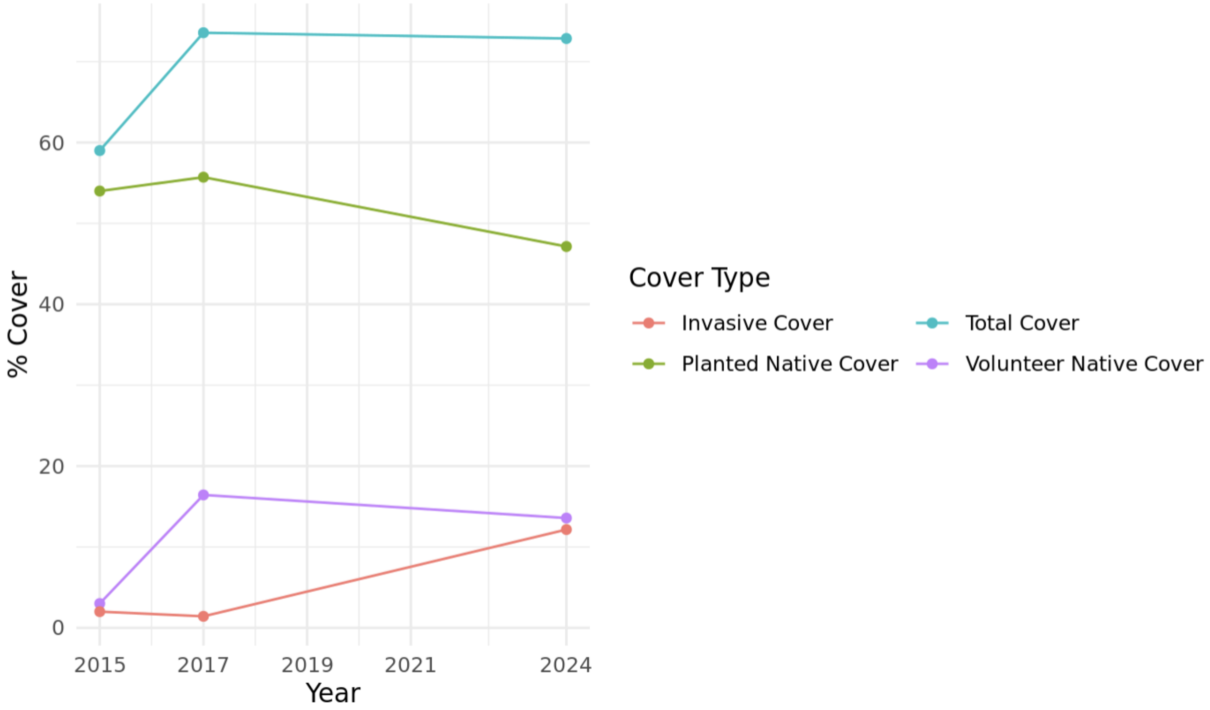

Figure 9. Vegetation cover by year at North Fork Restoration Site.

Table 7. Percent plant cover at Women's Faculty Club Restoration Site.

	2016	2024						
Plot	**Total**	**Planted**	**Volunteer**	**Invasive**	**Total**	**Planted**	**Volunteer**	**Invasive**
A	70	70	0	0	95	50	25	20
B	75	75	0	0	100	60	10	30
C	80	80	0	0	90	60	20	10
D	30	30	0	0	70	30	20	20
E	50	50	0	0	55	45	0	10
F	20	20	0	0	35	15	10	10
G	25	25	0	0	30	10	5	15
H	80	80	0	0	85	50	20	15
I	50	50	0	0	45	25	0	20
J	20	20	0	0	20	15	0	5
K	50	50	0	0	50	20	5	25
L	60	60	0	0	50	10	5	35
Average	50.83	50.83	0	0	60.42	32.5	10	17.92

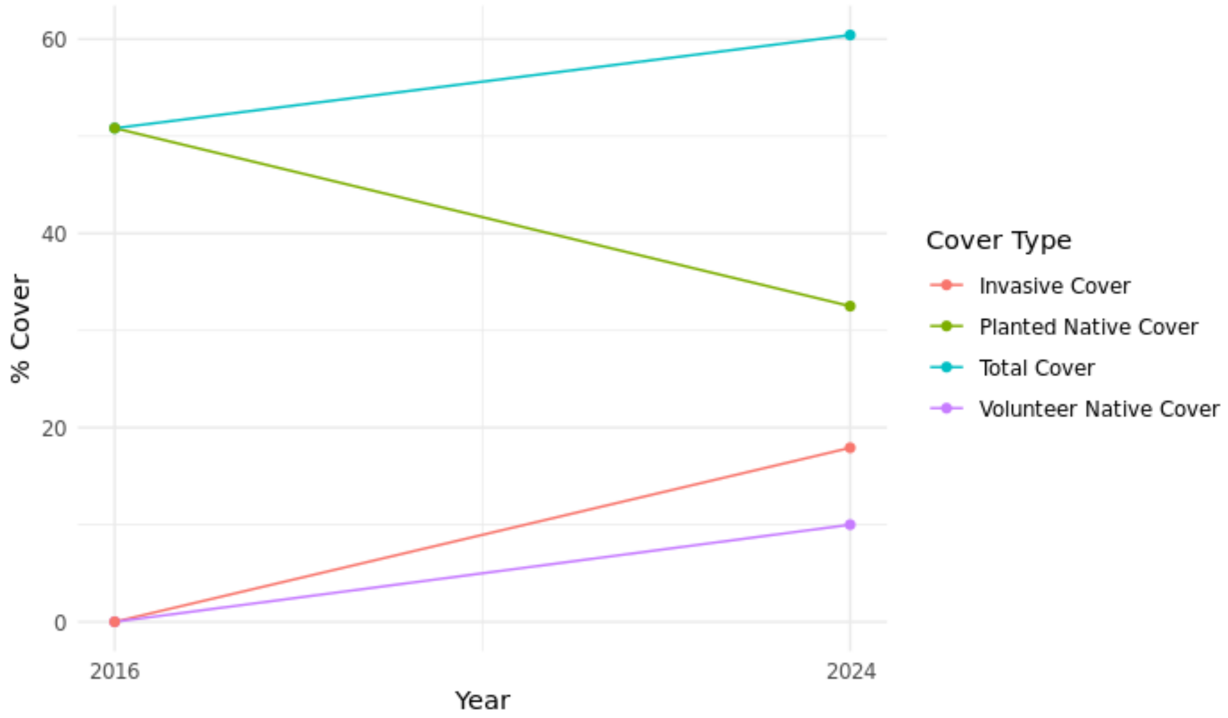

Figure 10. Vegetation cover by year at Women's Faculty Club Site.

Table 8. Resulting P-Values of ANOVA tests. Significance levels for variation in vegetation cover types at the North Fork Restoration site over time.

Cover Type	P-Value
Planted	0.826
Volunteer	0.414
Invasive	0.000016*
Total	0.300

* indicates statistical significance

Plant survival

I found that the studied restoration sites experienced different changes in survival in the time since restoration. The North Fork site had an average 36% survival in 2024, compared to 91% in 2015 (Table B1). The Women's Faculty Club had a 164% survival in 2024, which was higher than the 91% recorded in 2017 (Table B2). Both sites experienced 0% plant survival for several species. The reduction in survival at the North Fork Site was not statistically significant (p=0.126).

DISCUSSION

The Strawberry Creek restoration sites exhibited insignificant variation in channel stability in the ten years following restoration, despite experiencing significant changes in vegetative community. On average the restored channels received ratings of “good” stability during monitoring surveys conducted following restoration. The restoration sites experienced significant reductions in native plant richness and diversity, showing increases in total vegetative cover, with inversely proportional changes in invasive species and native cover. These results suggest that constructed channels in restoration sites successfully mimic naturally dynamic streams and require little management following their construction, whereas increased management of plant communities may be necessary in the years following restoration to ensure the development of natural resilience.

Channel stability

I found the channel to consistently be rated as having “good” stability, as well as no significant variation in average stability across years when comparing the stability scores recorded at the North Fork restoration site. These results provide an example of how constructed channels are successful in creating stable conditions while mimicking natural features, and require little management following their construction. The Women’s Faculty Club restoration site also received good channel stability ratings, further supporting the notion that constructed channels in restoration sites are successful in creating stable conditions while maintaining natural structure. If the restored channels were unsuccessful in mimicking natural conditions, and were unstable or poorly constructed, we would have observed significantly higher (worse) stability scores on average (Henderson 2006). With the understanding that stream systems self-stabilize with time we could also have expected to see much more dramatic changes in stability scores across time, with scores reducing with age (improving) as the channels stabilize (Henderson 2006, Riley 2016). The high channel stability observed at the studies sites is a result of deliberate stabilization efforts that occurred during restoration, and is not indicative of the creek’s ability to self stabilize. With the findings of this study suggesting the success of bank stabilization and channel construction it is important to consider these results in the broader context of stream restoration practices.

Since the 1990’s, a focus on channel stabilization has dominated some stream restoration practices despite there being no consensus on its effectiveness from the scientific community (Lave 2012). Dubbed the Rosgen Wars, the ongoing debate within the environmental community focuses on whether channel stabilization is an important metric in stream restoration, which some academics and practitioners argue is not productive in restoring stream systems health due to their dynamic nature (Gillilan 1996 and Ciotti et al. 2021). Traditional stabilization practices, including the use of concrete and engineered channelization have been found to have adverse effects on stream habitat, and have widely been replaced by morphological restoration methods, as advised under the Rosgen approach (Lave 2012). Morphological restoration seeks to achieve bank and habitat stability, with a focus on reaching equilibrium channel conditions, by classifying and modeling natural systems (Smith and Prestegaard 2005). A contrasting approach also commonly used in modern stream restoration, known as process-based restoration, focuses on reestablishing normal rates of physical, chemical, and biological processes within the system while addressing the root causes of degradation (Beechie et al. 2010) The studied restoration sites along Strawberry Creek employed a morphological approach with channel reconstruction focusing on channel capacity, cross section dimensions, and planform characteristics, all of which are outlined by Rosgen 1994 (Massell 2015). In this study I found that morphological stabilization practices are successful in stabilizing streams and do not show signs of degrading over time. However, other studies including Smith and Prestegaard 2005, have found that morphological stabilization created unstable conditions, particularly under storm flow and flooded conditions and that morphological stabilization reduced stream sinuosity. Sinuosity and meandering are considered key characteristics of stream health, and are indicative of streams as dynamic systems (Riley 2016). Due to limitations in the data, comparisons overtime could only be made at the North Fork Restoration site. The findings of this study show an example of a stream remaining stable over time, which some practitioners may view as a success, while others may view as a failure, indicating a need for further research into the significance of channel stabilization practices.

Vegetation assessment

I observed significant decreases in native plant diversity and richness across both sites, despite recording increases in vegetation cover, and varying levels of survival. These findings suggest that in the absence of active management, native plant communities in restoration sites have difficulty establishing and competing with pressure from invasive species and human traffic. The restoration sites were located along areas with varying levels of human traffic. Both of the study sites were established adjacent to walking paths and roads, and were subject to higher levels of traffic than elsewhere along the stream. Previous studies have recorded decreasing trends in vegetation community structure in riparian and stream habitats associated with increased human activity (Arihilam and Arihilam 2019 and Lin et al. 2022). I observed similar results in this study, documenting significant decreases in native plant diversity and richness at both study sites. I observed more significant decreases at the North Fork site than the Women's Faculty Club site. The North Fork Site was more exposed and was bordered by high traffic roads on two sides, compared to the Women's Faculty Club, which was bordered by a moderately trafficked road on only one side (Massell 2015).

The variation in human activity adjacent to the study sites may inform this variance in community structure reductions which I observed. This can inform the negative impacts which human activity has on restoration sites and system health, and how management practices can be improved to reduce activity at sites in high traffic areas, such as creating barriers between foot paths and restored areas or covering young plants. It is important to consider that these conclusions are made using data only including the native plant community, which is not representative of the entire stream system, as unidentified non-native species exist within the restoration area. Numerous invasive species were not included in the vegetation assessment of this study, thus the true diversity and richness of the studied systems may not support the same conclusions.

Human activity is strongly correlated to reductions in vegetative cover (Hobbs 2009 and Lin et al. 2022). Contrary to the previous conclusion that high levels of human activity resulted in decreases in plant community structure at the study sites, I observed trends of increasing vegetation cover and significant increases in invasive species cover. This finding suggests that changes in vegetation community structure may be due to species specific responses to human activity or invasive species competition. The species that I found had greater reductions in survival at both sites in 2024 were mainly ground cover or shrub like plants. Trampling as a result of human activity can negatively affect plant health, with the extent of impacts being species specific, and that smaller and shorter plant species such as shrubs, grasses, and ground cover are the most susceptible to degradation (Chardon et al. 2023). However, if degradation as a result of trampling was the main cause of the observed reductions in vegetation community structure I would likely have observed lower survival rates in all shrub, grass, and groundcover species at the study sites, as well as reductions in total cover, which was not the case. Several species in these groups even showed dramatic increases in population. Interestingly, many of the most common invasive species in riparian and stream habitat in the Western US are also shrubs, grasses, or other rapidly growing species, such as young tree shoots and saplings, which compete in similar ways (Ringold et al. 2008). Past studies have also found that urban streams are highly susceptible to invasive species, and that invasive plant species are generally successful in outcompeting native species in urban areas (Aronson et al. 2017). With the increases in invasive species cover that I observed, one can conclude the losses in diversity and richness recorded at the study sites may have been a result of direct competition between native and non-native invasive species. It is likely that human activity and trampling further weakened the studied systems and made them more susceptible to invasive plant species. However, the inferences made from the results of this study are limited due to the collected data. The primary limitations are due to limits in the plant count data, specifically the absence of invasive species counts. These conclusions suggest a need for more active management of restoration sites in urban areas, including routine weeding to remove invasive species before they establish, and implementing measures to reduce human activity in the area.

Synthesis

The purpose of this study was to better understand how restored urban streams change in the time following restoration. To address this, restoration sites along Strawberry Creek were monitored for changes in channel stability and vegetative community. Although the conclusions of the study were limited I was able to begin addressing temporal changes in restored urban streams. I found that morphologically restored streams maintained good channel stability in the time following restoration and demonstrated little change. I also found that the native plant community struggled to compete with the pressure from human activity and invasive species. Coupling these findings all together it is important to consider the numerous approaches to stream restoration and that these findings are only representative of a morphological restoration. With this consideration I found that morphologically restored urban streams struggle to reach a natural state, despite mimicking natural conditions. The studied sites did not demonstrate the natural dynamism which characterizes stream systems, although they were constructed to include natural features (Massell 2015). Despite including only native vegetation in the original restorations, there were great fluctuations in community structure and stabilization within the vegetative community never occurred. These findings may be unique to this restoration approach and reflect underlying degradative stresses on the stream ecosystems which were not adequately addressed.

Limitations

This study used methods adapted from restoration monitoring surveys that were not intended to provide data for any particular type of analysis or interpretation, as such this study and its implications were very limited. As stated previously, there were discrepancies in the data due to variations in methods employed at each study site which limited the analyses that were possible to conduct for this study. The greatest limitation in data was the lack of consideration given to invasive species when conducting the vegetation assessment, particularly the lack of counts of invasive species. The inclusion of all species present would have provided much more credible data regarding vegetative community structure and would have allowed for more detailed inferences about the effects of invasive species on community structure and restoration health. The native plant species counts are flawed as well due to physical variation in the observed species. Many grass and shrub species grow very densely and close to the ground making it difficult to obtain an accurate count. Due to the timing of this study, data collected in 2024 was collected in February, whereas all other observations were made in June, which may have impacted the resulting channel stability scores due to seasonal rainfall, as well as the vegetation assessment, as some plants in the study site may have only been present previously in June. The broader implications of this study are also limited due to the study sites. This study focuses on restoration sites along an urban stream in Berkeley, CA; it may not be appropriate to apply the conclusions made to other restoration sites that are not stream restorations or in urban settings.

Due to the gaps in data recorded in this study further research focusing more closely on plant community structure, including the presence of invasive species is necessary. Specifically it would be important to focus future research on answering the questions, how do invasive species compete with native species in urban restoration areas, and how does human activity affect competitions between native and non-native species? This study also raises further questions in the debate over the use of bank stabilization in stream restoration and found results that countered the opinions of stream and restoration ecologists. Following this study it would be important to continue monitoring channel stability at the study sites, as well as conduct further studies that focus on morphological channel stabilization in streams with varying flow regimes over greater time scales.

Broader implications

Urban stream restoration has become a common practice in the San Francisco Bay Area in recent decades, and has reintroduced dynamic ecosystems into severely degraded areas (Seavy et al. 2009). This study sought to understand how successful urban stream restorations were in developing resilient ecosystems and how key stream characteristics changed over time in restored systems. The results of the study found that the channels constructed during restoration were rated with high stability and remained stable as they aged. However these results raised further questions in the broader debate over the inclusion of bank stabilization in stream restoration (Lave 2012 and Smith and Prestegaard 2005). The study also found that vegetative communities in restored stream systems experienced reductions in native plant diversity and richness as a result of competition with invasive species and pressure from surrounding human activity (Chardon et al. 2023 and Ringold et al. 2008). The results of the study could not be used to conclusively determine the resilience of urban stream restoration over time. However, it is clear that more active management, such as weeding and protection of vegetative communities in restored systems is necessary to maintain diversity and community structure. The scope of this study, including limitations in data and diversity in study sites, limits the broader implications that can be drawn about ecological restoration, however, this study does provide a strong foundation to support further research with focuses on invasive species competition, the impacts of management on vegetative communities, and the use of channel stabilization in restored systems.

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APPENDIX A: Native lant Count Results

Table A1. Native Vegetation Counts at North Fork Restoration Site.

Plant	As Built (2014)	2015	2017	2024
Alum Root	10	10	9	1
Bay Tree	2	2	2	4
Big Leaf Maple	1	12	11	0
Black Twinberry	2	1	1	0
California Honeysuckle	9	9	10	3
California Rose	8	7	9	13
Common Rush	13	11	10	0
Douglas Iris	29	28	25	1
Red Willow	21	27	19	14
Sword Fern	26	28	17	1
White Alder	3	3	3	1
Wild Ginger	22	23	6	3
Wild Strawberry	9	4	2	15
Species Richness	13	13	13	10
Diversity Index	2.25	2.33	2.01	1.03

Table A2. Native Vegetation Counts at Women's Faculty Club Restoration Site.

Plant	**2016**	**2017**	**2024**
Big Leaf Maple	10	9	0
California Buckeye	5	6	0
Elk Clover	17	15	6
Wild Ginger	25	21	0
Native Grasses	84	76	12
Santa Barbara Sedge	31	31	148
Foothill Sedge	19	16	297
Wild Lilac	18	14	8
Red Twig Dogwood	8	10	3
Wood Strawberry	38	25	118
Cow Parsnip	21	12	8
Toyon	6	6	3
Alum Root	10	12	13
Creambush	10	11	5
Douglas Iris	18	15	5
Common Rush	54	61	54
Pink Honeysuckle	8	5	4
Twinberry	5	5	1
Monkey Flower	20	18	10
Pacific Wax Myrtle	18	20	2
Coffeeberry	20	17	5
Red Flowering Currant	16	18	36
Wild Rose	20	19	48
Thimbleberry	26	26	83
California Blackberry	5	5	26
Bee Plant	28	26	43
Hedge Nettle	8	3	40
Snowberry	21	25	10
Huckleberry	19	14	8
Western Chain Fern	31	25	13
Richness	30	30	27
Diversity	3.17	3.15	2.43

APPENDIX B: Plant Survival Results

Table B1. North Fork Restoration 10 Year Plant Survival.

Common Name	As Built (2014)	2024	1 year % Survival	3 year % Survival	10 year % Survival
Alum Root	10	1	100	90	10
Bay Tree	2	4	100	100	200
Big Leaf Maple	1	0	50	50	0
Black Twinberry	2	0	100	111	0
California Honeysuckle	9	3	88	113	33.33
California Rose	8	13	100	92	162.5
Common Rush	13	0	97	86	0
Douglas Iris	29	1	100	90	3.452
Red Willow	21	14	100	91	66.67
Sword Fern	26	1	100	65	3.856
White Alder	3	1	100	32	33.33
Wild Ginger	22	3	100	100	13.64
Wild Strawberry	9	15	44	22	166.67
Average Survival Rate			91	80.15	53.34

Table B2. Women's Faculty Club 8 Year Plant Survival.

Plant	As Built (2016)	2024	1 Year % Survival	8 Year % Survival
Big Leaf Maple	10	0	90.0	0
California Buckeye	5	0	120.0	0
Elk Clover	17	6	88.24	35.29
Wild Ginger	25	0	84.0	0
Native Grasses	84	12	90.47	14.29
Santa Barbara Sedge	31	148	100.0	477.42
Foothill Sedge	19	297	84.21	1563.16
Wild Lilac	18	8	77.78	44.44
Red Twig Dogwood	8	3	125.0	37.5
Wood Strawberry	38	118	65.79	310.53
Cow Parsnip	21	8	57.14	38.10
Toyon	6	3	100	50
Alum Root	10	13	120.0	130
Creambush	10	5	110.0	50
Douglas Iris	18	5	83.33	27.78
Common Rush	54	54	112.96	100.0
Pink Honeysuckle	8	4	62.5	50.0
Twinberry	5	1	100.0	20.0
Monkey Flower	20	10	90.0	50.0
Pacific Wax Myrtle	18	2	111.11	11.11
Coffeeberry	20	5	85.0	25.0
Red Flowering Currant	16	36	112.5	225.0
Wild Rose	20	48	95.0	240.0
Thimbleberry	26	83	100.0	319.23
California Blackberry	5	26	100.0	520.0
Bee Plant	28	43	92.86	153.57
Hedge Nettle	8	40	37.5	500.0
Snowberry	21	10	119.05	47.62
Huckleberry	19	8	73.68	42.11
Western Chain Fern	31	13	80.64	41.94

Total Vegetation	619	1009	109.36	163.0